FUTURE TALKS

013

LECTURES AND WORKSHOPS ON TECHNOLOGY AND CONSERVATION OF MODERN MATERIALS IN DESIGN

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013
LECTURES AND WORKSHOPS ON TECHNOLOGY AND CONSERVATION OF MODERN MATERIALS IN DESIGN

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EDITOR

DIE NEUE SAMMLUNG
THE DESIGN MUSEUM

...THE QUALITY AND THUS THE SUCCESS OF THE FUTURE TALKS IS AND SHOULD ALWAYS BE RELATED TO A DEEPER UNDERSTANDING OF THE TECHNOLOGIES AND MATERIALS USED, AND A PRAGMATIC APPROACH TO FINDING APPROPRIATE CONSERVATION STRATEGIES TO PROLONG THE LIFE SPAN OF DESIGN OBJECTS MADE OF MODERN MATERIALS...

CONTENT

LECTURES

PREFACE

The FUTURE TALKS conference has become something of a tradition at this stage. Organised for the first time in 2009, it now takes place every two years in Die Neue Sammlung, the Design Museum in the Pinakothek der Moderne in Munich. In a range of talks, workshops and podium discussions, FUTURE TALKS addresses current issues relating to technologies and materials in contemporary design in order to be able to develop strategies for its conservation and restoration.

The many expert guests from Germany and abroad make the Neue Sammlung an international centre of expertise that is respected and recognised the world over. The initiative, the concept and the execution of the deliberately interdisciplinary series of conferences is the responsibility of the Conservation Department. Head of the Department Tim Bechthold and his colleagues Julia Demeter and Barbara Schertel are responsible for the care and restoration of the extraordinary large collections, which total 100,000 inventory numbers. But they also research materials and their potential for change arising from environmental effects and they develop ways of preventing or limiting damage. Over time, the conservation team has become an authority on the subject, particularly in the area of plastics research, acquiring knowledge for which there is worldwide demand. Exchanges between experts from institutions like for example New York's Museum of Modern Art or the Cultural Heritage Agency of the Netherlands (RCE) in Amsterdam create an important research network. A museum whose collection by its very nature is always getting older and bigger has an obligation and a desire to take responsibility for the present and the future. Its mission is to preserve objects for future generations, not as an end in itself, but because such objects are a reflection of sociological and cultural phenomena. And it makes us even more aware that, in addition to their function and form, objects primarily also have material and surface designs that are significant for them and their users. In handling the materials and surfaces, the conservators take on a special responsibility, making important decisions about the appearance, and thus the reception, of an object.

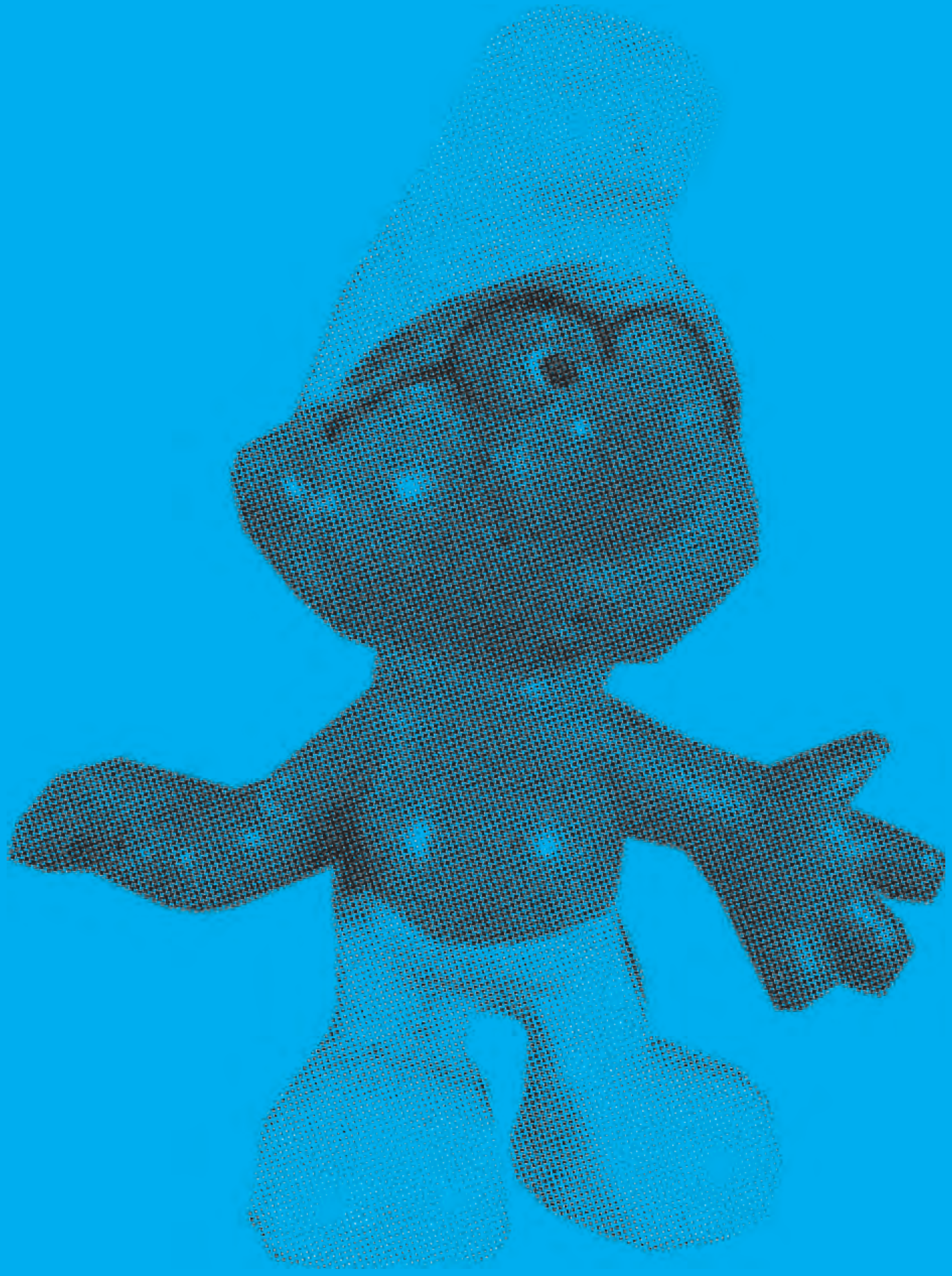
I would like to thank most sincerely the approximately 20 speakers, our guests for the podium discussion and our contributors for the 10 workshops offered during the FUTURE TALKS 013 conference. My heartfelt thanks also to our 200-plus guests from 21 countries for their interest and input. Their efforts have been fundamental to this publication, which documents the conference but also constitutes an expert manual and reference work for current conservation-related issues.

A big thank you to Tim Bechthold and his team for all their commitment and their responsible execution of this series. By the time this publication appears, the fourth conference – FUTURE TALKS 015 – will already be under way. Once again we will hear about new research projects and advances in knowledge.

Communication and dialogue about the processes involved in the restoration of design objects are crucial to the conservation of objects. But they are also necessary to analyse and understand the essence and power of the design and its execution.

ANGELIKA NOLLERT
DIRECTOR, DIE NEUE SAMMLUNG
THE DESIGN MUSEUM

LECTURES



LECTURE
001
NON-INVASIVE INVESTIGATION OF POLYMERIC MATERIALS USING UNILATERAL NUCLEAR MAGNETIC RESONANCE

BY CINDIE KEHLET

ABSTRACT

This paper discusses the use of unilateral Nuclear Magnetic Resonance (NMR) for the investigation of polymeric materials. NMR is an insensitive technique and relatively large sample sizes are therefore required. At the same time samples need to be small enough to fit into a magnet with a typical bore diameter of only a few centimetres. Until the development of the non-invasive single-sided NMR instrument the technique was not suitable for tests on objects of cultural heritage. Here we present how the Profile NMR-MOUSE® can be used as a diagnostic tool and for monitoring the state of degradation of artworks made of polymeric materials. The advantage of the technique is, that, unlike most other non-invasive techniques, such as Fourier transform infrared spectroscopy (FTIR), it can assess the degradation state of the material underneath the surface. The NMR-MOUSE® measures the mobility of protons, which changes in degrading materials as can be seen in the resulting relaxation decay.

We have applied this technique to a large set of test samples of various types of synthetic polymers. Principal component analysis is used to obtain a direct visual comparison of the samples, removing the need for individual fitting of the relaxation decay.

KEYWORDS

Polymeric material, unilateral NMR, principal component analysis, non-invasive, depth resolution, degradation

INTRODUCTION

Nuclear Magnetic Resonance (NMR) was developed in the late 1940's and it has proven to be a very powerful technique that has found applications within physics, chemistry, biology, and medicine *(Ernst 1987; Blümich 2005)*. More recently, it has been applied to the study of artist materials and objects of cultural significance *(Spyros 2004, 2006; Stamatakis 2010; Del Federico 2010, 2012; Blümich 2010a; Proietti 2011; Ulrich 2011; Kehlet 2013)*. The rather late use of the technique in conservation science can be ascribed to several factors. One reason certainly is that NMR is an insensitive technique requiring relatively large sample sizes which may not be possible to obtain from works of art. Additionally, NMR spectroscopy relies on expensive high-field superconducting magnets that require a specialist to operate *(Blümich 2010b, Capitani 2013)*. With the development of the NMR-MOUSE® in the mid-nineties by Blümich and his co-workers it was made possible to investigate materials non-invasively using NMR. The instrument was named based on its compactness and mobility with MOUSE being the acronym for mobile universal surface explorer *(Eidmann 1996)*. The NMR-MOUSE® has a low-field magnet that is inexpensive in comparison to traditional high-field NMR spectroscopy and it is often referred to as unilateral NMR due to its single-sided open design. The beneficial attributes of the NMR-MOUSE® come at the expense of spectroscopic resolution; instead we are left with a relaxation decay reflecting the mechanical properties of materials. About a decade after the introduction of the single-sided NMR instrument an updated system was launched which contains a lift system facilitating the non-invasive depth profiling of materials *(Perlo 2005)*.

Polymeric materials are particularly suitable for this technique due to their high hydrogen content and transverse relaxation properties. During the past decade conservators and conservation scientists focused increasingly on synthetic polymers in art and design artifacts, as they are particularly vulnerable towards degradation *(Waentig 2008, Van Oosten 2011, Levédrine 2012)*. Using unilateral NMR, polymers can be distinguished based on their physical properties, as flexible materials exhibit slow relaxation while more rigid materials relax faster. When polymeric materials degrade they often lose their flexibility which is measured as an increase in relaxation time. In the present study we have investigated a variety of different polymeric materials using unilateral NMR. Processing of the obtained transverse relaxation decays are in most cases done by exponential fitting. However, the decays are often multi-exponential

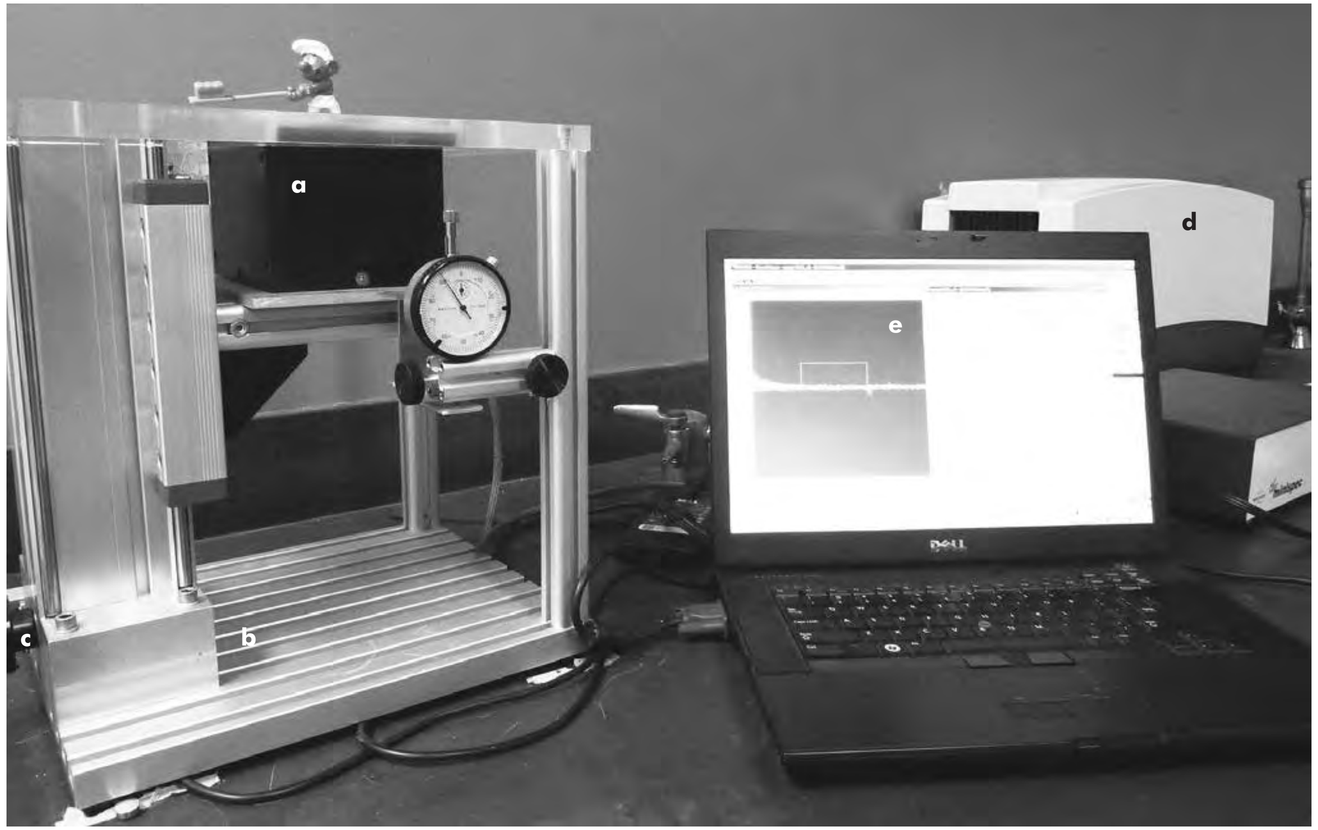


Figure 1
a. The NMR-MOUSE® magnet with the object placed on top
(the system can be laid down for non-invasive measurement of larger objects),
b. High precision lift controlled by the wheel at point c.
d. Bruker Minispec consol. The whole system is controlled by the laptop here collecting a CPMG decay (point e).
Photo: C. Kehlet, 2014.

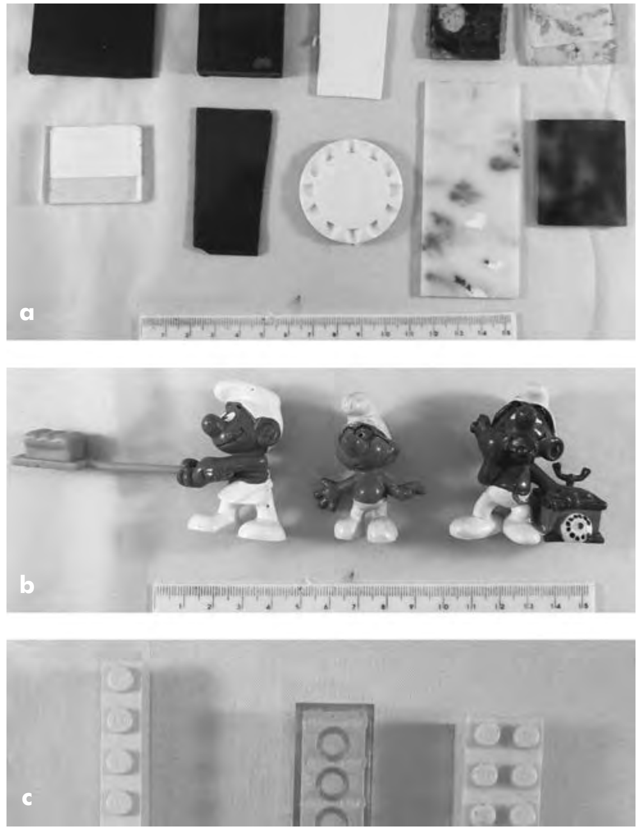


Figure 2
a) Polymeric materials provided by Collin Williamson at the POPART conference in 2012 [20]. From left to right: Vulcanite (51), High Impact Polystyrene (HIPS) (52), Urea Formaldehyde (53), PVC (54), Polycarbonate (55), Poly (methyl methaacrylate) (PMMA) (56), Melamine Formaldehyde (57), Casein Formaldehyde (58), High Density Polyethylene (HDPE) (59), and Cellulose Acetate (60).
b) PVC objects with different degree of plasticizer.
Smurf ~1980, Germany (61), Smurf ~1970, Germany (62), and Smurf ~1975, China (63).
c) Acrylonitrile (ABS) Lego brick ~1995 (64), Cellulose Acetate Lego brick ~1960 (65,66).
(see colour plate, p. 162)

which complicates the analysis and makes it difficult to compare the obtained data. The application of multivariate analysis directly on the relaxation decay essentially removes this step, providing a highly visual direct comparison of the samples. The method has furthermore proven to be useful for obtaining a non-invasive measure of degradation with spatial resolution.

EXPERIMENTAL

SAMPLES

In this study we used resins samples provided by Collin Williamson at the POPART conference in 2012 *(http://popart.mnhn.fr)*. The samples *(see Figure 2 top row)* are from left to right: vulcanite, high impact polystyrene (HIPS), urea formaldehyde (UF), polyvinyl chloride (PVC), polycarbonate (PC), and in the same image in the lower row: poly (methyl methacrylate) (PMMA), melamine formaldehyde (MF), casein formaldehyde (CF), high-density polyethylene (HDPE), and cellulose acetate (CA). As representative objects we included three PVC smurf toy figures with different degrees of plasticiser. Two of them were produced in Germany around 1970 and 1980, respectively, and one was produced in China around 1975 *(see Figure 2 middle row)*. Furthermore, three Lego bricks were investigated (see Fig. 2 bottom row). Two from circa 1960 made of cellulose acetate and one from circa 1995 made of acrylonitrile-butadiene-styrene (ABS). Synthetic elastomer rubber was used to study the degradation of polymeric materials under UV light. This sample was part of the ResinKitTM obtained from the Plastic Group of America (Woonsocket, RI, USA). Before placing the sample under UV radiation, with irradiance in the order of some kW/m^2 at 254 nm for five weeks, it was cut into two pieces, one serving as unaged reference sample. To perform the multivariate analysis, all samples from the ResinKitTM (http://www.plasticsgroup.com) were used. Further details on this study can be found in the reference *(Kehlet 2013)*.

UNILATERAL NMR

All NMR measurements were performed using an ACT (Magritek GmbH, Aachen, Germany) NMR-MOUSE® controlled by a Bruker Minispec (Bruker BioSpin, Rheinstetten, Germany) operating at 18.5 MHz ^{1}H resonance frequency with a field gradient G of 22.6 Tm^{-1} and a 90º pulse of 4.5 µs *(see Figure 1 for experimental setup)*. The instrument was equipped with a surface coil creating a sensitive volume of about 10x10 mm^2 times an adjustable thickness 2.5 mm away from the RF coil *(Perlo 2005)*. The transverse relaxation decays of ^{1}H were measured using the Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence with echo times of 30 µs and acquisition times of 10 µs which, in the presence of the field gradient G, defines a nominal resolution of about 100 µm *(Carr 1954; Meiboom 1958)*. The resin samples obtained at the POPART conference, the smurfs and the Lego bricks, were measured using 1024 scans, a recycle delay of 1 s, and 1000 echoes. For the synthetic elastomer rubber sample the number of scans (1024 at 150 µm, 2048 at 100 µm, and 8192 at 50 µm) was adjusted to provide the same signal-to-noise ratio for varying penetration depths and degradation degree of the material.*)*.

DATA ANALYSIS

Multivariate data analysis, as provided by the SIMCA 13.0.1 software (Umetrics, Sweden), was used to analyse the data. The normalised, even numbered echo intensities from the CPMG relaxation decays were entered into the SIMCA 13.0.1 software, where they were mean centred and scaled to unit variance. Odd numbered echo intensities were omitted in the analysis in order to minimise systematic errors introduced by pulse imperfections. We applied principal component analysis (PCA) which facilitates model-free classification of the data. The performance of the multivariate models was evaluated using goodness of fit R^2 and goodness of predication Q^2 parameters. The goodness of fit R^2 records how much of the variation is represented by the total model, while Q^2 indicates how accurately the data can be predicted. The R^2 parameter varies between 0 and 1, where 1 means a perfectly fitting model and 0 no fit at all while it approaches unity as model complexity increases. The Q^2 parameter is less inflationary and will not automatically come close to 1 with increasing model complexity. Without a high R^2 it is impossible to

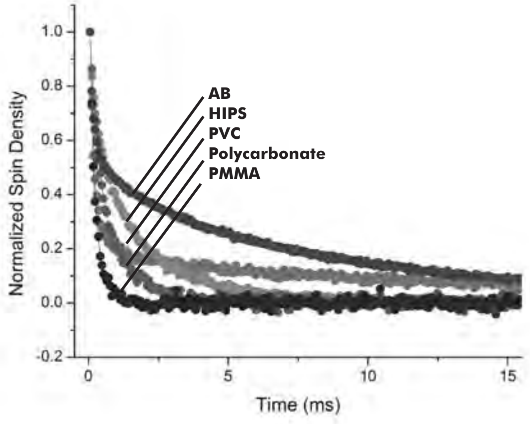


Figure 3
Representative relaxation decays.

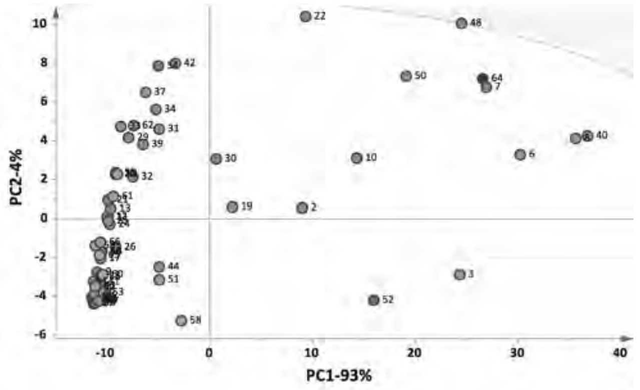


Figure 4
Score plot of first two component of the 66 samples investigated.

get a high Q^2. Generally a Q^2 larger than 0.5 is regarded as good and a Q^2 exceeding 0.9 as excellent. Cross-validation was performed by dividing the data in seven groups and subsequently developing a number of parallel models from the reduced data, with one of the groups kept out once and only once *(Eriksson 2004)*.

RESULTS AND DISCUSSION

The experimental setup is shown in *Figure 1*. The NMR-MOUSE® magnet is located in a high precision lift and the object is placed on top of the magnet. The ^1H spins in the sample, orients itself in the magnetic field, and can be manipulated using radio frequency pulses. The transverse relaxation of the nuclear spin is obtained as an exponential decay reflecting the mechanical properties of the sample. Different materials exhibit different relaxation behaviour as flexible materials relax slower than more rigid materials. The NMR relaxation times can be extracted from the decay using an exponential fitting function. However, the fitting procedure is not always straight forward as the decay is multi-exponential rather than mono-exponential due to the many unresolved ^1H signals resulting from the missing spectroscopic resolution. This fact is illustrated in *Figure 3* where HIPS, a copolymer, needs to be fitted by at least a tri-exponential decay function to give a meaningful result. Additionally, *Figure 3* illustrates that a rigid material like PMMA relaxes much faster than a more flexible material like ABS. To overcome the challenges related to multi-exponential fitting, principal component analysis (PCA) can be used. PCA provides a visual overview of the data by enhancing the visibility of small variations in data. To perform the PCA a datasheet consisting of 66 resin samples (X-variables) was constructed and loaded into the SIMCA software (50 of the samples were taken from the ResinKit™ to act as reference samples for the analysis). The PCA creates new variables (the scores) that summarise the X-variables. The scores are orthogonal and therefore independent. They can be represented in a score plot displaying how the observations are situated with respect to each other. It can be seen as a map of the observations showing e.g. groups and similarities in the data. The score plot of the 66 samples is shown in *Figure 4*. Scores located in the lower left quadrant are related to very fast relaxing samples e.g. PMMA (PC1 ~-10, PC2 ~-3). Polycarbonate relaxes slightly slower, obtaining scores located in the upper left quadrant of the score plot (PC1 ~-10, PC2 ~2). The scores for the relatively flexible ABS samples *(see relaxation decay in Figure 3)* show up in the upper right quadrant (PC1 ~27, PC2 ~7) and the highly multi-exponential HIPS samples have obtained scores in the lower right quadrant (PC1 ~16, PC2 ~-5). So, moving from left to right in an arching form in the score plot, we encounter scores related to samples that relax slower due to the higher flexibility of the material. As representative objects we included three PVC smurfs with different degrees of plasticiser *(see Figure 2 middle row)*. The smurf (middle) that feels most flexible obtains similar scores as the ResinKit™ soft PVC sample (PC1 ~-7, PC2 ~4), which is slightly above the two other smurfs (PC1 ~-9, PC2 ~1). The Lego bricks made of cellulose acetate have scores at (PC1 ~-10, PC2 ~-1), which is a little more to the lower left in the scores plot compared to the cellulose acetate reference sample from the ResinKit™ (PC1 ~-9, PC2 ~0). The faster relaxation for the Lego bricks is possibly due to some degradation of the more than fifty years old material. The model for the score plot in Figure 4 has three principal components (PC) with PC1 explaining the major part of the variation (93%) whereas PC2 only accounts for 4% (PC3 account for 1%). The model is considered good as 98% [R^2X(cum)] of the variance in the data set can be explained with the established model with a predictability of 97% [Q^2X(cum)].

It is well known that ultraviolet radiation has a damaging effect on polymeric materials. Prolonged exposure to UV radiation may lead to a reduction in molecular weight due to breaking chemical bonds in the polymer chains. We have studied this effect on a synthetic elastomer sample that was exposed to UV radiation for 5 weeks. The sample shows visible signs of change as pronounced yellowing has occurred. In order to examine to what extent the molecular structure of the material has changed we measured transverse relaxation decays in steps of fifty micrometre, moving from the surface further into the material. *Figure 5* shows the decays obtained at 50 µm, 100 µm, and 150 µm which indeed reveals a change in the mechanical properties of the material. In the

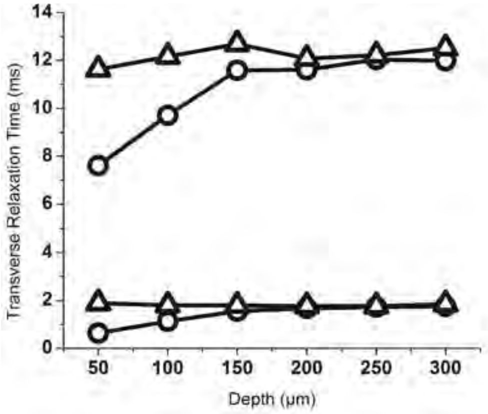


Figure 5
Transverse relaxation decays for the degraded synthetic elastomer sample at 50 µm, 100 µm, and 150 µm.

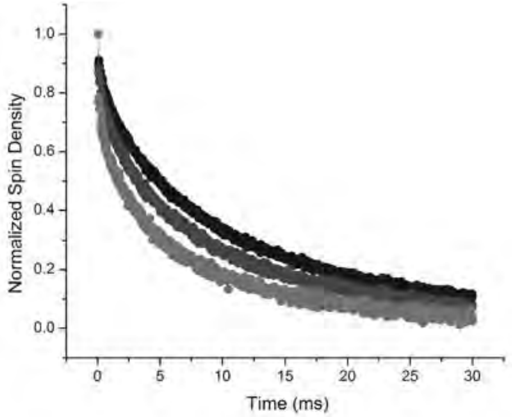


Figure 6
Depth profiles as a function of transverse relaxation time for the degraded (circles) and non-degraded (triangles) synthetic elastomer sample. The graph shows relaxation times determined by bi-exponential fitting of the decay curves measured as a function of depth.

present case, good approximations for the relaxation times of the decays can be obtained by applying a bi-exponential fitting function. The relaxation times for both, the degraded and non-degraded reference sample, are shown in *Figure 6*. The non-degraded sample essentially shows constant relaxation time throughout the sample, whereas both the long and short component for the degraded sample exhibits faster relaxation at the surface than further into the material. The relaxation time gradually increases with depth; deterioration is observed up to 200 µm, beyond this depth the relaxation time is equivalent to the reference sample.

CONCLUSION

We have shown that the profile NMR-MOUSE® is a highly suitable instrument for measuring a wide variety of polymeric materials as can be found in museum collections. Multivariate analysis offers a visual overview of the measured relaxation decays by enhancing the visibility of small variations in the data Furthermore, the degradation state of polymeric materials can be assessed non-invasively by measuring transverse relaxation decays at various depths as the signal will decay faster if the material is deteriorated.

ACKNOWLEDGEMENTS

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LECTURE
002
DISCOLOURATION OF PLASTIC OBJECTS: INVESTIGATION INTO COMPOSITION USING VARIOUS ANALYTICAL TECHNIQUES

BY SUZAN DE GROOT, HENK VAN KEULEN, LUC MEGENS, THEA VAN OOSTEN, HENK WIERSMA

ABSTRACT

Few would dispute that scientific research will continue to play a crucial role in the study, documentation and conservation of modern and contemporary art and design. There seems to be a never ending number of new materials and application techniques being used for works of art, each of which would presumably require the development of appropriate analytical methods for their identification.

At the Cultural Heritage Agency of the Netherlands (RCE) in Amsterdam research has been carried out into the conservation of plastics used for and applied to modern and contemporary art and modern design objects. For the conservation of these plastic art objects the composition of their main components and additives should be known. Various analytical techniques exist for the identification of the composition of plastics, of which non-invasive techniques are preferred. Mostly, the main components of the plastics are identified, whilst additives and colourants have not been researched in detail.

More and more coloured plastic objects, especially red coloured ones, show fading due to the discolouration of pigments. The types of pigments responsible for this phenomenon have not yet been researched, which is why this study has investigated more closely synthetic organic red pigments.

Various red synthetic organic pigmentsfs from the RCE Reference Collection were analysed with several analytical techniques: Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) and X-ray diffraction (XRD). Using the resulting reference data, different red synthetic organic pigments in plastics could be identified.

KEYWORDS

plastics, synthetic organic pigments, Raman spectroscopy, pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS), Fourier transform infrared spectroscopy (FTIR), discolouration

INTRODUCTION

More and more coloured plastic objects, especially the red ones, show fading due to discolouration of colourants. This is demonstrated in *Figure 1:* the objects presented are chosen from our plastic objects collection, the van Oosten Reference Collection of everyday plastic objects. The objects selected show fading of the red colourants. Also, the transfer of the colourant to adjacent differently coloured plastics can take place. This was observed in a woven basket and a molecule model where the red pigment has transferred to the adjacent white coloured plastic *(Figure 1).*

Although all synthetic organic pigments will fade under the influence of light; this research was focused on the red organic pigments in plastics, which seem more vulnerable to light than others. Which pigments are prone to this fading behaviour has not been researched as yet.

The identification of the organic pigments in plastics can contribute to formulating exhibition lighting guidelines for a particular object of art. Once it is known which colourants are present in an object, the light-fastness can be derived from literature and the sensitivity class can be determined. Objects containing pigments with poor light fastness may only be exposed to a low illumination dose, whereas others may be exposed to a higher dose *(Profilpigments, Supmat, Crenovo 2014).*

PIGMENTS AND DYES

In the world of plastics colouring there are two major categories of colourants: pigments and dyes.

A dye is a colourant that becomes soluble in the polymeric system as it has an affinity to the substrate and is therefore soluble in the medium. This does not imply the dye is soluble in the polymer itself; the dye can just as well be soluble in a component of the polymer system. Dyes are always composed of organic materials derived either from natural or synthetic origin. Dyes are used in clear plastics to provide clean, bright colours and transparent shades where optical transmission is important, such as acrylics, crystal polystyrene and polycarbonates. Dyes are easy to disperse and usually are readily soluble within the polymer matrix.

Dyes that have been designed for use in plastics generally are oil or solvent soluble, although some are only soluble in the polymer matrix. While many dyestuffs are water soluble, these generally are not used to colour plastics unless the objects are to be dip dyed. In certain applications, such as for synthetic fibres and sunglass lenses, the dye is coated onto the polymer surface. Dyes can also be precipitated with an insoluble binder, such as a

Figure 1
Objects from the Van Oosten reference collection showing discolouration (first 2 rows) and colour transfer from red to white plastic part (bottom row) ***(see colour plate, p. 162)***

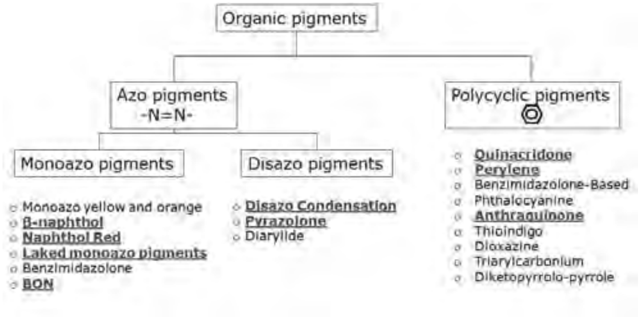


Figure 2
Division of pigment categories and pigment classes; classes which are used for colouring plastics are underlined

metallic salt, to produce a pigment lake.

A pigment is defined as a distinct particulate material that remains essentially unchanged during the processing and life cycle of a plastic product; it does not have an affinity for the substrate and is therefore insoluble in the medium it is used in. Pigments retain a crystal or particulate structure throughout the colouration process. A cross-section of a pigmented plastic may show the individual pigment particles or particle clusters using a magnification of 200x.

Pigments are usually introduced to the plastic production process in the form of a masterbatch, a concentrated mixture of pigments and/or additives. Masterbatches are supplied in a wide range of physical forms; as liquids, resinated blends (mixed with ground polymer), freeze dried concentrates, universal concentrates (including a carrier system), resin specific concentrates and encapsulated concentrates (coated fine granules of pigment). All types have strengths and weaknesses which should be considered for each application by the manufacturer. This paper will focus on the red organic pigments for colouring plastics.

Colourants (pigments and dyes) can range from highly transparent through varying amounts of translucency to opaque. Dyes will be truly transparent, plastics themselves can be transparent to opaque. These varying opacity levels of colourants and plastics are major factors considered when determining colourant formulations for plastic products.

'Strength' and 'tint strength', which are both used interchangeably by the industry, are no absolute properties. Tint strength is a comparative measurement of a colourant in a plastic. Strength refers to how much colourability a given colourant has relative to another colourant at a given concentration *(Charvat 2004)*.

A typical colourant loading level in a finished plastic product is 0.5-2.0%. If there are opacity and/or light stability requirements, or if the polymer system is inherently difficult to colour, 5% pigment or more may be required to obtain stable colours *(Charvat 2004)*. For the colouration of rubber the addition of 1-3% of pigment is required *(Abele, Albrecht, Eholzer et al. 1977; Alili 1995)*.

SYNTHETIC ORGANIC PIGMENTS

PIGMENT CLASSES

Organic pigments can be classified according to their colour properties or their chemical structure. For identification purposes classification according to chemical structure is most useful. Organic pigments can be divided into different categories of which two are the most important for the colouring of plastics: the azo pigments and the polycyclic pigments. The azo pigments can be further divided into the monoazo pigments, which have a single diazo group, and the disazo pigments, which contain two diazo groups.

Figure 2 presents the division of pigment categories and pigment classes; those classes used for colouring plastics are underlined. *Figure 3* shows the molecular structures of the described pigment classes; the characteristic group identifying the pigment class is circled.

AZO PIGMENTS

Many of the red pigments used within the plastics industry contain the azo chromophore (-N=N-) within the structure of the molecule and as such are termed azo pigments. A further subdivision is possible into acid, monoazo metallised (or laked) pigments and non-metallised azo pigments. Typically, each of the metallised types contain an acidic group, such as sulfonic (-SO_3H) or carboxylic acid (-COOH) that will ionise and complex with a metal cation, such as calcium, barium or manganese, to form an insoluble metallised azo pigment.

By definition, all classical azo pigments contain at least one azo group and are all produced by a similar reaction sequence involving the chemical reaction termed diazotisation followed by coupling. Diazotisation involves the reaction of a primary aromatic amine with nitrous acid to yield a diazonium salt, which is then immediately coupled with the other half of the molecule to yield the coloured pigment.

The three most important pigment classes for plastics colouring, which are part of the azo pigments, are the -naphthols, the Beta-oxynaphthoic acid (BON) reds and the Naphthol Reds.

The β-naphthol pigment lakes are produced by coupling the diazoniumsalt with 2-hydroxynaphthalin (β-naphthol). The development of the azo pigment lakes started with the invention of the β-naphthol pigment lake Lithol Red in 1899 *(de Keijzer 2014)*. They are used in the form of sodium, barium, calcium or strontium salts. The light-fastness of the β-naphtols is good but decreases when used at lower concentrations.

The BON red pigment lakes are manufactured by coupling diazotised 1-amino-4-chloro-3-methyl benzene sulfonic acid onto 3-hydroxy-2-naphthoic acid (Beta-oxynaphthoic acid). They can be metallised with barium, calcium, strontium or manganese. These reds were first commercialised in 1910 *(Charvat 2004)*.

The Naphthol Reds are chemically defined as monoazos of 3-hydroxy-2-naphthanilide without anionicsalt-forming groups. They were first introduced in 1912. As a class, this group of pigments exhibits good tinctorial properties combined with moderate fastness to light, heat and solvents.

Disazo pigments contain two azo chromophores and they form the group including those pigment classes important for plastic colouring: the pyrazolone pigments and the disazo condensation pigments.

The first pyrazolone pigments were developed as early as 1910, their commercial application, however, was delayed by some 20 years. They are produced by bis-diazotisation of 3,3-dichlorobenzidine dihydrochloride or 3,3-dimethoxybenzidine dihydrochloride followed by coupling with two equivalents of the corresponding pyrazolone derivative *(Herbst and Hunger 2006)*.

The manufacturing of the disazo condensation pigments proceeds via the production of a monoazo carboxylic acid derived from the diazotisation and coupling of an aromatic amine with 2,3-hydroxynaphthoic acid. The monoazo carboxylic acid chloride obtained through chlorination is then condensed with an aromatic diamine at both amine sides to give the disazo condensation product. These types of pigments have been available commercially in Europe since 1957 and in the United States since 1960. Their outstanding light-fastness has resulted in their use in high performance end-use applications *(Charvat 2004)*.

POLYCYCLIC PIGMENTS

The polycyclic pigments do not form a single pigment class but comprise all compounds with condensed aromatic or heterocyclic ring systems. The most important polycyclic pigment classes for plastics are the quinacridones, the perylenes and the anthraquinones.

Quinacridone pigments are manufactured by either the condensation of 2,5-diarylamino-terephthalic acid or the oxidation of dihydroquinadrones. The quinacridones attracted no particular attention until 1955, when chemists in the pigments department of DuPont discovered its excellent light-fastness and methods for the preparation of its different crystal forms *(de Keijzer 2014)*.

Most of the perylenes have a structure as shown in the generic formula given in *Figure 3,* based upon N,N'-substituted perylene-3,4,9,10-tetracarboxylic acid diimide. The first introduction of these compounds as pigments came in 1950. Perylene pigments generally possess excellent fastness properties with respect to light, heat and weather while offering colourants of high colour strength *(Charvat 2004)*. A number of them have excellent heat stability, which makes them suitable to colour polyolefins which are processed at high temperatures *(Herbst and Hunger 2006)*.

Anthraquinone pigments are derived from 9,10-anthraquinone. In addition to simple anthraquinone derivatives, which provide mostly dyes, highly condensed structures based on anthraquinone ring systems are also produced that can be used as pigments.

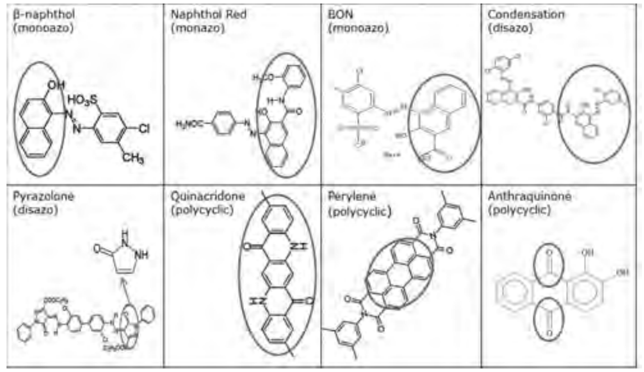


Figure 3
Molecular structures of the described pigment classes; the characteristic group identifying the pigment class is circled

Whilst other pigment classes may also be used for the colouration of plastics, this paper focuses on the most common pigments used in the plastics industry.

SYNTHETIC ORGANIC PIGMENTS USED FOR COLOURING PLASTICS

Table 1 shows the organic red pigments most frequently used in the plastics industry. It was compiled by comparing published data *(Charvat 2004)* with the available product variety of three different pigment suppliers (BASF, Profiltra and Crenovo) which sell pigments for plastics. In *Table 1*, seven of the pigment classes described above are represented.

The three pigments belonging to the β-naphthol pigment class are all metallised with barium; they show moderate light fastness, level 4-5 on a scale of 1 to 8 of the blue wool standard (BWS).

Pigment Red 48 (PR 48), a popular red pigment for plastics, can be metallised with a number of metals resulting in four different pigments with a different hue and different light fastness. PR 48:4, which is metallised with manganese, shows the best light-fastness of level 7 BWS.

Quinacridone Magenta (PR 122), Cromophtal Red BRN (PR 144), Perylene Scarlet (PR 149) and Perylene Maroon (PR 179) show the best light-fastness and are considered to be part of the high performance pigments. They show very good light and weatherfastness, solvent and bleeding fastness and low migration. Because of these properties, they are preferentially used in all applications which require excellent light and weather fastness, such as all outdoor applications like automotive coatings, exterior house paints and outdoor signs.

INSTRUMENTAL

Various analytical techniques can be used for the identification of the composition of plastics (POPART 2012) and organic pigments *(Lomax 2006)*. Although not always possible, non-invasive techniques like Raman spectroscopy and X-ray fluorescence (XRF) are preferred for material analysis of art objects.

Raman spectroscopy has proven to be successful in identifying synthetic organic pigments in paint layers *(Lutzenberger 2009, p.149; Vandenabeele, Moens, Edwards et al. 2000; Saverwyns and Fremout 2011)*. Hence, this technique was selected for this research.

X-ray diffraction (XRD), which is non-invasive for small objects, has also been used for identifying synthetic organic pigments in paint layers *(Lomax 2010)*. X-ray fluorescence, a non-invasive technique, can be used to identify inorganic compounds. The invasive techniques Fourier-transform infrared spectroscopy (FTIR) and pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) have proven their use for the identification of plastics (POPART 2012) and synthetic organic pigments *(Lutzenberger 2009, p.120)*.

For this research, Raman spectroscopy, FTIR, Py-GC/MS, XRF, and XRD were used to enable the identification of the widest possible range of types of plastic, additives and pigments.. Using these five different analytical techniques, reference plastics and red synthetic organic pigments were analysed. The resulting spectral data was collected in reference databases and used for the identification of organic pigments present in plastic objects from the van Oosten Reference Collection and objects of art.

FTIR

Spectra were recorded using a Perkin Elmer Spectrum 1000 FTIR spectrometer combined with a Golden Gate single reflection diamond ATR unit (sample size 0.6 mm^2). Spectra were recorded from 4000 to 600 cm^{-1}. The infrared spectra of the samples were compared with spectra of reference materials from the RCE Reference Collection.

PY-GC/MS

In coloured plastics, the pigment is incorporated into the polymer. Polymers can be identified by Py-GC/MS analysis, but analysing the pigments without the polymer by means of extraction or discrimination is not possible. Using pyrolysis as sample introduction technique, the polymer is fragmented and depolymerised. Additives like plasticisers, antioxidants and also the pigments are analysed together with the fragmented polymer. As a temperature of approximately 600 °C is needed to pyrolyse polymers, the pigment will also be decomposed into smaller molecular fragments. To avoid overload of the pyrolytic and chromatographic system, the sample amount used for Py-GC/MS analysis has to be small. Hence, the amount of fragments derived from any pigment contained within the sample will be even smaller, as the amount of pigment added to a polymer is only in the range of 0.5 % to 2 %. This means that Py-GC/MS, being a separation technique, can identify the pigments, as long as the produced pyrolytic fragments are specific enough.

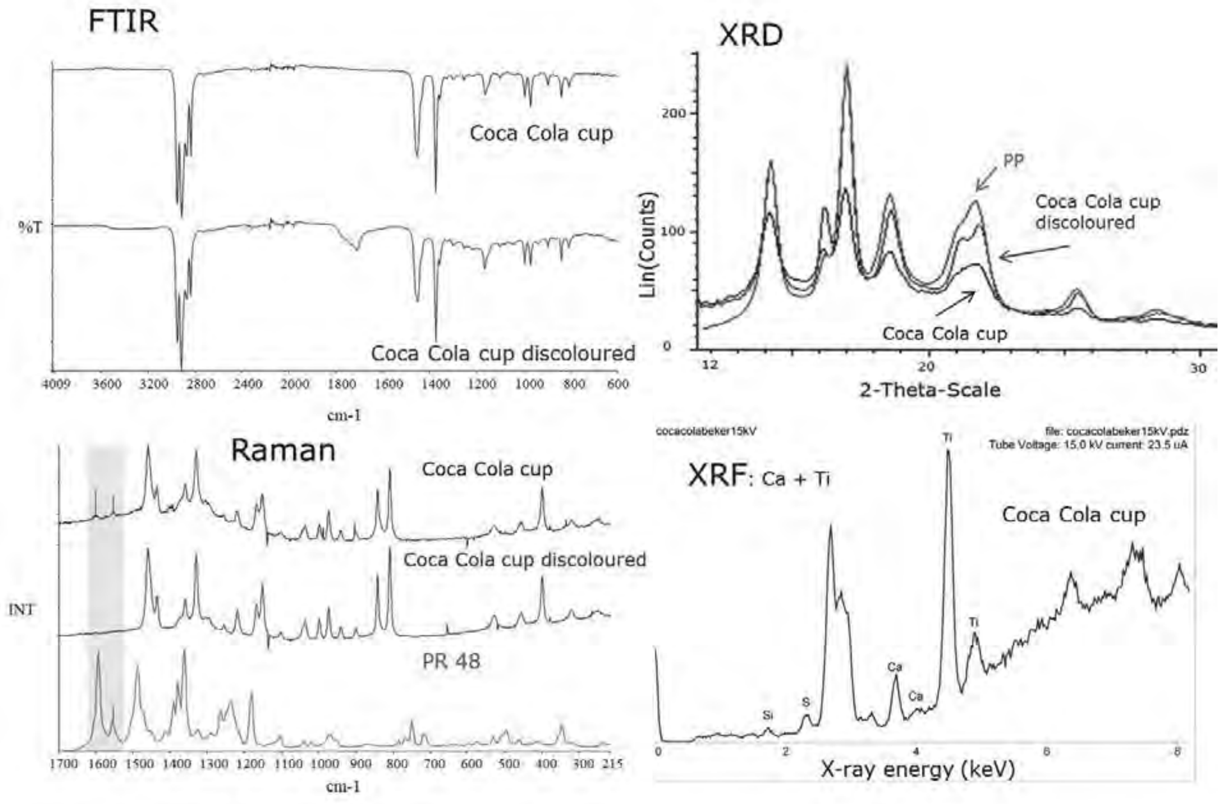


Figure 4
FTIR (upper left), XRD (upper right), Raman (lower left) and XRF (lower right) spectra of Coca Cola® cup

METHOD

The samples were analysed using pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). The sample material was placed in a steel pyrolysis cup. The cup was transferred into the pyrolyser and the sample was pyrolysed at 600 °C. The total component mixture was separated by gas chromatography and the separated components are detected and identified with mass spectrometry.

The pyrolysis unit used was a Frontier Lab 3030D pyrolyser mounted on a Thermo Scientific Focus GC / ISQ mass spectrometer combination. Separation takes place on a SLB5 ms (Supelco) column with a length of 20 meters, an internal diameter of 0.18 mm and a film thickness of 0.18 µm. Helium was used as carrier with a constant flow of 0.9 ml/min. The temperature program used was 35 °C kept stable for one minute, followed by heating at a rate of 16 °C per minute until 220 °C and then at a rate of 10 °C per minute until 315 °C, kept stable for 2 minutes. The column was directly coupled with the ion source of the mass spectrometer. The temperature of the interface was 250 °C, the temperature of the ion source was 220 °C. Mass spectra were recorded from 20 amu until 600 amu with a speed of 5 scans per second. Xcalibur 2.1 software was used for collecting and processing of the mass spectral data.

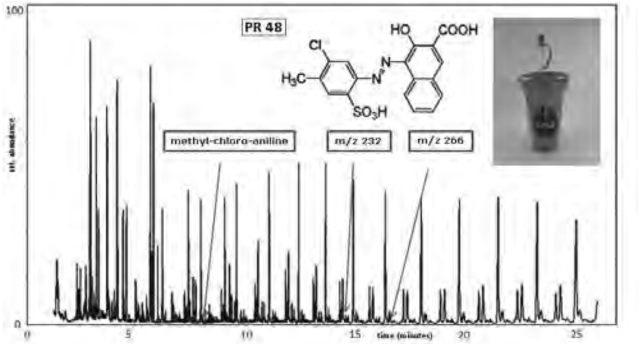


Figure 5
Py-GC/MS chromatogram Coca Cola® cup

Pigment	Class	Use	Light fastness (BWS)
Lithol Red (Barium) PR 49:1, 15630:1	**β-naphthol** pigment lake	Rubber, PE, PP	4
Pigment Scarlet (Barium) PR 60:1, 16105:1	**β-naphthol** pigment lake	PE, PP, PVC	5
Red lake C (Barium) PR 53:1, 15585:1	**β-naphthol** pigment lake	LDPE, PUR	4
Permanent Red F5KK PR 170, 12475	**Naphthol Red**	PE, PP, PVC	6
Permanent Red 2B Barium PR 48:1, 15865:1 Calcium PR 48:2, 15865:2 Strontium PR 48:3, 15865:3 Manganese PR 48:4, 15865:4	**BON** Pigment lake	PE (PS) PE, PP, PVC	4 5 5 7
Pyrazolone Red PR 38, 21120	**Pyrazolone**	Rubber	6
Quinacridone Magenta PR 122, 73915	**Quinacridone**	Rubber, PVC, PE, PP, PS	8
Cromophtal red BRN PR 144, 20735	**Disazo Condensation**	PVC, polyolifins, fibres	7-8
Perylene Scarlet PR 149, 71137	**Perylene**	PE, PP, PS, ABS, PET, PCV	8
Perylene Maroon PR 179, 71130	**Perylene**	PE, PP, PC, PS, ABS, PET, PVC, PA, PMMA	8

Table 1
Synthetic organic pigments used for colouring plastics

RAMAN SPECTROSCOPY

For Raman measurements, the Micro 300 Raman microscope was used in combination with a PerkinElmer Raman Station 400F. The Raman spectrometer was equipped with a CCD detector and a diode laser operating at 785 nm with a maximum power of 96 mW. For the Raman microscope measurements, the 50x objective was used, resulting in a spot size of 20 µm. To avoid degradation of the plastics, the power of the laser was reduced to values between 20 and 70 mW. An integration time of 10 seconds in combination with 50 to 60 exposures was chosen to obtain an adequate signal to noise ratio.

XRF

X-Ray Fluorescence Spectrometry (XRF) was performed with a Bruker Tracer III-SD instrument equipped with a thin Rhodium target X-ray tube, operating at 40 kV and 10.4 µA, and a 10 mm^2 Silicon Drift detector with a resolution of 145 eV. The instrument was placed in contact with the object and the measurement was performed for 60 seconds.

XRD

X-ray diffraction of the pigments and plastics was performed with the Bruker D8 Discover micro-diffractometer with GADDS (General Area Detector Diffraction System). The system was equipped with a HiStar 2D detector, a CuK radiation x-ray tube operating at 40 kV and 30 mA and a microscope camera system to position the samples. Samples were mounted on a zero background silicon wafer with a little cedar oil and placed on the XYZ-stage. The Bruker GADDS software (version 4.1.42) was used to integrate the 2D data to diffractograms which were compared with the PDF database (release 2000) using the Bruker Eva software (version 9.0.0.2).

ANALYTICAL RESULTS

CASE STUDIES OF REFERENCE OBJECTS

COCA COLA® CUP

A *Coca Cola®* cup from the 1990s shows discolouration on the outside, whilst the inside has not been exposed to light, hence showing no discolouration *(see Figure 1)*. The FTIR spectrum of the *Coca Cola®* cup *(Figure 4, top left)* shows the absorption bands specific for polypropylene and the carboxyl absorption band at 1714 cm^{-1} indicates that the polypropylene is highly oxidised. The FTIR spectrum does not show any absorption bands related to an organic pigment, but it is possible that the pigment concentration falls below the detection limit of the technique, which is around 4-5% depending on the components.

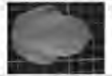
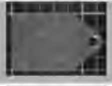
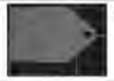
Object		Material	Raman	py-GC/MS
Rimpfishhorn Handicap, part 1		Isoprene + Styrene butadiene rubber (SBR)	Spectra Pac E Orange 16 (PO 16)	Spectra Pac E Orange 16 (PO 16)
Wolford® Red tights used by Madeleine Berkhemer for her works of art		PA6,6 + PA6	Acid Red 151	Cloth Scarlet (Acid Red151) Congo Red (Direct Red 28)
Mini Panton chair		Polystyrene (PS)	Aromatic pigment	Permanent Red 2B (PR 48)
Tulip flower		Polyethylene(PE)	Aromatic pigment	Possibly PR 149
Universal-Masterbatch Standard, Color Service GmbH&Co UN 33049		Polystyrene (PS)	Below detection limit	Permanent Red 2B (PR 48)
Universal-Masterbatch Standard, Color Service GmbH&Co UN 3673		Polystyrene (PS)	Below detection limit	Sunbrite rubine 4BK (PR 57)
Coca Cola® cup		Polypropylene(PP)	Aromatic pigment	Permanent Red 2B (PR 48)
Stopper		Isoprene + Styrene butadiene rubber (SBR)	Pyrazolone	Sunbrite red 38 (PR 38)
Cup		Polystyrene (PS)	Below detection limit	Permanent Red 2B (PR 48)

Table 2
Results Raman and py-GC/MS analyses of red coloured plastic daily live objects and works of art

The XRD spectrum *(Figure 4, top right)* only shows the presence of polypropylene whilst no evidence of organic pigments was found. The latter suggests that the pigment concentration falls below the detection limit of this technique, too. The XRD spectrum of the discoloured part of the cup shows sharper bands caused by crystallisation of the polypropylene due to ageing.

The Raman spectrum *(Figure 4, bottom left)* shows Raman shifts for polypropylene at 1457, 1329, 839, 809 and 397 cm^{-1} and Raman shifts at 1600 and 1554 cm^{-1}. The latter are specific for aromatic rings, which in this case presumably originate from the organic red pigment. These Raman shifts are not detected in the spectrum of the discoloured part of the *Coca Cola®* cup.

Py-GC/MS analysis of a sample of the *Coca Cola®* cup showed that the cup is composed of polypropylene. The organic pigment was identified as Permanent Red 2B (PR 48), the molecular structure of which is shown in *Figure 5*.

PR 48, one of the frequently used pigments for plastics, is a pigment of the BON class. All BON pigments contain beta hydroxy naphthoic acid in their molecular structure. Pyrolysis of the pigment will decompose the pigment into smaller molecules related to the original molecular structure. The presence of beta hydroxy naphthoic acid alone detected in a coloured plastic using Py-GC/MS analysis might indicate the pigment class; however it is not specific enough to identify the pigment itself.

Py-GC/MS analysis shows a large range of abundant component peaks, which arepyrolysis products originating from the polypropylene polymer *(Figure 5)*. Between these are a couple of small component peaks, polymer fragments, originating from the pigment. Marked in the chromatogram are chlorinated aniline and two other, yet unknown compounds with an abundant ion at mass 232 and at mass 266, respectively. The presence of these three compounds and also their variation in amount clearly identifies the pigment PR 48.

To locate these characteristic compounds in the complex matrix of the polypropylene compounds, the special Amdis® software was used. Amdis® was developed to locate target compounds in complex chromatographic analyses. By comparing mass spectral data present in the chromatographic runs with those data stored in an Amdis® mass spectral library *(Amdis 2014)*, target compounds can be located. The Amdis® pigment library used in this research was built by storing general and specific mass spectral data obtained from organic pigments used in plastics and gained from Py-GC/MS analysis of known pigments. Identification was done by comparing the located and identified pigment compounds and a decision tree.

XRF analyses provided additional information about the inorganic components in the *Coca Cola®* cup. The spectrum *(Figure 4, bottom right)* shows the presence of calcium and titanium. The presence of calcium suggests that Pigment Red 48 is present in the form of the calcium salt PR 48:2. The titanium was probably present in the form of titanium oxide and used as a filler *(Miller 1983)*.

From the results above it can be concluded that in this case FTIR and XRD are not suitable for the identification of low concentrations of organic pigments in plastics. Analysis of other red plastic objects confirmed this conclusion. Py-GC/MS and Raman give the best results for identifying organic pigments in plastics.

BOTTLE STOPPER

A stopper from our reference object collection *(Table 2)*, which was used for closing wine bottles, contains an orange coloured, degraded rubber material.

The Raman spectrum shows a strong Raman shift at 1597 cm^{-1} which is specific for the carbonyl in the pyrazolone functional group. From the Raman analysis it can be concluded that the pigment is a member of the Pyrazolone pigment class.

Py-GC/MS analysis of the rubber of the stopper shows that it is made of a mixture of isoprene and styrene butadiene rubber (SBR). Amdis® identified isocyanato benzene and a couple of chlorinated bi-phenyls. The combination of these compounds proves the presence of Sunbrite red 38 (PR 38) of the Pyrazolone class.

CASE STUDIES OF ART WORKS

RIMPFISHHORN HANDICAP, PART 1

The *'Rimpfishhorn Handicap, part 1'* (1991) is an object by Seymour Likely, an artist collective from Amsterdam. The object is part of the Dutch State collection which is part of RCE. The object is composed of orange coloured fins, normally used for swimming, adhered to a wooden circular board.

The material of the fins was analysed using FTIR and the resulting spectrum showed the specific absorption bands of isoprene and styrene butadiene rubber (SBR). The Raman spectrum showed Raman shifts which are also present in the reference spectrum of Pigment Orange 16. Py-GC/MS analysis confirmed the presence of Pigment Orange 16 as well as the presence of the isoprene-butadiene-styrene copolymer.

NYLON WORKS OF ART BY MADELEINE BERKHEMER

The artist Madeleine Berkhemer lives and works in Rotterdam, The Netherlands. She creates erotically charged work. Her sculptures, drawings and performances are defined by the heterogeneity of their materials and styles. They are an investigation of the dimensions of time and space and a radical examination of social and economic conditions. The artist's installations typically include nylon tights tied around objects which imparts mechanical stress on the nylon tights which in turn might affect the ageing of the work of art. Moreover, the environment in which the art works are displayed is affecting the stability of the object. Berkhemer contacted RCE expressing her worries about the possible loss of strength of the nylon tights. To prolong the life of these works of art research into the proper conservation was set up at RCE in close collaboration with Berkhemer. Berkhemer only uses high quality tights, in particular those of the Wolford® brand, and she gladly supplied the RCE with several of the red tights she used in her works.

The red nylon tights were analysed with Raman spectroscopy and the Raman shifts of Cloth Scarlet (Acid Red 151) were clearly present in the Raman spectrum. Cloth Scarlet is not a pigment but a synthetic dye. In this case, Cloth Scarlet was used to dye the nylon fibres. For testing a discoloured sample dyed with Cloth Scarlet, one of the red tights was artificially light aged. The Raman spectrum of this faded part showed that the Raman shifts of the dye were not present anymore; the Cloth Scarlet was no longer present as red coloured dye.

Py-GC/MS analysis of the red tights confirmed the presence of Cloth Scarlet, however, a second dye, Congo Red (Direct Red 28), was identified *(de Groot, van Keulen and van Oosten 2013).*

CONCLUSION

For the colouration of plastics, pigment concentrations ranging from 0,5% to 2% are used, and for the colouration of rubbers, concentrations ranging from 1-3% are used.

As these concentrations are too low for identification using either FTIR or XRD, these techniques are unsuitable for identifying organic pigments in plastics.

Using Raman spectroscopy, it was possible to identify the pigment class of the pigment in the rubber bottle stopper. In the case of the nylon stockings, it was possible to identify the dye due to the fact that the dye is present on the surface of the nylon fibre.

In contrast, Py-GC/MS enabled the identification of the organic pigment in many of the objects from the van Oosten Reference Objects Collection. This fact was confirmed by the analyses of the *Coca Cola®* cup.

Permanent Red 2B (PR 48) appears to be a popular red pigment for colouring plastics, as it was identified in several red plastic objects.

ACKNOWLEDGEMENTS

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LECTURE
003
REVERSIBLE AIRBRUSH RETOUCHING ON FADED GLASS FIBRE REINFORCED PLASTIC OBJECTS

BY MICHAELA TISCHER, JULIA DEMETER (NEE REISCHL)

ABSTRACT

Experience shows that retouching monochrome plastic surfaces can be a very challenging task: manual paint applications by hand very rarely match the appearance of industrially produced plastic surfaces. Therefore, the conservation department of Die Neue Sammlung, The International Design Museum, Munich, initiated a research project in collaboration with the Chair of Restoration-Conservation, Art Technology and Conservation Science at the Technische Universität München in 2011 to investigate the use of airbrush as an alternative retouching technique for artworks made of plastics. In this context, a method for retouching glass fibre reinforced unsaturated polyester resins (GR-UPs) was developed, composed of a reversible multilayer system. The project resulted in the conservation of a sun lounger designed by Luigi Colani, from the furniture collection of Die Neue Sammlung. The following paper outlines the conservation treatment of the lounger's heavily worn and discoloured surfaces with a special focus on the use of an airbrush retouching method.

KEYWORDS

Airbrush, retouching of monochrome surfaces, plastic discolouration, glass fibre reinforced unsaturated polyester resin, GR-UP, GRP, Luigi Colani

INTRODUCTION

In our daily work as conservators, we are often confronted with objects made from different kinds of plastics, which have irreversibly changed not only by climatic influences and light exposure but also by wear and tear or inappropriate treatments.

These chemical and physical changes in the material often result in a visual alteration of the surface such as loss of gloss, discolouration or greying induced by micro-cracks.

Design pieces that display these kinds of condition issues often suffer from a general lack of acceptance and remain in storage or are less likely to be displayed.

Therefore, it is desirable to find conservation treatments that improve the visual appearance of aged plastic surfaces, especially in terms of gloss level and colour. Past experience has shown that retouching monochrome surfaces with a brush can be very challenging as the texture of brushstrokes rarely matches the plastic's uniform factory produced finishes. That is why Die Neue Sammlung initiated a research project in collaboration with the Chair of Restoration-Conservation, Art Technology and Conservation Science at the Technische Universität München to investigate better methods for the retouching of heavily altered plastic surfaces by using airbrush.

The one year research project, which took place in the conservation department of Die Neue Sammlung from 2011–2012 was divided into two main parts: First, the workability of conservation graded materials via airbrush was subject to an extensive series of tests. This included examining suitable materials, which would work as surfactants, keying agents, barrier coats and coatings on different kinds of plastic. Finally, a reversible layer structure for retouching glass fibre reinforced plastics (GRPs), consisting of a suitable barrier coat, paint layer and coating, was developed. The second part focused on the practical application of these results to an aged GRP object. The Colani sun lounger made of glass fibre reinforced unsaturated polyester resin (GR-UP) from the collection of Die Neue Sammlung was chosen since its heavily weathered and partially faded surface made it a perfect case study object *(see Figure 1)*.

LUIGI COLANI´S GARDEN LOUNGER

The orange lounger is part of a garden furniture collection, designed by German designer Luigi Colani in 1967, and was produced in 1969 by Essmann KG, Bad Salzuflen, in a small edition (1). The chair, which measures 173 x 80 x 96.5 x 28cm (L/W/H), is made of glass fibre reinforced unsaturated polyester resin (GR-UP) and manufactured by hand lay-up,

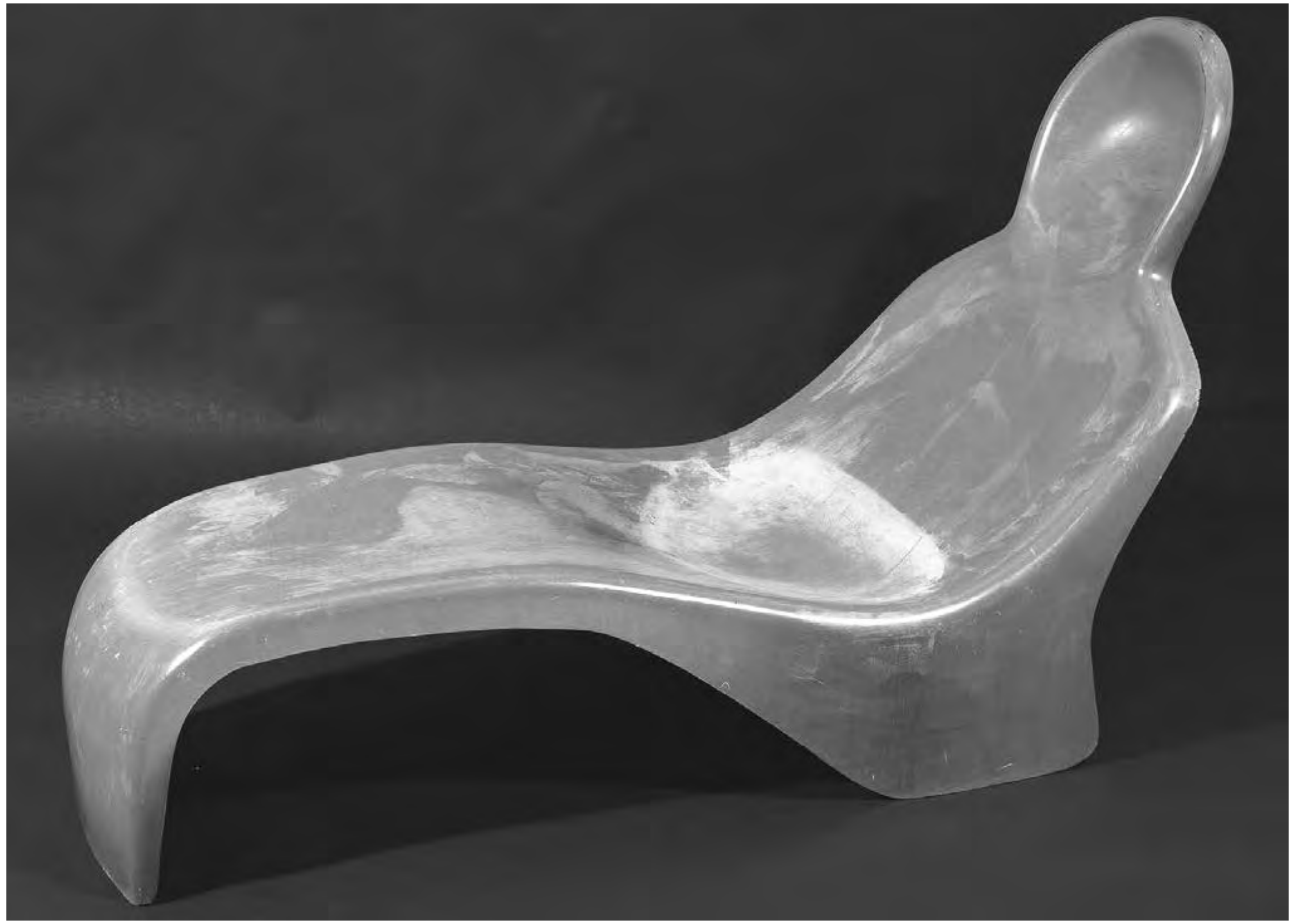


Figure 1
Garden lounger before conservation treatment

which we will briefly discuss below.

Based on Colani´s principle of „Biodesign“, the lounger's shape is organically flowing without any hard edges or right angles. With his seating furniture, Colani intended to create negative forms for the positive shape of the human body *(Dunas 1993: 74):* the lounger with its anthropomorphic and ergonomic shape fits well into this concept.

MANUFACTURING GLASS FIBRE REINFORCED PLASTICS (GRPS): HAND LAY-UP

With this simple and cost-efficient production method, the laminate, which is composed of epoxy (EP), or unsaturated polyester resins (UP) and glass fibres, is applied to a mould. First, several resin layers are applied all over the inside of the mould, which has been prepared with a release agent. These top layers of resin are referred to as a "gel coat", since the resin has to be slightly cured ("gelled") before the next step. Then, a layer of reinforcing material such as glass fibre (fabric or loose fibres) is placed inside the mould, and the next resin layer is applied with a roll or brush to saturate the reinforcing layer. Additional layers may be applied until the required thickness is achieved (usually 0.5–1cm). When the resin product is fully cured, it can be removed from its mould: the gel coat is now the exterior layer of the GRP product.

This production method is used, in particular, for the manufacturing of prototypes, large sized objects, individual items, and small-scale series *(Taprogge et al. 1975: 59).*

DAMAGE SYMPTOMS AND ALTERATIONS

The garden lounger was added to the collection of Die Neue Sammlung in 2003 (Inv. No. 337/2003). Previously, it was privately owned and was presumably stored outdoors, at least periodically, as is customary with garden furniture. Thus, the piece was exposed to environmental influences such as weathering, fluctuations of temperature and humidity, and UV-radiation. As a result, the lounger showed characteristic damages, including losses in the gel coat (especially along the edges), and inner layer delamination in the GRP bond *(see Figure 2).* Additionally, mould and foxing stains affected not only the visual appearance, but also the material itself. The most evident change was the lounger's severe, partial white discolouration, which was particularly present on the seating and back, and involved loss of the surface gloss *(see Figure 3).* The colour change, from bright orange to a grey-light orange, was caused both by weathering, and, very likely, also by improper cleaning methods. Through outdoor use of the lounger it was exposed to rain, with water collecting in the seat area, which affected the plastic surface, and caused leaching and micro cracks. Due to incorrect cleaning white-coloured traces of wiping are visible where the gel coat was thinned by an aggressive detergent, containing, for instance, acetone. Finally, there were typical signs of use and wear, such as a range of scratches, abrasions and dents.

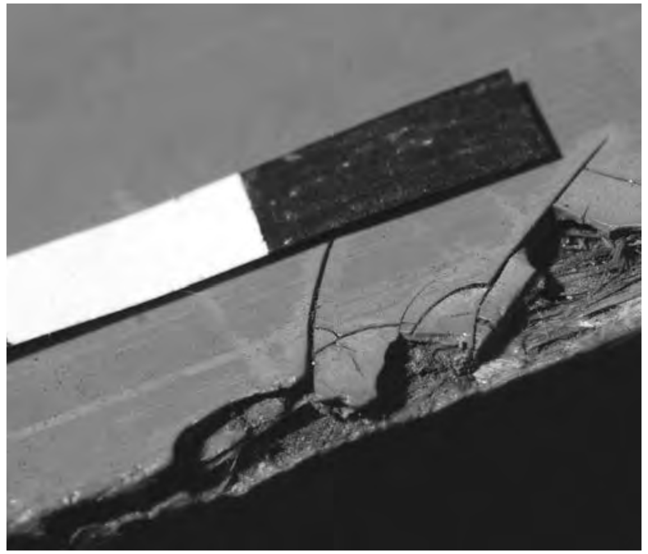


Figure 2
Delamination and losses along the edges before treatment

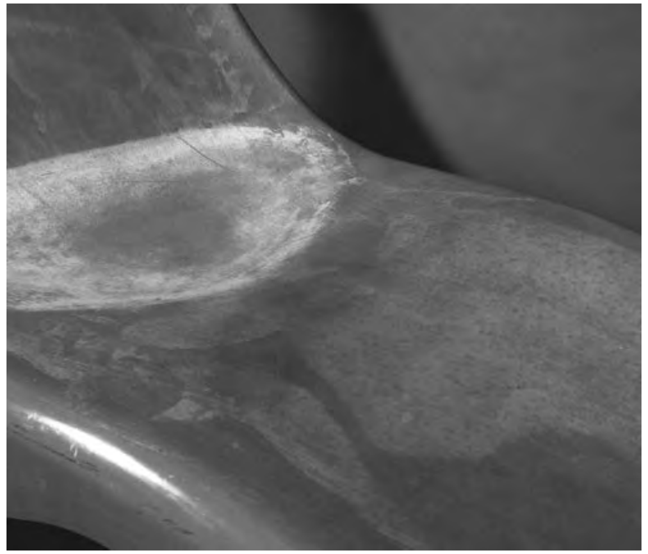


Figure 3
Discoloured seating area before treatment

CONSERVATION CONCEPT – CONSIDERATIONS AND AIMS

The curators of the museum decided that the lounger should not go on display in its compromised condition, because the prominent condition changes and damages - above all the whitish discolouration - would have distracted the viewer´s attention from the designer's intended organically flowing appearance.

The plastic material was not only affected visually, but also physically due to the mould infestation. Therefore, conservation treatment was urgently required. In dialogue with the conservation staff and the curators in charge, it was defined precisely which changes and alterations should remain to preserve the history and read-ability of the lounger, and also which conservation treatment would be realistic based on the available time and capabilities of the staff.

Two key aims for the conservation treatment were formulated:

1) *Traces of common usage of the lounger as a piece of utilitarian furniture, like scratches at exposed positions, should be left visible*
2) *Other damages, which visually affected the appearance of the piece, such as losses, mould and discolouration, were to be treated.*

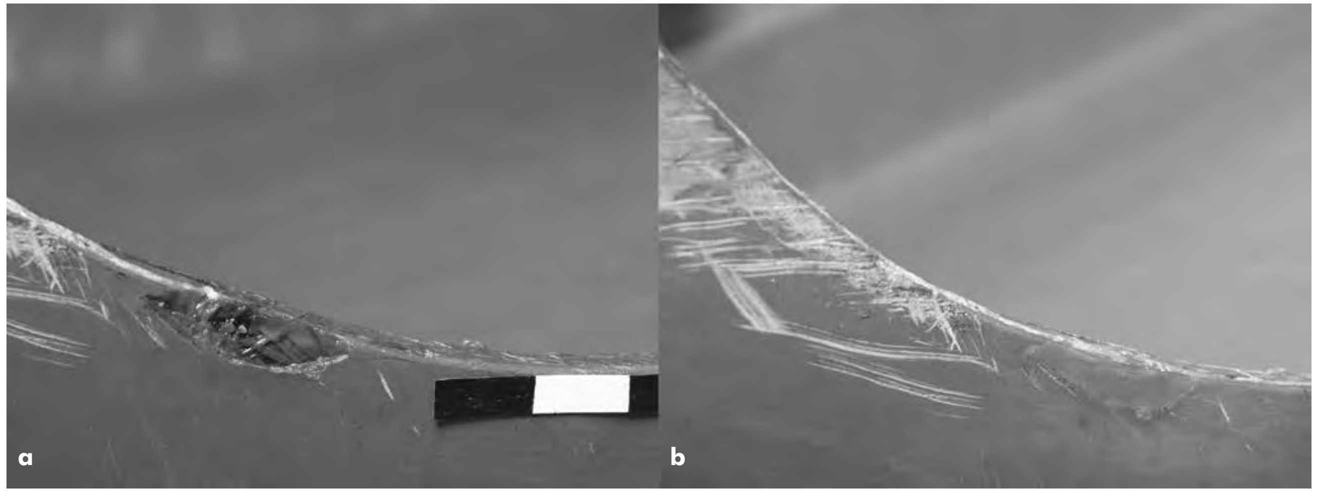


Figure 4
Losses before (a) and after filling (b)

The treatment was meant, not only to stabilise the lounger's condition from a conservation point of view (in terms of cleaning, disinfecting and consolidating), but also to obtain a more uniform and aesthetically pleasing appearance with regards to surface colour and gloss.

DISINFECTION AND CLEANING

As a first step in the treatment, the mouldy surface was disinfected with alcohol and demineralised water (70:30). The reduction of the mould stains immediate alleviated the patchy appearance of the surface. The slightly greyish film of dirt was removed by cleaning with a non-ionic surfactant solution (Marlipal® 1618/25 0.5% in H_2O).

CONSOLIDATION

Contradictory recommendations were found in the conservation literature with regards to the consolidation of losses and delamination. After carrying out consolidation tests with cold-setting fish glue and different synthetic resins, the acrylate resin Paraloid® B72 proved to be the most suitable to re-adhere the very stiff, lifting gel-coat flakes. The acrylate resin was dissolved in Toluene, since GR-UP´s are not soluble and do not swell in this solvent *(Braun 2003: 112)*. Hence, the bond between the adhesive and the plastic was not created by chemical fusing, but by the physical process of adhesive bonding (2).

IN-FILLS

The losses were filled with an orange-pigmented glue-chalk-filler (3) *(see Figure 4)*. The fillings had a dual function. On the one hand, it has a protective function as exposed glass fibres can be seen as the GRP bond's "weak spots" due to their capillary action. Humidity destabilises the cohesion between fibre and resin layers, and can therefore lead to breaks in the composite structure *(Waentig 2004: 262)*. On the other hand, the in-fills have an aesthetic function: they ensure that the beholder can read the outlines of the lounger again without the distraction of losses along the edges.

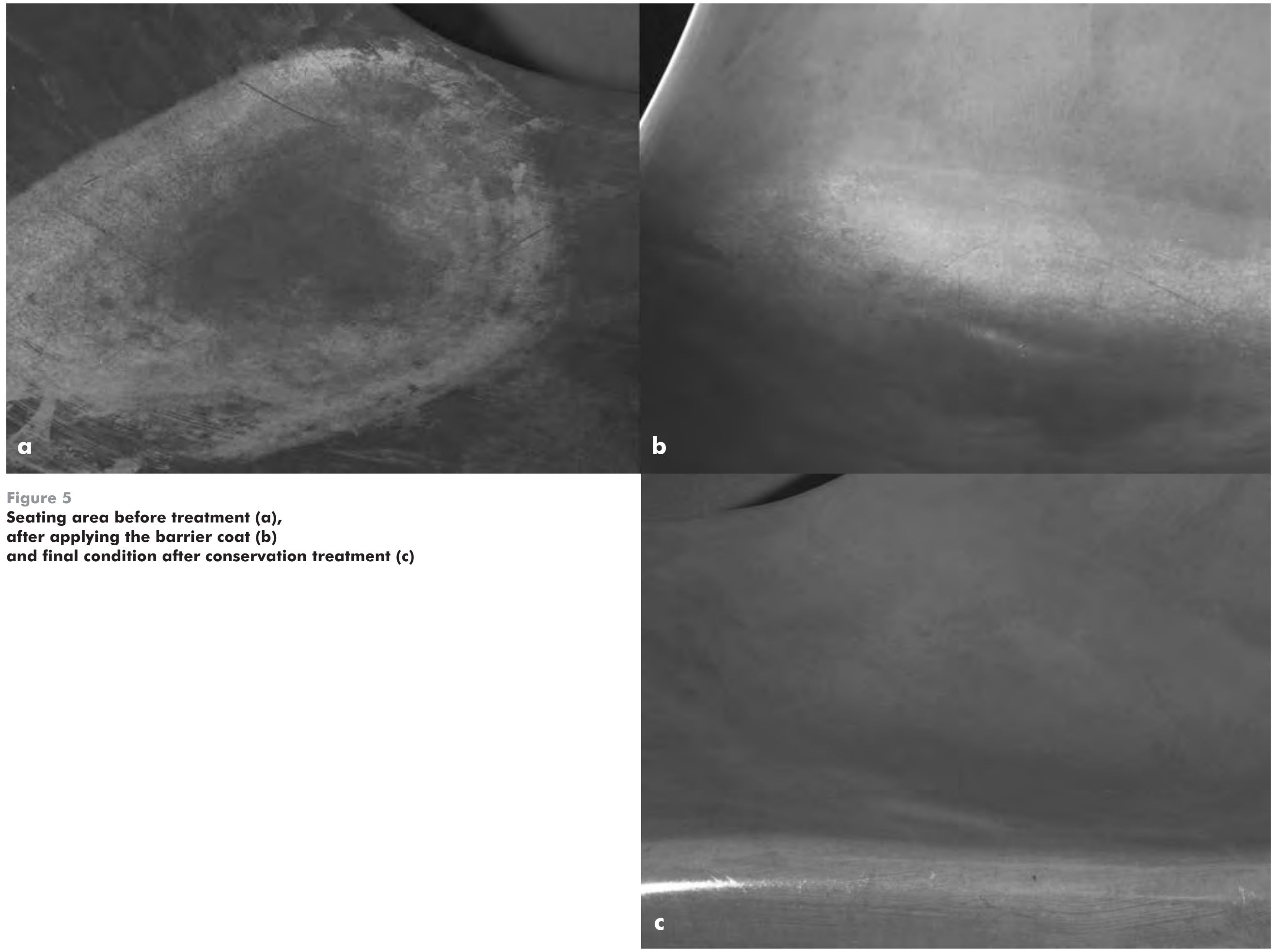


Figure 5
Seating area before treatment (a), after applying the barrier coat (b) and final condition after conservation treatment (c)

CONSIDERATIONS ON RETOUCHING

As mentioned above, the conservation team and curators decided to keep scratches and traces of usage visible, but to reduce the conspicuous white discolouration of the seating area and the patchy surface of the backrest that negatively affected the overall impression of the lounger. The aim was to achieve a monochrome surface, which matched the original industrially manufactured look of the lounger, as it was visible in the more homogeneously aged and intact surface of the sides of the lounger.

Reducing the discolorations without "overpainting" the surface was a challenge. Given the damages and chosen treatment plan, it was clear that in terms of adapting surface colour and gloss a new method had to be considered. A traditional retouching technique, carried out with a paintbrush and paint, would not have worked on this piece. The impression that the very fine and detailed brushstrokes and the personal "ductus" of the conservator would create, did not fit the appearance of the monochrome, industrially manufactured plastic surface. Instead, to avoid an opaque finish and to only optically reduce the discolorations while keeping traces of normal usage visible, a homogeneous and translucent paint coat was required. These considerations led to the decision to try airbrush as a „non-contact“-retouching tool.

THE AIRBRUSH TECHNIQUE

Airbrushing is a painting technique, which employs a spraying gun, connected to a compressor. Air is blown through a tube to a nozzle at the front of the airbrush. The correct working pressure depends on the paint viscosity, the nozzle size and the airbrush gun itself. The lower one sets the working pressure, the narrower the spray becomes and vice versa (4). The speed of the air creates a pressure drop, which causes suction, pulling paint from the reservoir. Then, both air and paint are blown out as an atomised spray (5). The separately diffused paint droplets almost dry out before they impact the surface, obtaining a matt finish and a transparent paint layer. Airbrushing thus differs from varnishing, where the paint particles - which are rich in binder agents - merge, obtaining a highly glossy appearance and a sealed coat of paint.

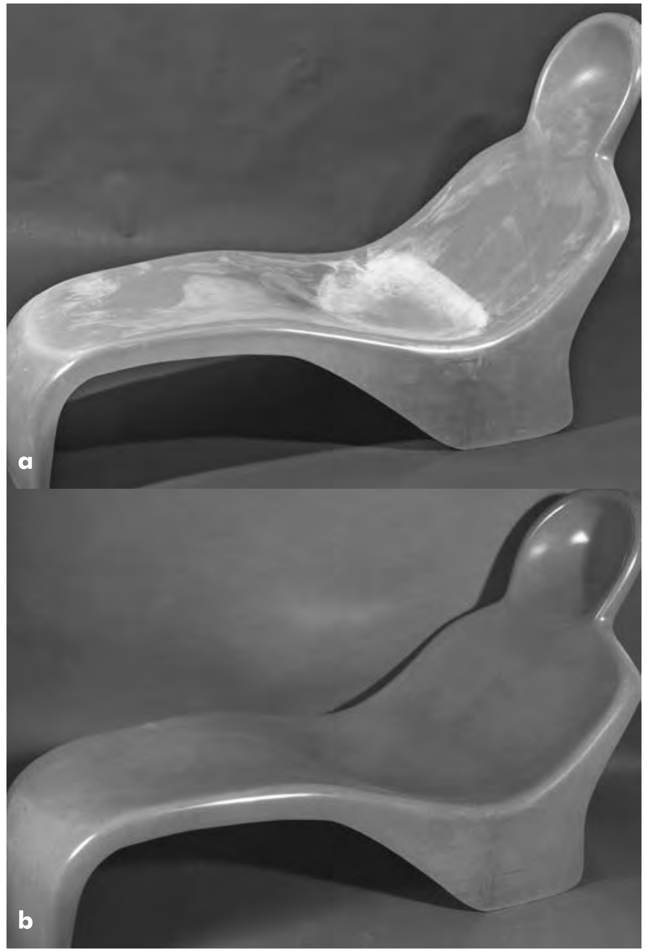


Figure 6
Garden lounger before (a) and after conservation treatment (b)
(see colour plate, p. 162)

AIRBRUSHING AS RETOUCHING TOOL ON GRPS

There is a large amount of literature on the use of airbrushing within the arts and crafts field, but despite the fact that some conservators have been empirically working with airbrush as a retouching, consolidation or cleaning tool, we could hardly find any specialized conservation literature about the use of airbrushing in general, or more specifically on plastics. As a result, a series of tests had to be undertaken first, to learn which conservation-graded retouching paints could be used with a standard airbrush gun. Extensive tests on Bristol board and different plastics made clear which paints, surfactants, keying agents, barrier coats and coatings work to obtain an appropriate colour and surface appearance that would also be reversible (6).

CONSIDERATIONS ON THE LAYER STRUCTURE OF THE RETOUCHING

A barrier coat between the plastic and the retouches was needed to act as an adhesion agent, and as a barrier to protect the plastic from a finely dispersed paint coat.

It was necessary to take into account that the different layers (plastic, barrier coat and retouching) should be soluble in solvents of different solubility ranges to ensure that the barrier coat could be removed easily from the plastic surface without damaging it, and the retouching could be removed from the barrier coat (in case the colour does not match after the first try, or if it would change after several years). A finishing coat finally protects the retouching from abrasion and allows the modulation of the final gloss level.

THE BARRIER COAT

Aged GRPs, whether epoxy or polyester resins, are not resistant to polar solvents like keton or ester. Therefore, a barrier coat dissolved in a nonpolar solvent is required. In this case the synthetic hydrocarbon resin Regalrez® 1126, which was recommended by the manufacturer as coating and is highly stable while soluble in petrol seemed suitable.

Prior to applying Regalrez® 1126 (10% dissolved in the hydrocarbon solvent Shellsol® T), tests were carried out to examine the best way to apply the coat: spraying via airbrush, or brushing via a brush. Applying the Regalrez layer with a paintbrush proved to be the most suitable since a continuous and even film was achieved, which was required to obtain a closed surface structure and to level out unevenness in the GRP surface. The sprayed coat proved to be too thin and not continuous, and it therefore would not have worked as a successful protective barrier coat.

An additional benefit became apparent after the application of a thin layer of Regalrez® 1126 to the entire surface with a broad badger hair brush (7): the mould stains were reduced and the surface showed a more homogeneous appearance. After 24 hours, a matt even film was created due to the great film-formation properties of Regalrez® 1126.

RETOUCHING

To ensure the removability of the paint used for the retouches from the barrier coat, water-soluble paint was needed. In the test phase, gouache paints had shown good results with regards to their workability with an airbrush gun. For the retouching, highly stable, non-fading Schmincke Horadam® Gouache paints were therefore chosen. To obtain a homogeneous coat, a surfactant needed to be added, which reduced the water surface tensions of the single paint drops.

For the retouching process, two Gouache mixtures (8) with a drop of Surfynol® 61 (9) as surfactant were prepared. The spraying was carried out crosswise and lengthwise with an airbrush gun with a nozzle of 0.2mm diameter (10). Altogether, ten coats of the gouache mixture were applied from a spraying distance of 20–25cm, and 3 bar working pressure.

The result of this treatment, that took place in 2012, is quite satisfactory. A slightly transparent colour veil was achieved, which reduced the intensity of the whitish discolouration and the stains *(see Figure 5)*, while the scratches and surface irregularities remained visible.

FINISHING COAT

To complete the treatment, the sensitive Gouache layer had to be sealed with another coating. This was also desirable because the appearance of the retouches was a little too matt, and had to be adjusted to match the gloss level of the homogeneously aged sides of the lounger. Tests on dummies were first carried out to find a suitable product for the finishing coat like hide glue, gum arabic, shellac, microcrystalline wax, and Regalrez® 1126.

Regalrez® 1126 (25% in Shellsol® T) applied using an airbrush gun with a nozzle of 0.4mm diameter (11) showed the best results, achieving a homogeneous film with a gloss level close to the intact original surfaces.

It should be noted here however, that although the Regalrez-coating created a favourable surface appearance, a coating of the same solubility as the retouching paint should be favoured, as this would facilitate the simultaneous removal of the coating and retouching from the barrier coat in case a colour change should occur at any time. In 2013, prior to the Future Talks 013 conference, further tests were therefore carried out to find suitable coating methods and materials. One of the methods explored was to first polish the slightly grainy Gouache retouching, and then spray it with the water-soluble synthetic resin Aquazol® 200 as a coating. This method was chosen because it became apparent that densifying the Gouache layer, would increase the gloss level of the coating. After polishing the paint layer however, the gloss level of an Aquazol coating – which before could not nearly reach the gloss level of the sprayed hydrocarbon resin Regalrez – could, in most cases, achieve a satisfactory gloss level.

CONCLUSIONS AND PROSPECTS

The case study of the Colani lounger thus proved that reversible airbrushing could be a viable treatment method on a faded GRP object. At the same time, it is clear that there is a further need for research as the method currently also has its limitations. In practical terms, it takes quite some experience in the spraying technique before a homogeneous paint coat is achieved, especially in the case of larger surfaces. It is, in addition, not easy to achieve the exact colour hue when preparing the retouching paint.

There is a particular need for further research regarding materials and methods for coating. A suitable finishing coat not only secures the paint layer, but also achieves a particular level of gloss that can range from high-gloss to matt. Since it can affect the paint layer through changes in the colour, colour depth or transparency, the impact of a specific coating on the appearance of retouches should be tested prior to its application onto the actual retouched areas. From our tests we learned, for example, that a polished microcrystalline wax may create high-gloss surfaces successfully, but it darkens the retouches and makes them considerably more transparent. Test series prior to deciding for a suitable coating material are thus required taking into account the specific conditions of the GRP object considered for treatment using airbrush coating.

Through our experiments and chosen treatment plan, the Colani lounger's condition could be stabilised from a conservation point of view with the aid of disinfection, cleaning and consolidation. Through in-fills, barrier coat, retouching and coating, the damages and alterations were optically reduced. The appearance of the lounger is no longer dominated by blotchiness and discolouration, but is characterized by a homogeneous surface, close to the still intact surface of the sides of the lounger (see Fig. 6). The very obvious white discolouration of the seating area was reduced in its intensity, but is, together with the scratches and dents, still partially visible. In this way, the history and usage of the lounger are visually preserved, enabling us to experience Luigi Colani´s lounger for what it is: a great design piece.

ACKNOWLEDGEMENTS
The authors would like to thank Dipl. Rest. Univ. Tim Bechthold, MA Barbara Schertel and Dr. Josef Straßer from Die Neue Sammlung, The International Design Museum Munich for sharing their knowledge and experience. Many thanks also to Prof. Dipl. Rest. Erwin Emmerling from the Chair of Restoration-Conservation, Art Technology and Conservation Science at the Technische Universität München.

ENDNOTES

(1) *In spring 1969, the lounger was produced in small numbers and in different colours: white, yellow, red, orange, blue, green, black: "Colani provided this furniture with brilliant colours thus inviting to have a seat already by the attractive colouring" (md 1969: 82).*

(2) *For the consolidation of GRP's Waenting does not recommend adhesives that contain a component like ethyl acetate or acetone, which dissolves the plastic. The bonding would be created through irreversible fusing – structural changes could entail accelerated ageing at the bonded areas.*

(3) *Filler made of 7% hide glue and chalk from Champagne and from Bologna (1 pbw : 1 pbw); pigmented with cadmium yellow and cadmium orange dark.*

(4) *Usually 1 to 3 bar working pressure is required.*

(5) *While working with airbrush one must not forget to take health and safety precautions into considerations: it is advisable to use an extraction unit and suitable respiratory protection, especially when working with solvents. When inhaled, finely dispersed paint and solvents can result in to serious health hazards.*

(6) *For further details concerning the test series, see Michaela Tischer's project paper from the winter semester 2011/12: Die Retusche mittels Airbrush auf Kunststoffoberflächen, Technische Universität München, Chair of Restoration-Conservation, Art Technology and Conservation Science (unpublished)*

(7) *To achieve a homogeneous gloss over the entire gel coat surface, the decision was taken to apply the thin barrier coat to the entire upper part of the lounger. This also had the advantage that the original surface was protected from the spreading of the finely dispersed paint particles when re touching selected areas. The removability of the barrier coat was tested prior to applying it (removing via microfibre cloths and compresses).*

(8) *Mixture 1: (Cadmium orange [2.5 GT] + Cadmium red dark [0.25 GT] + Cadmium yellow middle [0.25 GT]) : 3 GT* H_2O*. Mixture 2: (Cadmium orange [2.0 GT] + Cadmium red middle [0.5 GT] + Chromium oxide green brilliant [0.25 GT] + Ivory black [0.25 GT] : 3 GT* H_20*.*

(9) *3.5-Dimethylhex-1-in-3-ol. Multifunctional surface-active agent. Due to its volatility, Surfynol evaporates after providing the required substrate wetting. The surfactant provides excellent wetting characteristics on polymeric films such as polyethylene and polypropylene (http://www.kremer-pigmente.com/media/files_public/78010e.pdf, 08/2012).*

(10) *Airbrush gun Rich® AS-2; nozzle 0.2mm, double action function principle.*

(11) *Colani Airbrush made by Harder & Steenbeck Metallwarenfabrik e. k.; nozzle 0.4mm, double action, 2.5 bar working pressure.*

LECTURE
004
THE USE OF POLYURETHANE FOAM IN CONTEMPORARY ITALIAN DESIGN: CASE STUDIES FROM THE TRIENNALE DESIGN MUSEUM IN MILAN, ITALY

BY FRANCESCA CATERINA IZZO, BARBARA FERRIANI, SILVANA ANNICCHIARICO, PAOLA BIOCCA, HENK VAN KEULEN, ELISABETTA ZENDRI

ABSTRACT

This paper reports the study of several design objects from the Triennale Design Museum in Milan – all of which are part of the Multipli series by the Italian brand Gufram® – including three examples of a sofa called Pratone, three stone-shaped seats called Sedilsasso e sassi, a coat stand in the shape of a Cactus and the Capitello recliner. All of these design objects were produced at different times from the early 1970s to the present day using "polyurethane foam and washable latex", and are already showing signs of different degradation processes. In addition to identifying the various material compositions and degradation phenomena that affect these artefacts, in order to develop preventive conservation plans for their future maintenance, our study sought to identify any differences in the materials and manufacturing techniques used to produce the same series over the years and if these differences can be correlated to their state of conservation. Samples of the objects were collected and examined by optical and electron microscopy, FTIR-ATR, XRF and pyGC-MS to obtain information relative to the compositional materials involved (PUR foams, painted layers, varnishes and protective coatings) and the relative degradation processes.

KEYWORDS

Polyurethane foam, latex, Triennale Design Museum, Gufram, polymer degradation, pyGC-MS

INTRODUCTION

The fourth edition of the Triennale Design Museum Dream Factories - People, Ideas and Paradoxes of Italian Design in 2011-2012 (1) was focused on the people behind (and inside) the creation of products. While the third edition entitled The Things We Are (2) explored the question of how some products can play a crucial role in defining the identity of the people we come into contact with every day, the fourth edition asserted the creativity of those who may not design or create objects, but who have the ability to produce them effectively, taking them out from the virtual dimension and placing them in the hands and the lives of all of us. As they entered the exhibition, visitors were greeted by a large lawn consisting of 14 patches of hypertrophied grass, placed one next to the other *(Figure 1)*, entitled *Pratone*.(3)

For the exhibition, in fact, the Italian company Gufram had been asked to make fourteen new units of Pratone. Each *Pratone* consists of forty-two soft blades of grass in polyurethane foam, mounted on a modular support, which is also made of polyurethane foam. The surface, as described in the Gufram® catalogue, is "cold-painted with green Guflac® latex paint and subsequently with a final transparent film". Still in production in limited editions, *Pratone* was designed in 1972 by Giorgio Ceretti, Pietro Derossi and Riccardo Rosso, and produced by Gufram. Expressing a Pop culture which sought to disorient the public through irony and through an irreverent reinterpretation of reality, with a gesture typical of the avant-gardes, *Pratone* revealed the theoretical irrelevance and backwardness of the nature-nurture dichotomy. *Pratone* brings nature into the house, but at the same time the hyperrealism of the green colouring and the gigantism of the detail clearly reveals it as an artificial form of nature and a contrived imitation of the natural world. It mocks the "bourgeois" ideology of comfort, for it does not offer the body an erect seat or a preconceived posture but asks users to settle into a comfortable, secure position, finding a niche of their own in the soft polyurethane. This material, which has the extraordinary ability to take on any shape and then return to its original one, made it possible to create unstructured, playful pieces of furniture, introducing a new, unconventional way of living at home. Gufram stood out for its original research into these forms and for its extensive use of polyurethane foam. In the mid-1970s, Gufram stopped production of the first Fun Foam series of objects in polyurethane foam, but started up production again in 1986 with a series called *Multipli.*

In addition to *Pratone,* the most famous series of *Multipli* are *Cactus,* designed by Guido Drocco and Franco Mello, Sassi

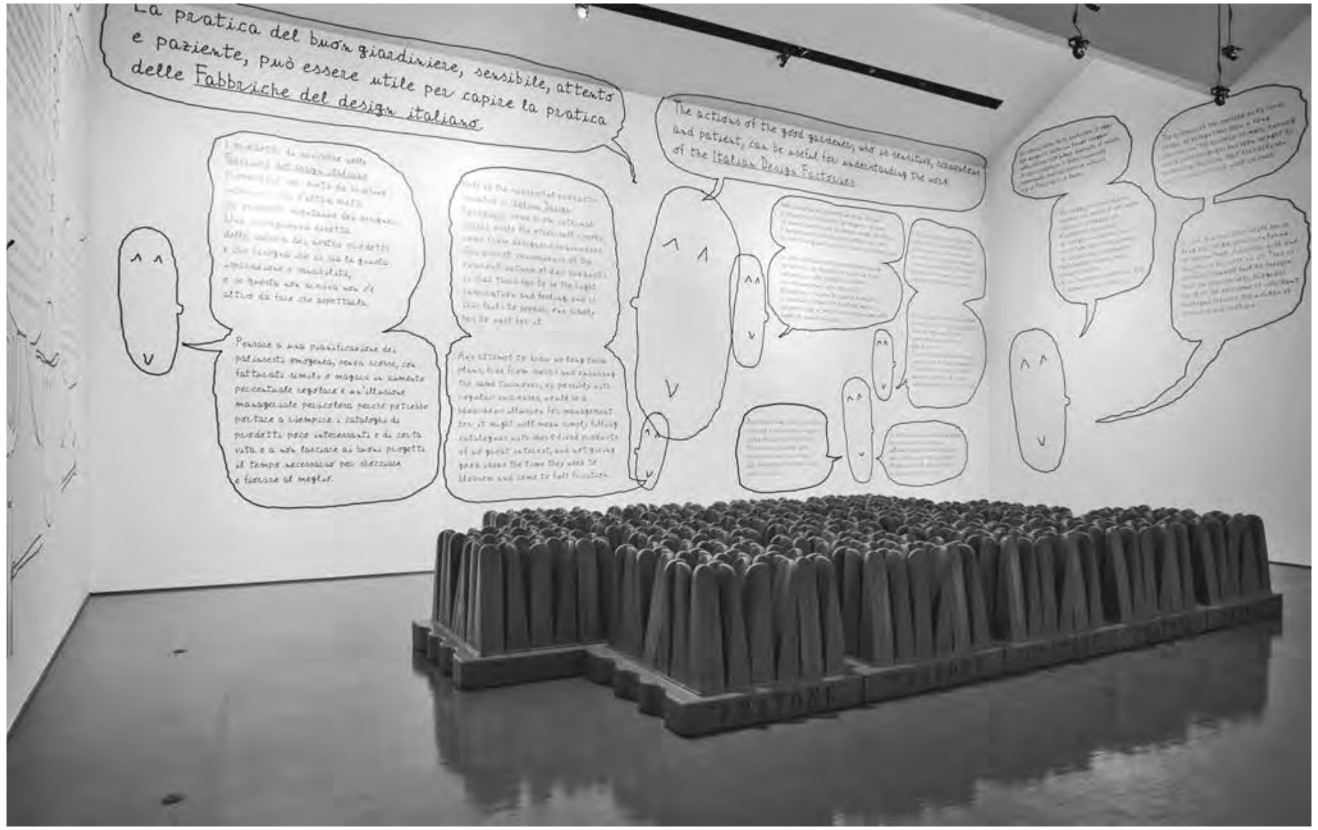


Figure 1.1
Images from the exhibition Dream factories-People, ideas and paradoxes of Italian design at the Triennale Design Museum, Milan

Figure 1.2

by Piero Gilardi, and Capitello by Studio 65.

After some initial hesitation, the visitors who entered the 2011-2012 Triennale exhibition experienced the many facets and functions of this giant lawn, which can be a place for resting, talking and chatting, but also for fun and games. After a year of exposure, typical signs of deterioration caused by prolonged and intensive use started appearing on the surface and the Pratone bore the traces of everyday use by visitors and by entire classes of children.

When these fairly new design objects were compared with two others in the Triennale Design Museum collection (made at different times), differences were noted in the physical and mechanical properties of the materials. They did not appear to be entirely due to use and aging but also to the nature of the materials and to the production techniques used.

The two "historic" specimens in the Triennale Design Museum collection, "Gufram Multipli '86 – Pratone 12/200" and "Gufram Multipli '86 – Pratone24/200", belonged to the series started in 1986.

In the historic *Pratone* examples, the 12/200 and the 24/200, the coats of colour and transparent protective film were applied by brush, whereas in the more recent samples they were sprayed on. The colour was applied to all the multiples in a number of coats before assembly, as reported in *(Bützer J. 2002)* who, referring to the *Pratone* acquired in 1997 by the Kunstmuseum Dusseldorf, noted that "these coatings were applied to the foam elements before they were fitted together". However, careful visual examination of the connections between the blades of grass and the support of the more recent multiples showed that , in these areas, localized applications of colour and protective film had been made also after assembly.

In the first *Pratone* specimen 12/200 *(Figure 2),* the protective film was considerably altered and browned, and the original bright green had also become much darker. Close inspection showed streaks and irregularities throughout the entire surface of the object, caused by patchy, irregular application by brush of the transparent coat. In areas where the foam had been repeatedly subjected to bending and crimping, the green colour beneath the dark coat had become apparent. This suggested different physical behaviours of the two layers under mechanical stress.

Some blades were also stuck together, probably as a result of decomposition processes in the constituent materials, and several impressions left by packaging materials were detected on the surface. The green coating also proved to have numerous lacerations and loss of colour, exposing the underlying polyurethane foam. The foam appeared yellowed and brittle in the areas where it was exposed.

The second *Pratone,* specimen 24/200 *(Figure 3)* looked very similar to the first, except that the coats did not present the degenerative phenomena that had caused the blades to adhere to each other and to the packaging materials. There also appeared to be less damage to the green coat, perhaps as a result of less extensive use.

The transparent protective coating in both "historic" specimens appeared to adhere well to the green layers below and, in those places where it had been damaged, there were none of the detachments and delaminations that were detected on the ones on display.

The condition of these the historical specimen was then compared to the fourteen *Pratone* commissioned for the 2011-2012 Triennale. Of the fourteen *Pratone,* one piece, "Gufram Multipli '86 – Pratone94/200", was selected as the best sample for study and comparison, because it presented all of the degradation phenomena noticed on the other Pratone on display. Although made more recently, Gufram Multipli '86 – Pratone94/200" belonged to the same series as the two historic examples discussed above.

Furthermore, since the Triennale Design Museum owns other objects of the *Multipli* series by Gufram®, it was also decided to include in this study three stone-shaped seats, called Sedilsasso e Sassi, together with a coat stand in the shape of a red *Cactus* and the Capitello recliner *(see Figure 4).(5)*

All of these design objects were produced at different times during a period spanning from the mid-1970s to the present day, using "polyurethane foam and washable latex" (as indicated in the Gufram® catalogue). All of them already show the effects of different degradation processes.

The main aim of this research was to examine the selected design objects to identify the constituent materials and production techniques, and relate them when possible to the degradation patterns exhibited by the objects. The study was conducted using visual observations of the foams with the naked eye and with UV-VIS optical microscopy, and the identification of the constituent materials (PUR foams, painted layers, varnishes and protective coatings) was achieved with a range of analytical techniques including SEM-EDS, FTIR-ATR and Py-GC-MS.

RESULTS AND DISCUSSION

Table 1 compiles the results obtained by analyzing the PUR foams, painted layers and coating of the selected design objects. The results are discussed and compared below.

POLYURETHANE FOAMS

Observation of the samples using an optical microscope made it possible to assess the distribution and size of the polyurethane cells. It also revealed the different states of degradation of the polyurethane foams, with yellowing of the foam accompanied by the disintegration of the honeycomb structure, particularly in the multiples made in the 1980s. *(Figure 5a)*. Measurements of the polyurethane cell structures revealed degradation patterns typical of polyurethane foams, mostly thinning and deformation of the segments, accompanied by breaks in the polyurethane membrane in the more deteriorated Capitello and Sasso foams *(Michalski and Hubery 1978; Lewis et al 1996; van Oosten 2011)*. The observation of the three samples of Pratoni under UV microscopy was very interesting, because the different levels of fluorescence emitted *(Figure 5b)* seemed to relate to the different degree of aging of the three multiples.

For all the design objects, FTIR-ATR analyses of the polyurethane foams identified the polyol as being of the ether type through the strong absorption relative to the ether bond at 1088 cm^{-1} *(van Oosten 2011)*. Bands related to symmetric stretching vibration of the NH bond of the primary amide at 3350 cm^{-1} were identified *(Lovet and Eastop 2004; Garside and Lovett 2006; van Oosten and Keune 1999)*. Peaks around 1000 cm^{-1} were attributed to stretching of the Si-O-Si silicate bonds used as fillers in the industrial formulations (Randall and Lee 2002). With regard to the degradation of the foams, comparison between the absorption rates of FTIR-ATR of the carbonyl and hydroxyl groups of the different foam samples pointed to an increase in particular bands attributable to the photo-oxidative degradation typically found in ether-based polyurethanes *(van Oosten 2011; Shashoua 2008; Quye and Williamson 1999; Waenting 2008)*.

Sulfur (S) and phosphorus (P) were detected in all the samples analyzed by XRF. The former is attributable to inorganic pigments used as inert additives in the manufacturing process, and the latter to organophosphate groups used as plasticizers and flame retardants, such as tri-(chloropropyl) phosphate *(Andresen et al 2004; van der Veen and de Boer 2012)*.

The py-GC/MS results gave further details on the composition of the PUR interiors of the objects. The foam is a TDI (toluene diisocyanate) based urethane ether with polypropylene glycol as the polyol. In the case of the more degraded objects, such as *Pratone* 12/200 and *Capitello*, the presence of toluene di-amine (TDA) was detected. This compound was probably formed as a product of hydrolysis of the TDI, thus constituting a marker of the deterioration of the polyurethane material *(Lattuati- Derieux et al. 2011; Hall et al 2001)*. It is interesting to observe that Gufram objects have different compositions depending on the time of production: in fact, the PUR foams from more recent objects such as Capitello and *Pratone* 94/200 are composed of TDI- polypropylene glycol urethane ether with the addition of styrene acrylonitrile (SAN), as displayed in the pyrogram in *Figure 6.*, probably to enhance the mechanical properties *(Hummel and Scholl 1983; Saechtling 2004)*. Several additives were identified in all the pyrograms, including butylated hydroxytoluene (BHT) and dioctyldiphenylamine as antioxidants and tris(3-chloropropyl) phosphate, dibutylphthalate (DBP) and dioctylphthalate (DOP) as plasticizers *(Stapleton et al. 2011; Sayigh and Reymore 1973)*.

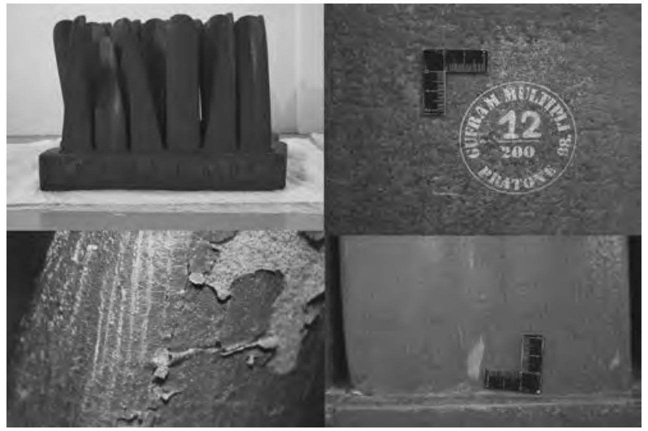


Figure 2
Gufram Multipli '86 – Pratone 12/200: front image and details
(see colour plate, p. 163)

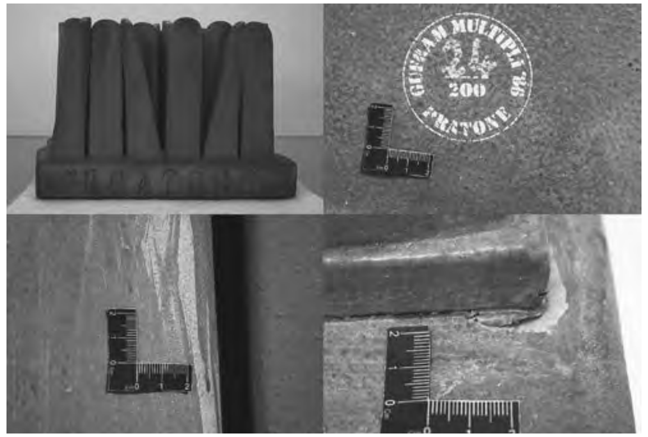


Figure 3
Gufram Multipli '86 – Pratone 24/200: front image and details

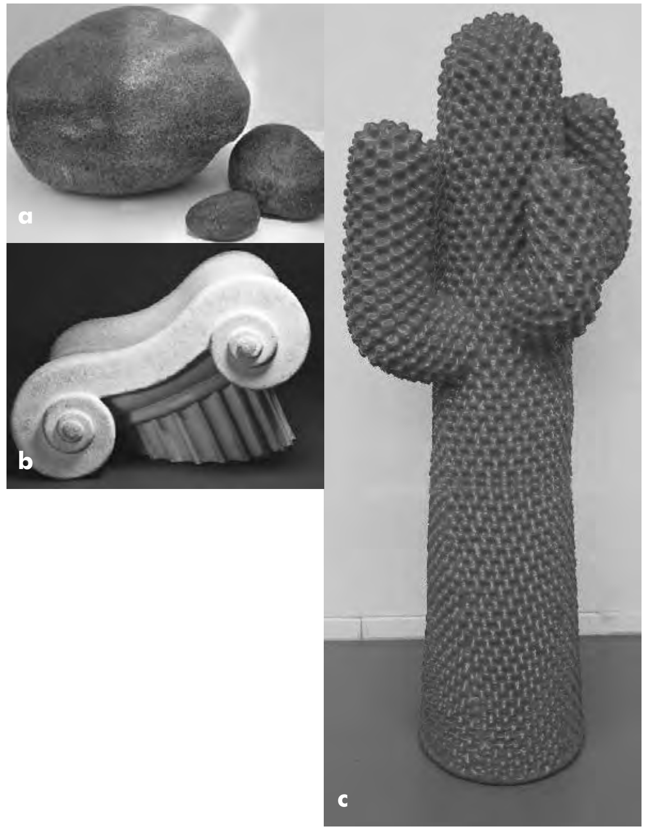


Figure 4
Gufram Multipli: Sedilsasso e sassi (a), Capitello (b) and Cactus (c)

PAINTED LAYERS

In all the cases examined, the painted layers appeared to be composed of a polyisoprene-based latex, as indicated by the typical IR absorptions at 3080 cm^{-1} (=CH), 1660 cm^{-1} (C=C), 1130 cm^{-1} (C-C), 837 cm^{-1} (=CH) [28]. Py-GCMS analysis confirmed the presence of polyisoprene: in the pyrograms, benzimidazole and benzothiazole – used in the vulcanization process of the isoprene – were also detected *(Saechtling 2004)*. The composition of the painted layers is generally quite complex, since they contain a great variety of inorganic and organic pigments, fillers (silica, kaolin) and extenders (calcium carbonate, gypsum) *(See Table 1)*.

ADHESIVE

The adhesive material used to attach the blades of grass in the Pratoni has been identified as a mixture of chloroprene and toluene-hydroxy-butylate, in which there are also traces of plasticizers and flame retardants, most likely from the adjacent coat of green paint. The chloroprene and hydroxy-toluene adhesive also contains traces of coumarone-indene resin, generally used to increase the degree of adhesiveness *(Hummel and Scholl 1983; Baccaredda Boy 1976)*.

PROTECTIVE COATINGS

The coatings were found to have different formulations. Based on Py-GC/MS results, a urethane ester- IPDI (Isophorone diisocyanate)-apidic glycol coating was probably used as protective layers for Capitello, Sasso and Pratone 12/200 and 24/200, while Cactus was coated with a urethane ester- HMDI (1,1-methylene-bis(4-isocyanato)cyclohexane)-apidic glycol resin.

Urethane ester coatings are known to be subject to hydrolysis and yellowing with time: this may explain the degradation of the finishing layers observed in *Pratone* 12/200 and 24/200 *(Figure 2 and 3)*.

EPDM (Ethylene-Propylene Diene Monomer) rubber copolymer with a flexible part was probably used as the protective layer for Pratone 94/200. EPDM is a high-performance polymer with good resistance to UV and ozone, and it is not subjected to yellowing, but if subjected to stress it can be affected by whitening and a loss of elasticity. This would explain the different behaviour of the coating on the *Pratone* 94/200 from that of the others.

CONCLUSIONS, OUTCOMES AND FUTURE PERSPECTIVES

The research focused on the study of the constituent materials of six works in the *Multipli* series made by the Gufram company, now in the TDM collection, first assessing the state of conservation and then analyzing the composition of the materials used in their construction. Analyses of the six design objects revealed similarities and differences in the products and in the formulations used over the years. The formulation of the polyurethane foam is based on TDI urethane ether-PPO in all the works analyzed, except for the sample from the more recent works Pratone 94/200 and Capitello, in which, as revealed by pyGC/MS analysis, the TDI-PPO-type polyurethane also had the addition of styrene-acrylonitrile (SAN) copolymer. The SAN was probably added to improve the mechanical properties of the foam. In the most deteriorated works, the degradation observed with optical and electron-microscope analysis, such as yellowing and embrittlement of the honeycomb structure, is most likely due to the nature of the polyol used in the polyurethane formulations. The effects of photo-oxidation and humidity have also led to the chemical alteration of the polyurethane (the presence of TDA resulting from hydrolysis of TDI is indicative of this). These effects of chemical degradation are likely to be responsible for the deterioration of the mechanical properties and loss of functionalities in the objects examined, which (except for *Cactus*) act as sun-chairs and have thus been subject to constant mechanical stress.

The coats of paint on the various objects were all found to be based on a polyisoprene latex (Guflac latex produced by Gufram), indicating that the composition of the washable polymer emulsion has not changed over the years.

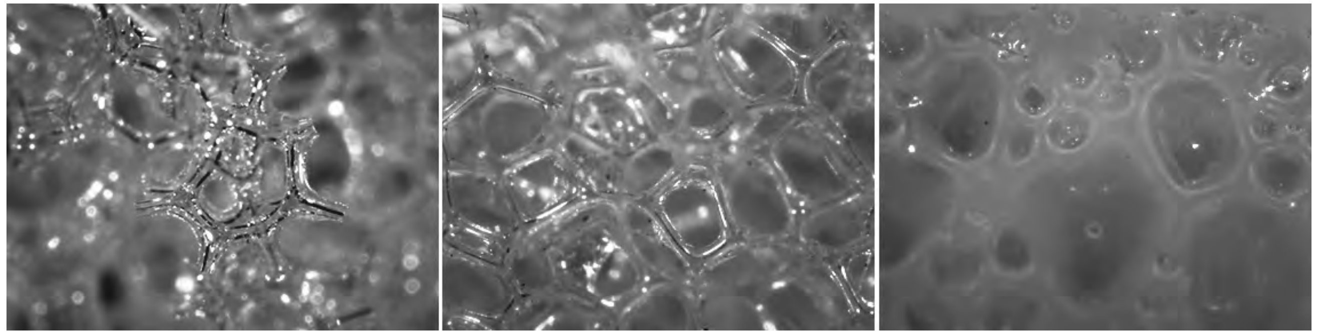


Figure 5a
Optical microscopic images of PUR foams from Sedilsasso (left), Capitello (middle) and Cactus (right) –visible light, 220x

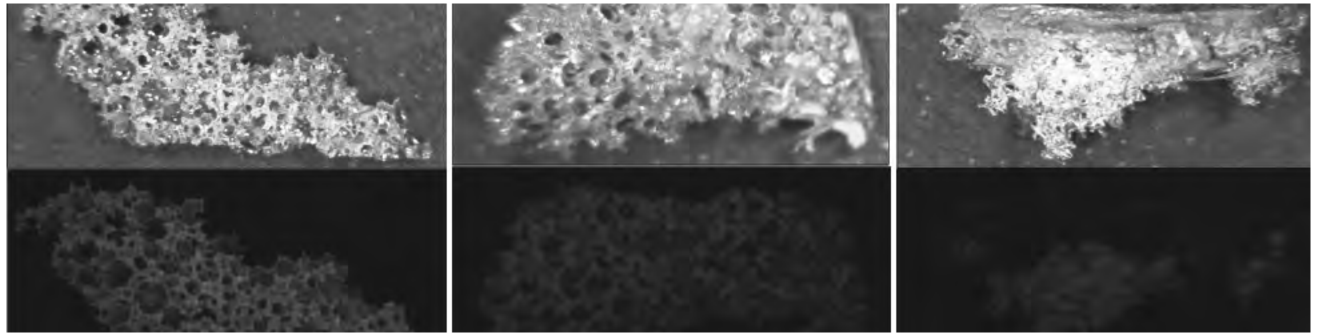


Figure 5b
Optical vis-UV microscopic images of PUR foams from Pratone 12/200 (left), Pratone 24/100 (middle) and Pratone 94/100 (right) - visible light, 60x (top) and UV light, 60x (bottom)

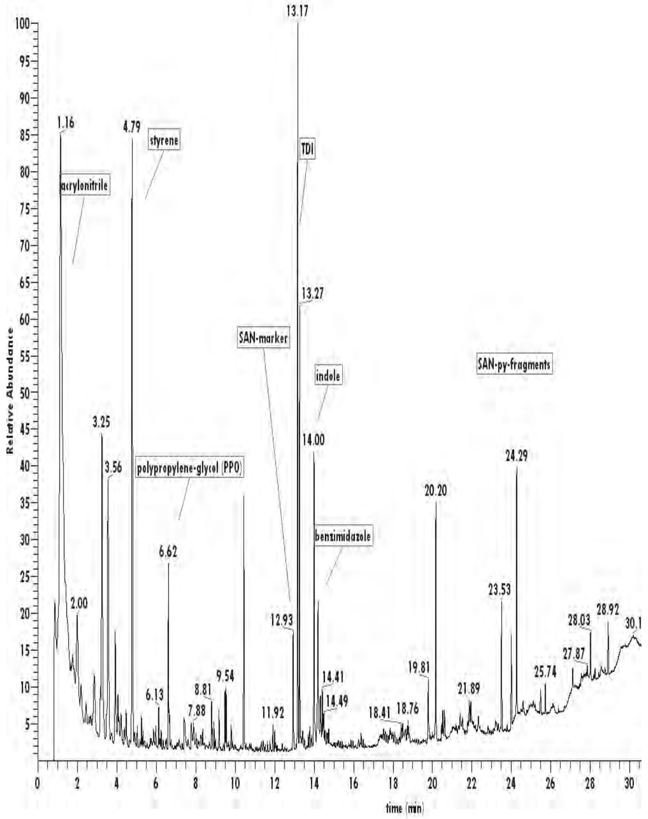


Figure 6
PyGC-MS analysis of PUR foam from Pratone 94/200: The composition is analyzed as a mixture of TDI urethane ether with polypropylene glycol as the flexible part and Styrene Acrylonitrile (SAN). Indole and benzimidazole are used in the production of the urethane.

One evident change was however found in the choice of materials used as top clear coats. In the case of the samples of *Pratone* 12/200 and 24/200, *Sasso, Capitello* and *Cactus,* the coating is based on urethane ester-adipic glycol paint (with a distinction between the different isocyanates involved), while in the case of the *Pratone* 94/200 an ethylene-propylene copolymer rubber appears to have been used. The difference in formulations, together with the mechanical stress to which the works were subject, is presumably the cause of the different state of degradation observed in the protective layers: particularly in the case of the Pratoni 12/200 and 24/200, the protective film had become extremely brown probably due to the yellowing and hydrolysis of the urethane ether resin, while the embrittlement, loss of elasticity and bleaching in the *Pratone* 94/100 may be due to the reaction of EPDM rubber when subjected to stress. Moreover, in the case of Pratoni, the presence of a chloroprene /toluene-hydroxy-butylate adhesive might have indirectly contributed to the detachment of deteriorated painted layers and foams.

In addition to the identification of the constituent materials of the works (from the inner layers of polyurethane to the surface finishes), the analyses thus made it possible to understand the different behaviours of the materials and formulations used in the assembled objects. This will help predict future degradation processes, and help establishing preventive conservation strategies. It is hoped that the study will continue with the help of the owners of Gufram®, who can provide the reasons behind variations in the production processes and changes in the material composition of the PUR used in these objects. This, along with the analytical results obtained and a thorough understanding of the material history of the object will hopefully provide a very complete understanding of the various contingent factors which can affect the aging process of PUR-based objects.

APPENDIX: EXPERIMENTAL DETAILS

SAMPLING

Samples were taken from different areas of the artworks, trying to avoid any aesthetic damage. The removal of micro fragments from the polyurethane foams, the painted layers and the protective coatings was performed with a scalpel or lancet; the samples were stored in dark glass vials before being analyzed.

OPTICAL AND ELECTRONIC MICROSCOPY

Samples were examined with an Olympus SZX16 optical stereo microscope equipped for microphotography in both visible and UV light. Polished cross-sections of selected painting samples were prepared and observed with a JEOL JSM 5600 LV scanning electron microscope coupled with an OXFORD-Link Isis series 300 microanalysis system (SEM-EDX).

X-RAY FLUORESCENCE

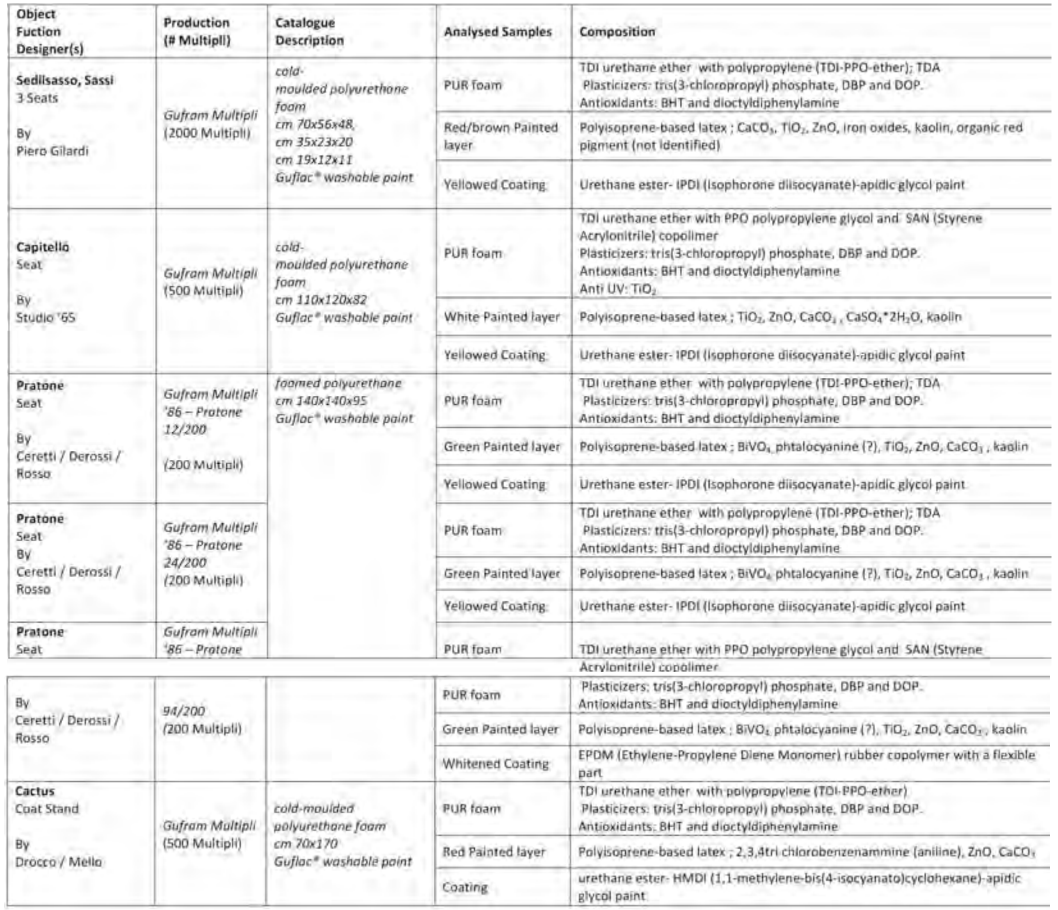
Elemental XRF analyses were carried out using a Philip Minipal spectrometer operating at 40-120 kV and 2.2 uA. The data were processed using Minipal software.

FTIR-ATR

FTIR-ATR analyses were performed using a double-beam Thermo Nicolet FTIR NEXUS 750 instrument with a Smart Endurance ATR Smart Orbit Nex Diamond Crystal W/Spa – 2 Tower accessory. The transmittance percentage (%) was collected in the range of 4000-400 cm^{-1} for 64 scans at 4 cm^{-1} resolution. IR spectra were processed using Omnic® 10 software.

PYROLYSIS GAS CHROMATOGRAPHY / MASS SPECTOMETRY (PY-GC/MS)

The samples were analyzed using pyrolysis Gas Chromatography Mass Spectrometry (py-GC/MS). Sample material was placed in a steel pyrolysis cup. The cup was transferred into the pyrolyzer and the sample was pyrolyzed at 600 °C. The total component mixtures were separated by gas chromatography and the separated components detected and identified with mass spectrometry. The pyrolysis unit used was a Frontier Lab 3030D pyrolyzer mounted on a Thermo Scientific Focus GC / ISQ mass spectrometer combination. Separation took place on a SLB5 ms (Supelco) column, 20 meters in length, with an internal diameter of 0.18 mm and a film thickness of 0.18 µm. Helium was



Object Fuction Designer(s)	Production (# Multipli)	Catalogue Description	Analysed Samples	Composition
Sedilsasso, Sassi 3 Seats By Piero Gilardi	*Gufram Multipli* (2000 Multipli)	*cold-moulded polyurethane foam* *cm 70x56x48,* *cm 35x23x20* *cm 19x12x11* *Guflac® washable paint*	PUR foam	TDI urethane ether with polypropylene (TDI-PPO-ether); TDA Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine
			Red/brown Painted layer	Polyisoprene-based latex ; $CaCO_3$, TiO_2, ZnO, iron oxides, kaolin, organic red pigment (not identified)
			Yellowed Coating	Urethane ester- IPDI (isophorone diisocyanate)-apidic glycol paint
Capitello Seat By Studio '65	*Gufram Multipli* (500 Multipli)	*cold-moulded polyurethane foam* *cm 110x120x82* *Guflac® washable paint*	PUR foam	TDI urethane ether with PPO polypropylene glycol and SAN (Styrene Acrylonitrile) copolimer Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine Anti UV: TiO_2
			White Painted layer	Polyisoprene-based latex ; TiO_2, ZnO, $CaCO_3$, $CaSO_4{*}2H_2O$, kaolin
			Yellowed Coating	Urethane ester- IPDI (isophorone diisocyanate)-apidic glycol paint
Pratone Seat By Ceretti / Derossi / Rosso	*Gufram Multipli '86 – Pratone 12/200* (200 Multipli)	*foamed polyurethane* *cm 140x140x95* *Guflac® washable paint*	PUR foam	TDI urethane ether with polypropylene (TDI-PPO-ether); TDA Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine
			Green Painted layer	Polyisoprene-based latex ; $BiVO_4$ phtalocyanine (?), TiO_2, ZnO, $CaCO_3$, kaolin
			Yellowed Coating	Urethane ester- IPDI (Isophorone diisocyanate)-apidic glycol paint
Pratone Seat By Ceretti / Derossi / Rosso	*Gufram Multipli '86 – Pratone 24/200* (200 Multipli)		PUR foam	TDI urethane ether with polypropylene (TDI-PPO-ether); TDA Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine
			Green Painted layer	Polyisoprene-based latex ; $BiVO_4$ phtalocyanine (?), TiO_2, ZnO, $CaCO_3$, kaolin
			Yellowed Coating	Urethane ester- IPDI (Isophorone diisocyanate)-apidic glycol paint
Pratone Seat By Ceretti / Derossi / Rosso	*Gufram Multipli '86 – Pratone 94/200* (200 Multipli)		PUR foam	TDI urethane ether with PPO polypropylene glycol and SAN (Styrene Acrylonitrile) copolimer Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine
			Green Painted layer	Polyisoprene-based latex ; $BiVO_4$ phtalocyanine (?), TiO_2, ZnO, $CaCO_3$, kaolin
			Whitened Coating	EPDM (Ethylene-Propylene Diene Monomer) rubber copolymer with a flexible part
Cactus Coat Stand By Drocco / Mello	*Gufram Multipli* (500 Multipli)	*cold-moulded polyurethane foam* *cm 70x170* *Guflac® washable paint*	PUR foam	TDI urethane ether with polypropylene (TDI-PPO-ether) Plasticizers: tris(3-chloropropyl) phosphate, DBP and DOP. Antioxidants: BHT and dioctyldiphenylamine
			Red Painted layer	Polyisoprene-based latex ; 2,3,4tri chlorobenzenammine (aniline), ZnO, $CaCO_3$
			Coating	urethane ester- HMDI (1,1-methylene-bis(4-isocyanato)cyclohexane)-apidic glycol paint

Table 1
Description and analytical results from *Gufram Multipli* objects from the Triennale Design Museum

used as the carrier with a constant flow of 0.9 ml/min. The temperature program used was as follows: 35 °C stable for one minute, subsequently heated at a rate of 16 °C per minute up to 220 °C and at a rate of 10 °C per minute up to 315 °C, and then held stable for 2 minutes. The column was directly coupled to the ion source of the mass spectrometer. The temperature of the interface was 250 °C, and the temperature of the ion source 220 °C. Mass spectra were recorded from 20 amu to 600 amu at 5 scans per second. Xcalibur 2.1 software was used for collecting and processing the mass spectral data. The results of the analysis of the unknown samples were interpreted by comparison with reference samples.

ACKNOWLEDGEMENTS

The authors would like to thank Rafaela Trevisan and Alessandra Fabiana Guarascio (Conservation Department- Triennale Design Museum) Giulia Zago (former Master student at Ca' Foscari, University of Venice) for their collaboration.

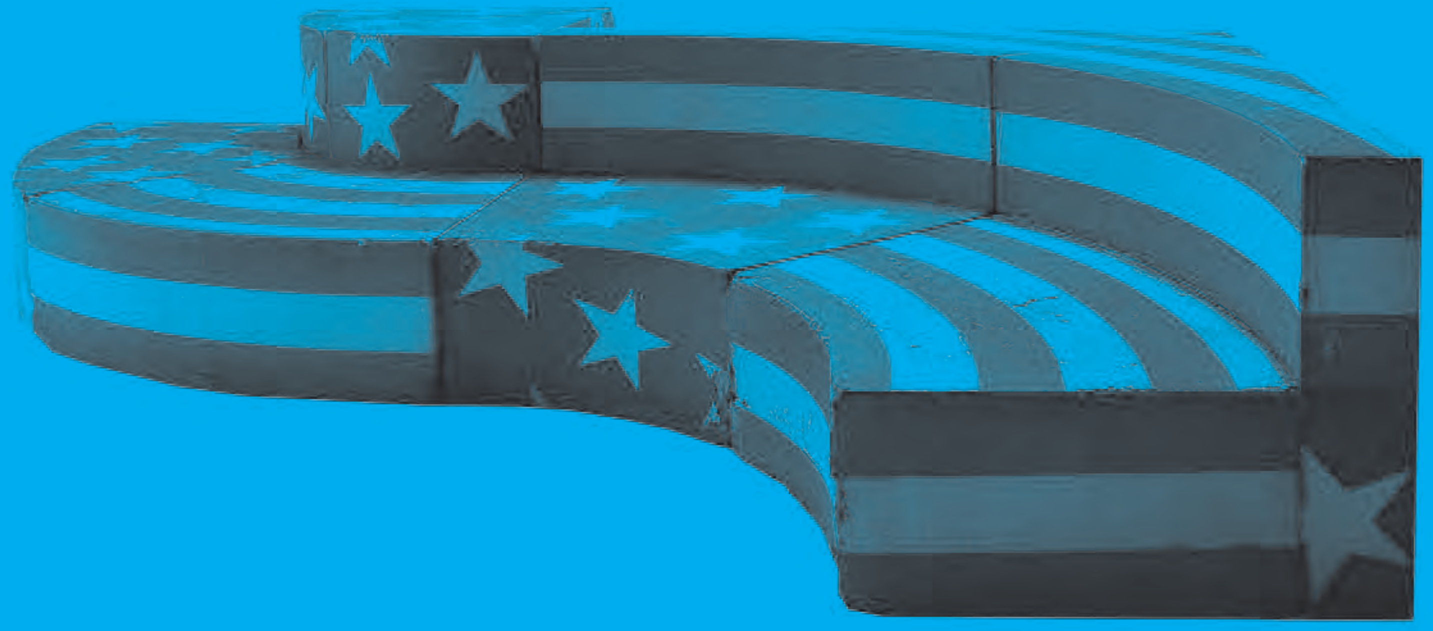
ENDNOTES

1) *Le fabbriche dei sogni – Dream Factories: People, Ideas and Paradoxes of Italian Design, scientific curator Alberto Alessi, 5 April 2011 – 26 February 2012*

2) *Quali cose siamo, The Things We Are, scientific curator: Alessandro Mendini, 27 March 2010 – 27 February 2011*

3) *Pratone, seat, 1971, Ceretti, Derossi, Rosso, 200 multiples, foamed polyurethane, Guflac washable paint, 140 x 140 x 95 cm*

4) *Sedilsasso, Sassi, seat, 1968, Piero Gilardi, 2000 multiples, cold-moulded polyurethane foam, Guflac washable paint, 40 x 56 x 48, 35 x 23 x 20 cm, 19 x 12 x 11 cm Cactus, coat stand, 2012, Drocco, Mello, 3000 multiples, cold-moulded polyurethane foam, Guflac washable paint, 70 x 170 cm, Capitello, seat, 1972, Studio 65, 500 multiples, cold-moulded polyurethane foam, Guflac washable paint, 110 x 120 x 82 cm*



LECTURE
005
WAVING THE FLAG
THE CONSERVATION AND EXHIBITION OF THE SEATING COMBINATION LEONARDO BY STUDIO 65

BY SUSANNE GRANER, LUISE LUTZ

ABSTRACT

The seating combination *Leonardo* was designed by the Italian design group Studio 65 in 1969 and is part of the collection of the Vitra Design Museum (VDM).

Leonardo is made of 12 individual foam elements in three basic shapes that can be arranged in variable configurations and show the design of the flag of the United States - stars and stripes. The sofa is part of a small series produced by the Italian company Gufram. It is made of polyurethane (PUR) block foam, cut to shape and coated with several layers of Guflac paint, named after the manufacturer.

Due to degradation processes in the materials and improper storage and handling of the sofa prior to entering the museum's collection, *Leonardo* was in a very fragile state of preservation. In preparation for displaying *Leonardo* in the traveling exhibition Pop Art Design, the object was extensively treated by the conservators of the VDM. The conservation included: surface cleaning, consolidation of foam and coating, reshaping of deformed edges of the coating, securing the edges of the coating with synthetic netting, filling losses in the foam body with inlays, and retouching of the inlays.

In addition to the enormous conservation efforts, it was necessary to address the problem of how to transport such as large piece of degraded PUR foam. The paper illustrates different approaches that ultimately lead to a solution that includes the use of customized boxes and different layers of 3D textile, so-called 3mesh spacer fabric. When this paper was presented at the Future Talks 013 conference, the exhibition had already travelled to two venues.

From the beginning, the conservation of *Leonardo* was accompanied by an exchange of diverse opinions and ideas concerning the visual appearance of the sofa afterwards. One main concern in terms of a "conservation treatment only" approach was the response and reception of the museum visitors. Will they appreciate the value of this unique piece despite its visible degradation? And will they understand the condition as "patina" or as damage that should be repaired?

In the end, *Leonardo* was one of the main attractions in the exhibition, and encouraged new discussions and opinions about visitors' perception of the aging of plastic.

KEYWORDS

PUR, conservation,
transport, 3-D textile, Studio 65,
Gufram

INTRODUCTION

The *Leonardo* seating combination was designed by the Italian design group Studio 65 in 1969 and produced by the Italian company Gufram. Founded in 1952, Gufram had already executed several concepts on behalf of Studio 65 by that time.(1)

The sofa is part of a small series. Only one other example of *Leonardo* is known to exist today. *Leonardo* is made of twelve individual foam elements in three basic shapes with four elements of each shape. Respectively two elements are striped red and white and two are designed blue with white stars. The elements can be assembled in variable configurations. An early image of the sofa from 1971 shows one of the possible arrangements.(2) With its pattern of stars and stripes, the sofa shows the design of the flag of the United States *(Figure 1)*.

The object has been part of the Vitra Design Museum's collection since 2000. The whereabouts of the sofa from the time of its production up to 2000, when it was purchased from Christie's, are unknown. However, based on the condition, it was evident that the sofa had been used. Together with the original foam elements the museum received twelve additional foam cushions of inferior production quality and slightly different in colour from the original. After examination it became clear that they were added to the sofa at a later point of time. They are not exhibited with *Leonardo* today.

The twelve original foam elements each measure about 30 centimetres in height. Their lengths and widths differ depending on the shape. The measurements of the entire sofa in the configuration as it is exhibited today including the full seating area and integrated backrests are 60.5 x 266 x 198 cm (H x W x D). In December 2011, Gianni Arnaudo, one of the early members of Studio 65, visited the Vitra Design Museum. The designer was interviewed about *Leonardo* and was able to provide useful information about the object.

FABRICATION

The elements of the *Leonardo* sofa were made of ether-based (3) polyurethane foam covered with Guflac paint. The coating – named after the manufacturer Gufram – is presumably based on a polyurethane elastomer or latex.(4) The single segments are cut from polyurethane block foam. Four right triangles of foam of the same size were each divided into three differently shaped forms – a segment of a circle, a ring segment and a completing end piece, resulting in four sets of each of the three forms. The foam pieces of identical shapes differ up to one centimetre in their measurements – an indication that the sofa was not

Figure 1
***Leonardo*, Studio 65, 1969, Vitra Design Museum, photo: Andreas Sütterlin**

fabricated with large-scale production methods. Characteristic marks of a cutting tool are visible in some areas under raking light.

Each foam element is coated. The first layer, a white primer, was applied on all sides with a brush. Irregular brush strokes and drips are evidence of manual application. Examinations showed that on some areas of the object two layers of primer were applied. In a later step, either a red or blue layer of paint was sprayed on through a stencil. The stencils were individually positioned on the surface so that each element presents a specific arrangement of stars or stripes. The red and blue paint layers show partly blurred edges that were caused by the removal of the stencils. Were the stencils covered the surface the white priming remained the only surface coating.

CONDITION AND DAMAGES

The object was in a very fragile state of preservation due to degradation processes of the polyurethane foam, and the inadequate storage and handling prior to entering the museum's collection. The foam and coating had become rigid and brittle, which makes handling the object very difficult. Already the slightest pressure on the surface causes the coating and foam to break. In addition, the foam has yellowed over time. Under the stereomicroscope the foam showed broken cell walls.

The coating has cracks ranging from fine hairline cracks to deep fractures. The primer often shows a more distinct cracking pattern than the paint layer. Especially along the edges of the elements, major losses of the coating had occurred. In these areas the foam is exposed resulting in additional losses of the material. The edges of the coating were deformed and foam and coating separating. Particles had broken off the coating and were lying on the surface unsecured and in danger of falling off.

CONSERVATION TREATMENTS

The conservation treatments on the *Leonardo* sofa aimed to secure and stabilize the materials in preparation for the display in the exhibition Pop Art Design at the Vitra Design Museum in Weil am Rhein.(5) Another goal of this project was to make it possible to transport the sofa to other exhibition venues in Europe, as its current state was not stable enough for travelling.

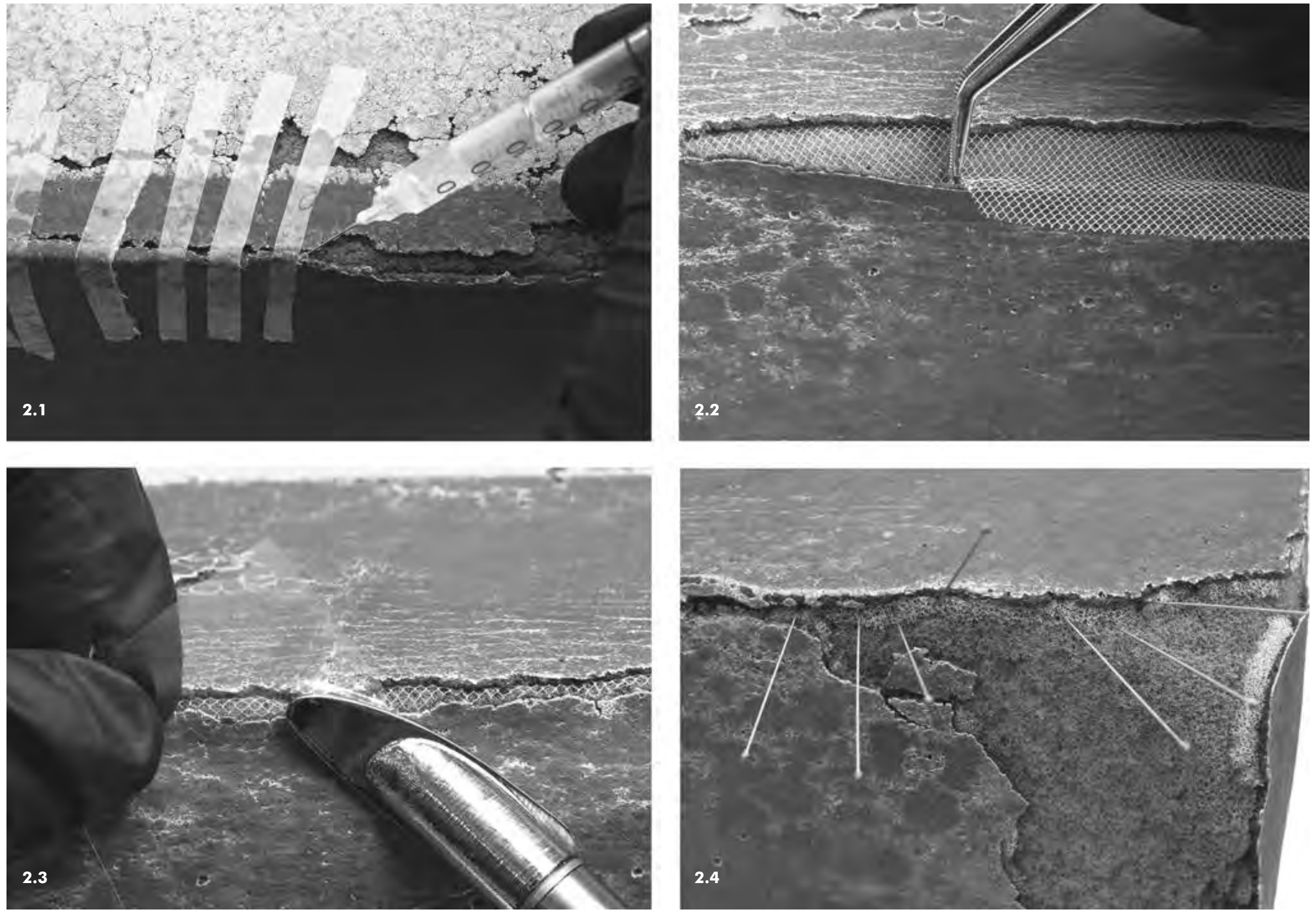


Figure 2
Conservation treatments – consolidation of the coating, securing the edges of the coating with synthetic netting, reshaping of the deformed edges of the coating, filling losses in the foam body with inlays
(see colour plate, p. 164)

The conservation process included the following steps: cleaning the surface of all twelve elements, consolidating the foam and the coating, backfilling the edges of the coating with synthetic netting, reshaping the deformed edges of the coating, filling the losses in the foam body with inlays and retouching the foam inlays. First the largely closed surface of the sofa was carefully dry cleaned with a soft brush and vacuum. Different stains and deposits such as traces of dried liquids or chewing gum had affected the original appearance of the object. Solvent tests in due consideration of published information regarding the solubility of polyurethane were carried out to determine the properties of the degraded material and dirty deposits.(6) Following these tests, very small amounts of distilled water and white spirit 100/140 in short residence times were used for the cleaning of persistent stains. Dust that had accumulated in areas where the foam was exposed had to be removed with fine pointed tweezers. This procedure assured minimal contact and manipulation of the open and delicate foam surface.

For the consolidation of the foam, a 5% solution of polyurethane dispersion Impranil DLV in Isopropanol and distilled water with an addition of the UV absorber Tinuvin B75 was applied with a nebulizer.(7) The application was carried out with a distance of 2.5 cm using an air pressure of 2 bar and a spraying time up to 60 sec. A more stable and flexible foam structure could be achieved without clogging the pores.

Polyurethane dispersion PU52 undiluted was used for the consolidation of the coating. It was injected under the layer with a fine needle. Small pieces of acid-free Filmoplast P90 paper tape helped to secure cracks in the coating that were closed by gently pulling the edges together. The tape was left in place during the drying process and carefully removed afterwards *(Figure 2.1)*.

Gaps in the coating, too large to be pulled back together, were secured with synthetic netting. The netting was first cut to the shape of the gap, then applied into the opening with tweezers, and finally adhered with polyurethane dispersion PU52 *(Figure 2/2)*. After drying, the white netting was inpainted with Paraloid B-72 and pigments.

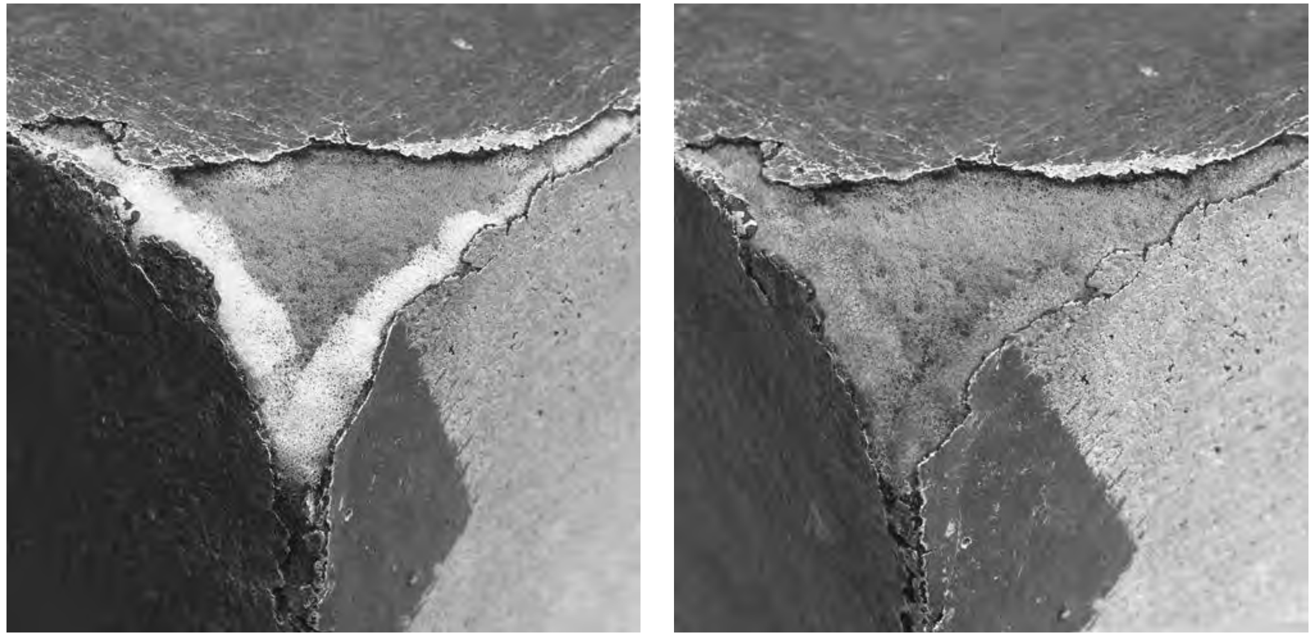


Figure 3
Detail: foam inlays before and after retouching

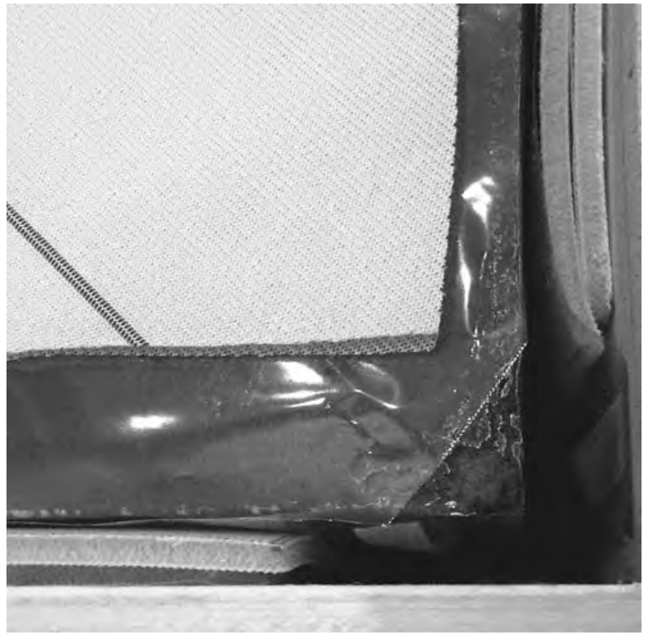


Figure 4
Different layers of spacer fabric and Hostaphan® to protect the object during transport

Figure 5
Catalogue cover

Flattening of the deformed edges of the coating turned out to be more challenging. A first approach to use solvents or solvent vapours proved ineffective for returning the material back to its original form. The treatment with solvents was also hard to control because they penetrated deep into the structure of the surface. Better results were achieved by selective heating of the deformed edges with a heating spatula to 60 to 75°C. Warming the layer and letting it cool off in the required position successfully brought it back onto the foam. *(Figure 2/3)*.

In a next step, losses in the foam substrate were filled with foam inlays. An open-pored polyurethane foam with similar characteristics to the original material was chosen as the replacement material. The inlays were fitted into the gaps using tweezers and micro-scissors. Insect needles helped to hold the inlays in place while polyurethane dispersion PU52 was injected at selected points *(Figure 2/4)*.

The foam inlays were finally inpainted with Paraloid B-72 and pigments *(Figure 3)*. Stable pigments such as ivory black (Gamblin), Prussian blue (Gamblin), chromium oxide green dull (Kremer), cadmium yellow and cadmium red (Gamblin) were chosen. The colours were applied on the foam with a bristle brush.

TRANSPORT AND PACKAGING

From the very beginning, the feasibility of transporting the *Leonardo* sofa in its fragile state had to be considered. The final decision was delayed several times, as it needed to be based on the results of a thorough condition assessment of the entire sofa, and to ensure that traveling would not damage it any further. A consensus on the decision to put the Leonardo sofa on display in the Vitra Design Museum was already reached, but the feasibility of sending the piece to other venues in Denmark, Sweden and the UK was questioned.

A first step was to establish parameters for a packaging system, taking into account slight differences in the size of the individual elements due to the condition, the concave or convex deformation of their surfaces, as well as their exposed corners and edges. It became clear that each individual element required its own custom-built crate. The padding material inside the crate would need to be of variable thickness in order to provide even support on all foam surfaces to avoid concentrated pressure that would surely destroy the foam structure. However, the corners and edges posed an additional problem. Due to their fragility and irregular contours any contact, whatsoever, even with the padding material, must be prevented. In addition, the crates should be constructed in such a way that it would be easy to insert and remove each sofa element.

A basic prerequisite for all of the steps that followed was to record and photographically document the position of every element within the sofa as well as its footprint. This was very important to ensure that none of the pieces would be accidentally reversed, that each piece would always be positioned in the same place, and that each section would be packed in its respective custom-built crate.

Then the footprint of each element was precisely traced on paper to serve as a template for the individual crate design. The museum's in-house joinery workshop built each crate to be approximately one centimetre larger on all sides of the sofa element it would house. The crate design also made it easy to disassemble the top and side walls, allowing the sofa element to be safely inserted into or lifted out of the crate. Six individual crates were put together in one very large crate with a total number of two large crates.

The next task was to fill the space between crate and object with a material that is flexible enough to accommodate the idiosyncrasies of the surfaces, while also providing enough shock absorption. It had to be available in thin layers and easy to work with. Sheets of foam materials such as Ethafoam seemed to be the most obvious choice. The close relationship with the furniture manufacturer Vitra lead to the discovery of a material more suitable: a so-called technical textile. Technical textiles have been commercially used for some time now in many different sectors, including sports, the automobile industry and in furniture production. Available in a wide range of shapes and colours, these, also called spacer fabrics are very popular because they combine the properties of cushioning and breathability with elasticity and durability. Vitra uses large quantities of this innovative material for the upholstery of its office furniture. A synthetic spacer fabric consists of top and bottom layers of fabric joined together by a connecting layer of pile yarns. The properties of the pile yarns and the two outer layers can be selected independently allowing for a wide variety of composite textiles with diverse characteristics.

After considering numerous samples, a polyester spacer fabric with a thickness of 4.3 mm was used. This particular type is available in rolls with a width of 1.4 m. A total of 25 running metres were necessary to cover a surface area of 35 square metres. In addition to its tear resistance another great advantage of the fabric is its reasonable price.

The fabric was easily cut with scissors into strips and attached to the walls of the crate with double-sided adhesive tape – in several layers, as needed to bridge the uneven gap between crate and object surface. It was important to attach the different fabric layers in such a way that the corners and edges of the sofa elements would remain free of contact. A layer of silicone coated HOSTAPHAN® was used on top of the padding.

As part of the loan agreements, the Vitra Design Museum reserved the right to reassess the sofa's condition after every exhibition, and to decide whether it would be safe enough to lend the sofa to each following venue. After being displayed at three venues so far, the sofa's condition shows no visible damage due to its transport.

APPEARANCE: PRESERVATION VERSUS PRESENTATION?

The demand for the display of fragile objects such as the *Leonardo* sofa is a common issue and should always take into consideration that these vulnerable materials need to be preserved and protected using the best methods possible. The overall condition of an artwork, and its physical state and visual appearance, need to be key aspects in conversations about the feasibility of displaying it in an exhibition. In the case of the *Leonardo* sofa, these aspects led to complex discussion between the conservators, the museum's trustees, and the directors. The decision-making process also included an additional examination of the sofa together with the curators and exhibition designers. Eventually a request was made by the curators asking if it would be possible, to fill the damaged areas of the sofa in order to achieve a more appealing overall appearance.

From the very beginning, all of the involved parties communicated on a regular basis. This collaborative process had been a learning experience for everyone involved and lead to a mutual understanding of different opinions. The discussions, although focusing on the *Leonardo* sofa in particular, developed into broader conversations - a serious and lively engagement - about general problems related to the display of aging foam objects and whether museum visitors would accept their appearance as such. As the discussions evolved, the group learned to accept and even appreciate the current state of *Leonardo's* condition, including the signs of use and of the material's degradation.

CONCLUSION

The sofa was ultimately selected as the exhibition's key object. It was even chosen for the front cover of the exhibition catalogue as well as the invitation card, the exhibition poster and for the eye-catching banner at the entrance of the Vitra Design Museum. The Pop Art Design exhibition offered a unique opportunity to educate visitors about the deterioration of modern materials and their limited life span, by exposing traces of decay on an aging design icon such as the *Leonardo* sofa, but also juxtaposing it with better-preserved objects such as consumer products of iconic status. In addition, the conservators conducted public guided tours of the exhibition with a focus on conservation. During these tours it became clear that visitors often misinterpreted the sofa's battered appearance as a result of negligence or the conservator's ability to 'properly' restore it. That's why it is important to provide visitors with additional background information on labels or during gallery tours. It helps them to better understand the conservation issues of modern artworks, the thought processes behind certain treatment decision, and to appreciate the history of objects and how they have survived.

ACKNOWLEDGEMENTS

The authors would like to thank Gianni Arnaudo, Mathias Schwartz-Clauss and Julia Knöpfle for their support.

ENDNOTES

(1) http://www.studio65.eu/prof1.htm

(2) Francesco De Bartolomeis, Ennio Chiggio: Studio 65, Milan 1986, p. 86.

(3) No reaction in contact with KOH-solution. See Thea van Oosten: PUR Facts – Conservation of Polyurethane Foam in Art and Design, Amsterdam 2011, p. 81.

(4) Not analysed.

(5) Mateo Kries, Mathias Schwartz-Clauss: Pop Art Design, Vitra Design Museum, Weil am Rhein 2012, p. 152.

(6) Friederike Waentig: Kunststoffe in der Kunst, Petersberg 2004, p. 299.

(7) Thea van Oosten: PUR Facts – Conservation of Polyurethane Foam in Art and Design, Amsterdam 2011, p. 88

LECTURE
006
IT'S NEVER TOO LATE TO GET IN SHAPE! THE CONSERVATION OF WOMBTOMB BY FERDI. APPROACHING THE REPLACEMENT OF DETERIORATED POLYURETHANE FOAM PADDING.

BY ANNA LAGANÁ, SUZAN MEIJER, SUZAN DE GROOT, THEA VAN OOSTEN

ABSTRACT

Wombtomb (1968, Rijksmuseum collection) by Dutch artist Ferdi is a playful Pop Art style reproduction of a coffin. The work consists of a base (the coffin), cushions and a lid, which are all upholstered with colourful synthetic furs and completely padded with flexible foam.

The *Wombtomb,* although only 44 years old, was in very poor condition as the foam material used by Ferdi to pad the piece had collapsed and completely crumbled, thus unacceptably compromising *Wombtomb's* appearance and the artist's original intention. FTIR analyses were performed to identify all the materials used by Ferdi. The degraded foam was identified as polyurethane ester foam. The foam was so degraded that the only option for conserving the *Wombtomb* was the total replacement of this material. This paper presents all the steps taken during the conservation treatment of the *Wombtomb:* from the understanding of what the lost original construction of the padding looked like and the considerations and analysis undertaken for selecting suitable replacement foam to the reconstruction of the piece. Using this treatment as an example, the paper aims to provide conservators with useful information and a methodology for approaching the problem of replacing severely degraded foam used as padding materials in works of art or design objects.

KEYWORDS

Polyurethane foam (PUR), foam, padding, replacement, plastic degradation, synthetic furs

INTRODUCTION

In the 1960s and '70s many works of art, as well as design objects and furniture, were often padded with foam matching perfectly the needs of the time; a period known for its aesthetic playfulness and creativity using new materials. With the passing of time many of these works have begun to show signs of degradation in that the padding loses its shape and its appearance.

The *Wombtomb,* made by the Dutch artist Ferdi *(Tajiri-Jansen, 1927-1969)* in 1968 and acquired in 2012 by the Rijksmuseum in Amsterdam, was one of them. In 2012 the foam material used by Ferdi to pad her ironic reproduction of a coffin showed to be in very poor condition; the foam had completely crumbled. The construction built up by Ferdi using several shaped pieces of foam was totally lost. The degraded foam was identified as polyurethane ester by FTIR analysis (1). The rate of degradation of the polyurethane ester foam was so advanced that the only option for conserving the object was the total replacement of this material. This paper discusses the steps and considerations undertaken during the whole treatment of *Wombtomb:* the identification of the materials used in the object; the understanding of what the original construction of the padding looked like; the unravelling of the degradation process; the decisions about the approach taken for its replacement; the choices made over the suitability of the new foam; subsequent analysis of the new materials used in the replacement; and the reconstruction process which employed the use of a prototype model to gauge the work's original appearance before the final restoration.

THE WOMBTOMB

The *Wombtomb* is an ironic and playful Pop Art style reproduction of a coffin with a double motif; dead and birth. This work, of which there are two versions, is one of the most reviewed of Ferdi's three-dimensional organic objects known as Hortisculptures. Ferdi's Hortisculptures were an ode to the female body, eroticism and sexuality in which nature was used as a sexual metaphor. They were an expression of the 60s, a period in which people tried actively to achieve more freedom in the political, social and sexual fields, eradicating taboos *(Westen 2008).*

The sculpture is the first version of Ferdi's *Wombtomb (Figure 1).* The piece, with overall dimensions of 60 cm x 225 cm x 85 cm, consists of two main elements: a base (the coffin) and a lid.

The inner part of the base was shaped by Ferdi to accommodate a body like in a real coffin and it is covered with 6 cushions (one on top of the head, two along the arms and three along the length of the body). Base, cushions and lid are upholstered with several colourful, furry, synthetic fabrics (in purple, green,

Figure 1
The Wombtomb in 1968. Ferdi and her daughters posing in the piece.
Photos: Ad Petersen.

beige, pink, orange, red) hand stitched together and completely padded with flexible foam. In the centre of the lid is a vulva-shaped opening which gives the work the appearance of a mother's womb. The *Wombtomb,* with its double meaning of death and birth, represents a place where people could lie, experiencing the darkness of a tomb and the softness of a womb, whilst undergoing a rebirth by putting their head through the opening in the lid. Ferdi's Hortisculptures were not only intended to be looked at from a distance; with their organic and playful shape (given by the use of soft foam padding) and the colourful fluffy, long-haired, fake furs were invitations for viewers to touch them or sit on them. Numerous photographs document Ferdi and her daughters posing playfully in the Wombtomb or both in or on other Hortisculptures.

While the sculptures were standing in her studios visitors or interviewers were allowed to touch, lie or sit on them. When the Hortisculptures started to be exhibited in museums (except for the "First International Exhibition of Erotic Art" organized in Kronhausens in 1968), this policy changed; touching was banned due to both museum and exhibition ethics and rules as well as to prevent the fake furs from becoming tangled and dirty *(Westen 2008).*

EXAMINATION AND CONDITION

After Ferdi's death in 1969, *Wombtomb* has been owned by her family and, in 2012, it was acquired by the Rijksmuseum in Amsterdam. Before this acquisition, the piece was shown several times during exhibitions and, when not on display, it was stored in the family's house at Scheres castle in Baarlo, Limburg.

In December 2012 the sculpture was examined to evaluate its condition and to investigate a possible conservation treatment, so that this piece could be displayed in the Twentieth Century permanent collection of the Rijksmuseum for its re-opening in April 2013. It was already decided by the curator that the *Wombtomb* was to be displayed in a showcase in order to avoid any risk of the public's interaction with the piece.

Unfortunately, after only 44 years, the coffin made by Ferdi had completely lost its shape; its playful and massive/stately appearance and consequently its meaning was no longer in line with the artist's original intention *(Figure 2).* In order to better evaluate the condition of the padding and the inner side of the synthetic furs it was decided to remove parts of the original stitching of the upholstery.

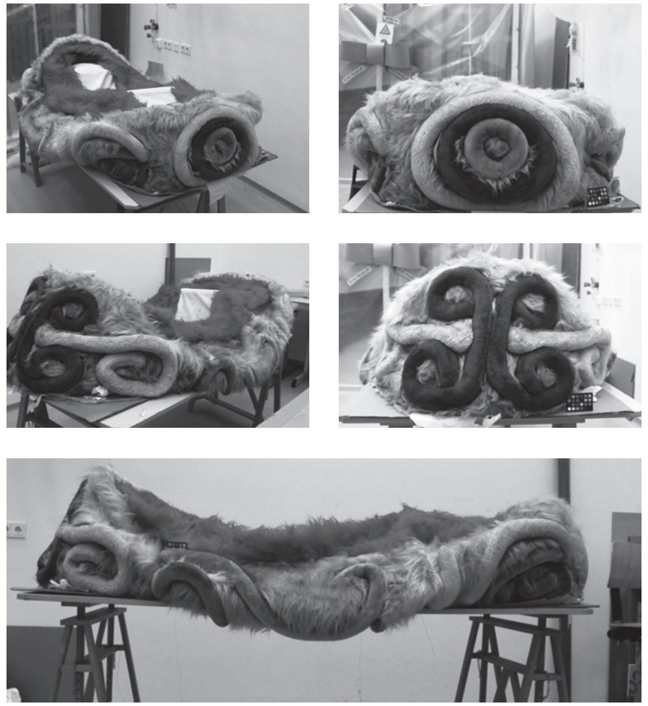


Figure 2
The Wombtomb in 2012.
The photo shows how the coffin had completely lost its shape and its massive appearance compromising the artist's intention.
(see colour plate, p. 165)
Photos: Anna Laganà

The foam material used by the artist to pad the coffin was in very poor condition and showed the typical signs of the degradation of polyurethane ester foam: the foam had collapsed and completely crumbled, totally losing its flexibility and resilience. Moreover, it was extremely sticky, releasing a strong smell. The construction built up by Ferdi, using most likely shaped blocks and sheets of foam, was totally lost. The only parts that remained in good condition were two small blocks of foam and the thin layers of adhesive that Ferdi used to both join all pieces of foam together and to fix them to the fabrics.

It is well known that there are two types of polyurethane: polyurethane ether foam is sensitive to light exposure whilst polyurethane ester foam is susceptible to degradation when in contact with moisture *(Rek 1989; van Oosten 2011).* The different condition of the padding foams in the *Wombtomb* led us to hypothesize that Ferdi had used both kinds of polyurethane foams to construct this work, most likely without knowing the chemical difference between the two.

Therefore, in the *Wombtomb,* the thick furry synthetic fabric protected the polyurethane ether foam from light; however, it allowed moisture to pass through it, triggering the degradation of the polyurethane ester foam. The fake fur fabrics, consisting of a pile made of colourful synthetic fibres looped through and interlaced with a knitted backing structure *(Langeveld-van Lith 2007),* were generally in good condition except for a few areas (lid, opening, cushions and bottom edges) were the fibres were somewhat tangled and dirty. This is most likely due to the public's interaction with the piece that occurred when touching was not yet banned and to its direct contact with the floor.

However, the main problem affecting the fabrics was associated with the layer of adhesive used by Ferdi to fix the padding to the upholstery and the degraded sticky foam, which were both stuck to the knitted backing structure on their inner side.

FOURIER TRANSFORM INFRARED (FTIR) ANALYSIS – MATERIAL IDENTIFICATION

FTIR analyses were performed at the Cultural Heritage Agency of the Netherlands (RCE) to identify the materials used by Ferdi in order to better understand their condition, degradation behaviour and to properly approach the conservation of *Wombtomb*.(2)

Two of the coloured synthetic fur fabrics used by Ferdi were analysed. The pile of the red fur located on the inside of the coffin contains two different fibres: one consists of a polyacrylonitrile vinylchloride blend and the other one is a blend of polyacrylonitrile and polyamide (nylon) or polyacrylamide. The beige pile of the exterior of coffin and lid consists solely of fibres composed of a polyacrylonitrile blended with polyacrylate or polyacetate. The analysis also proved that the knitted backing structure of the synthetic furs consists of cellulosic fibre, which is most likely cotton. The adhesive used by Ferdi was identified as a rubber adhesive. Concerning the padding, FTIR analysis confirmed our hypothesis; the surviving blocks still in good condition after 44 years inside the *Wombtomb* were identified as polyurethane ether foam, while the degraded foam was identified as polyurethane ester type. The spectrum of the degraded polyurethane ester showed the presence of adipic acid which is one of the chemical components used to make this foam, confirming that the degradation was so advanced that the polyurethane ester was breaking down into its starting components.

CONSERVATION TREATMENT – SETUP

As the rate of degradation of the polyurethane ester foam was so advanced, the only option for conserving *Wombtomb's* appearance and meaning was the total replacement of this foam.

Following both the evaluation of the condition of the sculpture and material analysis, a conservation treatment was planned which included the following steps:

Figure 3
Interior of the Wombtomb. Left: removing the degraded foam and examining the remains of the padding. Right: the layers of the adhesive used by Ferdi to join the pieces of foam together.
Photo: Anna Laganà

- *Determining the original construction of the padding*
- *Removing the degraded polyurethane ester foam*
- *Cleaning the blocks of PUR ether foam which are still in good condition and the internal, knitted structure of the fabrics*
- *Choosing an appropriate and suitable replacement foam*
- *Carrying out analysis to investigate the suitability of the replacement foam*
- *Replacing the PUR ester foam and rebuilding Wombtomb with a new foam*
- *Investigating suitable materials and methods to clean the synthetic furs*
- *Cleaning the synthetic furs.*

UNDERSTANDING WOMBTOMB'S ORIGINAL APPEARANCE AND CONSTRUCTION

The first step of the conservation treatment process was to collect information on the original appearance of *Wombtomb* and to research its physical history. Written and photographic documentation of Wombtomb was examined first.

Ferdi's daughters, Giotta and Ryu Tajiri, were contacted in order to gain more knowledge about the piece. They provided several photographs documenting *Wombtomb's* appearance in 1968 and useful information about its "condition history". It is important to mention that Ferdi's daughters have detected the first structural failure of the padding during the installation of the piece for the exhibition "Ferdi Hortisculpture" in the art and architecture centre Stroom in Den Haag in 1992. The piece was installed again in 2002 during the exhibition 'Van Cuypers tot Dibbets' at the Bonnefantenmuseum in Maastricht *(Laganà 2013)*. This was the last time that *Wombtomb* was on display because its condition started to get worse, meaning that the degradation of the polyurethane ester foam had speeded up during the last 10 years resulting in its total loss.

After collecting information and documentation on the physical history of *Wombtomb* and its original appearance, it was necessary to thoroughly understand what the construction of the padding looked like.

The questions were then: how many blocks and how many sheets of foam did Ferdi use? What were the measurements of each part? How did she join these elements together and in which spots? Did she use soft foam or a stiffer one, or even both?

To find an answer to all these questions, the team of conservators started to examine *Wombtomb's* interior while removing its degraded foam. Like working at an archaeological site we 'excavated' carefully, recording and interpreting all the remains of *Wombtomb* which included the surviving foam blocks, the layers of adhesive that Ferdi used to join the pieces of foam together and the traces of marks that she made with different coloured markers during the building process *(Figure 3)*. All these remains were measured as well as the upholstery of the coffin and that of the lid.

The interpretation of all the remains and their measurements led us to hypothesize how the original padding was built up: how many pieces were used, what shape and size those pieces had and in which spots they were joined both to each other and to the upholstery. Based upon the conclusions, a list stating the number of pieces, their size and their shape needed for the complete reconstruction was made.

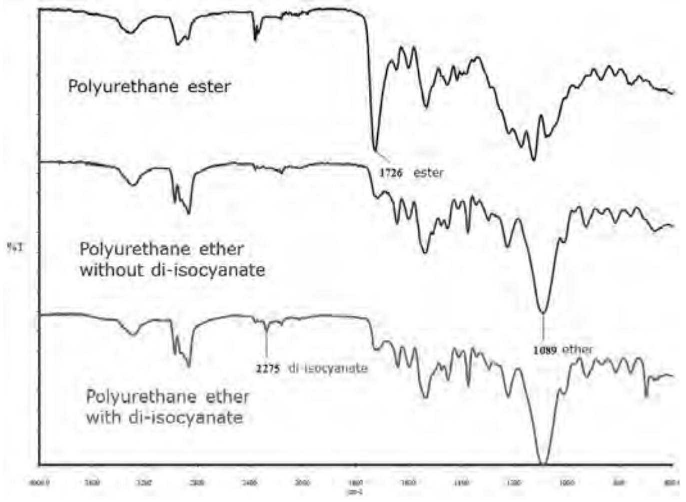


Figure 4
FTIR spectra polyurethane foam;
upper spectrum: polyurethane ester reference,
middle spectrum: polyurethane ether reference,
lower spectrum: polyurethane ether foam showing isocyanate absorption band at 2275 cm^{-1}

CLEANING AND PROTECTING

It was necessary to remove all the padding remains from both the coffin and the lid in a studio that contained no other works of art in the surrounding. This was to avoid any risk of unintentionally spreading the extremely sticky and degraded foam crumbs on other objects and materials. For the same reason, the fibres of the synthetic furs on the outer side of the coffin and the lid were covered with a masking and dust protecting polyethylene film which was temporarily attached to the fabrics with bobby pins. Foam crumbs and remains were removed mechanically and mainly by hand, because their stickiness did not allow removal using a vacuum cleaner. The conservators wore protective clothing and gloves. After removing the degraded foam, the entire workspace had to be meticulously cleaned to remove all bits and pieces of degraded foam before the space could be used again.

After completely emptying the base piece from the padding remains, both the inner side of the synthetic furs and the intact blocks of PUR ether foam were cleaned. Cleaning the inner side of the fabrics by removing the layer of adhesive and the degraded sticky foam from the backing of the fake furs was not a simple matter. Whilst it was quite easy to remove these residues from the protective clothing and gloves using soap and warm water, wet cleaning was not considered an option for the object. The fake fur cover consists of several pieces of coloured synthetic fur fabrics hand stitched together and it has decorations made of padded and upholstered foam. The bottom of *Wombtomb* is covered with synthetic leather. Wet cleaning could cause dimensional changes due to shrinkage of the cotton backing of the fake fur fabrics, and could cause changes in the appearance of the furs. Furthermore, water would merely swell the adhesive but not dissolve it. The adhesive has penetrated deeply into the knitted structure of the backing, preventing complete removal of the residues by wet cleaning without damaging the textile. And, last but not least, it would be impossible to prevent residues, once removed from the backing, from sticking to the furry side of the textiles.

Therefore, several mechanical cleaning materials and methods were tested, such as the use of a vacuum cleaner, synthetic spatulas with different shapes, rubber brushes, paper strips generally used for hair removal waxing, as well as the application of freezer blocks to facilitate residue removal through the action of cold. The cleaning material that proved to be the most efficient was a brush made of natural rubber (Handy Rubber brush) specially sold in household stores for sweeping dust and grains from clothing and upholstery. Using this tool, most residues were removed from the inner side of the fabrics and the still intact PUR ether foam blocks, apart from some areas in which the residues did not come off completely. It was therefore decided to line the inner side of the fabrics and the two original small blocks of foam with Tyvek; a spun bonded olefin based textile which is a flexible, strong and quite stable material often used for storing and protecting textiles and other sorts of art works.

Figure 5
The reconstruction of the padding made by Ferdi (prototype model) before it was build piece by piece into Wombtomb's upholstery. Photos: Anna Laganà

This way, we hoped to provide a further protection layer for the new padding material. After applying this lining *Wombtomb* was ready for new padding.

DECISION MAKING FOR THE REPLACEMENT OF THE FOAM PADDING

The knowledge gained about the original appearance of the piece, the technique used by Ferdi to build up *Wombtomb's* complex construction, the materials she used and their degradation behaviour, all these led us to understand the major requirements for choosing a good replacement material for the PUR ester. It was decided that a suitable replacement material should have:

- *the same or similar properties as the original, such as density, hardness, flexibility, easiness to work with, easiness to cut and shape to name but a few,*
- *it should be a more stable material than the PUR ester foam originally used by Ferdi*

The foam materials available, with respect to these properties and/or chemical stability are foam rubber, polyethylene foam and polyurethane foam.

Foam rubber has nearly identical properties to polyurethane foam but was discarded due to its susceptibility to oxygen which makes this material even more unstable than the polyurethane ester foam.

Polyethylene foam has proven to be the most stable foam available these days. However, it is a relatively rigid material not comparable in its mechanical properties and workability to polyurethane foam. Moreover, polyethylene is a material difficult to adhere due its low surface tension.

The last option was the polyurethane ether foam, the material of the intact foam blocks in *Wombtomb*. This material was finally chosen for the replacement because of its suitable properties (ie, being almost identical to the original material to be replaced) and because it can be a rather stable material if protected from light exposure shown by the fact that the two PUR ether foam blocks in *Wombtomb* are still in good condition after 44 years.

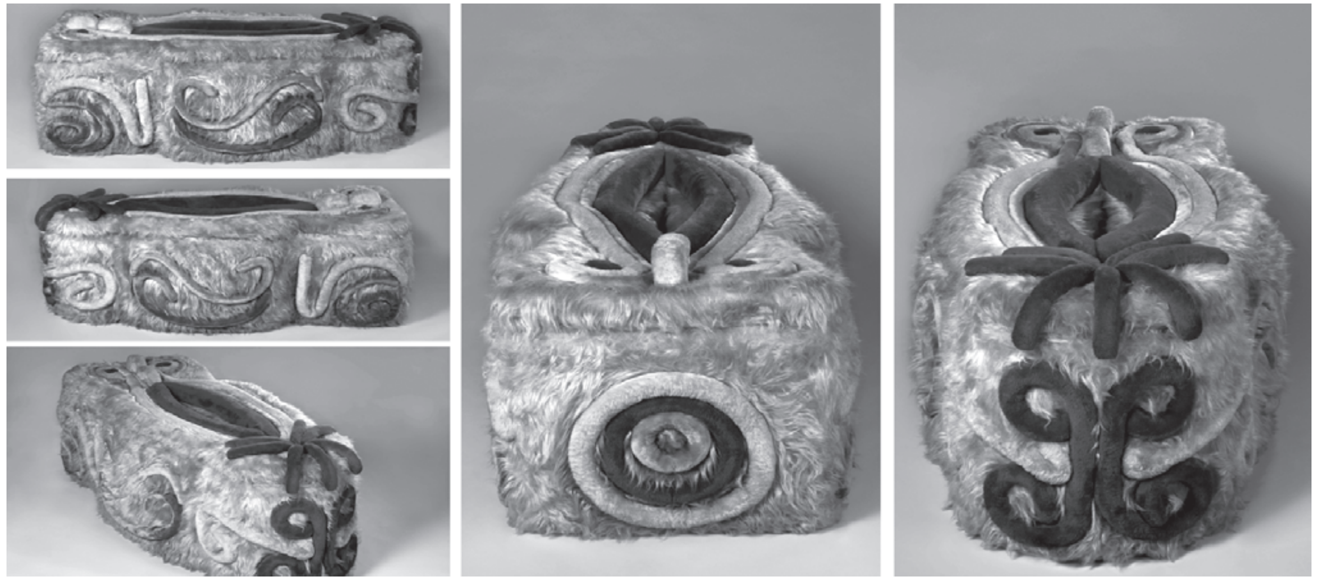


Figure 6
The Wombtomb in 2013 after the treatment. Photo: Copyright Rijksmuseum, Amsterdam

ANALYZING THE NEW REPLACEMENT FOAM AND ASSESSING ITS SUITABILITY

New uncoloured polyurethane ether foam of suitable density and flexibility was bought from a retailer of padding materials in March 2013. Before proceeding with the reconstruction of the padding, a sample of the new foam was taken and submitted to FTIR analysis to check if the material was really an ether type as guaranteed by the retailer. The analysis confirmed that this foam was indeed an ether type; however it showed also an unexpected result. This freshly fabricated polyurethane showed the presence of traces of di-isocyanates, which can be seen in the FTIR spectrum *(Figure 4)*. Di-isocyanates are used in the production of polyurethane foam because polyurethane foam is formed by the reaction of a di-isocyanate and a polyol. A catalyst, such as dibutylamine, starts the initiation reaction. The composition and the amount of the di-isocyanate and the polyol can vary leading to a variety of properties from flexible foam to rigid foam.

Ideally, all di-isocyanate will be used up by the polymerisation reaction with the polyol during the gas-forming reaction. However, the process is never ideal and unreacted di-isocyante will off-gas from the PUR foam. This is why it is known that freshly made polyurethane foam always has to remain in the PUR foam factory for one week to give the unreacted di-isocyantes and unreacted butylamine time to evaporate. Di-isocyanates can cause respiratory disorders, asthma, allergic contact dermatitis, other health conditions *(Pronk 2006)* and non determined risks to objects of art and to other surrounding materials.

The freshly made polyurethane foam bought at the retailer in March 2013 showed di-isocyanates in the FTIR spectrum, meaning that the off gassing of the di-isocyanates was not completed. Hence, we searched for other new, uncoloured foams with appropriate density and hardness at all the retailers in Amsterdam, but all of them, too, showed the presence of di-isocyanate detected by FTIR analyses.

Therefore, considering the risks that an off-gassing material can cause for the museum personnel, the public and the object, and the fact that *Wombtomb* would be displayed in an airtight showcase in a museum resulting in accumulating concentrations of di-isocyanate in the showcase, it was decided not to use this foam for the reconstruction of *Wombtomb* until all di-isocyanate had evaporated.

Tests were performed at the RCE on samples taken from the freshly made foam bought in March, in order to evaluate if a complete off-gassing was actually possible. Total off-gassing of the freshly purchased foam was achieved at elevated temperature of 100°C in an oven in about 18 days, hence demonstrating that complete off-gassing was indeed possible. However, off-gassing at room temperature was estimated to take certainly longer than a couple of months.

RECONSTRUCTION OF WOMBTOMB

Due to the short time available to perform the entire treatment before the upcoming re-opening of the Rijksmuseum in April 2013, it was decided to make a temporary reconstruction by not using the freshly made block of PUR ether foam but an 'older' one (made some months before and purchased from the same retailer) that showed no traces of unreacted di-isocyanate at FTIR-analysis. Although the 'older' foam available did not have the proper density and flexibility, it was nevertheless considered suitable as a temporary material for a temporary reconstruction (in the following referred to as prototype model) whilst waiting for the complete off-gassing of the selected new PUR ether foam. Hence, this foam was cut, shaped and used to temporarily building up *Wombtomb*.

The original construction by Ferdi was made by first building the massive padding by joining the pieces of foam together with an adhesive, and then by fitting, sewing and gluing the upholstery over it. However, for the reconstruction it was decided not to copy the original process because it would have required the unstitching of the whole upholstery made by Ferdi, thereby removing original materials and traces of her original manufacturing technique. Once the reconstruction tests were done *(Figure 5)*, the prototype model was built up step by step and piece by piece into Wombtomb's cover using the two openings, that we previously unstitched along the upper part of coffin and the edges of the lid for emptying the piece, until the work's original appearance was achieved *(Figure 6)*. In order to facilitate removal for replacement at a later date, the pieces of foam in this temporary reconstruction were joined together with long pieces of Tyvek inserted into small horizontal cuts in the foam and tied instead of using an adhesive *(Figure 5)*.

This extra step that was merely included in the treatment process due to the unexpected finding that new foam was unsuitable until complete off-gassing, actually turned out to be very useful. The use of a temporary material for making a temporary reconstruction gave us the chance to check whether our interpretation of the padding construction (ie, the number of foam pieces, size, shape and flexibility) and our analysis of the technique used by Ferdi were correct.

Thus, the temporary reconstruction became a real prototype model that we used to both properly understand how and where the foam should be adhered in the final reconstruction and consequently to gauge the work's original appearance before the final restoration.

TO CLEAN OR NOT TO CLEAN?

To untangle the long fibres of the synthetic furs at the bottom of the coffin and along the opening in the lid, and to improve the object's appearance, different types of combs and brushes were tested. The best results were achieved using a very soft rubber brush bought in a pet shop and especially made for unravelling and brushing delicate hairs.

Although the fur was somewhat dirty in areas that were frequently touched by visitors during the period before *Wombtomb* became a 'museum object', no attempts were made to clean it yet. Removal of the dirt is still under discussion, because it is a direct result of use of the object as it was intended by the artist. This dirt could thus be considered as an integral part of the history of the object and its use. Since it is most likely not causing any harm to the object, its removal does not seem absolutely necessary. However, as the cleaning treatment of these areas is still under discussion, further research on suitable materials and methods for cleaning fake fur fabrics will be carried out in the meantime, using study objects from the 70's.

CONCLUSION

At the beginning of April 2013, *Wombtomb* was on display with its temporary padding, ready for the re-opening of the Rijksmuseum. The final and permanent replacement of the padding material using the new uncoloured polyurethane ether foam of appropriate density and hardness, will be performed in 2014, because FTIR analysis shows that the di-isocyanate in the foam has nearly disappeared after seven months, meaning that the off-gassing of this foam is almost complete.

The successful reconstruction of the *Wombtomb,* although temporary, proved that polyurethane ether soft foam is a material with suitable properties for the replacement of flexible padding in very poor condition. Moreover, this type of polyurethane can be a rather stable material if well protected from light exposure as shown by the fact that the two blocks of PUR ether foam used by Ferdi are still in good condition after 44 years in the Wombtomb. However, the results of the FTIR analyses also showed that when buying new polyurethane ether foam from a retailer one has to check whether off-gassing components are present or not.

This case study highlights the complexities in making informed decisions about new, stable and suitable materials when replacing foam padding. It addresses how analysis played an important role in these choices and hopefully provides useful information to conservators and a methodology for approaching the problem of replacing severely degraded foam used as padding materials in works of art or design objects.

ACKNOWLEDGEMENTS

The authors would like to thank Carola Holz (textile conservator, Rijksmuseum, Amsterdam), Ludo van Halem (curator of 20th century art, Rijksmuseum, Amsterdam), Frederique van Reij (museum curator), and both Giotta and Ryu Tajiri (Ferdi's daughters) for helping us to bring Wombtomb back to its original appearance.

ENDNOTES

(1, 2) Spectra were recorded using a Perkin Elmer Spectrum 1000 FTIR spectrometer combined with a Golden Gate single reflection diamond ATR unit (sample size 0.6 mm^2). Spectra were recorded from 4000 to 600 cm–

LECTURE
007
CONSERVATION TREATMENT OF A POLYURETHANE ESTER SHOE SOLE FROM A BEN VAUTIER'S WORK OF ART

BY LUCILLE ROYAN, ELEONORA PELLIZZI

ABSTRACT

This article describes part of the investigation and conservation work realised at the Institut National du Patrimoine (INP), on a Ben Vautier installation entitled In the spirit of Fluxus, belonging to the Musée d'Art moderne de la Ville de Paris and dating back to 1965-66/2003.

In the spirit of Fluxus consists of an accumulation of different objects set in a painted Vuitton® Wardrobe. Among these objects, the sole of an Adidas® shoe, a Rod Laver model, showed an advanced state of degradation. Unless a conservation solution was found for this shoe, presenting *In the spirit of Fluxus* to the public could no longer be possible. For this reason it was decided to attempt a consolidation of the degraded polyurethane ester sole.

Aerosolisation, airbrushing and application of micro drops of aminoalkylalkoxysilane (AAAS) consolidant were tested on recent polyurethane reference samples artificially degraded.

Since the results indicated that it would be possible to treat one of the two parts of the original sole, it was decided to try to consolidate this part of the original sole and missing parts were recreated in a more stable material.

It then became possible to place the shoe back in *In the Spirit of Fluxus*, and the work could once again be shown to the public.

KEYWORDS

Consolidation, Aminoalkylalkoxysilane, PUR ester, accelerated degradation, Ben Vautier.

INTRODUCTION

French artist Ben Vautier (born in 1935) first created *In the spirit of Fluxus* in1965, by coating a trunk, a Vuitton® Wardrobe model, with black acrylic painting and adding white inscriptions in French – these acts, in his mind transforming it into what he called an "erotic" trunk *(Figure 1)*.

The work, however, only took the name *In the spirit of Fluxus* in 1993 when it was futher modified and shown in an eponym Fluxus exhibition at the Walker Art Center of Minneapolis *(Rothfuss 1993)*. At the time, the artist divided the inside of the trunk, opened from the front and from above, in four levels, by the adjunction of three wooden panels. He set up an electrical lighting system inside. He affixed some items in the trunk, mainly salvaged objects or small creations, by nailing, pining or hanging them up. Other items were just positioned inside. Ben also painted and covered some parts of the installation with felt-tip marker and white out English inscriptions.

After 1993, no documentation on the work is known until 1996, when Ben transformed it again in Blois (France)(1). This new transformation included the addition of an Adidas® shoe, a Rod Laver model(2). At the time, Ben Vautier transformed this industrial and serial object into a unique one by filling it with cement(3) and integrating it in *In the spirit of Fluxus*.

In the spirit of Fluxus was bought by the Musée d'Art moderne de la Ville de Paris (MAMVP) in 2003 from the Issert Galery (Nice, France), which had been the owner of the artwork for an unknown length of time. It, was on display as part of the MAMVP's permanent exhibition between 2006 and 2010, and exhibited in Lyon in 2010 as part of a Ben Vautier monographic exhibition (MAC Lyon 2010). Ben Vautier introduce further modifications to the piece and its presentation on this occasion. Since then, it has remained unchanged in storage in the MAMVP.

The artist therefore modified *In the spirit of Fluxus* several times (in 1993, 1996 and 2010) to adapt it to the specificity of each exhibition project and location. Because of the transformations he made on the artwork since its creation, the trunk might be considered a "work in progress" which has had already several iterations. This characteristic had to be taken into consideration at the moment of making conservation choices: it was decided to conserve the installation as it was in 2010, at the moment of the exhibition, because this was when the artist last intervened on the artwork.

Moreover, *In the spirit of Fluxus* hasn't been exhibited since 2010 because of the alarming state of conservation of the Rod Laver shoe's sole. When the work was returned to the MAMVP

Figure 1
General vue of *In the Spirit of Fluxus* after conservation treatments in the INP's photo lab. © Ghyslain Vanneste.(INP).

after the 2010 exhibition, the rear part of the sole broke away while the shoe was being manipulated.

As most elements from *In the Spirit of Fluxus,* the shoe seemed degraded because it had been worn before being integrated to the artwork. These degradations were already part of the object when it was included in the artwork. For this reason, it was decided to make a distinction, for all components of *In the Spirit of Fluxus,* between the "degradations" inherent to any ordinary use of the objects before integration to the artwork, and the "damages" that occurred after *(Elarbi 2009).* However, these were virtually impossible to differentiate with certainty. Instead, it was then decided to establish two categories of "alterations" according to their liability to endanger the piece's integrity, regardless of the theoretical difference between "degradation" and "damage" defined earlier. All ongoing degradations were classified according to their emergency level. Alterations that represented a real danger of loss of material or meaning/information in the short term had to be treated immediately. The degradation of the shoe sole was classified as part of these alterations and thus required an intervention.

Because it was originally a serial object, the option of replacing the whole element had beenfirst considered when the piece was still stored in the museum - but only on condition that the replacement could be effected by the artist himself. However, when asked to replace the sole, Ben Vautier couldn't do so. In the museum' staff view, a replacement done by the artist himself was at this moment considered as more authentic than a replacement with an identical shoe done by museum' staff . Besides, because the shoe had been transformed into a unique object by Vautier's intervention, it was then decided to try to conserve a maximum of original material, which involved to reconstruct the parts (or fragments) that have been lost and a retouching in order to recover the visual appearance it had before the foam began to crumble. A literature search indicated that treatments tested so far for degraded polyurethane ester porous material had remained unsatisfactory *(Waentig 2008: 307; Van Oosten 2011),* it was decided to experiment a new consolidant, which had been investigated in a recent doctoral research *(Pellizzi 2012).*

Figure 2
The Adidas® Rod Laver shoe at the moment of its arrival at the INP's conservation workshop.

The artist's point of view on these conservation treatment proposals was requested. He wasn't opposed to them but pointed ironically that the conservator spent more time in some interventions than the artist took to create the artwork(4).

MATERIAL AND CONDITION

When it arrived at the conservation studio by the end of 2012, the shoe sole was crumbling and exhibited extreme loss of elasticity and cohesion *(Figure 2).* According to archive documentation, this degradation has been in constant evolution since at least 2008 (MAMVP 2010).

Attenuated Total Reflection - Fourier Transform Infrared Spectroscopy (ATR-FTIR) analyses was performed at the INP laboratory on the two different parts of the sole, the blue wear sole and the yellow intermediate one. Both parts were identified as polyurethane ester. Observations with Scanning Electron Microscopy (SEM) gave information on their structural morphology. The yellow intermediate part of the sole presented an open porosity with cells of 100-150 µm of diameter, while the blue one had a closed cell structure with small cells of 30-50 µm of diameter.

The FTIR analyses indicated the presence of adipic acid, a known polyurethane ester hydrolysis product *(Van Oosten 2002).*, The adipic acid appeared as small white crystals visible with the naked eye on the blue wear sole. Hydrolytic depolymerisation of the polyurethane ester was thought to be the cause of its degradation. This hydrolytic depolymerisation was most likely accelerated by the hygroscopic cement introduced by the artist into the shoe at the moment of its integration in*In the spirit of Fluxus*.

TESTING CONSOLIDATION METHODS

In a recent research, artificially degraded polyurethane ester foams were successfully consolidated with aminoalkylalkoxysilanes (AAAS) *(Pellizzi 2011, 2012b).* The AAAS are a family of silicon-based molecules that can hydrolyse and then condensate giving polymer chains with a siloxane backbone. The aim of the present investigation was to evaluate the possibility to apply, on

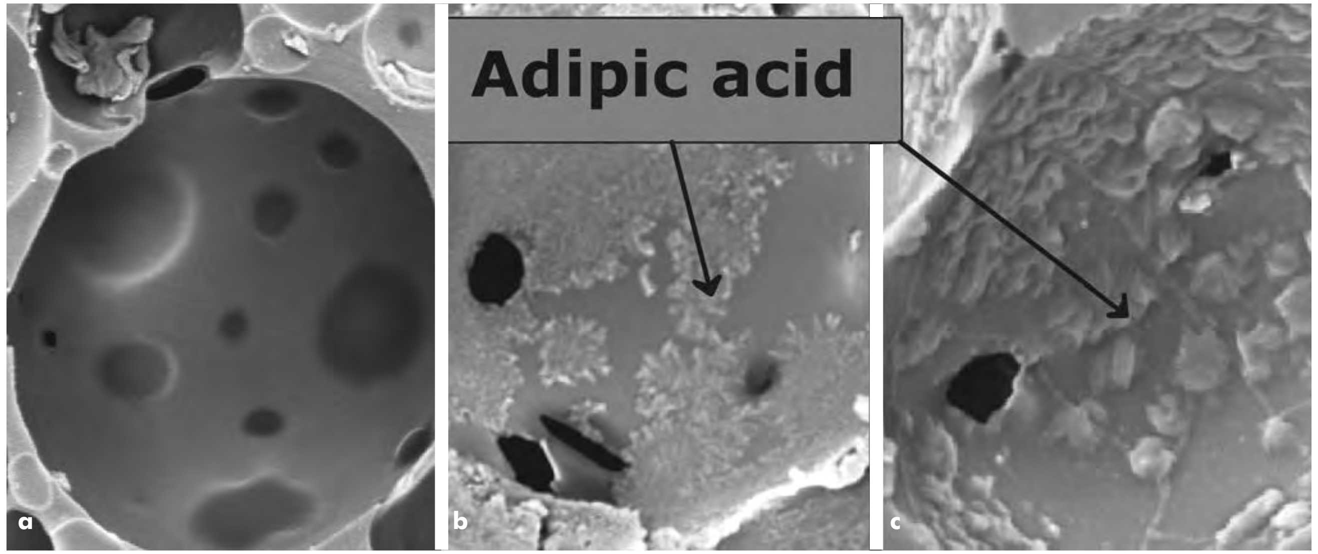


Figure 3
Morphology (SEM pictures x750) of the samples before (A) and after (B) degradation. Highlight of adipic acid crystals on the pre-aged sample and on the original one (C).

and in the degraded shoe sole, an AAAS based consolidant.

The testing had to take into account the degradation state of the original sole, which was so weak that no pressure or any kind of stress could be applied on the material. For this reason, a preliminary study on the application of the consolidant by different techniques on polyurethane reference samples was conducted.

TESTING MATERIALS

Two kinds of polyurethane ester sheets with a thickness of one centimetre, corresponding to the two different parts of the sole, were supplied by Elastogran (BASF® Polyuréthane France), the manufacturer of polyurethanes sole for Adidas®.

ATR-FTIR and Pyrolysis – Gas Chromatography – Mass Spectrometry (Py-GC-MS) analysis showed that the chemical composition of the polyurethane samples from BASF® was similar to that of the original material of the sole. The only difference between the two polyurethane sheets was in the porosity of the two foams.

The samples provided by BASF® were brand new. However, to be representative of the real condition of the shoe, the consolidation tests had to be performed on degraded polyurethane. The samples were subjected to a preliminary ageing process. The reference foam sheets were cut in squares of five centimetres which were then pre-aged for four weeks in an ageing chamber, at a temperature of 90°C and a 50% of relative humidity. After the ageing process, the degradation observed on the samples was visually and chemically very similar to that of the original sole. The ATR-FTIR spectra of artificially aged samples showed that adipic acid had formed, like in the original material.

A visual observation of the samples after artificial ageing under a daylight lamp and colorimetric measurements revealed that their colour had shifted from white to brown for the wear sole samples and from white to red-orange for the intermediate sole samples. The original materials of the Ben Vautier shoe as well presented a darkening when compared to recent photographs of an identical model.

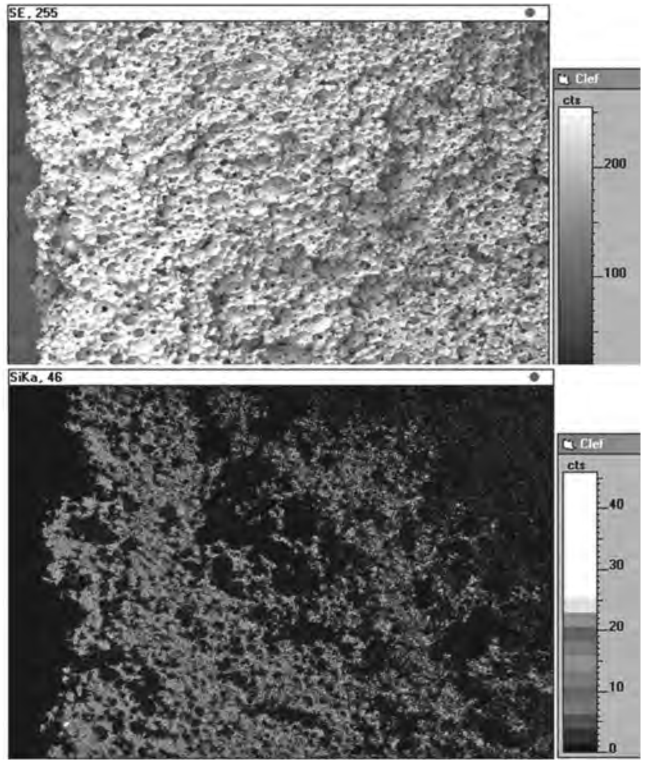


Figure 4
SEM image and silicon cartography (x35) of an intermediate sole kind sample cross section submitted to two applications of 10 millilitres of DIAMINO in HMDS in a concentration of 5% (vol/vol) with a pro-pipette.

SEM images confirmed that the structural morphologic modifications of aged samples were similar to those of the original material *(Figure 3):* after artificial ageing of the test samples of foam, the walls of the cells were covered with small crystals of adipic acid as in the original foam.

In order to obtain a surface as similar as possible to that of the original sole, it was decided to remove the moulded surfaces of half of the samples and to break some of them to access to the porous interior during the treatment application.

MODEL SAMPLES TREATMENTS

The AAAS chosen for the tests was the 3-(2-Aminoethylamino) propyl-dimethoxymethylsilane (DIAMINO) because it had proven to be the most effective of all AAAS investigated by the previously mentioned doctoral research. This consolidant creates a thin coating (few microns) on the surfaces of the foam and restores elasticity and resistance to the whole structure of the treated foam. DIAMINO was used in Hexaméthyldisiloxane (HMDS) solvent solution.

Three application techniques were tested: aerosolisation, airbrushing and micro-drops application.

Aerosolisation with an ultrasonic nebuliser allows the solution to be delivered to the polyurethane ester material as extremely small particles of solution (5-15µm of diameter) *(Lohnas 2010)*. These particles are expected not to condense while entering into a porous material and, consequently, to spread more deeply inside of it. The application of the consolidant by airbrushing and by micro-drops were also tested in order to determinate the penetration of the AAAS solution by capillarity.

For the realisation of the aerosolisation treatment, a homemade nebuliser was built by assembling an ultrasound generator in a small water container containing a smaller flask carrying the consolidant. The ultrasound generator allowed the creation of a cloud of consolidant droplets. The nebulised blending was then driven out through a pipe thanks to an aquarium pump.

For each of the 3 application techniques, up to 3 applications of 10 millilitres were operated on each sample. Three concentrations (0,5%; 2,5%; 5% vol/vol) of DIAMINO in HMDS were tested. The samples were left to dry 24 hours between each application, and one week at the end of the treatment before the evaluation tests.

EVALUATION OF RESULTS

After the samples had completely dried, the following parameters were evaluated at the Centre de Recherche sur la Conservation des Collections (CRCC) laboratory: change in colour, weight uptake, modifications in the mechanical properties, polymerisation and penetration of the treatment in the foams.

The changes of colour were evaluated by visible spectrophotometry while mechanical properties were monitored by indentation mechanical test (Buchholz test). ATR-FTIR analysis and SEM imaging and elemental cartography allowed the investigation of the AAAS polymerisation and distribution through the thickness of the samples.

Samples treated by aerosolisation showed no difference with the untreated ones. The homemade nebuliser was not effective; it didn't allow the deposition of the consolidant on the sample surfaces. This, however, might be attributable to the device used. The results observed on the two kinds of polyurethane treated by airbrushing and applications of micro-drops were quite similar. Every sample treated showed a slight yellowing and darkening. The samples with moulded surfaces and all the closed cell foam samples appeared shinier after the application of the consolidant. These modifications increased with higher consolidant concentrations and number of applications.

The samples were weighed before and after the application of the consolidant with an analytical balance: the weight increased with the concentration of DIAMINO in HMDS and with the number of applications. In general, the weight uptake for the close cell foam was lower than that of the open cell foam samples, suggesting a less effective penetration of the consolidant. The results of the indentation mechanical test revealed an increase in mechanical strength after treatment for all the samples treated both by airbrushing and micro-drop deposition.

The Buchholz test didn't allow the evaluation of the material resistance to the upper part of the shoe's weight; this parameter was evaluated by other means. After the measurement of the sole's surface area and the evaluation of the weight of the cement added inside the shoe, a consolidated sample of 1 cm^3 was submitted to a weight of 20 g during 24 hours. No deformation or squashing of the sample was observed. This result confirmed that the consolidation was effective and that the consolidated material could mechanically resist to the shoe weight.

ATR-FTIR spectra of treated samples showed the absorption band at 1003 cm^{-1} corresponding to the Si-O-Si group. The presence of this band is evidence of the polymerisation of the DIAMINO monomers into poly-DIAMINO on the surfaces of the treated samples.

The penetration of the consolidation solution was evaluated by silicon cartography obtained by SEM elemental analysis on sample sections. On the cross sections of open cell foam samples, silicon was detected up to three millimetres deep with a homogeneous distribution *(Figure 4)*. However, cartographies of cross sections of close cell foam samples show that the consolidant only penetrates a few microns deep *(Figure 4)*. The extremely low porosity of this kind of polyurethane does not allow the penetration of the DIAMINO solution.

The conclusion of this investigation was that a consolidation of the original shoe sole was possible only on its yellow intermediate part, corresponding to open cell foam samples. The DIAMINO solution can only penetrate through the broken, and not moulded, surfaces of this intermediate part. Although the thickness of the penetration evaluated by SEM silicon cartography was about three millimetres in the test samples, an application on various spots was expected to promote a higher penetration in the Ben Vautier original shoe sole.

However, some aspects of the treatment could not be assessed. As the material's porosity is irregular, it was impossible to really assess how far the consolidant would penetrate in it. Furthermore, the ageing behaviour of the consolidated polyurethane remains unknown.

CONSERVATION TREATMENT OF THE SHOE SOLE

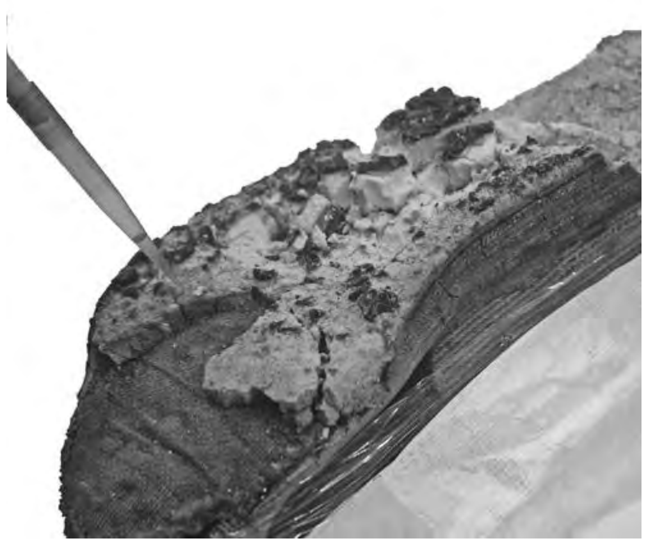


Figure 5
Application of the AAAS solution with a pro-pipette on the original sole

Because the degraded polyurethane of the original shoe was threatened with complete destruction in the near future, it was decided to proceed with the consolidation despite the uncertainties on the ageing behaviour. The non-porous blue part of the sole was crumbling to a powder. It was too degraded to be consolidated, so it was removed. A brush was used to remove the small broken fragments and a scalpel to release the parts that were still connected to the intermediate sole. The blue wear sole was then recreated in a more stable material (a plextol B500 aqueous dispersion and paper pulp blend).

On the porous yellow intermediate sole, the application of the AAAS consolidant in a concentration of 5% in HMDS was operated by the application of micro-drops with a pro-pipette and by airbrushing, depending on the orientation of the surfaces. Two or three applications were performed on all accessible surfaces of the sole. A drying time of 24 hours between each application was allowed.

Figure 6
The shoe before (A) and after (B) conservation treatment.
(see colour plate, p. 165)
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After consolidation, the shoe sole remained very fragile because of the presence of many broken fragments and cracks on its structure. As the gluing of the fragments and the consolidation of the cracks was not possible with the DIAMINO solution because of its very low viscosity, adhesives with a capacity to both glue the fragments and fill the cracks were selected: Lascaux® 360HV and 498 HV aqueous dispersions were chosen. They have been used for gluing ether PUR foams *(Van Oosten 2011:103:53; Frohlich 2009; Melchar 2009)* and allow a polymerisation in a water-soluble film. As the action of water on PUR ester isn't immediate, the aqueous content supply of these adhesives, limited at the application and drying time, was not expected to cause any damage.

The chosen adhesive was expected to fulfil the following conditions. Durable and chemically inert, it should be a well-known conservation product. Compatible with polyurethane, poly-DIAMINO and the shoe canvas, it should ensure adhesion between these materials. The adhesive's physical parameters, such as hardness and flexibility, should match those of the materials to avoid tensions and it shouldn't fill the cellular structure of the polyurethane foam, meaning a higher viscosity was desired. It should fill the polyurethane cracks in order to avoid empty spaces inside of it, which would highly weaken the material's structural resistance.

Thus, broken parts of the intermediate sole were glued with the Lascaux 360 HV adhesive, more flexible than the 498 HV one, applied with slight wooden sticks. Cracks were consolidated by applying the adhesive with a needle. After consolidation, gluing of fragments and filling of the cracks, the shoe could be handled without damage and its crumbling aspect was diminished. But it remained impossible to put the shoe down, on its sole. The reconstitution of the blue wear part of the sole and of the missing parts of the yellow intermediate one had two important functions: to provide structural support to the original polyurethane and to allow a better understanding of its form and volumes by appearing visually similar to the original object.

Since both the blue wear and yellow intermediate sole were originally made of polyurethane, it was decided to use the same material for both, colored differently. This also permitted to limit the number of new materials introduced in the object. Indeed, treating the whole artwork, and not only the shoe, involved a reflexion on the introduction of different conservation material in an object that was already extremely composite. Based on the same reasoning, it was also decided to use the acrylic aqueous dispersions for all kind of adhesions and consolidations (the use of the AAAS consolidant was the only exception to this rule).

The materials used to replace the missing parts of the sole had to fulfil the conditions described below. As they should be durable, chemically inert and removable, conservation products would be privileged to all kinds of silicones or polyurethane expansive foams. The replacement materials' mechanical strength had to be good enough to resist the shoe's weight while being flexible enough to fit its curved form. It was accordingly decided to make use of the conservation Plastazote® polyethylene foams. The visual aspect and colour that had to be similar to the original parts (including brand logo) would be reconstituted by the addition of a thin layer of moulded material on the foam surface. A silicone mould was cast on the sole of an identical shoe model.

The adhesive selected as biding medium for the recreation of the surface's appearance was an aqueous acrylic dispersion, Plextol® B500, chosen because of its high flexibility, its low shrinkage during the drying process and its durability and stability. Two charges were tested to strengthen the system and recreate the degraded surface aspect: paper pulp and glass micro balloons, combined and separate. Paper pulp alone was eventually chosen because it provided the expected strength and surface aspect. A1:1 ratio of charge to binding medium was used. For the intermediate yellow sole reconstitution, the Plextol® B500 was casted with a blend of paper pulp and pigments in a thin layer in the silicone mold, and filled with the high density Polyethylene foam (Plastazote®). The blue wear sole was thin enough to be reconstituted only with Plextol® B500 blend molded in the silicon mold. Both reconstitutions were glued with Plextol® B500n order to form an entity easily removable from the original shoe. After a Mylar® interface was put between them, the reconstructed parts were attached to the shoe by three non woven polyester strips (Bondina®) whose (of which?) both sides had been sized with the Plextol® B500 adhesive. The reconstructed parts were retouched with acrylic paint. *Figure 6* shows the shoe before and after the conservation treatment.

CONCLUSIONS

The treatment with AAAS was successful in improving the structural stability of the Rod Laver shoe sole of *In the Spirit of Fluxus,* but not enough for the remaining original sole to support the entire weight of the cement-filled shoe. The parts of the sole that were missing were replaced using more stable materials made to imitate the PUR ester foam, and the replacement also provided structural strength to the shoe. After the conservation treatment, the shoe was inserted back in *In the Spirit of Fluxus* and the piece could be presented to the public in the permanent exhibition of the Musée d'Art moderne de la Ville de Paris. However, the shoe remains fragile and requires a regular monitoring - every six months is recommended. An adapted storage case was elaborated for the shoe, as well as instructions for the handling and installation of the artwork. In the shoe storage packaging, sealed polyethylene bags containing treated and untreated fragments of the original polyurethane ester shoe sole with and without desiccant (silicagel type E) were stored. The aim was to monitor later on the difference of ageing between those conditioned at 0% RH and those conditioned at 40-50 % RH at ambient temperature. Monitoring the shoe will also permit to assess in the long-term the stability of the AAAS treatment. As the consolidation operated on the polyurethane ester of the sole will not last forever, another conservation solution is planned. The entire sole could be moulded with the reconstitution material used.

ACKNOWLEDGEMENTS

The authors want to acknowledge the Musée d'Art moderne de la Ville de Paris, especially the conservator/curator Dominique Gagneux. We thank Juliette Levy and Maria Letizia Profiri for fruitful discussions. Finally we are grateful to Charlotte Lejeune for her wise advices and revisions of the text.

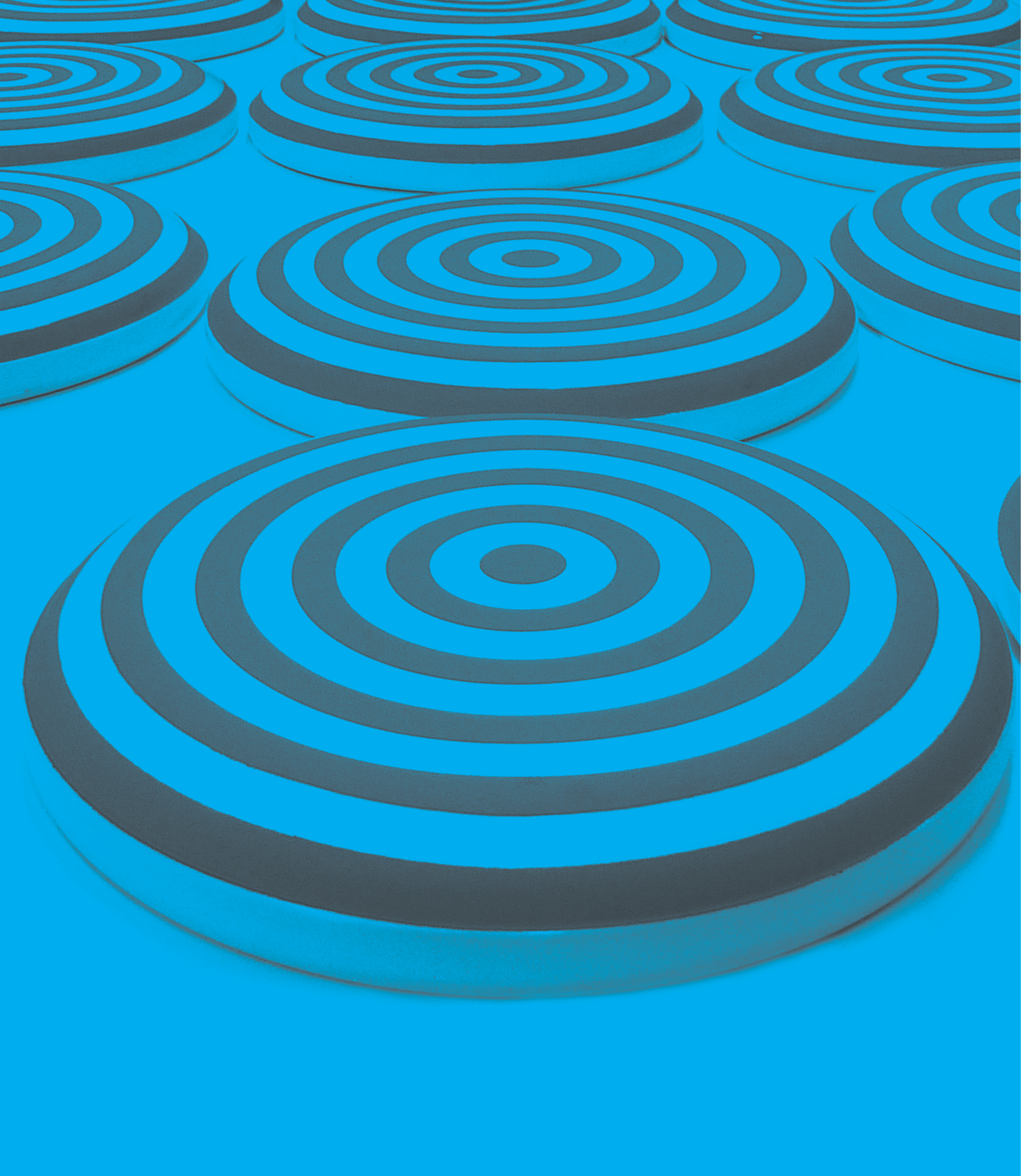
ENDNOTES

1) *Two sources were consulted to collect details about the material history of In the Spirit of Fluxus until 1996. The first one is an intern documentation of the Musée de l'Objet of Blois (France) illustrating how the installation was exhibited and what techniques and materials had been used by the artist since the artwork's creation. Another documentation, only photographical, retracing some exhibitions of the work, was given by Eva Vautier, daughter of the artist.*

2) *Rodney George "Rod" Laver, born in 1938 is an Australian tennis player that turned professional in 1962 who holds the record for most single titles won in the history of tennis. He is the only man that won the Gran Slam twice (in 1962 and 1969). The shoe model was created by Adidas® in 1970.*

3) *A sample of the material filled in the shoe was submitted to a calcium carbonate detection spot test with muriatic acid. The positive results obtained confirmed that it was a kind of cement.*

4) *This information was collected during a personal phone conversation with the artist in March 2013.*



LECTURE
008
EFFECTS OF CLEANING GEL SYSTEMS ON PLASTICISED POLY(VINYL CHLORIDE): NEW INSIGHTS

BY CLÉMENTINE BOLLARD, NATHALIE BALCAR, GILLES BARABANT, SARA KUPERHOLC

ABSTRACT

With the purpose of determining whether cleaning gel systems are suitable for the cleaning of plasticised poly(vinyl chloride), a first stage of research had been conducted to test their short and long term effects on pristine and un-aged samples, and the preliminary results were presented at the FUTURE TALKS 011 conference.

As recent and aged material can possibly react differently to cleaning agents, the present stage of research, in the continuity of the first one, consisted in performing the tests again, this time on artificially aged material.

Pemulen™ TR2 based gel systems with and without the addition of chelating agents (triammonium citrate) and solvent (cyclohexane) were tested. To assess the benefits and disadvantages of using gels pure cyclohexane and a triammonium citrate solution were also tested. The tests were evaluated using various scientific techniques, providing information on the physical and chemical changes induced by the cleaning techniques as well as on their potential to accelerate the ageing rate of plasticised poly(vinyl chloride).

To study the short-term effects of the tested cleaning methods, the sample surfaces were examined before and after cleaning at different magnifications. In addition, surface roughness was measured, plasticiser extraction was investigated by analysing the gels recovered after cleaning and an attempt to estimate plasticiser distribution in the material was performed. Long-term effects were evaluated by exposing once again both un-aged and artificially aged samples to artificial light ageing, and by studying them again with the same scientific techniques previously used.

Despite the fact that many questions remained open, the comparison of the results of both stages indicate as expected that plasticised poly(vinyl chloride) is not equally sensitive to chemical cleaning agents when tested on un-aged or on artificially aged material.

KEYWORDS

Cleaning, gel systems, plasticised poly(vinyl chloride), surface roughness measurements, LCMS, Raman imaging, FTIR-ATR spectroscopy.

INTRODUCTION

Plasticised poly(vinyl chloride) (pPVC) presents conservation issues typical of polymers plasticised by external plasticisation. Since plasticiser molecules are non-polymerised substances, they tend to progressively migrate to the surface of the material and/or to evaporate. In terms of cleaning, one of the main concerns is to select a technique which doesn't contribute to plasticiser migration or extraction at too great an extent, in order not to modify the mechanical properties of the material nor accelerate its ageing rate. It was therefore the main focus of the two stages of this investigation.

As possible cleaning techniques for pPVC, the properties of gel systems appeared very promising, given the example of their interesting results on paintings. Plastics would benefit from their various advantages: limited mechanical action during the cleaning process, localised application of the cleaning agents as well as control and variation of their exposure time, cleaning of textured surfaces and removal of sturdy soil such as adhesive residues or oily substances. Therefore, Pemulen™ TR2 based gel systems with and without the addition of chelating agents (triammonium citrate) and solvent (cyclohexane) were tested. To assess the benefits and disadvantages of using gels, pure cyclohexane and a triammonium citrate solution were also tested.

As a first step in the study, short and long term effects of cleaning gel systems were investigated in order to determine whether these gels are suitable for the cleaning of pristine and new pPVC (stage 1). The preliminary results were presented at the conference Future Talks 011 and published in its postprints in 2013 *(Bollard, C. et al. 2013)*. Since the first conclusions of stage 1 showed that none of the tested cleaning techniques seemed to accelerate the ageing rate of new material so far, a second stage of research (stage 2) took place in 2012, this time on aged material. Unlike other materials found in collections, objects or artworks made of synthetic polymers such as pPVC can age and change within the time frame of a few decades. Therefore, during the second stage of research, some of the cleaning techniques investigated during the previous stage were tested on artificially aged samples.

The same methodology and scientific techniques were used on aged pPVC and compared to the results from the first stage. Afterwards, samples of each stage were artificially aged a second time, allowing a study of the long-term effect of the cleaning agents applied on both new and aged material. The results on un-aged and artificially aged samples were then compared, providing interesting information about the sensitivity of pPVC to cleaning agents in accordance to the age of the material. The compared results are presented in this paper along with numerous new questions and research perspectives which arose from this research.

METHODOLOGY

For stage 2, the same batch of Diisooctyl phthalate (DiOP) plasticised PVC and the same overall methodology and test procedure were used(1) as for stage 1. However, due to machine breakdown and sometimes because of unsuccessful results some of the scientific instrumentation was withdrawn or replaced. Sample surfaces were studied for short-term effects of the cleaning methods both before and after cleaning. *(Figure 1)*

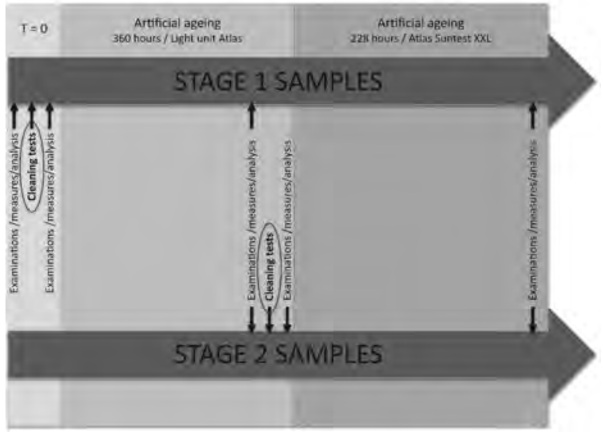
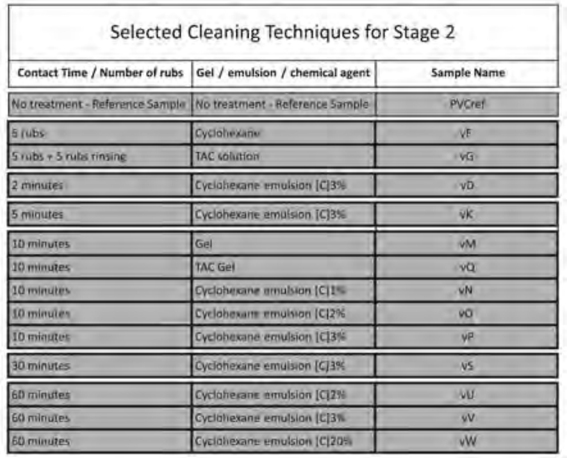


Figure 1
Process timeline of the research. © Clémentine Bollard



Selected Cleaning Techniques for Stage 2

Contact Time / Number of rubs	Gel / emulsion / chemical agent	Sample Name
No treatment - Reference Sample	No treatment - Reference Sample	PVCref
5 rubs	Cyclohexane	vF
5 rubs + 5 rubs rinsing	TAC solution	vG
2 minutes	Cyclohexane emulsion [C]3%	vD
5 minutes	Cyclohexane emulsion [C]3%	vK
10 minutes	Gel	vM
10 minutes	TAC Gel	vQ
10 minutes	Cyclohexane emulsion [C]1%	vN
10 minutes	Cyclohexane emulsion [C]2%	vO
10 minutes	Cyclohexane emulsion [C]3%	vP
30 minutes	Cyclohexane emulsion [C]3%	vS
60 minutes	Cyclohexane emulsion [C]2%	vU
60 minutes	Cyclohexane emulsion [C]3%	vV
60 minutes	Cyclohexane emulsion [C]20%	vW

Figure 2
List of cleaning techniques tested in stage 2. © Clémentine Bollard

TEST SAMPLES AND AGEING PROCEDURES

For stage 2, a selection of these methods was then tested on artificially aged pPVC samples which were exposed in a Light unit Atlas Solar under constant lighting at 180 klux with a UV content starting at 350 nm. Exposure time was 360 hours consisting of three five-day cycles at 50°C and 43% relative humidity, which alternated with two cycles lasting two days each at 38°C and a very high relative humidity of over 80%.

After cleaning, the samples were cut in two: one half to be artificially aged for a second time and the other to be kept as reference of cleaning agents tested on one time aged pPVC. For handling purposes, the halves that would be artificially aged were placed on a glass plate.

In order to gather comparable data about long-term effects of the tested cleaning methods (i.e applied on un-aged or artificially aged pPVC), samples from both stage 1 and 2 were exposed to artificial ageing.

Because of the failure of the previously used ageing chamber, another chamber was used which implied some changes in the artificial ageing parameters and procedure. Samples were exposed in an Atlas Suntest XXL under constant lighting at 140 klux with a UV content starting at 320 nm. Exposure time was 228 hours at 50°C (+/-2) and 50% (+/-2) relative humidity. Unlike the previous artificial ageing parameters, the tempera-ture and relative humidity remained constant while less UV was filtered, but samples surfaces received more klux.

CHEMICAL AGENTS AND CLEANING TECHNIQUES

Just like for stage 1, the tested gel systems included Pemulen™ TR2, a block copolymer consisting of a poly(acrylic acid), used as a thickener for aqueous gels and which also acts as a surfactant. Triammonium citrate (TAC), a mild chelating agent and cyclohexane, a solvent which solubility parameters, are located outside the solubility area of PVC and which is suitable for removing oily or greasy substances, ink, paint or adhesives, were also used for cleaning.

Three types of gels or emulsions were tested: a pure Pemulen™ TR2, a Pemulen™ TR2 gel containing TAC and emulsions prepared by mixing various amounts of cyclohexane to the pure Pemulen™ TR2 gel. At the end of the exposure time the gel or emulsion was removed using a flexible spatula and saved for further analysis. The sample surfaces were then rinsed by rolling cotton buds moistened with deionised water, and any residual deionised water was absorbed with cotton tissue. Cyclohexane as a free solvent and TAC solution applied with cotton swabs were also tested in order to assess the benefits and disadvantages of the gel technique compared with non gelled cleaning agents that combine mechanical and chemical action. Therefore, a TAC solution was prepared by dissolving 1% citric acid in water with addition of triethanol amine until reaching pH 6. This was applied by rolling a moistened cotton bud five times on the sample surfaces. After application, the TAC solution was rinsed by rolling a second cotton bud moistened with deionised water five times over the test surface.

Given the results of stage 1, the following parameters deemed more interesting to pursue in stage 2 *(Figure 2):* all gels and emulsions at 10 minutes exposure time, cyclohexane emulsion (3%) at various exposure times (2, 5, 10, 30 and 60 minutes) and cyclohexane emulsions (2% and 20%) applied for 60 minutes. Cyclohexane as a free solvent and TAC solution were also tested further.

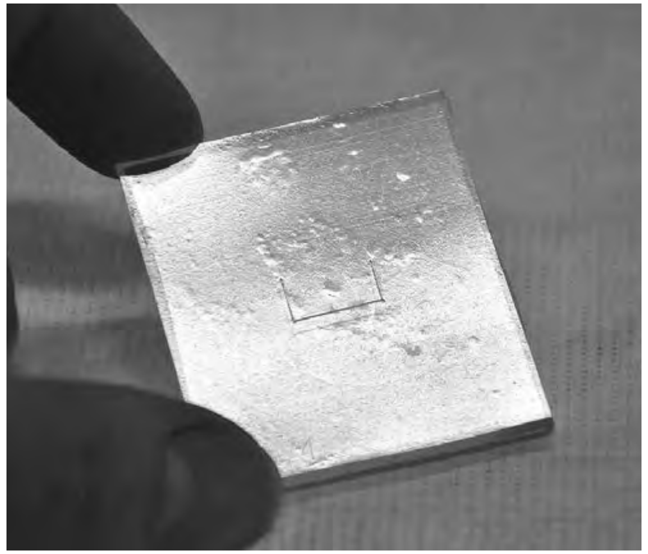


Figure 3
Picture of the disrupted surface of pPVC when cleaned with cyclohexane emulsion (20%) applied for 60 minutes.
(see colour plate, p. 165)
© Clémentine Bollard

SCIENTIFIC EXAMINATION AND ANALYTICAL TECHNIQUES

Similar to the first stage, the second stage main issue was to assess whether the cleaning techniques changed the appearance of the material, extracted plasticizer and accelerated the ageing rate of the material. For that purpose, several examinal and analytical techniques were used. Surface examination at different magnifications was performed, from naked eye observation to digital microscope (Hirox KH-7700), with which surface roughness measurements were also taken thanks to multi focus image capture which allows the creation of a 3D model of the surface and measurement of its irregularities. Plasticizer extraction was investigated by analysing the gels recovered after cleaning with liquid chromatography-mass spectrometry (LCMS). The change in plasticizer distribution was estimated by Raman spectroscopy imaging on the surfaces and on the edges of the samples. Chemical changes of the pPVC were investigated by measuring colour and by Fourier-transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR).

ASSESSMENT OF RESULTS

NAKED EYE OBSERVATION

It was observed that on stage 2 artificially aged sample surfaces looked matte and dusty before cleaning, as compared to unaged pPVC, and non-homogenous tidelines were observed. Tidelines were also present on the glass plate, mainly where there was contact with the pPVC. Although these tidelines were not analysed, they were supposedly made of plasticiser having migrated from the pPVC.

On stage 2 samples, after cleaning and artificial ageing, it was observed that the overall sample surfaces looked brighter and cleared from dust, tidelines and matte substances. Only three samples showed surface changes right after cleaning: pure cyclohexane caused small marks on the surface, cyclohexane emulsion (2%) applied for 60 minutes seemed to cause a slight surface disruption and cyclohexane emulsion (20%) applied for 60 minutes caused blisters on the pPVC *(Figure 3)*.

These alterations disappeared with time, but cyclohexane and long time exposure seem likely to promote disruptions when applied on aged material.

All samples of stages 1 and 2 released a strong odour after having been aged for the second time. Their surfaces were covered in a matte substance which is possibly plasticiser. They showed an incongruous yellowing as a general feature and new tidelines appeared on the glass plate as well. *(Figure 4)*.

Both the yellowing and the tidelines distribution appeared heterogeneously on each sample and seemed to be correlated to the irregular contact between the pPVC and the plate: areas of close contact show a higher yellowing, whereas areas of no contact show less yellowing.

OBSERVATIONS AT MICROSCOPIC SCALE AND SURFACE ROUGHNESS

During stage 1, samples were observed with a stereo-microscope and surface roughness was measured using a confocal white light microtopography device. At stage 2 they were examined with a digital microscope HIROX KH-7700 at magnification x 350. This device also enables 3D image caption, as well as data acquisition such as surface roughness measurements. When examining the samples surfaces at magnification x 350, no particular changes other than those visible with the naked eye were noticed after cleaning and before ageing. After ageing, all samples showed droplets on their surface *(Figure 5),* corresponding to the matte substance observed with the naked eye.

When studying changes in surface roughness(2) before and after cleaning, only samples cleaned with techniques containing cyclohexane show an increase in surface roughness(3). The cyclohexane emulsion with the highest solvent content (20%) applied for the longest exposure time (60 minutes) showed the highest surface roughness increase (196%). As noticed during experiments at stage 1 on new pPVC, cyclohexane appears to promote surface roughness increase after cleaning. This roughness increase could be related to either surface disruption or plasticiser removal from the surface. In regard to changes in surface roughness before and after ageing, with the exception of four samples cleaned with cyclohexane based techniques(4), all samples including the untreated reference show a surface roughness decrease after ageing. This decrease in surface roughness could be related to surfaces smoothed by the presence of plasticiser, confirmed by the appearance of droplets observed under the digital microscope.

PLASTICISER EXTRACTION

LCMS was used to detect the amount of DiOP possibly extracted from the pPVC. The analyses were performed on the gels, emulsions and cotton swabs recovered after cleaning. Similar procedures were used in both stages of research. From stage 1 it was concluded that emulsions containing high amounts of cyclohexane (20%) and at high exposure time (30 and 60 minutes) would extract detectable DiOP residues, but only at threshold levels (≤ 0.5 ppm). An exception was the 2% cyclohexane emulsion, applied at 10 minutes exposure time. As for stage 2, a slightly higher quantity of DiOP was detected from the sample cleaned with cyclohexane on a cotton swab (14 ppm). Only traces of plasticiser were detected for the TAC solution (1 ppm), the cyclohexane emulsions (3%) at 2 and 5 minutes exposure time and the TAC gel at 10 minutes exposure time (0.2 ppm).

So far, it seems that exposure time and cyclohexane content are not significant parameters concerning DiOP extraction. The plasticiser is probably removed from surfaces, but not extracted from the core of pPVC. The presence of DiOP in slightly higher proportions in stage 2 gels, emulsions and cotton swabs, recovered after cleaning, is probably due to the fact that the aged samples had more plasticiser on their surface from the outset.

Raman spectroscopy was used in mapping mode and anticipated to detect and localise the plasticiser, as well as to identify distribution changes. It was also expected to determine the presence of tidelines visible on the glass plate as evidence for a loss of plasticiser. This analytical technique was merely approached upon during the initial stage and many technical issues arose during the second stage. First, pPVC being a soft material, it was hardly possible to cut even and flat sample edges and thus to focus along the whole width of the sectional view. This resulted in a loss of signal and in incomplete data acquisition. The use of a micro-tome would have been helpful for this task. Second, the fluorescence of yellowed areas in the aged samples caused laser saturation and thus loss of signal. The time frame was too short to make the required improve-ments, therefore Raman imaging was withdrawn.

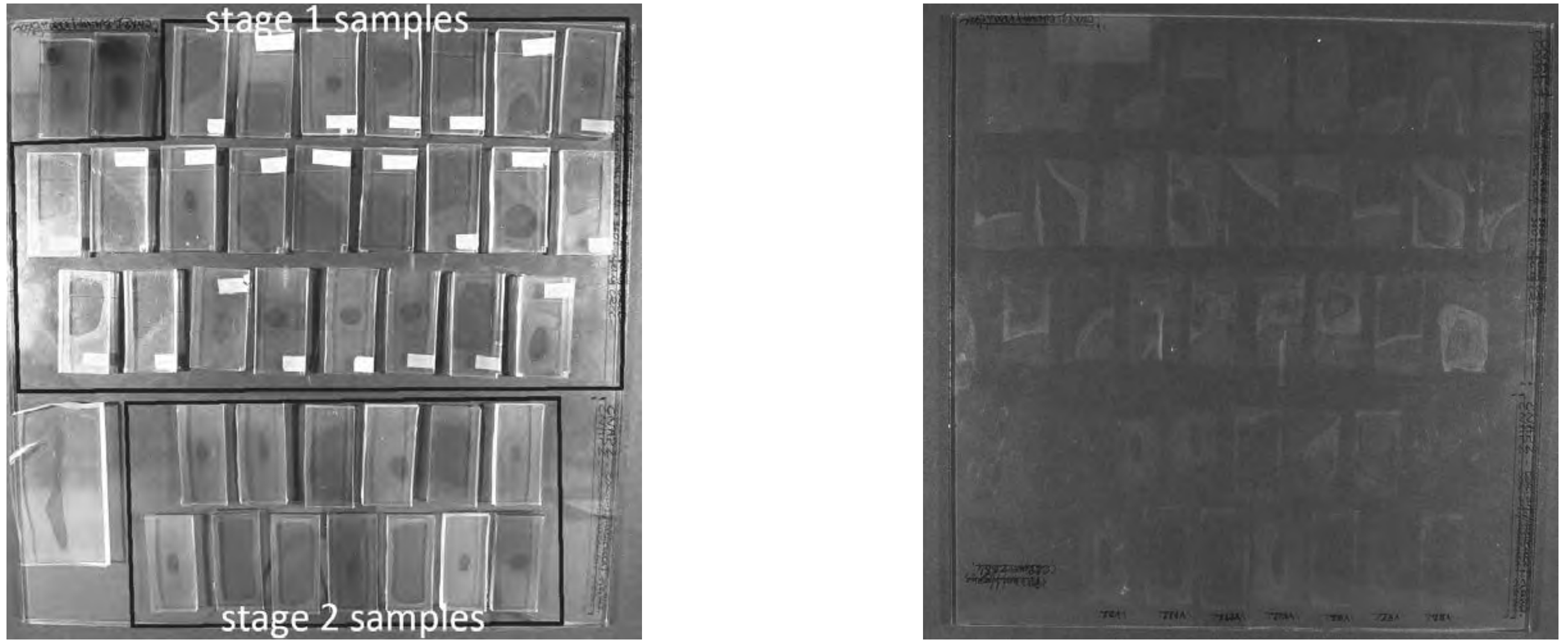


Figure 4
On the left side: stage 1 and stage 2 samples after artificial ageing. On the right side, tidelines left on the glass plate after removal of the samples.
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CHEMICAL CHANGES

Spectrocolorimetry was used to monitor colour changes after ageing. Three measures were performed on each sample, before and after ageing. Averages were calculated and a*b* chromatic data were then compared. After ageing, all cleaned samples of both research stages showed more yellowing than the un-cleaned reference sample. The highest grade of yellowing was around three times more than the untreated sample. It can therefore be concluded that cleaning does promote a certain change in pPVC. Globally, data clouds of stage 1 and 2 graphs have the same morphology and are situated within the same scale which allow us to compare, in terms of yellowing, the impact of the cleaning techniques applied to un-aged or to aged pPVC *(Figure 6)*.

When applied on both new and aged pPVC the techniques that caused the highest yellowing mostly had a low cyclohexane content. In descending order of yellowing:

- *cyclohexane emulsion (3%) applied for 2 minutes*
- *cyclohexane emulsion (5%) applied for 2 minutes*
- *cyclohexane emulsion (2%) applied for 10 minutes*
- *TAC solution (5 rubs)*
- *cyclohexane emulsion (2%) applied for 60 minutes*

It was observed that several samples do not have the same coordinates when depicted in stage 1 or stage 2 graphs, meaning that pPVC cleaned with the same technique did not yellow to the same extent if applied to un-aged or to aged pPVC. Some techniques caused higher yellowing when applied to new pPVC: cyclohex-ane emulsion (3%) applied for 10 and 30 minutes, as well as pure cyclohexane. Others caused higher yel-lowing when applied to aged pPVC: cyclohexane emulsion (1%) applied for 10 minutes, cyclohexane emul-sion (3%) applied for 60 minutes, citrate gel applied for 10 minutes, pure gel applied for 10 minutes, and cyclohexane emulsion (20%) applied for 60 minutes. These techniques mainly represent long exposure times. This suggests that some cleaning techniques do not have the same impact on pPVC, depending on whether they were applied to new or aged pPVC. Indeed, new pPVC seems more sensitive to cyclohexane than artificially aged pPVC, which seems to be more sensitive to long contact with water based techniques.

FTIR-ATR measurements were taken at different stages of ageing in order to assess the loss of plasticizer, the formation of degradation products and chemical changes. Unexpectedly, a comparison of the spectra of all samples before and after ageing showed no significant difference. It was then impossible to correlate FTIR-ATR and colour measurements, thus the compound in pPVC responsible for the yellowing remained unidentified.

Possible explanations are that either the compound responsible for the yellowing is available only in very low concentration, at least under its detection limit with FTIR-ATR, or that the FTIR technique is not suitable for its detection.

CONCLUSIONS AND TENDENCIES

Some main tendencies were detected in terms of harmful effect of the cleaning techniques tested on pPCV, and they should be balanced considering that they are possibly specific to pPVC with DiOP and that all cleaning tests have been performed on pristine material and not on dirty objects, thus possible interaction between the cleaning agents and dirt has not been taken into account.

All cleaning procedures led to slight physical changes, cyclohexane and its emulsions causing the most. However, surface changes that were visible with the naked eye were not permanent, as the surfaces of the samples recovered to their original appearance with time.

LCMS analysis reveals that the risk of plasticiser extraction from pPVC is very weak. The DiOP compounds detected in the gels, emulsions and cotton swabs were already present on its surface. At various degrees, all treatment techniques seem to cause more yellowing of the pPVC compared to the untreated reference. The chemical sensitivity of pPVC to cleaning agents seems to vary according to its age.

On the whole, the use of pure Pemulen™ gel, TAC gel, cyclohexane emulsions, pure cyclohexane and TAC solution seems to be appropriate for the cleaning of pPVC, but the tendencies previously described show that certain chemical agents or exposure times are preferable, depending on the pPVC's age and condition.

ONGOING DEVELOPMENTS OF THE RESEARCH

This research found its limitations in the full understanding and correlation of the various phenomena ob-served: in fact some questions were solved but much more arose. For example, are the changes in surface roughness a sign of surface disruption, or is the surface covered in plasticiser and/or other compounds? What component did cause yellowing of pPVC: the polymer, the plasticiser or other additives?

Interpretation limitations have been an encouragement for continuing research about pPVC in order to better understand these first results and questions. The understanding of plasticiser behaviour within the polymer matrix, its evolution with time and its response to conservation treatment, such as cleaning, is still a

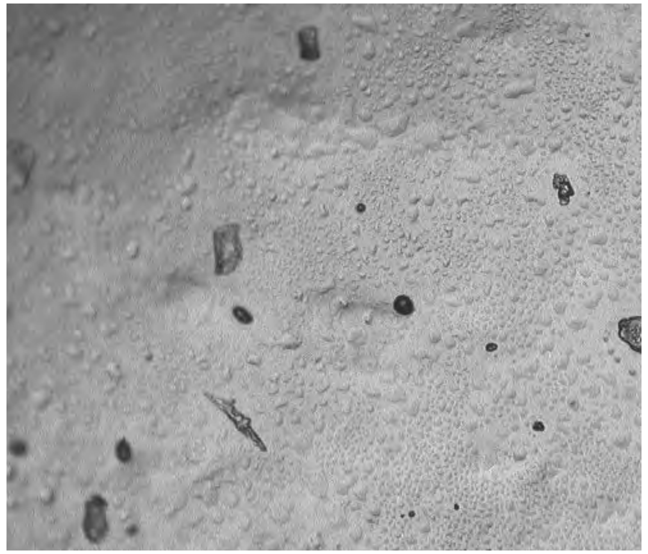

Figure 5
Sample tested with cyclohexane emulsion (3%) applied for 2 minutes, after artificial ageing. Examination with videomicroscope, magnification x350, polarised light.
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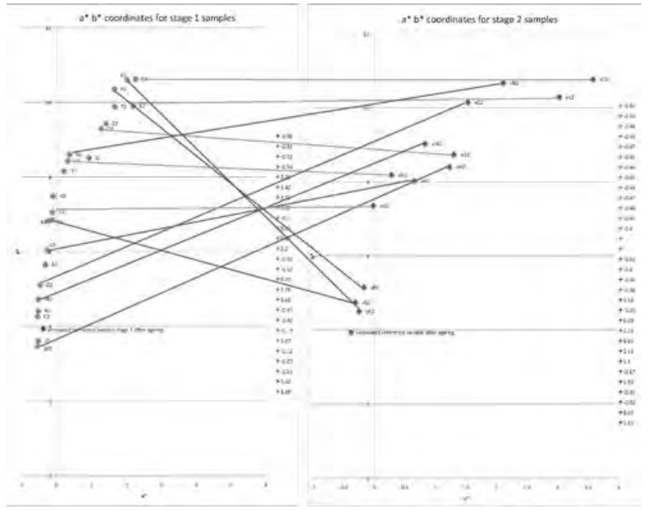

Figure 6
Graphs showing colorimetric data of stage 1 and 2 samples.
Green lines show correspondences between stage 1 and 2 samples, red lines highlight differences.
(see colour plate, p. 165)
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major concern for the conservation of pPVC.

Therefore, a collaborative research project was set up with a wider range of partners(5) involving conservation scientists, art historians and conservators. With an interdisciplinary approach in conservation and analytical chemistry, the appearance of plasticiser exudates and their kinetics are investigated. The con-sequences of cleaning treatments and contact with packing materials on further plasticiser migration and modification of the ageing rate of pPVC are also investigated.

ACKNOWLEDGEMENTS

This ongoing research conducted in collaboration with the Centre de Recherche et de Restauration des Musées de France has been funded by the Centre National des Arts Plastiques (Ministère de la culture).

For their kind help and for the time they dedicated to this study we would like to thank: Richard Wolbers (University of Delaware, U.S.A) for performing LCMS analyses; Alain Colombini (CICRP, France) for his suggestions and time spent on Raman imaging; and for their advice: Jean-Jacques Ezrati (C2RMF, France); Martine Gillet and Agnes Lattuati (CRCC, France).

ENDNOTES

(1) *Manufacture of pPVC samples, gels and cleaning agent formulations, as well as cleaning and application techniques are fully described by the author in: Bollard C., Kuperholc S., Balcar N., Barabant G., 2013. 'Effects of cleaning gel systems on plastics: a preliminary study on plasticised poly(vinyl chloride)'. In Future Talks 011, Technology and conservation of modern materials in design, postprints of the conference held in Munich, 26-28 october 2011, 119-126.*

(2) *MoutainsMap® software was used to extract the surface roughness parameter Sq. The surface roughness parameter Sq is the root mean square of the distance between the peaks and the valleys of the surface relief, expressed in micrometers (µm). To evaluate surface roughness changes after cleaning, the àSq parameter was used (àSq = Sq before cleaning - Sq after cleaning). The percentage of change in surface roughness was then calculated using the following formula: (Sq after cleaningx100)/Sq before cleaning. To evaluate surface roughness changes after ageing, the àSq parameter was used (àSq = Sq before ageing - Sq after ageing). The percentage of change in surface roughness was then calculated using the following formula: (Sq after ageingx100)/Sq before ageing.*

(3) *Samples tested with pure cyclohexane (vF), cyclohexane emulsion (3%) applied for 5 minutes (vK), cyclohexane emulsion (2%) applied for 10 minutes (vO), cyclohexane emulsion (3%) applied for 10 minutes (vP), cyclohexane emulsion (2%) applied for 60 minutes (vU), cyclohexane emulsion (3%) applied for 60 minutes (vV), cyclohexane emulsion (20%) applied for 60 minutes (vW).*

(4) *Cyclohexane emulsion (3%) applied for 5 minutes (vK), cyclohexane emulsion (2%) applied for 10 minutes (vO), cyclohexane emulsion (2%) applied for 60 minutes (vU), cyclohexane emulsion (20%) applied for 60 minutes (vW).*

(5) *Centre de Recherche sur la Conservation des Collections (CRCC), Centre de Recherche et de Restauration des Musées de France (C2RMF), Laboratoire de Physicochimie des Polymères et des Interfaces (LPPI)*

LECTURE
009
THE HISTORICAL COLLECTION OF THE ADI COMPASSO D'ORO AWARD: TWO CASE STUDIES FOR THE RECONSTRUCTION OF VOLUMETRIC AND INDUSTRIAL SURFACE LOSSES

BY ELENA BOZZO, GIUSEPPE CUTOLO, ENRICO MORTEO, SANDRA VAZQUEZ-PEREZ

ABSTRACT

A collaboration between two foundations, the 'Italian Association for Industrial Design' (ADI), and 'La Venaria Reale', has been established to tackle different aspects of the conservation of the Historical Collection of the ADI Compasso d'Oro Award, the oldest and most influential international design award in the world. As a result, the collection was declared Italy's National Heritage in 2004.

For years, the objects from the Compasso d'Oro (CdO) Collection were packed away and stored in external warehouses without any particular attention being paid to correct conservation, as they were not necessarily destined to become museum pieces.

Since 2008, the Centro Conservazione e Restauro La Venaria Reale (CCR)(1) foundation has been working on the CdO Collection, an innovative project with the objective of defining specific intervention methods on each design object. As a result, every object was examined with the aim to produce a careful analysis of constituent materials as well as the assessment of degradation patterns. The database set up for the collection allows the search of objects through parameters which respond to the combination of features requested.

This article briefly introduces the range of objects in the Collection CdO Award and quotes two case studies.

KEYWORDS

Italian design, Compasso d'Oro Award, documentation, data-base, casting, adhesion

INTRODUCTION

The Compasso d'Oro Historical Collection resulted from a straight-forward accumulation of objects and designs that have received the Compasso d'Oro Award since its first edition of 1954 up to the present day. It is clear that an award scheme that has lasted this long and the choices of which have been determined by 21 different juries gathered periodically over the course of years can claim to be neither consistent nor a constant yardstick. The highly particular nature of the collection means that it clearly has its pros and cons. The most obvious disadvantage – and one that has frequently been cited – is that the collection is limited only to the actual winners of the Award, excluding all shortlisted award entries. More than once the idea has been mooted to bring together all the objects neglected by the Compasso d'Oro and, it must be said, this would surely make a fabulous exhibition.

There is probably no other design collection in the world that is as extensive, putting together simple everyday household objects with complex industrial machinery, measuring tools and toys, cars and decorative fabrics, construction systems and publications, theoretical research and graphic design, to mention just a few of the areas that have been taken into consideration by the Award's juries. What the entire Collection conveys is a complex and articulated vision of design in which materials that otherwise would be relegated to industrial history or scientific research live together with semiotic analyses, the history of costume and fashion and the world of theoretical experiments; a design that is much more intimately connected to social and cultural changes and not just simply dedicated to managing the aesthetic appearance of things and objects.

For these reasons, it is interesting to analyse the history and the development of CdO Collection during the 20 century.

THE COMPASSO D'ORO AWARD – HISTORICAL BACKGROUND

The Compasso d'Oro Award is the most prestigious acknowledgement dedicated to design, products, research and merit; its international prestige is unquestioned. The Compasso d'Oro was mainly the idea of architect Gio Ponti, the Vice Director General of the La Rinascente department store in Milan, Cesare Brustio, and the art critic Augusto Morello, as a result of the popular exhibition 'Aesthetics of the Product' held at La Rinascente in 1953. The success of the 'Aesthetics of the Product' exhibition convinced La Rinascente to create and present an award aimed at recognising and promoting the cultural qualification inherent

Figure 1
Installation view of the exhibition, "Compasso d'Oro, la collezione del Design italiano 1954-2004". Reggia di Venaria Reale (Turin-Italy)

Figure 2
Some awarded objects at the external warehouse of the ADI showing examples of their condition state and damages:
a) Detail of Doney TV by Marco Zanuso & Richard Sapper for Brionvega (CdO 1963). The metal parts show some corrosion which at certain points caused the galvanic surface finish to delaminate. In addition, the end part of the antenna was missing.
b) Spinamatic tapster, designed for the Splügen Bräu Pub by A. & P.G. Castiglioni, (CdO 1964). Detail of marks of the bubblewrap imprinted on the protective surface paint.
c) Zizi, The Monkey was designed by Bruno Munari. It is a flexible toy made of expanded polyurethane foam with a twisted wire core and hand-painted face (CdO 1954). The image shows details of the damage in the polyurethane.
d) Detail of the children's chair K1340 design by M. Zanuso & R. Sapper for Kartell showing a breakage of the plastic material.

in products, which would also act as a stimulus to the growth, if not the actual creation of companies based around quality and design. The Award's logo, which relates to Adalbert Goeringer's compass and to the golden section, was created by the graphic designer Albe Steiner.

The first edition of the award was set up in 1954 in conjunction with the X Triennale and coincided almost simultaneously with the launch of Stile e Industria, the first Italian magazine dedicated entirely to design and edited by Alberto Rosselli. Fifteen awards were presented in the first edition to a selection of products that made use of vastly different materials and technologies (Olivetti Lettera 22 typewriter, Murano glass vases, articles for sports and leisure, dinner services, chairs, toys, etc.).

The first four editions of the Award were held on an annual basis and were organised by La Rinascente itself. In 1958-59, the organisation was shared jointly with the ADI, which was established in Milan in 1956 at the behest of eight designers (De Carli, Gardella, Magistretti, Munari, Nizzoli, Peressutti, Rosselli and Steiner), two companies (Kartell and Officine Meccaniche Pellizzari) and one critic (Dorfles). The award was handed over completely to the ADI in 1964, which has looked after its management and its archive ever since; collecting the materials (objects, drawings, photos and other documentation), appointing the juries as well as organising the award ceremonies and the related exhibitions and catalogues.

In the 18 editions hosted by the ADI, 255 designs were awarded the Compasso d'Oro. In addition, 51 Compasso d'Oro Awards were presented to designers for career achievement, whilst 38 companies or institutions were recognised with the Award for their work as a whole.

Prior to 1970, the juries were drawn exclusively from the Italian design world. However, the juries have since broadened to include foreign designers and individuals working in related fields. The Award criteria have also been broadened to include products designed by non-Italians but manufactured in Italy, and vice-versa, underscoring the internationalisation of the Compasso d'Oro.

FROM THE DESIGN WORLD CAPITAL 2008 TO THE ADI PROJECT.

In 2008, coinciding with the Design World Capital year, the ADI awarded the 21st edition of the Compasso d'Oro Award with the ceremony taking place in Turin for the first time. Simultaneously, an exhibition called 'The Compasso d'Oro, Italian Design Collection 1954-2004' was organised in the Reggia di Venaria Reale *(Figure 1)*.

Figure 3
Some objects from the Historical Collection of the Compasso d'Oro Award after conservation treatment.
(see colour plate, p. 166)

Within this context, strong support was given to the exhibition by the Centro Conservazione e Restauro La Venaria Reale (CCR)1 through a variety of actions, such as environmental surveillance and focused mainte-nance, which initiated the creation of a study and research project focused on the conservation and restora-tion of the entire Historical Collection of the Compasso d'Oro. Within a broader context, the main focus of these studies was to analyse the design collection beyond its historical, social, artistic or aesthetic relevance and to extract the importance of its symbolic value, considering functional and ergonomic aspects of these objects. The analysis sought to establish the types of use, the material technology and ergonometric dimen-sions – all aspects which are intimately related with the objects' life-span.

THE ADI PROJECT

The ADI project gave the CCR the opportunity to carry out studies and observations related to the materials and production technologies which have characterised the creation of objects

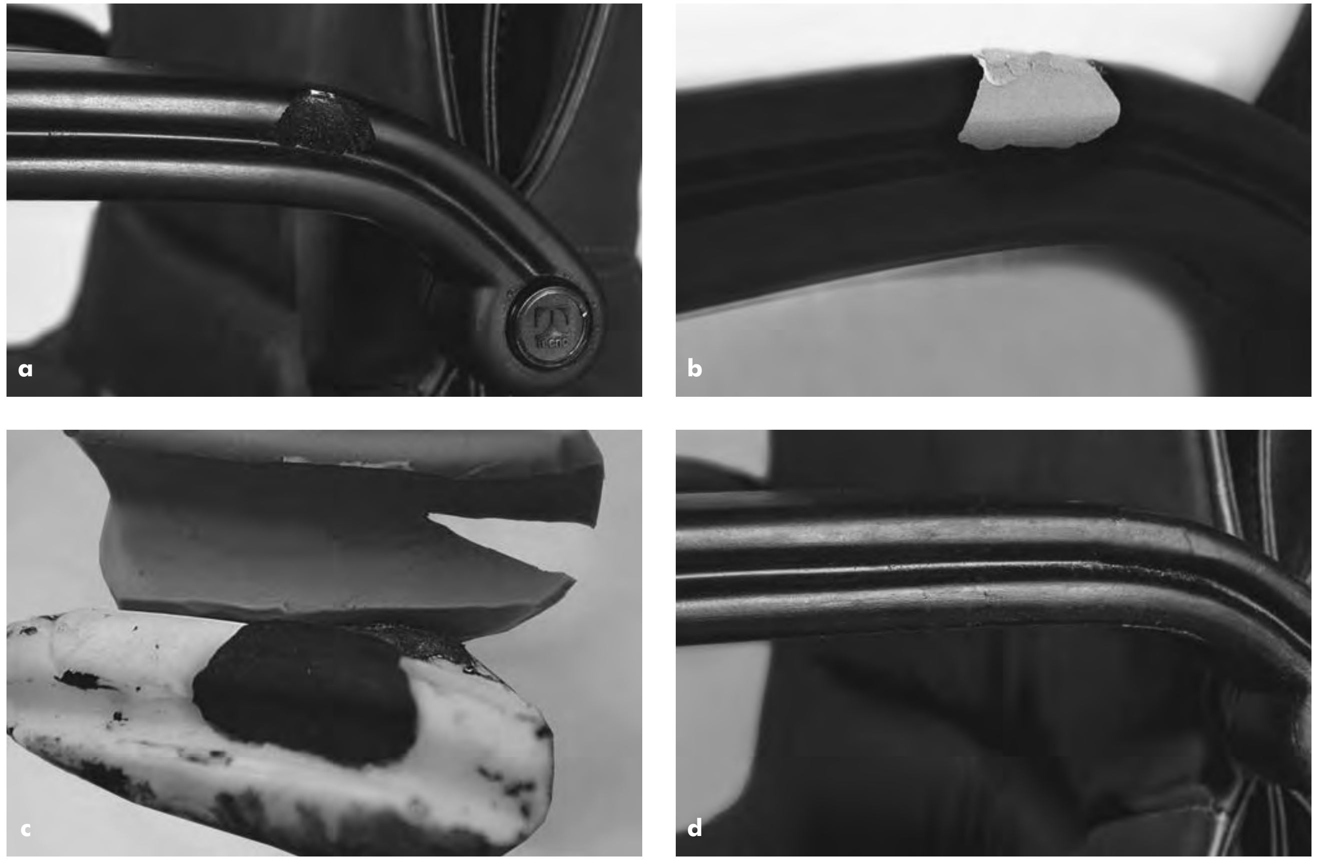

Figure 4
Treatment phases of Qualis
a) Photograph of the polyurethane gap damage
b) Testing the into the prepared model casts
c) Model made of Sintagom Neutro into a small rubber mould 'bivalva'
d) After treatment

and works of art dating from the second half of the 20th century, all of which are objects requiring further research.

The project was divided into three work phases, which can be described as follows:

The First Work Phase (2009-2010) consisted of the data base compilation including all the objects of the Historical Collection which were housed at the Foundation's warehouses *(Figure 2)*.

The Second Work Phase (2010-2011) included the first part of conservation work executed on these objects *(Figure 3)*. The results of this process were published in the catalogue of the Italian Design Exhibition 'Unicità d'Italia' (Rome, 31st May – 25th September 2011) which was organised in celebration of the Italian Unification, and they were also presented in Madrid at the XII International Conference on the Restoration of Contemporary Art (15th -17th February 2012).

The Third Work Phase (2012-2013) continued with the conservation and restoration but also included new interventions with the objects, some of which will be described as Case Studies in this article to illustrate their condition and conservation options. The different conservation actions were aimed at preparing the collection for exhibition at the new ADI Headquarters and at the further development of design conservation procedures through an international exchange program, including specialist publications which are forthcoming in spring 2014. In all the project phases, diagnostic analyses were carried out when necessary in order to improve the information about the objects by our scientific laboratories. For this purpose, techniques such as ultraviolet-visible light (UV-VIS) optical microscopy, x-ray fluorescence spectroscopy (XRF), scanning electron microscopy with x-ray microanalysis (SEM-EDS) and Fourier-transform infrared spectroscopy - attenuated total reflectance (FTIR-ATR) were used.

DOCUMENTATION: CREATING THE DATA BASE

One of the key challenges the team had to face was the creation and development of a data base(2) that gathered the main information on different aspects (eg, designer, materials, exhibitions, etc.) of the objects within the Compasso d'Oro Collection. The management of the data previously stored as paper info cards (which were not conducive to the development of the studies) resulted in a complex research process and the creation of a digitised data base. This gave the researchers many advantages, such as:

- *simple data management*
- *the creation of shared themes and vocabularies*
- *using search engines and keywords to obtain/cross-link information on the objects*
- *easy navigation of data*
- *continuous updating of research material*
- *the possibility to access information via mobile technology.*

In addition to these aspects, a key element in the development of the data base was the creation of a shared portal in which the team can find information on the condition reports and other related documents, which enables the immediate assessment of the damage of the different pieces.

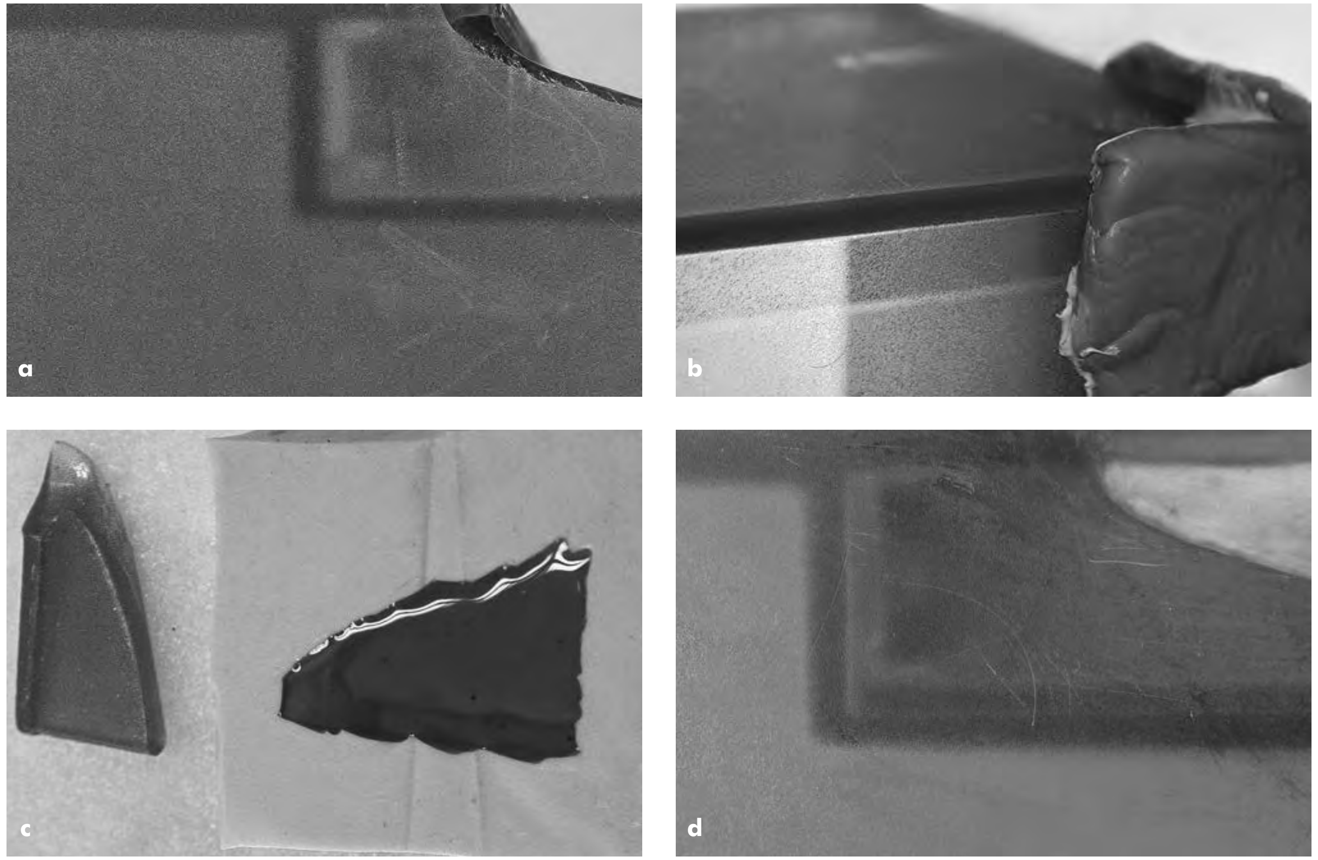

Figure 5
Treatment Mobil
a) Photography of the gap damage
b) Detail of the stamping process.
c) Testing the epoxy resin into the prepared model casts
d) After treatment

THE TWO CASE STUDIES

1. THE OFFICE ARMCHAIR QUALIS BY E. AMBASZ FOR TECNO S.P.A (CDO 1991)

Qualis is a contemporary office armchair created by the designer Emilio Ambasz. The Qualis armchairs are a series of fully upholstered chairs, the models ranging from operative through to managerial and executive, always with articulated backs. Qualis received the Compasso d'Oro Award in 1991.

MATERIALS AND TECHNICAL DESCRIPTION

This chair is characterised by two main elements; thin upholstered seat cushions made of leather and a patented backrest pivot mechanism lockable in three-positions. The chair can be fully upholstered, fixed or adjustable in height. The armrests are of soft PVC(3), as described by the manufacturer. The five-spoke base is made of steel covered with a polypropylene shell. The Qualis armchair of the CdO Collection is in a good conservation state, but shows a small round loss of around 2 cm in the left armrest *(Figure 4a)*.

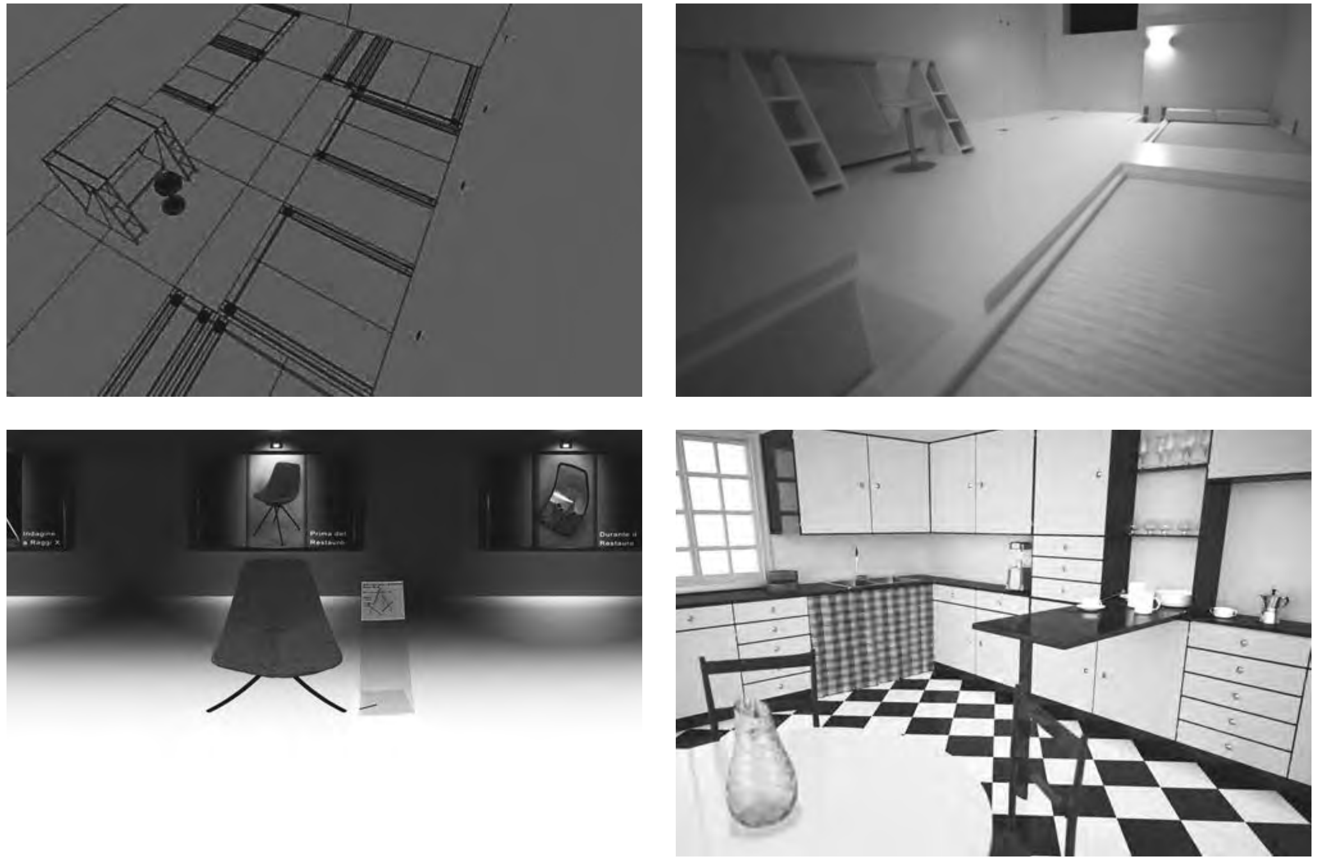
Figure 6

Some solutions for interventions in Computer Aided Restoration.

TEST SERIES AND CONSERVATION TREATMENT

FTIR analysis indicated that the upholstery and the armrest are made of polyurethane resin (self-skinning polyurethane) instead of poly(vinyl chloride) (PVC) as described in the technical data sheet provided by the manufacturer. This is probably due to a change in the production line, or alternatively this chair may be a prototype that differs slightly from the general production line.

For reconstructing the loss in the armrest, the multidisciplinary staff of the CCR had to try new methods and materials of similar flexibility and mechanical properties to the original material made of self-skinning polyurethane.

Unfortunately, there are only few references in the literature which describe the reconstruction of polyurethane materials *(Laganà 2008; Laganà and van Oosten 2011)*. The research of new solutions pointed the team towards companies that produce polyurethane materials for the cinematic industry and the production of film sets (www.prochima.it). Hence, the multidisciplinary team compared three different bicomponent polyurethane systems by Prochima:

- *Espak 90, a two-part liquid polyurethane free of Freon (halocarbon), which produces closed-cell polyure-thane foam with a density of 100* kg/m^3. *It has good dimensional stability and a high resistance to impact and compression.*
- *Espak Soft, a two-part liquid polyurethane for casting, which produces soft and bulky material similar to foam rubber; and*
- *Sintagom Neutro, a two-part, cold curing liquid polyurethane which produces an elastic compound similar to rubber that shows no shrinkage. According to the manufacturer's technical data sheet (Prochima) this rubber elastomer is supposed to show similar properties to the self-skinning polyurethane and is recommended for casting shapes using silicone moulds.*

Using a material of similar texture, chromatic and volumetric features to the original self-skinning polyurethane, the research team created samples replicating the original material. After a series of pre-tests, it was shown that the Espak polyurethane systems did not reach the compact and uniform appearance of the original arm rest material. On the other hand, Sintagom Neutro showed indeed similar properties in flexibility, strength and visual features to the original material and it was finally selected for further use by the multidisciplinary team.

Small samples of cured Sintagom Neutro of the size of 3 cm x 4 cm x 0.4 cm were exposed to accelerated ageing tests, where the samples were placed into a Solarbox Ageing Chamber(4) (radiant power: 500 W/m^2; wavelength: 300-800 nm; T_{max}: 45 °C). After light ageing for 100 hours, the material indicated thermal sta-bility and moderate oxidation with slight shrinkage of the material (<0,05 mm after 100 hours). This was con-sidered acceptable for a fill material and no other tests were conducted.

Once the material selection was concluded, the team examined the choice of adhesive materials to fix the infill in the void. After extensive consultation of specialist literature *(Keneghan and Egan 2009; Shashoua and Ling 1998: 33-36; Totelin, Calonne and Bechoux 2011; van Oosten 2011; van Oosten, Shashoua and Waentig 2002)*, the team opted for the 360HV Lascaux adhesive, a butyl acrylate-methacrylate copolymeric dispersion thickened with butyl acrylate (Kremer) which presents optimal physical properties; it is easy to work with and shows a smaller resistance to tensile forces than the polyurethane used for the armrest.

TREATMENT

In order to fill the missing section of the armrest, the surface of the void was protected with cyclododecane spray (Kremer) to prevent any contact between the armrest and the material used to mould the missing part. A dental plaster (C.T.S) was then used to fill the void in order to obtain a provisional cast of the lost material. After curing, the provisional cast was removed from the object and used to create a silicone mould which constituted the negative form of the provisional cast (ie, a replication of the void in the armrest). Finally, this silicone mould was filled with the bi-component polyurethane resin Sintagom Neutro (Prochima), which was coloured using black Pentasol Un colour paste(5) (Prochima), a pigment pre-dispersed in an inert carrier, to replicate the lost material. After hardening, the reconstructed polyurethane fill was fixed in the void with Lascaux 360 HV (Kremer) and the remaining gaps were sealed with the same coloured polyurethane resin *(Figure 4d)*.

2. CONTAINER AND SHELF MOBIL BY A. CITTERIO AND O. LÖW FOR KARTELL, (CDO 1994)

Mobil is a system of storage units with drawers by Kartell. It has a chromed steel structure and transparent or coloured poly(methyl methacrylate) (PMMA) shelves and drawers with a semi-transparent effect finish. The main feature of *Mobil* is the possibility to customise the product: it is designed to contain two to six drawers or one, three or four drawers plus a shelf. Each version is available either with wheels or castors and some versions are also endowed with handles.

CONSERVATION STATE

The *Mobil* chest of drawers of the CdO Collection was in a fairly good conservation state. Initial examination revealed that the appearance of the object was impaired by the presence of atmospheric particles that had deposited on the surfaces and by common scratches of different sizes. Abrasion damage and minor wear was found predominantly on the front of the chest. In addition to these surface impairments, the *Mobil* unit also had some cracks and losses, especially at the front corners of the drawers *(Figure 5a)*. The major factors that had contributed to the damage of the material were found to be the metal tracks mounted for sliding the drawers which, in severe cases, had become completely detached from the structure. In many instances, the cracked and loose PMMA pieces were found inside the drawers or in the packaging system used during storage.

MATERIALS AND METHODS FOR TESTING, FILLING AND BONDING

The need to compensate for the missing PMMA parts directed the study towards the testing and evaluation of several epoxy resins in order to evaluate their effectiveness and suitability as a replacement material. After an initial phase of study and research of the availability of suitable polymers, three resins were selected for their quality and visual features, all of which were subjected to comparison before and after dyeing with Pentasol Un colour pastes (Prochima) and Orasol® dyestuffs(6) (Kremer). Using previously prepared silicone moulds, the following three resins were tested:

- *Araldite® 2020 (Bresciani), which is a two-component, room temperature curing, low viscosity adhesive specifically designed for glass bonding,*
- *E-30 (Prochima), a perfectly transparent product mostly used in the artistic field, in handicraft and model craft for imitating water effects or to mount objects inside a transparent body, and*
- *Hxtal* NYL^{-1} *(Conservation Support Systems), a crystal clear, non-yellowing epoxy adhesive formulated to perfectly match the refraction index of most glass.*

After the manufacture and preliminary testing of various samples and a thorough study of the available literature *(Shashoua and Ling 1998; Totelin, Calone and Bechoux 2011)*, Hxtal NYL^{-1} was chosen as replacement material for its low viscosity and good handling properties which prevent the introduction of air bubbles into the polymer.

CONSERVATION TREATMENT OF *MOBIL*

The main objective of this work was the cleaning and reconstruction of losses in the PMMA material. Considering the material's vulnerability to scratches, a microfiber cloth moistened with deionised water was used to remove surface deposits. The cleaning was finished using a cotton swab soaked with a solution of the hydrophilic non-ionic surfactant, Dehypon LS45 (Conservation by Design Ltd.), at a concentration of 2% in deionised water.

The cleaning was followed by the creation of an initial mould of one of the drawer corners still in good state of preservation using a kneadable silicone rubber, Silical 110 (CTS), to reproduce all the details of the corner shape. Once the silicone had cured completely, the resulting mould was transferred to the surrounding edge of the missing corner *(Figure 5b)* where it was temporarily fixed and sealed with paper tape to keep the mould well attached to the drawer surface. In the following, several casting materials, such as dental plaster and liquid silicone, were tested to create a first (preliminary) cast of the missing corner. The liquid silicone was deemed most appropriate for its flexibility and ability to reliably maintain the shape of the loss. In order to prevent unwanted adhesion between the silicone mould and the silicone casting material, a release agent, Silical 100 (CTS), was applied to the silicone mould. Subsequently, the liquid silicone was poured into the mould for obtaining the preliminary cast of the missing corner. From this cast, a final mould, ie, the negative of the missing corner, was cast using non-stick silicone rubber after coating the preliminary silicone model with a release agent.

To reproduce the transparency and colour of the original PMMA material of the drawer, the Hxtal NYL^{-1} was coloured with Pentasol Un colour pastes and cast into the final mould *(Figure 5c)*.

Finally, the most appropriate solution was sought for bonding the reproduced corner with the original material. It is known that PMMA is very sensitive to mechanical stresses, especially when exposed to solvents or monomers contained in adhesives, which can cause the development of cracks in the PMMA. To assess the potential risk for damage caused by different adhesives in contact with PMMA, the University of Bern had evaluated different types of adhesives by performing mechanical and bonding tests on the naturally aged reference samples in 2006 *(Bechthold 2011)*. Among the adhesives tested, the acrylic resin Plexigum® PQ 611, a polymer in powder form based on isobutyl methacrylate (Kremer) dissolved at a concentration of 30% in isooctane and tinted with Pentasol Un colour pastes, showed good optical properties and did not seem to encourage crazing when in contact with PMMA. It was thus chosen for optimal bonding of the Hxal NYL^{-1} fill to the original PMMA *(Figure 5d)*.

COMPUTER AIDED RESTORATION: SOLUTIONS FOR INTERVENTIONS.

In order to aid the actual conservation and restoration treatments of the objects of the CdO Collection, support is given by our imaging workshop. One of its great benefits is the planning of the different restoration actions through three-dimensional (3D) surveys of the pieces – acquired by laser-scanner or photogrammetric techniques – and the performance of virtual simulations of planned alterations. An illustrative example of these methods is the bespoke reconstruction of the Spinamatic Splügen Bräu tapster(7) using CAD methods: the remains of the original electric sign were captured using a photogrammetric campaign to define the geometric model for prototyping the new electric sign by craftsmen.

A further technique which can be utilised during the restoration and reconstruction of objects of the CdO Collection is rapid prototyping: In order to reproduce some parts of the objects which need restoring, our technicians made a 3D survey of the parts to be reconstructed, and then they created digital models of these elements using CAD software. The digital models were converted into negative ones that represent the digital model of the respective moulds which were then prototyped by 3D-printing. These prototype moulds are finally used by restorers to cast the integration pieces and reconstruct the original integrity of the objects, ensuring a uniform aspect, colour, surface etc.

A relevant example of a further advantage of the imaging workshop is the selection process of an adequate material to display the Zizi monkey toy. This object, too, was digitised using photogrammetric techniques. The resulting 3D model was then used to plan, within a virtual environment, different display proposals using diverse mounting structures and materials. This helped to protect the fragile toy by preventing unnecessarily handling. The 3D modelling technique also aided the study of the different surface finishings and materials of the *Saffa Modular Kitchen* by Augusto Magnaghi for S.A.F.F.A. Spa, Milan (CdO 1954) in that a virtual 3D model was built to which photorealistic rendering was applied *(Figure 6 d)*.

The Concealment 1972, a multifunctional bedroom with table by Ugo La Pietra(8), G. Arosio and Sons and Viscardi Brothers (CdO 1972), which can alternately be used as a bedroom, lounge and play room, was also reconstructed using computer graphics in order to illustrate its function and the mechanics of each of its working components *(Figures 6 a, b)*.

All these case studies show that computer graphics techniques constitute a valid tool which assists our teams in deepening our knowledge and understanding of the functional aspects that characterise many of the objects in the Collection. In the first instance, the use of 3D renderings enables our researchers to visualise the working mechanisms of each piece as well as the objects in their everyday use, as they were conceived and designed. These rendering techniques are used in conjunction with technical illustrations of the mechanical components as well as internal sections illustrating the working components, as shown, for example, in *Figure 6 c* for a model of the DU 30 chair (CdO 1954) by Gastone Rinaldi produced by Rima.

CONCLUSION & OUTCOMES

Conservation and restoration of design objects raise new issues, regarding both methodological and cognitive aspects. In fact, they require not only new restoration methods but also profound knowledge and understanding of the chemical and physical properties of the new materials involved.

The computer graphics techniques constitute a valid tool which assists our teams in planning restoration intervention and also constitute an operative instrument to produce or reproduce missing parts or entire pieces of the Collection by virtual reconstruction or rapid prototyping.

Most importantly, and not to be forgotten, the virtual and digital representations can also generate a clear understanding of the design concept, characteristic functions, design operating principle and logical operation of some pieces of the Collection which otherwise might not be communicated so easily.

At CCR, some studies have begun to focus on the identification of products, particularly plastic ones that could be mouldable, transparent, semitransparent or opaque, coloured and colourless. Some other studies concern the integration of lost, damaged or decayed parts of objects realised with different materials, such as design objects.

Through this multi-year project, our team started to check on a new methodology based on innovative materials and a multidisciplinary approach. To respond to the new conservation and restoration issues we would like to investigate thoroughly and improve our knowledge on new materials that are emerging from different fields, such as the clinical or cosmetic field, as these materials have in fact already demonstrated to have distinctive characteristics which are useful for the restoration of design objects. Therefore, we will be continuing to test the compatibility, reversibility, durability and applicability of photopolymerised resins, bi-component systems and composite materials for reproducing industrial techniques for conservation purposes.

ACKNOWLEDGEMENTS

We would like to thank all those who participated in this project, especially our colleagues at CCR (Sara Abram, Marco Demmelbauer, Roberta Genta, Paolo Luciani, Bernadette Ventura), without whom the project would not have been possible; and our scientific laboratories (Anna Piccirillo, Tommaso Poli) who provided us with the artificially aged dummies and all the analytical techniques.

Further thanks are due to Dr Marcello Manfredi and to SRA Instruments of Cerrusco sul Naviglio (Milan) for FTIR non-invasive analyses performed on some ADI objects; to Anna Laganà for her technical and scientific consultancy (Phase II); and to Arch. Laura Casullo for her help with the text and slide translation.

ENDNOTES

(1) *The Foundation Centro per la Conservazione e il Restauro dei Beni Culturali 'La Venaria Reale' (www.centrorestaurovenaria.it) was founded in 2005 as an institute for advanced training and research in the field of conservation and restoration of cultural heritage. The work of CCR is based on a methodology that integrates the skills of conservators, art historians and scientists.*

(2) *The database was created and developed by Sandra Vazquez using File Maker Pro12 Advanced.*

(3) *The characterisation of the material of the armrest was verified by FTIR analysis.*

(4) *The Solar Box Ageing Chamber is a high-speed exposure unit Suntest CPS (Heraeus, Germany) equipped with a Xenon lamp and a UV filter that absorbs wavelengths lower than 320 nm. It was used to simulate light exposure through a glass window. Irradiation was set at 500 W/m^{2} and the maximum tempera-ture on the sample was kept below 50 °C by forced air circulation.*

(5) *Pentasol Un colour pastes by Prochima are pigments pre-dispersed in an inert carrier which are compati-ble with epoxy resins and polyesters. They are particularly suitable for colouring the matrix of casting resins.*

(6) *ORASOL® dyestuffs are easily soluble in a mixture of 80% ethyl alcohol, 5% water and 15% Methoxypropanol PM (propylene glycol dimethylether). http://www.kremer-pigmente.com/media/files_public/94400-94416e.pdf (last accessed on 5th March 2015).*

(7) *Spinamatic, a draught beer dispenser designed by Achille & Pier Giacomo Castiglioni, was produced by Splügen Bräu of Poretti s.p.a. (CdO 1964). http://www.achillecastiglioni.it/it/projects/arch-3.html (last accessed on 5th March 2015).*

(8) *Ugo La Pietra – 'L'occultamento'. http://www.artribune.com/dettaglio/?type=event&id=29935 (last accessed on 5th March 2015).*

LECTURE
010
INDUSTRIAL CLAY AS A DESIGN MATERIAL. TECHNICAL INVESTIGATION AND SUITABLE CONSERVATION TREATMENTS.

BY SILVIA DI GIORGIO, TIM BECHTHOLD

ABSTRACT

Research on industrial clay and its applications through the recent history was necessary to study and plan the conservation treatments of a group of car models, realized in Germany during the 1930s. Due to its recent origin, industrial clay is still almost unknown as a design material in the conservation literature, and various testing methods and analysis had to be considered. Therefore FT- IR spectroscopy, Raman microscopy and Py-Gas-Chromatography analysis were run on samples from both the car models and modern clay used in the car industry. The chemical analysis showed that industrial clay is a wax-based modeling clay, which commonly contains inorganic fillers, various additives and a very complex organic component.

The characteristic damages shown by the car models have been classified and analyzed separately; the research identified several major conservation problems, which required immediate attention. Various suitable cleaning, consolidating and filling procedures were considered. The research contains recommendations for preventive conservation, regarding storing, transporting and exhibiting conditions. A 3D documentation of the car models was realized using the laser scanning technique, to have a precise, digital reconstruction of the artifact without danger of further damages.

KEYWORDS

Industrial clay car models, FT-IR spectroscopy, Raman microscopy, Py-GC/MS, preventive conservation, laser scanning

PROTOTYPES

Models and prototypes, in reduced or full scale, play an important part in the design process. In many fields, there is great uncertainty as to whether a new design will actually do what is desired. Prototyping allows engineers to explore a design and its alternatives, and to confirm the performances of a product prior to starting its actual production. In general, an iterative series of prototypes will be constructed and tested, as the final design emerges and is sent to the production. A common strategy is to test, evaluate and then modify a design based on the analysis of its prototype.(1)

MATERIALS AND PROCESSES

There is a huge variety of materials and processes to visualize a designer's idea. Depending on skills, knowledge, possibilities and stage of development, this ranges from first models, handcrafted in traditional materials like paper, wood, clay and gypsum, to more complex visualizations, mechanically produced using for example the process of injection molding for hard foam, computerized numerical control milling (CNC) or generating complex models by means of rapid prototyping processes.

It is a common denominator that most products, resulting from this early design process, are not intended to last longer than just a few days or months. Instead of durability, the focus is on workability, re-workability, availability, efficiency and price; factors which are very challenging for a design museum, interested in collecting and teaching design processes, and which is obliged to conserve these products for further generations. In the following we will have a closer look to some of the oldest models at *Die Neue Sammlung – The Design Museum*.

INDUSTRIAL CLAY AT *DIE NEUE SAMMLUNG*

The automotive sector of the collection consists of real cars, motorcycles, and first and foremost of models, mainly made of industrial clay, dated from the early 1930s to the latest 2012.

Model making with industrial clay was first introduced in the automotive design process in 1927, when designer Harley Earl from the Art & Color Section of General Motors, Detroit, USA, decided to use this material for his design studies.(2) The car models of our collection reflect both the range of combinations and the production processes available at their time.

Apart from examples of rather new automotive designs, the core pieces of this section is a collection of historic car models, which document both a crucial turning point in the car design history and an incredible early application of industrial clay.

THE COLLECTION OF CAR MODELS OF BARON REINHARD VON KOENIG-FACHSENFELD

Baron Reinhard von Koenig-Fachsenfeld was born 1899 in Stuttgart, Germany. His passion for motors and car races led him into becoming one of the first aerodynamics experts in the world. Today his legacy is preserved through a few real-size prototypes mostly made of metal, but his work can be appreciated and analyzed through the industrial clay models he used to make while studying the possible improvements of the bodyworks. A group of 11 objects, realized between the 1930s and the 1940s, entered the collection of *Die Neue Sammlung* in 1997. Most of them are in a 1:10 scale, two are cutaway models. Most of these objects consist of a wooden core (lime wood), covered with industrial clay with a thickness of approximately 40 mm. The partial application of pieces of metal wire and paper served to imitate bumpers and window shields.

OVERALL CONDITION OF THE MODEL COLLECTION AND GENERAL MATERIAL CHARACTERISTICS OF INDUSTRIAL CLAY

Due to the fact that industrial clay remains soft and workable, even after much time spent in drying conditions, its surface is prone to dust accumulation and relatively sensitive to mechanical inputs, like pressure marks, scratches, dents or the like. Related to the broad range of ingredients included, a varying sensitivity to light damages can be observed. This ranges from very good color stability to a dramatic darkening. As mentioned above, these models mainly consist of a combination of different materials, mainly industrial clay and wood. Because of their different thermal expansion coefficients, it is thus clear, that they are most sensitive to fast fluctuations of climatic conditions. This results in a characteristic cracking of the industrial clay layer, a process that leads eventually to the loss of original material. It is obvious that those models, which have a compact, pure clay structure, are the most stable ones. Those that are assembled by means of clamps, wires etc., consisting of several materials, are discolored, deformed, brittle and torn *(Figure 1)*.

Therefore, the condition of this series of models is quite delicate and presents a broad variety of alterations, many due to unknown factors. Each time the objects are handled, the risk of further damages and loss is very high. The main problem while deciding how to correctly handle and conserve this collection, was that industrial clay is still almost unknown as a design material in the conservation literature: there's barely any published reference about the argument. To define an appropriate conservation concept it was essential to learn more about the composition of the material.

The aims of our study were the following:

- *Understanding the material and its structure*
- *Documenting the models through imaging techniques*
- *Understanding their conservation state*
- *Investigation of possible conservation treatments through a literature research*
- *Defining any possible risk due to handling and exhibiting*
- *Final assessment and development of a first conservation concept*

TERMINOLOGY

Due to the variety of its properties industrial clay has been called in different ways through the years:

- *Plasticine (1897, HARBUTT, England)*
- *Plastilin (1980, KOLB, Germany)*
- *Plasteline (1982, CHAVANT C.)*
- *dauerplastische Modelliermasse (2007, FRIESE K., Germany)*
- *Ölton, Knetemasse, Modellierpaste, Modellierwachs*
- *clay, molding clay, modelling clay*
- *plastic modelling wax*

In this paper the term industrial clay was chosen - according to the terminology established by the current international producers of this material for the car industry. The term plasticine is more used in a toying and modeling context, while the term modelling clay is more used in the art field.

ORIGIN AND PRODUCERS

Industrial clay was first formulated in 1880 by Franz Kolb in Munich, Germany, and is still available on the market. There are currently 3 major producers of industrial clay on the international market:

- *Kolb Technology GmbH, based in Germany, which develops products for the car industry designing process (with such customers as Porsche, Daimler, BMW, VW, Nissan, Volvo, a.o.);*
- *Staedtler Mars GmbH & Co. KG, based in Germany, which develops modelling clay for artists, designers and also car industries;*
- *Chavant Inc, based in the USA, which also develops modelling clay for artists, designers and car industries.*

Other minor producers are Becks Plastilin and Carl Weible KG (both German).(3)

APPLICATIONS

Industrial clay is used in different fields. Since the 1890s artists have used it as sculpting or casting material. Often combined with paper, wood, polystyrene hard foam and plaster, this material has also been used for architectural models. Another modern application regards the so-called Stop- Motion movie industry.

The largest application of this material nowadays is in the industrial field: in many factories, especially in metallurgy, 1:1 industrial clay models are used to mold casts (usually silicon ones) for the object produced. A specific kind of industrial clay developed for this purpose is the Fill-it mould makers putty by Chavant.

For what concerns our research field, the most important application of industrial clay is in the car industry, for the automotive design process. The three dimensional modelling of the car usually starts with small models (1:5 - 1:4), which are used to run the first tests in the wind tunnel. Then a real-size model – using clay, wood, resin, urethane foam, a.o. materials - is made to determine the final style of a car. Hereby the final appearance of a vehicle is fixed, and its CAD model for manufacturing purposes is generated. To bestow a realistic impression on the model, the visible industrial clay surface can be lacquered or covered with a clay modelling film as mentioned earlier; the tires are usually real and the glass parts are rendered with black tape.

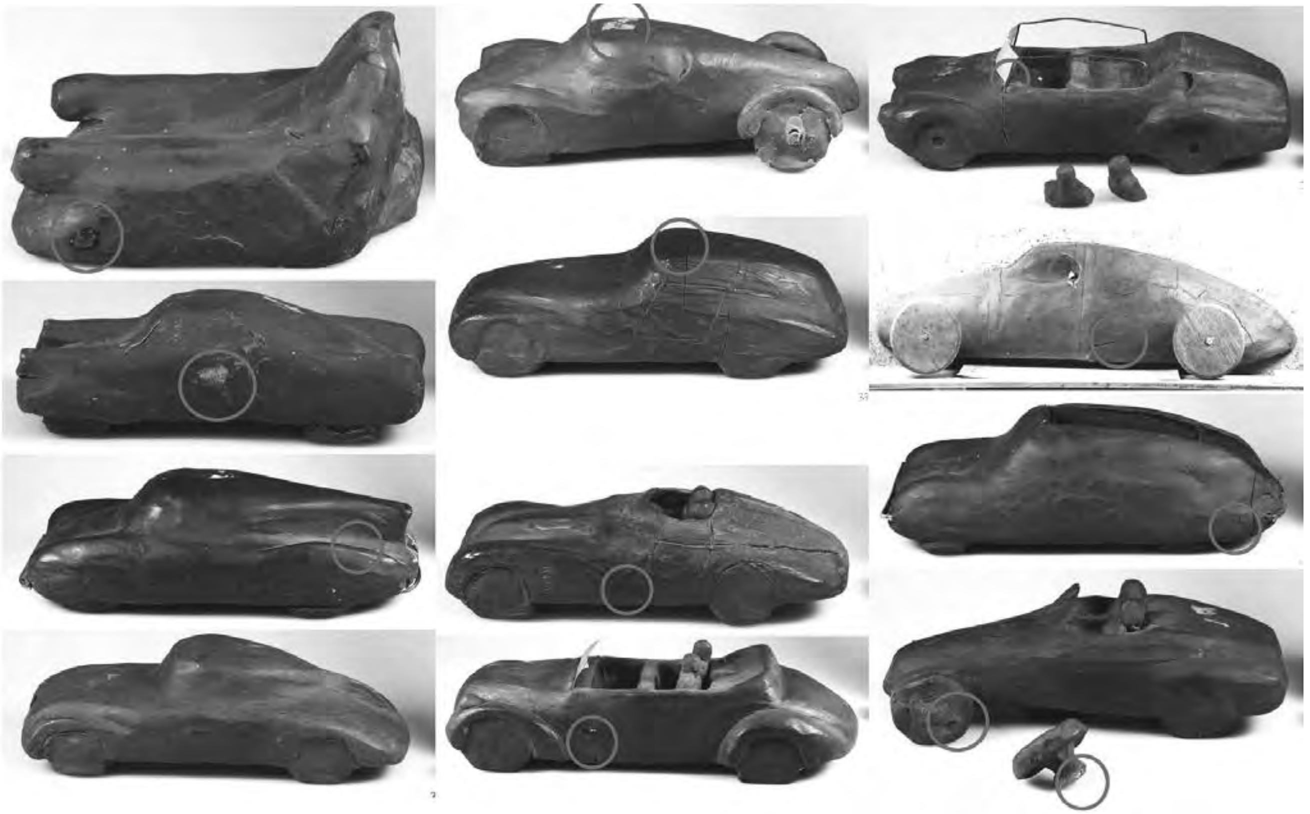

Figure 1
Car models made of industrial clay
(Baron Reinhard von Koenig-Fachsenfeld, 1930s - 1940)
(see colour plate, p. 167)

PHYSICAL CHARACTERISTICS

Industrial clay could be described as a permanently malleable, thermoplastic material, made from fats, oils and/or waxes, inorganic fillers, combined with numerous additives. Due to the oily component, which does not evaporate, industrial clay remains soft and workable even after spending long times in drying conditions, unlike fired clay and wax. It also cannot be fired in an oven. That is why it can not be considered a ceramic material. Heated up to 60°C it can be easily shaped, thus enabling designers to create prototypes to visualize the idea of a product and to easily re-model it several times.

The plasticity of this material, its characteristic feature, is due mainly to its organic components. The phyllo-silicate structure of kaolinite, which as discovered was used in almost all the car models as inert filler, provides only a minor malleability. For this reason, plasticity can vary depending on two major factors:

1. *The quality of organic binders chosen: to produce different modelling clays with different plasticity levels, the industries change the organic content, choosing one with more or less viscosity. Tallow for example is added when major lubrication is needed.*
2. *The temperature of the environment in which the material is stored. This parameter influences the viscosity of the organic binders, changing their status from solid to flowing. Waxes vary greatly in consistency and solubility with the temperature. They are normally solid at 20° C but melt above 40 °C.(4) Some of the paraffin waxes identified in the car models melt already at 23 °C.*

> *The melting point of some unsaturated wax esters is even lower.(5) On the contrary, industrial clay can be easily cut or bent under 18 °C, and at this temperature many of the degradation processes stop. It hasn't been proved yet, if a lower temperature could cause mechanical stresses in the material.(6)*

CHEMICAL FORMULATION OF INDUSTRIAL CLAY

As mentioned earlier, little is known about the chemical formulation of industrial clay; it can vary depending on its specific use, the application field, and even the season.(7) Moreover, industries that produce this material are quite reluctant to provide specific information about its chemical composition, qualitatively and quantitatively speaking. Therefore it was absolutely necessary to study the chemical formulation of old and modern industrial clay.

SAMPLING AND ANALYTICAL METHODS

Nine micro-samples were taken from eight car models (one model consists of two different kinds of clay). Three more models were excluded from the analysis, because of close similarities in color, consistency, degradation and date of origin to models already included in the tests. The micro-samples were taken from the bottom of the models. Some of the models were originally labeled with paper badges including short descriptions of the prototype; these covered surfaces should have been more protected from dirt and superficial dust over time. Two samples of modelling clay used by the contemporary car industry were also included in the tests.(8)

As a first analytical method, mainly applied to characterize the inorganic component of industrial clay, Fourier Transform Infrared Spectroscopy (FT-IR) was chosen.(9)

Raman microscopy was later used to confirm the inorganic compounds detected with the FTIR spectroscope.(10)

The organic, very complex part was detected and identified using a Pyrolysis Gaschromatograph device coupled with a Mass Spectrometer (Py-GC/MS).(11)

Thanks to the previous works of Friese, K. (2007) and Demandewitz, M. (2004) a list of possible chemical compounds was available to be retraced in the sampling, and used as guidance for the interpretation of the results.

RESULTS AND DISCUSSION

FT-IR SPECTROMETRY

The assignment of the various IR absorbance bands easily confirmed the presence of inorganic fillers such as kaolin, barium sulphate, calcium sulphate and gypsum in the old industrial clay samples *(Figure 2a, 2b and Table 1a, 1b)*.

The FT-IR spectrometer also detected the presence of fatty acids (paraffin, waxes) and metal soaps (zinc soaps), but because of the complexity of the organic components other, more precise results were impossible. Therefore the organic binders were investigated through PYGC/MS analysis. Both modern samples show very similar IR-spectra; here the peaks of zinc soaps are obviously the most important ones *(Figure 3 and Table 2)*.

The typical peaks of paraffin wax and microcrystalline waxes could be present, but hidden by those of the metal soaps. These soaps are metal salts of fatty acids; the most common are zinc oleate, zinc palmitate and zinc stearate.(12) They are insoluble in polar solvents such as water, alcohol and ether, but soluble in aromatic hydrocarbons (for example benzene) when heated, and in fats and fatty oils. In the TecClay sample a large band between 1200 and 900 nm could reveal the presence of the micro glass-spheres - a modern, inert filler.

RAMAN SPECTROSCOPY

The detection of pigments in all samples using FT-IR spectroscopy was impossible, implying a possible presence of iron oxides. Therefore it was decided to investigate them with the Raman spectroscopy technique. This complementary investigation confirmed the presence of three inorganic fillers, already detected by the previous analytical method (calcium and barium sulphate, quartz), but didn't allow the identification of the pigments *(Figure 4a, 4b)*. Therefore we could exclude the presence of iron oxides, ochers and modern red C.I. pigments. Having a strong detectable Raman effect, they should have been recognized with this method.

PY-GC/MS

Present in the Py-GC/MS pyrograms were peaks coming from the molecules formed by the thermal decomposition of binders and additives: metal soaps, resins, castor oil, tallow, palmitoleic acid, linoleic acid, linolenic acid, stearic acid, beeswax, rose or lemon oil, menthol,sulphur, vegetal and animal fats *(Figure 5)*.

The instrument detected different substances with a different electronic sensitivity, therefore the intensity of the signal in the pyrograms is not proportional to the amount of its components. The chromatographic test confirmed that the organic part of the material is much more complicated than the inorganic one. On the other side, almost all these organic substances have very similar chemical and physical properties: e.g. they are all unsolvable or very poorly solvable in water or polar solvents. Since the pigment question wasn't clear, we tried to identify the colors via microscopic observation.(13) Old and modern samples were dissolved in white spirit or toluene. In the modern samples was recognized the presence of a very fine-grained red pigment, probably synthetic. The particle size and shape resembled that of quinacridone, an organic synthetic pigment applied to make high performance paints, also used in the car industry for automobile coatings.

In the old samples couldn't be retraced the presence of any visible pigment. Theoretically the color could be a result of a color synthesis of all the components of the material.

AGEING AND DETERIORATION PROCESSES OF INDUSTRIAL CLAY

Analyzed the physical characteristics and the chemical composi-

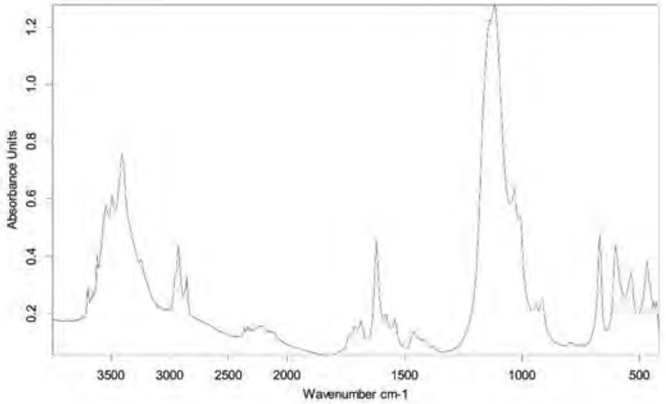

Figure 2a
IR absorption bands of the historic samples

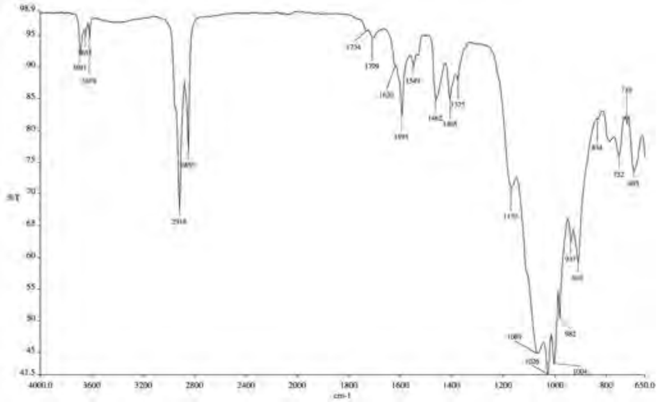

Figure 2b
IR transmittance bands of the historic samples

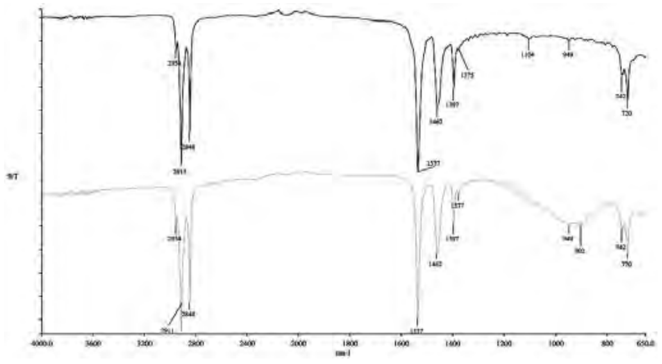

Figure 3
IR transmittance bands of the modern samples (SuperClay: top, TecClay: bottom)

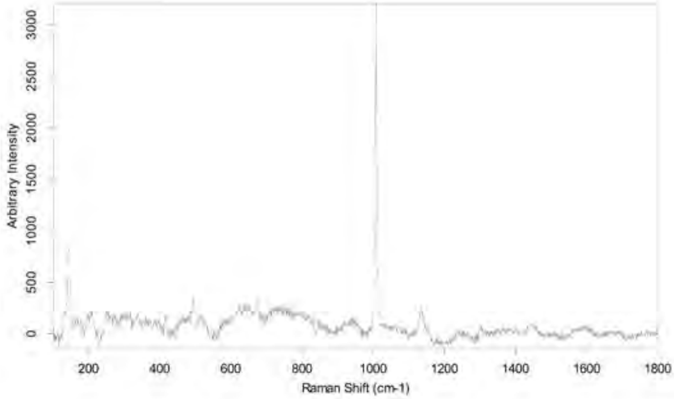

Figure 4a
Raman spectrum of one of the historic samples

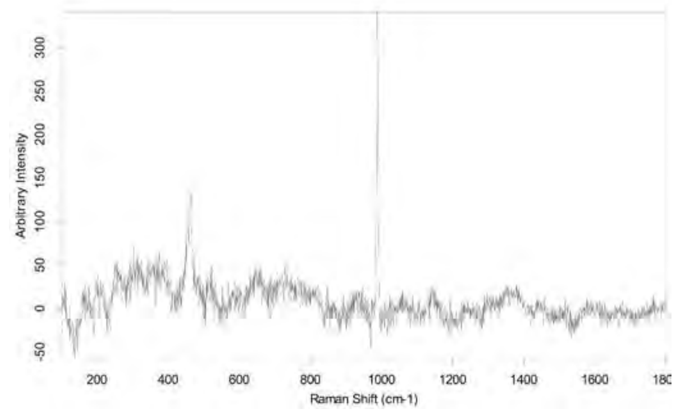

Figure 4b
Raman spectrum of one of the modern samples

Wavenumber (nm)	Assignment
3700, 3620, 1120, 1030, 1010, 940, 915, 690	Kaolin
3525, 3400, 1680, 1620, 1110, 665	Calcium sulphate/Gipsum

Wavenumber (nm)	Assignment
2950, 2920, 2850, 1730, 1460, 1375	Ester- or paraffin waxes
2950, 2920, 2850, 1550, 1460, 1400	Metal soaps / zinc soaps
3700, 3620, 1120, 1030, 1010, 940, 915, 690	Kaolin
1380, 1170, 1120, 1080, 980	Barium sulphate

Table 1a, b
IR absorption bands of the historic samples.

Wavenumber (nm)	Assignment
2966, 2915, 2850	Metal soaps and Paraffinwax
1540, 1465, 1400, 740, 720	Metal soaps / zinc soaps
1200-900	Inorganic filler (micro glass spheres)

Table 2
IR absorption bands of the modern samples

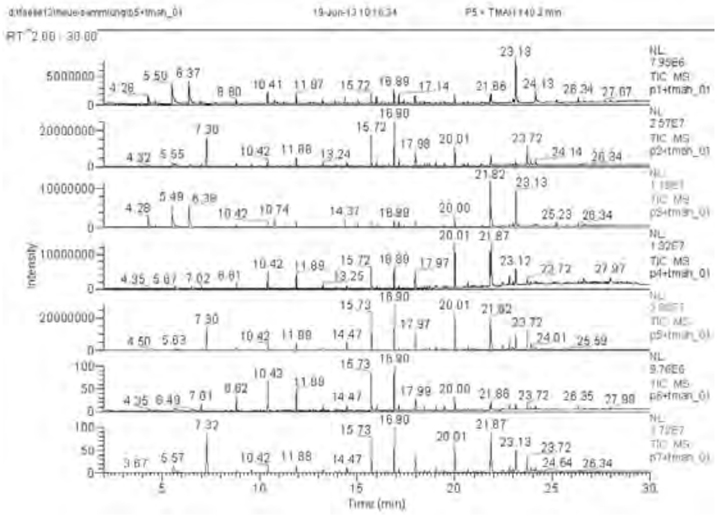

Figure 5
Py-GC-MS pyrogram

tion of the material, it was noticed that there were mainly two kinds of damages in the clay models: superficial and structural ones. The most recurring damage causes are:

- *Physical degradation (wrong handling, storing and transportation conditions / procedures, variations in climate, internal tensions and others). Most of these can be avoided or limited applying correct handling and storing procedures.*
- *Chemical degradation (aging reactions, oxidations and other damages caused by elevated temperatures - e.g. IR-radiations, natural lighting – and other factors) Some of the damages appear because of the natural aging process of industrial clay, and cannot be avoided or reversed.*

SURFACE MODIFICATIONS

SCRATCHES AND IMPRINTS

As mentioned earlier, industrial clay is a permanently plastic, malleable thermoplastic material, which remains soft and workable in time. This is why it is prone to dust accumulation, scratches and imprints/dents. If scratched or roughened, industrial clay surfaces show a lightening in the color. This depends on the increased porosity of the scratched area, which causes a scattered reflection of incident light.

DISCOLORATION AND EMBRITTLEMENT

Many organic components of the industrial clay are subject to oxidation reactions. Most of the binders are made of unsaturated fats; facing a radical chain reaction that occurs in the presence of oxygen and UV radiation, called autooxidation, leading to superficial discoloration (yellowing of the binders) and increased brittleness of the material *(Etyemez 2014: 140)*. This process is accelerated under elevated temperatures. More oxidation reactions are initiated in the turpentine components by UVradiations.

MIGRATING SUBSTANCES AND EFFLORESCENCE

Industrial clay could also release part of its organic binders with time, especially if stored in a closed environment with elevated temperatures. This may result in increased hardness of the clay. The organic components that migrate typically leave oily stains or even efflorescence on the materials with which they are in contact. These stains can be described as a high viscous, dark brown substance. In case of direct contact to iron wire this was identified as zinc carboxylates stemming from the oleic acid of the industrial clay *(Etyemez 2014: 36 ff)*. In fact it can be assumed that the direct contact of industrial clay with metals catalyzes the release of oily substances. Moreover it can be stated, that the presence of iron acts as a local softener.

Another phenomenon that takes place during the aging of industrial clay is the possible release of sulphur from its surface. This actually occurs when the model contains elemental sulphur. Its migration and the following development of sulphuric acids can result in an accelerated corrosion of the metal components present in the models. Therefore, it must be taken into consideration that the durability of adhesives and storing materials could be severely affected by the migration of these substances.

EMBRITTLEMENT AND SHRINKAGE

Although plasticity is the main characteristic of industrial clay, this material tends to harden gradually because of its natural aging process. With time, the molecules of the organic binders change their asset into building crystalline structures, because the intermolecular interaction in this state is optimal. This process increases the hardness of industrial clay, leading to its brittleness; its molecules can no longer move *(Lang, 2011)*.

Moreover it can be assumed, that an irreversible shrinkage of material is related to the chain scission and the migration of free fatty acids (palmitine and stearine acids) and low molecular components *(Etyemez 2014: 37)*. Typically this shrinkage effect results in great, linear, gaping tears.

TEARS

As mentioned earlier, industrial clay is mainly composed of non-polar materials, meaning that it is quite resistant to polar solvents. Instead it is properly soluble in non-polar solvents, such as white spirit or toluene. For this reason, hydrolysis isn't really considered as degradation factor (see the storage advices below). On the other hand, it is quite common to associate industrial clay with other materials. As said, car models usually have cores made of much more resistant structures, such as wood or metal in the past, or polystyrene/polyurethane hard foam today. Almost half of the car model collection of *Die Neue Sammlung* possesses a wooden core. When exposed to climatic changes, this combination of different materials can lead to an increasing internal stress, resulting in the development of deep tears.

CONSERVATION OPTIONS AND APPROACHES / REFERENCES

The scientific investigation of modern and old industrial clay reveals a broad spectra of components ranging from metal soaps to various waxes, from talcum to kaolin, from gypsum to different flavoring additives. This mix assigns specific properties and a specific chemical and physical behavior to the material. This knowledge is the base for the development of suitable conservation treatments and the definition of correct handling and storing instructions. This research project didn't include testing of different conservation techniques or materials, but helpful references can be found in the previous works of Miriam Gielow; born Demandewitz *(Demandewitz, M. 2004: chapter 5)* and Katja Friese *(Friese, 2007: chapter 5)*, who researched on modelling clay for artistic sculptures and stop-motion animation movies. Testing of proper adhesives for waxes can be found in the research performed by Johanna Lang *(Lang 2011)* on the moulages of the Deutsches Hygiene Museum, Dresden, Germany.

CLEANING

Demandewitz recommends that superficial dirt should be removed in a mechanical way, using a soft brush. For this purpose Friese tested successfully a small vacuum cleaner, tweezers and scalpels. More compact dirt and degradation products were removed by using cotton swabs with deionized water. Ethanol could also be applied, but with high risk of removing some superficial clay components. Other solvents are not advisable.

BONDING / CHOICE OF ADHESIVES

Demandewitz tested three adhesives on both smooth and irregular clay surfaces:

- *Mowilith® DMC2 (very good adhesion)*
- *Plextol® B500 (good adhesion)*
- *Airflex® EP17 (average adhesion)*

All three are soluble both in acetone and ethanol, but insoluble in water. Mowilith® DMC2 proved to be the best product, especially for its good adhesion properties and flexibility. Other adhesives successfully tested on modelling clay were: Primal 33, Primal 35, Mowiol 4-88 (10% in water) and Paraloid B72 in toluene. They generally show good adhesion, but like Plextol and Paraloid, not all of them are reversible *(Friese 2007)*.

FILLING AND RETOUCHING

As a filling medium, a combination of Mowilith® DMC2 (5 g), hollow glass micro-spheres (0,5 g), cork powder (0,2 g) and chalk (0,3 g) was used by Demandewitz, presenting good flexibility and adhesion properties. The retouching was completed with watercolors. Friese used a mixture of Mowilith® DMC2 (20 g), hollow glass micro-spheres (3 g) and synthetic iron oxides or ochres (0,1 g up to 3 g).

PREVENTIVE CONSERVATION: STORING, HANDLING, EXHIBITING

As mentioned earlier, models made of industrial clay often contain different kinds of plastic, paper, metal or tape. This fact has to be considered to establish correct storing parameters.

CLIMATE-CONTROLLED ENVIRONMENTS

Industrial clay artifacts should be stored in climate-controlled environments. Although relative humidity doesn't quite affect them, it is true that these models are usually supported by a core of hygroscopic materials. For this reason, the RH parameter of the deposit should be set depending on these collateral structures; if wood is present, a RH between 45% and 55% is recommended; for paper components, 40-55%; for metals 15-40%. It should also be considered that normally, in historic models, wood plays a much bigger role than metal or paper, so as a standard value a range between 45% and 50% of RH is recommended. This value shouldn't change more than 5% in 24 hours; fast variations must be avoided.

TEMPERATURE

As mentioned earlier, temperature is a much more important parameter for a correct preservation of industrial clay artifacts, keeping in mind that these already show superficial release of binders and sulphur at 23 °C. This phenomenon is reduced if the model has already aged and its organic components rearranged themselves into crystalline structures. Values between 18°C and 20°C are optimal. Nevertheless the presence of other materials in the model should be taken into consideration. Variations of temperature need to be avoided.

LIGHTING

Since UV radiations start many oxidation processes on industrial clay surfaces, exposure to this light range should be reduced at all costs. Therefore sunlight and fluorescent lights should be excluded. To protect the objects from UV light, it is possible to apply filter films on the windows or directly on the display cases. Nevertheless, since IR radiations damage clay artifacts through their heating properties too, it is recommended to avoid sunlight at all. For the same reason incandescent lamps are neither suitable. In general, it is recommended to reduce the exposure to light as much as possible.

DUST AND MECHANICAL INPUTS

As mentioned earlier, industrial clay surfaces are pressure sensitive and attract dirt very easily. Cleaning procedures are invasive and difficult; moreover the accumulation of dirt can create a substrate for microorganisms. To avoid corresponding damages, the construction of storage cases is advisable. Storage cases protect the models from dust, keep them separated, are easy to handle and to transport. The use of non-absorbent, inert materials for the wrapping is essential to avoid further migrations of binders and sulphur to the surface. Moreover the case material shouldn't touch the industrial clay surface. The storage case structure needs to be very easy to open and handle.

HANDLING

While handling industrial clay artifacts, we recommend using powder-free latex gloves at all times. For an immediate identification, the inventory number of each model could be written directly on the object, using water-based pigments. Moreover we recommend to affix the number also on the object's case.

EXHIBITING

The car models should always be displayed in show-cases. The climatic and lightning conditions inside should follow the values mentioned earlier. Good lightning solutions are fiberglass and LED sources. Since the clay models are displayed into showcases, it is possible to combine them with other objects – actively showing the link between a prototype and its final product, like for example real cars. To avoid any further damage, they could be displayed one at the time, rotating the exhibition every 2 or 3 months. It is also possible to think about reproductions.

PRESERVATION THROUGH VIRTUAL DOCUMENTATION (3D LASER SCANNING)

In recent years, 3D laser scanning has become an increasingly indispensable tool to rapidly capture shapes, dimensions and structures of objects on a virtual base, for the preservation of cultural heritage. Beneath the detailed description and documentation of the dimension and surface structure of the object, its virtual 3D model, the so-called rendering, enables the production of exhibition copies, research items or the like via various rapid prototyping processes. This procedure can be a great benefit when it comes to fragile objects which are prone to degradation. After making sure that the laser beam wouldn't have damaged the industrial clay surface, the most relevant of them (for design history and conservation issues) were scanned using a Romer Cimcore Infinite Arm Model 5028.(14) The data obtained opens up a multitude of new ways to monitor and represent an important part of the automotive history.

CONCLUSION

Industrial clays present a great variety of organic and inorganic components, depending on when, where and why they were produced. This relates to their durability and their various forms of degradation processes. Our analytical research confirmed components found in literature and added some more interesting results, especially for what regards contemporary industrial clay artifacts. Because of the variety of their composition, it is not possible to develop a 'standard' treatment protocol. Procedures and materials used for cleaning, filling and consolidating need to be tested and optimized on every object. Keeping in mind the challenges connected to preserving industrial clay artifacts, it is possible to responsibly display this small car model collection in the museum, to show the dynamics and the creativity that lie behind the car designing process, both in the past and today.

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ENDNOTES

(1) *http://en.wikipedia.org/wiki/Prototype, last accessed August 2015*

(2) *http://en.wikipedia.org/wiki/Clay_modeling, last accessed August 2015*

(3) *Friese K., 2007. Plastilin / Dauerplastische Modelliermasse. Werkstoff in der zeitgenössischen Kunst und im Animationsfilm. Diploma thesis, Hochschule der Künste Bern.*

(4) *Sayers R., 1983. Wax, an Introduction. London, Gentry Books.*

(5) *Lang J. M., Mühlenberend S., Rössiger S., 2010. Körper in Wachs. Moulagen in Forschung und Restaurierung, Dresden, Sandstein.*

(6) *Demandewitz M., 2004. Plastilin Als Werkstoff - Überlegungen und Versuche zur Konservierung und Restaurierung am Beispiel eines Projektionsmodells aus dem Nachlass des Bühnenkünstlers Heinrich Wendel. Diploma thesis, Fachhochschule Köln.*

(7) *In the past, the chemical composition of modelling clay was changed depending on the season of the year. In winter the producers used to add more binders (e.g. beeswax) to maintain a high level of plasticity even at low temperatures.*

(8) *Both purchased by Kolb Technology GmbH: a sample of SuperClay, harder and with a sulphur component, and a sample of TecClay, a sulphur-free lighter industrial clay, which contains hollow micro-spheres of glass.*

(9) *The analysis were performed at the Bayerisches Landeskriminalamt and at the Doerner-Institut in Munich, using respectively a Bruker Optik Tensor-27 FT-IR spectrometer, with a Hyperion 1000 IR-Microscope (recording a spectral range from 10.000 to 450 cm^{-1}) and a PerkinElmer Spectrum One (spectral range from 4.000 to 650 cm^{-1}) combined with an UATR internal reflection diamond cell.*

(10) *LabRAM HR Vis Spectrometer with a spectral range of 400-1100 nm, coupled with a 785 nm laser and an Olympus BX41 confocal microscope.*

(11) *Thermo TRACE 2000 GC (program used: 40 °C for 3 min, heating of 10°C/min up to 300 °C, 300 °C for 5 min), coupled with a pyrolysis Autosampler CDS Analytical Inc. AS-2500 (operating temperature of 750 °C, chamber temperature 240 °C) and a Thermo TRACE MS. Two different derivatization reactions were used, to separate and identify the broadest range of organic compounds possible: with tetramethylammonium hydroxide (TMAH, 25% in methanol) and hexamethyldisilazane (HMDS).*

(12) *Zinc stearate is the most powerful mold release agent among all metal soaps. It contains no electrolyte and has a hydrophobic effect. Its main application is in the plastic and rubber industry, where it is used as a releasing agent and lubricant.*

(13) *Leica DM2500 M polarization microscope.*

(14) *Measuring accuracy: 0,254 mm, rotation ability: 360°, measuring range: 2 m*

LECTURE
011
CATALIN – A THERMOSETTING PLASTIC USED FOR VINTAGE JUKEBOXES

BY JULIA GREDEL

ABSTRACT

Since 2004 Julia Gredel is specialized in the conservation of jukeboxes from the 1930 through the 1950. The following paper is based on the observations made during the conservation treatment of a Wurlitzer Model 800 jukebox in her workshop in Munich, Germany.

In general, the coin-operated phonographs of the 1920s through the 1930s were derived from mechanical musical instruments and originally made of wood. The use of modern materials introduced during this period enabled designers and technicians to develop new designs that aimed for optical effects, such as kinetic elements. This change allowed jukeboxes to acquire a unique position in the fields of design and technology. This project was initiated in 2012, when the material composition of the Wurlitzer 800 was studied by Elena Hügel in cooperation with the scientific department of the Goering Institute in Munich as part of her final term paper(1).

One of the materials identified by Hügel is the thermosetting polymer “Catalin”. Catalin is a phenol formaldehyde resin derived from “Bakelite” and developed by the American Catalin Corporation. In 1938, the new translucent synthetic polymer Catalin was first used in the production process of jukeboxes.

Designed by Paul Fuller, the Wurlitzer 800 was presented in 1940. Its wooden case is decorated with nickel-plated castings and contains sections of coloured Catalin that are lit from behind. The focus of this paper is Catalin. It seeks to provide a history of this material and establish its aging properties, methods to identify it, and approaches to proper conservation treatment.

KEYWORDS

Catalin, phenoplastic, jukebox, bakelite, casting, Wurlitzer

INTRODUCTION

Catalin is the trademarked name for a coloured thermosetting polymer developed in the United States. It was derived from Bakelite, which had become a material for everyday objects by the 1920s but was limited in colour-range. At this time, a market opened up for more colourful goods, but the General Bakelite Company did not respond to this market demand.

Due to its specific production process that used fillers and moulded items under pressure and heat, the General Bakelite Company was only able to add dark brown or black pigments to the moulding compound. This lack of colour and the loss of patent protection in 1926 and 1927 forced the Bakelite Corporation to share the market with new competitors producing coloured phenolic resins *(Meikle 1995: 75)*.

One of these competitors was the Catalin Corporation, which had imported a new process, developed by German chemists, for making colourfast cast phenolics. A wide range of coal-tar dyes could be dissolved in the resin to colour it throughout. This material could be produced to be opaque, translucent or transparent. However, this resin could not be used as a moulding compound, because the moulding process, which requires pressure, high temperatures and incorporated fillers, destroys the material’s clarity. Therefore, a new method of casting without compression and fillers was developed. In 1928, the Catalin Corporation, located in the state of New York, announced the creation of a new plastic material with “a depth of colour” previously unknown. Named Catalin, it was the gem of modern industrial processes, combining “the sparkle and luster of precious stone with the toughness and strength of metal” *(Meikle 1995: 75)*. It should be emphasized that Catalin is a cast phenolic resin, while Bakelite is a compression phenolic resin.

RANGE OF USE

Initially, the Catalin Corporation produced coloured phenolic resin in billets that were available in different shapes such as rods, tubes, slabs, sheets, or other profile shapes. These billets were further processed by specialized companies and even by Arts and Crafts workshops *(Figure 1)*. The product range included small items such as knobs, handholds, napkin rings, and especially jewellery. Catalin became the foremost material of modern jewellery at that time.

In the early 1930s, Catalin began to be used in the manufacture of larger products. Popular at the time were, for example, candy-coloured Catalin radio cabinets. After a period of legal wrangling, American Catalin Corporation licensed its imported process to other companies, for example Marblette, Fiberloid, and even Bakelite. As a consequence, other trade names for the cast phenolics appeared on the market. From 1933 onwards, the General Bakelite Company produced cast phenolics named Bakelite Cast Resinoid in various colours *(Meikle 1995: 76)*.

PRODUCTION PROCESS

During our investigation, we noticed that Catalin is often referred to incorrectly as Bakelite, and that the names are not clearly distinguished from one another. Bakelite and Catalin are both phenol formaldehyde resins and, therefore, have similar characteristics. However, due to their different production processes - Catlin is a cast type and Bakelite a moulded type -, they have also distinct differences and visual appearances. In the following paragraph we will compare the two production processes.

Both materials were produced via polycondensation of phenol with formaldehyde in the presence of a basic catalyst. However, the proportions of phenol and formaldehyde differ. For Catalin, one part of phenol and up to two parts of formaldehyde are used for the polycondensation process. For Bakelite, the proportion is one to one. In both cases, the final product is a thermosetting polymer, but they look different due to their respective production processes and specific additives.

Another important difference is that during the Bakelite polycondensation of phenol with formaldehyde, the water that is produced during the process is extracted from the compound by vacuum pumps, while during the polycondensation of cast phenolics for Catalin the water remains present. At this point in the production of Bakelite, the resin is a brown syrup that turns into powder, called Novolac, after solidification. It is the main raw material for the moulding process under pressure.

The Catalin cast phenolic resin syrup is further dehydrated until it begins to acquire viscosity. Then, the condensation process is temporarily interrupted by adding an organic acid, such as a lactic. The dehydration process continues until the water content has been reduced to 5 -12 per cent. As long as the syrup is hot, the finished resin is bright, clear and has the consistency of honey. If colour is required, the dyes are added during this dehydration period. Afterwards, it is poured into open moulds without further cooling or the addition of fillers *(Figure 2)*.

The filled moulds are put into an oven that is heated to a temperature between 70 and 80 degrees Celsius. Depending on the colour, the curing time can be several days. “During the curing process, the resin is slowly converted to a hard infusible gel. With progressive hardening, it gradually loses its water tolerance and the water contained in the resin is deposited in the form of minute droplets throughout the gelled resin, producing an opaque chalk-white product. The addition of glycerol, or similar materials and their derivatives, creates final products which are translucent, or water-white, chiefly because of the effect which these ‘plasticizers’ have on the manner in which the separated water is dispersed in the gelled resin” *(Plastic Catalogue 1944: 114)*. After curing, the castings are hammered out of their lead moulds. This means that every mould could just be used once. The lead is then molten and reused.

The Bakelite moulding compound contains Novolac powder and fillers, such as wood, asbestos, textile fibres, as well as, in some cases, pigments. This powder mixture is now turned into the final moulding resin with heated rollers. The Phenolic resin is crushed again and finally moulded under pressure while being heated for several seconds. The mould consists of two interlocking parts made of steel, so the products can be removed easily and the mould can be used repeatedly. Because of the smooth surface of the mould and the applied pressure, the surface of the Bakelite product already has a gloss, when it comes out of the mould. This is an advantage, as the surfaces of Bakelite products generally don’t require polishing after the production process. By contrast, Catalin castings have rough surfaces and must be reworked into finished products. Catalin items were also much thicker than Bakelite items, because of the lack of filler materials and due to the difference in their production process. The minimum thickness that could be achieved with Catalin was about 5 mm.

THE APPLICATION OF CATALIN IN JUKEBOXES

Jukeboxes were developed based on mechanical musical instruments. Their initial design was characterized by a wooden exterior that made them look like a piece of furniture. During the 1930s, the market for jukeboxes expanded dramatically as new, independent design features were explored. To impress their audience and incite people to put a coin in the slot, jukebox companies like AMI, Mills, Wurlitzer and Seeburg searched for new optical effects to add to their products. In 1938, Seeburg was the first manufacturer to use illuminated plastics for the jukebox cabinet, thereby creating a magical composition of sound and light. That same year, the Wurlitzer Company of North Tonawanda, New York, introduced a new model decorated with translucent plastics. In the years that followed, all major jukebox companies sold about 22 different models furnished with coloured illuminated plastic parts. Each model had an average production rate of approximately 10,000 units. The inclusion of Catalin plastics strongly influenced the design and modern appearance of the jukebox so that these models were later referred to as “Jukeboxes of the Golden Age.” During World War II, cast phenolic resins were used for the manufacture of military items because of the specific material characteristics and the way in which they facilitated the implementation of new designs with ease and economy. The fact that cast phenolics were used by the military and the resulting shortage of phenol and formaldehyde stopped the use of Catalin for jukeboxes in 1942. Due to the development of less expensive plastics and increasing competition, the Catalin Corporation ended production in 1953. Its inventory was then bought by the Marblette Corporation, which produced cast phenolic resins until 1973 *(Segrave, K. 2002: 48 – 164)*.

Figure 1
Advertisement for Catalin “The gem of modern Industry”

CHARACTERISTICS AND PROPERTIES

Advertisements for Catalin and other cast phenolics highlighted the following characteristics: “The cast phenolics are available in unlimited colour ranges from opaque to transparent. They have excellent water resistance, good dimensional stability, and excellent machining qualities. Furthermore, the material is tasteless and odourless. In overall strength characteristics they compare favourably with other synthetic materials. By employing split moulds the range of possible designs and castings is almost unlimited and the resulting castings are ready for use with only minor finishing operations” *(Breskin 1944: 116)*. The surface of phenolics is smooth and glossy. Besides their availability in a wide range of simple colours, cast phenolics could also have a marbled appearance by mixing several different colours. The intensity of the marble effect varies. It is possible to dye cast phenolics. The Plastics Catalogue from 1944 describes the dyeing process as a bath containing a heated mixture of butyl alcohol, glycerine and a dye within which the casting should be boiled for three to five minutes *(Breskin 1944: 574)*. Cast phenolics are heat resistant and non-inflammable. They are insoluble in most solvents but could be affected by strong acids and bases. Aging causes a typical yellowing and tarnishing, but covered parts show the original colour and gloss. When the casting is rubbed, the rubbing produces an odour typical of phenol and formaldehyde. Catalin was used for a huge number of different items, but they all share similar characteristics. Every single one of them has been reworked by sizing, sanding, polishing and carving. In most cases it is thus possible to detect the marks of these post-production processes. Unfortunately, there are no trademark imprints on Catalin items to help recognize them.

IDENTIFICATION

There are three steps to help identify the material used for the plastic parts of jukeboxes. The mandatory first step is to gather all the available information about the object, to get a first idea of possible materials used. Today’s collectors of jukeboxes usually talk about Catalin plastics when they refer to the cabinets’

Figure 2
**Production process of Catalin items:
Clear syrup is poured into open leadmolds**

WURLITZER

Steps Up The Eye-Appeal And Earning Power Of Its Automatic Phonographs With

CATALIN THE GEM OF PLASTICS

Bearing a name famous in music for over two hundred years, Wurlitzer sells more automatic phonographs than all other makes combined! • Appreciating that a phonograph must be seen before it will be played, Wurlitzer styles its pace-setting instruments with brilliant emphasis on eye-appeal, using colorful pilasters of Catalin, *the Gem of Plastics.* • Wurlitzer selected Catalin for the same reasons that would make it a forceful sales stimulator if applied to *your* product—quality . . . forged with strength, fused with economy and fired with beauty! • *We cordially invite your inquiry.*

CATALIN CORPORATION
ONE PARK AVENUE • NEW YORK, N. Y.

Figure 3
**Catalin Corporation advertise its own product,
Catalin, which was used in the manufacture of Wurlitzer Jukeboxes**

plastics of the "Golden Age" period. This oral tradition may give us a preliminary idea about the material but does not provide conclusive evidence, because the term "Catalin" may have been used as a synonym for other phenolic resins produced by other corporations. Unfortunately, as mentioned above, the castings do not bear their manufacturer's imprint. Internet research and relevant literature do not give us a clear result. Further investigation leads us to the advertisements of jukebox companies. Each model was advertised by means of a brochure that included a description of the model's new features and its special characteristics. Most brochures talk about the use of plastic pilasters. Only a few advertisements mention Catalin by name. In the following, excerpts from two different advertisements are discussed.

The first is from a brochure advertising the jukebox models manufactured by Rock-Ola in 1940. This page shows the factory and pictures of the production process. One picture presents a workman on a belt sander with the caption: "PLASTIC – Large areas of colorful translucent plastics are used for 1940. Tons of this material are received in rough form, then sized, sanded and finished piece by piece to a high luster. Luxury light-up phonographs are famous for their gay lighting effects made possible by the use of Catalin" *(Rock Ola, 1940)*. The second advertisement was received from a collector specializing in jukeboxes made by the Wurlitzer Company. The Catalin Corporation ran an ad in this brochure to advertise its own product, which, as we have seen, was used in the manufacture of Wurlitzer Jukeboxes *(Figure 3)*.

These two brochures thus provide us with good evidence that the coloured plastics used in jukeboxes dating from around 1940 were likely Catalin castings.

The second step in identifying Catalin is a visual inspection. An inspection of this kind aims to compare the typical characteristics of Catalin with the plastics at hand and to search for matches. In the specific case of the Wurlitzer 800, our comparison confirmed the assumption that the material used for its plastics was indeed Catalin.

To collect further evidence, there is the third step, which requires that we perform several chemical analyses to identify phenol plastics. These chemical analyses include a variety of tests, such as density tests, burning tests, pyrolysis tests, and solvent tests. They further include checking for the Liebermann-Storch-Morawski reaction *(Braun 2003: 58)* and for the presence of phenol and formaldehyde. All these analyses were performed in the case of the Wurlitzer Model 800, and they confirmed that its plastic material was indeed a phenol formaldehyde resin. Because several companies produced phenol formaldehyde resins, it is not possible to identify Catalin by chemical analyses alone. In addition, Fourier Transformations Infrared Spectroscopy (FTIR) was performed in the department of conservation at the Technical University of Berlin (HTW-Berlin). The spectrum revealed similarities to the German-made phenoplastic *Trolon,* which was the closest reference sample available in the database.

Figure 4
**Illustration of a Wurlitzer model 800 part of the
brochure of Wurlitzer from 1940**

AGING PROPERTIES

One of the characteristic aging properties of Catalin is yellowing. The stability of Catalin is similar to other phenoplastics, which were the most stable plastics available at the time. The aging-behaviour of phenoplastics depends on their composition. For other phenoplastics such as Bakelite, the filler substances provided the crucial factor that influences their aging behaviour. For example, certain types of fillers such as wood and textile fibres could cause hygroscopicity. As no filler is used in the making of Catalin, this material is not hygroscopic and has a good water resistance. Catalin does, however, shrink over time, because of the continuing process of cross-linking of the polymer. The degree of shrinkage depends on the grade of polymerization during its production and the material's exposure to heat in general. The shrinkage could vary from 1 to 4 per cent and in turn cause stress-cracks. The heat generated inside radio-cabinets, for example, could cause intensive shrinking. Since the cabinet construction did not allow for shrinking, the material broke where its mobility was blocked. By contrast, the particular construction of jukebox cabinets, in which the Catalin castings were fitted between nickel-plated iron-castings like a filling in a frame, prevent this kind of stress-cracks. The worst that could happen when the castings shrunk, was that they became so small that the light of the bulbs inside might peer through little gaps. While heat is also generated inside jukeboxes by the tubes and bulbs, the relatively larger cabinets allow the heat to dissipate, and the resulting shrinkage is negligible.

The most noticeable aging property is the distinctive yellowing caused by exposure to ultraviolet light and heat. This yellowing may be due to oxidation products created by free phenols, which are brown in colour and accumulate on the surface. There could also be other additional decomposition products, but this has not been investigated yet. Areas where the Catalin remained covered are not affected by discolouration and yellowing. Finally, there is no apparent change in mechanical properties, such as brittleness or stickiness.

CONSERVATION TREATMENT

Our specimen for conservation treatment is the Model 800 Jukebox, made by the Wurlitzer Company, designed by Paul Fuller and produced in 1940 *(see Figure 4)*. In 2011/2012 we examined and treated a jukebox of this model. It is one of the biggest jukeboxes to have been produced at the time with a width of 94 cm, a depth of 72 cm, a height of 155 cm and a weight of about 200 kg. The record changer has a capacity of 24 gramophone records (78 rpm). The motor-driven coin equipment is dimensioned for nickels, quarters and dimes. The cabinet contains 14 Catalin castings in the colours of red, green, ivory and 1 transparent varnished one. In addition to the illumination of the Catalin pilasters there are kinetic elements such as motor-driven, coloured cylinders behind the Catalin pilasters on the left and right of the front, and bubble tubes in the lower front door behind a transparent varnished Catalin pilaster. The Catalin pilasters are framed in nickel-plated iron castings.

Before the conservation treatment began, the jukebox showed signs of ageing, former restorations and various types of damage.

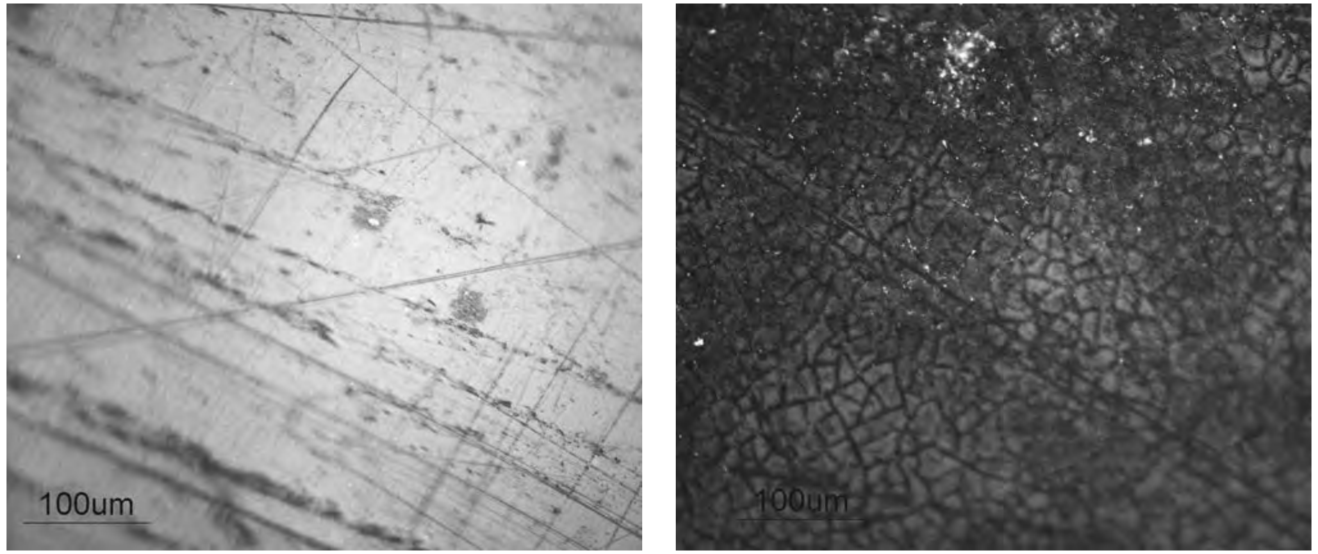


Figure 5
Microscopic image: covered and uncovered area

The first step in this process was to define the goals of the conservation treatment. These were formulated as: presenting an operational jukebox, to treat or reverse some of the previous restorations, and to preserve all original materials, as well as signs of wear from use. The brownish and tarnished colouring of the Catalin plastics showed that they had veered rather dramatically from their original appearance. Except for the red ones, the coloured plastics seemed nearly monochrome. In addition, their brown layer interfered with the effect of translucence. Further damage included scratches, burn marks, water spots, paint splatters and some varnish residue on the edges of the castings. We also noticed some shrinkage of the castings that caused small gaps. The scratches were interpreted as evidence of usage in public locations. Customers could, for example, have produced these scratches while inserting coins. The burn marks were caused by customers holding cigarettes close to the machine. The varnish deposits on the edges of the castings were the result of a previous restoration of the wooden cabinet.

After dismantling the cabinet, we discovered that the castings showed a significant difference between the covered and the uncovered areas. The covered areas retained the original colour and gloss *(Figure 5)*.

The insides of the castings were covered by a lighter brown layer, while the areas next to the bulbs were darker. This confirmed our assumption that the yellowing was exacerbated by the additional influence of heat. The goal of the conservation treatment was to remove this brown layer, the dirt and paint splatters and the varnish without destroying the original surface and simultaneously attempting to preserve the patina. It was therefore decided to let the scratches and burn marks remain as evidence of this jukebox's history of handling.

Because phenolics have relatively few aging properties, we couldn't find any antecedents for the conservation treatment in the literature. What we did find were descriptions of the treatments of yellowed Catalin items posted by collectors on the internet. They advised to remove the brown discoloured layer through sanding and polishing. For obvious reasons, this treatment was incompatible with our conservation goals. So we devised our own testing methodology instead. To choose the correct testing solvents we needed to know what the exact composition of the brown layer was. Given the fact that phenolic plastics yellow as they age we had to search for other external causes for the discoloration. Since the jukeboxes were formerly housed in restaurants and bars, the possible agents of pollution affecting the castings might very well be either cigarette fumes, or heat and steam from cooking. It is also likely that the conditions of the storage, where the jukebox was kept after its retirement, were not optimal. It could have been exposed to sunlight, heat, changes in humidity, and a variety of polluting agents.

Figure 6
left side of the Wurlitzer 800 before and after conservation treatment
(see colour plate, p. 167)

To begin the test series, we acquired a single casting that once was part of a similar jukebox and which had a similar aged and polluted appearance. This piece of Catalin was then examined with a microscope. Using a magnification of 200, we noticed fine cracks across the areas where the surface had been uncovered, while they did not appear on the covered areas. Both showed fine parallel scratches that had been caused by a belt sander during the original post-production treatment and that had remained after the final polishing. Small dirt particles seemed to have become cemented into the brown layer.

After the visual examination, we initiated tests with solvents, all the while closely monitoring the condition of the cracks before and after a test. We chose various classes of solvents. The solvents we used were distilled water, water with Surfynol 61, isopropanol, ethanol, mineral spirits, toluol, ethyl acetate, acetone and a mixture of isopropanol, ammonia, and demineralized water. Distilled water cleaned the surface superficially without harming the material. The brown layer remained. Nearly the same could be observed with an addition of 6 per cent of Surfynol 61, though the original layer acquired marginal damage. Isopropanol, ethanol, ethyl acetate and acetone cleaned superficially, but further harmed the aged surface of the material. Mineral spirits did not have any effect. Toluol removed the superficial grime but also harmed the Catalin. The mixture of isopropanol, ammonia and distilled water dissolved the dirt and even the brown layer, but, unfortunately, also affected the material in a harmful manner. From the tests we concluded that the aged, exposed surface was vulnerable to most solvents, while the covered areas seemed to remain stable. The best cleaning results were achieved by using the last solution; but in order to use it for conservation treatment it needed to be modified to not further damage the Catalin. The behaviour of the isopropanol, led to the decision to do an additional test series with different concentrations of ammonia hydroxide. We tested 5 per cent, 2.5 per cent, 1.25 per cent, 0.625 per cent ammonia with water and smaller concentrations with pH 10 and pH 9. As expected, the first four mixtures cleaned and removed the brownish layer with relative ease, but still damaged the material. A mixture containing a smaller amount of ammonia with pH 10 showed similar results for cleaning, without harming the original surface. After removing the brown layer, with this combination of solvents, what remained was a light, yellowed layer with a gloss that is close in appearance to the unaltered covered areas, and left the patina of aging intact. Tests with the pH 9 mixture had less effect on the brownish layer.

Therefore, the solvent mixture with pH 10 was chosen. Cotton swabs proved to be most suitable for this cleaning method. After the brown layer was removed, the wetted cotton swabs did not dissolve any further layers allowing us to safely remove the brown layer entirely. The final step in this part of treatment was to clean the casting with demineralized water and to dry it with a microfiber cloth.

While working on the jukebox and the Catalin castings, we observed that, in addition to yellowing, the green plastics seemed to have lost colour. There was also a distinguishable difference between the left and the right side of the plastic, possibly caused by unequal exposure to ultraviolet light.

During reassembly, we centred the plastics between the nickel-plated castings to avoid gaps. After the conservation treatment, the different colours of the Catalin castings are visible once again, without harming the original surface and without compromising the jukebox´s aged appearance *(Figure 6)*.

CONSIDERATIONS FOR ONGOING RESEARCH AND TREATMENT

The jukeboxes we treat for collectors, and those that are in our care are jukeboxes that have been or are still in use, and are a part of people's homes. They are not placed in storage. To keep them in working order, jukeboxes have to play music. To slow down further aging processes, we shield them from light and heat as much as possible and try to ensure stable climate conditions. To avoid the generation of too much heat inside the jukebox cabinet, we need to replace the bulbs with ones that do not produce heat, but so far we have not been able to identify a suitable option.

We suspect that exposure to ultraviolet light might cause the brown layer to reappear. The conservation treatment of the Catalin might have two different outcomes. On the one hand, the removal of the brown layer could result in further decomposition products. On the other hand, it could also protect against the effects of such decomposition products. Ongoing observation of the Catalin inserts will help us to answer that question. Subsequently, the definition of patina could be further discussed.

During the year that the Model 800 Jukebox discussed in this paper remained in our care it was protected from exposure to ultraviolet light. Continuous observation did not reveal new development of the brown layer, nor any changes in colours.
As jukeboxes are contemporary witnesses to the social, technological and design history particular to the United States of America, they deserve more attention from professional conservators. In most cases, jukeboxes are treated by their collectors, who do their best, but often do not take care of the original materials in the proper manner and strife to achieve a "as-good-as-new" appearance. Through our work and in the articles we write for collectors' magazines, we try to underline the importance of protecting and preserving the original materials in order to remain true to the authentic appearance and to let the piece reveal its actual age.

As experts, we also monitor the jukebox market and keep close contact to collectors and salesmen worldwide. We noticed that in recent years, prices for original, preserved jukeboxes have gone up attesting to an increasing acceptance on the part of collectors of jukeboxes with an aged appearance that shows sign of use.

So far, this trend can mostly be seen in Europe however. The opposite is often still the case when it comes to the conservation of jukeboxes in the United States where the appreciation for the jukebox as an authentic artefact documenting the development of technology, new materials, modern culture and design is not held as important. A Possible explanation for this difference in approach might be the large number of jukeboxes that is still available in the US, making it seem as an unlimited supply.

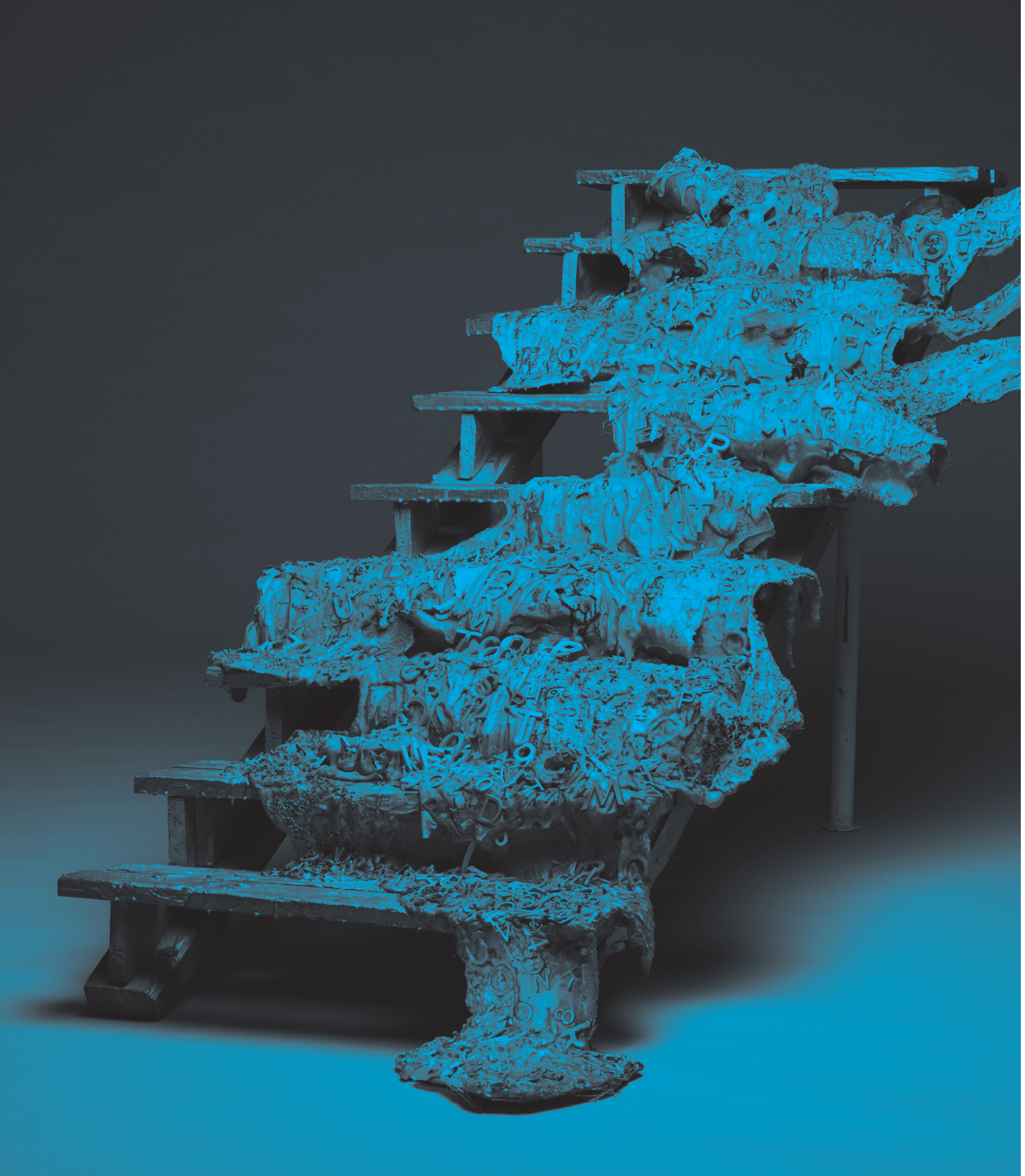
Today, they are often still sold by the container to buyers all over the world. Hopefully, this will change and the awareness of their significance in authentic state will soon also be raised in their country of origin.

ACKNOWLEDGEMENTS

The author would like to thank Elena Hügel and her husband Christian Gredel for being great team players during the research, restoration and conservation work, particularly regarding the Wurlitzer 800, but also for their participation in other collaborative projects in the field of jukeboxes.

ENDNOTES

(1) *Unpublished final term paper, Goering_Institut München. The Goering Institute is a "State-Approved Professional Academy for the Conservation of Furniture and Wooden Objects."; Giselastraße 7, 80802 München, Germany*



LECTURE
012
PRACTICAL ASPECTS ON THE TESTING AND USE OF ADHESIVES ON POLYSTYRENE

BY THEA WINTHER, JUDITH BANNERMAN, HILDE SKOGSTAD, LENA WIKSTRÖM, TOM SANDSTRÖM, ULRIKA BRYNNEL

ABSTRACT

Seven adhesives were tested for their effect on polystyrene before and after light ageing. The impact of adhesives for treating general purpose and high impact polystyrene in the museum environment was investigated studying such factors as stability, working properties, aesthetics, ageing of the joint and the question of reversibility. Based on a survey, the adhesives included were acrylates (Paraloid B72, Paraloid B67, Primal AC-35, Acrifix 116), epoxies (Hxtal NYL-1, Araldite 2020), and one cyanoacrylate (Loctite Super Attak Precision). Adhesives were tested on extruded sheets of transparent, general-purpose polystyrene, and white high impact polystyrene. Methods applied before and after light ageing were visual assessment, colour measurement, hardness testing, ATR-FTIR, SEM-imaging, tensile testing, assessment of working properties, and type of break.

Based on the outcome from this project some of the adhesives were chosen to be tested on naturally aged objects. These results were further applied to the conservation treatment of the polystyrene parts of the sculpture Trappan by Kjartan Slettemark, from the collection of the Moderna Museet, Stockholm.

The experience derived from joining these polystyrene objects will be presented in this paper as well as a comparison of test results gained from samples and objects.

KEYWORDS

polystyrene, PS, adhesives, GPPS, HIPS, Kjartan Slettemark

INTRODUCTION

There are occasions when the use of adhesives on cultural heritage objects is inevitable. The application of an adhesive can be considered necessary for several reasons, for example to increase the understanding and readability of a damaged object or as a measure to prevent further damage. For preservation purposes it is important to choose an adhesive that will stay stable over time and has as little impact as possible on the original material. The conservator will need to know what adhesive can be used for what kind of plastic, how it can affect the object and how it will age. Seven adhesives commonly used by conservators have been studied on samples of polystyrene. The research results were applied to naturally aged objects and artworks and the outcome is discussed in this paper. In addition, some of the results and conclusions from the research project are summarised.

BACKGROUND

The starting point for the research project on polystyrene was an earlier project called *Plast - Morgondagens kulturobjekt* (Plastic - the cultural heritage of tomorrow) undertaken at The Swedish National Heritage Board 2005-2008 *(Nord et al. 2008)*. The project analysed damages, degradation processes and plastic materials found in Swedish museum collections. A survey including fifty-one Swedish museums and a more extensive damage assessment at nine museums were carried out. The participating museums house collections of art, design and cultural history objects. One noted damage was found on polystyrene objects that is characterised by cracks and fractures. Until recently, little research has been undertaken into the repair of polystyrene and the need for finding appropriate adhesives has been pointed out by conservators *(Moomaw et al. 2009)*. A research project was therefore carried out in 2012 together with the Royal Institute of Technology, Stockholm and the research institute Swerea KIMAB *(Winther et al. 2013)*. Specific research studying adhesive joining of plastics from a preservation perspective had been carried out mainly for poly (methyl methacrylate) and unsaturated polyester *(Sale 1995, 2011, Roche 2011, Lagana and van Oosten 2011)*.

The investigation focused on the following questions: How stable are the adhesives used by conservators? What effect do the adhesives have on the original material? And finally, what chemical and mechanical changes will take place? The methods and parameters used for evaluation were the assessment of working properties, appearance, colour measurement, tensile testing, hardness measurement, assessment of break type, SEM-

Figure 1
Adhesives used in the initial test trial.

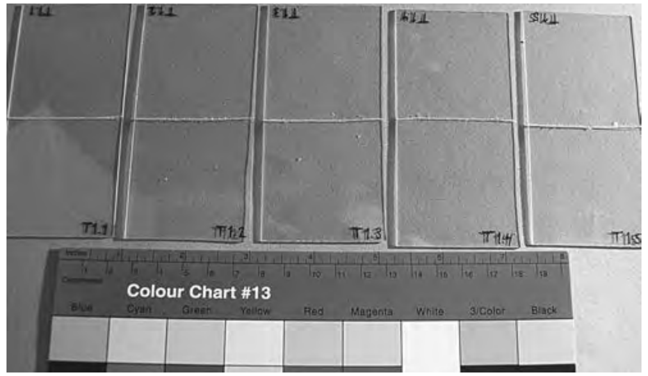


Figure 2
Samples of extruded polystyrene sheet material

Figure 3
General purpose polystyrene samples.

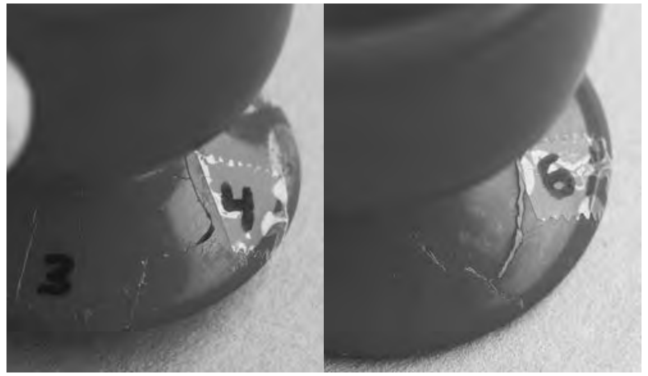


Figure 4
Broken eggcup adhered with bonds of Hxtal -NYL 1 (4) and LoctiteSAP (6)

imaging, ATR FTIR-imaging, and assessment of reversibility. Artificial ageing was performed by light ageing with a UV light component.

The investigation of conservation methods using test material requires that factors important for the conservation of original material are elucidated and applied in the test protocol. There is often a gap between the testing that can be performed in the laboratory and how the results can be applied in real life to cultural heritage collections. Therefore a test trial applying the results to naturally aged objects performing as dummies was carried out. The results were later applied to the conservation of a sculpture, Trappan by Kjartan Slettemark dating to the 1960´s in the collection of Moderna Museet, Stockholm, Sweden, to re-attach several detached polystyrene parts.

SUMMARY

The project was a comparative study of seven adhesives and their effect on polystyrene after light ageing. The project investigated substrates and adhesives through comparison before and after ageing and before and after joining. The main impetus for the choice of adhesives was what adhesive conservators would use, or consider using, for polystyrene. A questionnaire was sent to Swedish conservators likely to come across polystyrene in their work. Replies from approximately 20 conservators formed the basis for a screening test trial of 20 adhesives *(Figure 1)*. A selection of seven adhesives *(Table 1)* was chosen for further investigation, following initial testing which included an assessment of working properties, aesthetics and an evaluation of damaging effects observed through visual inspection, and after discussions with a peer review panel.

The adhesives chosen fall mainly into three categories: acrylates, epoxies and one specific cyanoacrylate. The solvent based acrylates were Paraloid B72 in acetone:ethanol, Paraloid B72 in ethanol, Paraloid B67 in isopropanol, and Acrifix 116. The epoxies were Hxtal NYL^{-1} and Araldite 2020. The acrylate in dispersion was Primal AC-35 and the cyanoacrylate was Loctite Super Attak Precision (LoctiteSAP) *(Table 1)*.

Degradation processes were studied quantitatively by assessment of bond strength using tensile testing, their effect on hardness of plastic and adhesive, and by the visual changes that could be observed through comparison of colour values. Degradation effects were primarily studied by an analysis of micro scale changes induced by adhesive joining using Scanning Electron Microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). Moreover, degradation phenomena and type of breakage were assessed visually with the stereomicroscope to evaluate the compatibility of adhesive and plastic. Compatibility was also evaluated through an assessment of working properties and reversibility.

The experiments were conducted in two series on transparent general-purpose polystyrene (GPPS) and white high impact polystyrene (HIPS). The test material samples were cut from extruded plastic sheet material of 1 mm thickness. The first series of samples were cut to a size of 50 x 100 x 1 mm *(Figure 2)* and subjected to an initial pull-to-break test in the tensile tester before being joined with the adhesives (ten test specimens for each adhesive on GPPS and HIPS respectively). The broken edges of the plastic were subsequently abutted and joined using the seven different adhesives mentioned above. Working properties and visual appearances were assessed before half of the samples were subjected to pull-to-break testing in the tensile tester. The other half of the samples was subjected to light ageing before a second visual assessment followed by tensile testing. Break force values before and after light ageing were compared and the type of breakage assessed by microscope and SEM-imaging. After the application of the adhesives, the joined pieces were pressed together manually and laid flat to cure.

In the other test series, a one millimetre thick open adhesive layer was applied with a draw-down technique to cover the centre of samples sized 108 x 215 x 1 mm. All samples were cut in half and one half was subjected to light ageing. The results of the visual assessment, hardness testing, colour measurement, SEM-imaging of the border area between adhesive and plastic, and FTIR-imaging of cross-sections of the interface between adhesive and plastic were compared in both sample groups.

CONCLUSIONS FROM THE RESULTS OF THE TESTS ON POLYSTYRENE SAMPLES *(TABLES 2 AND 3)*

A damaging effect on the plastic was observed on the open layer samples with Acrifix 116 and LoctiteSAP by visual inspection and on a micro level by SEM-imaging in the form of cracks and deformation. Stress-crazing of the plastic was not visible on the samples with joined edges by visual inspection or in the stereomicroscope before or after ageing. For the cyanoacrylate a change in surface was visible in the SEM on the plastic.

The tensile strength of the adhesive joints of most of the adhesives tested was not severely affected by the artificial ageing procedure. The cyanoacrylate joint of the GPPS sample was weakened whereas the Acrifix 116 (on GPPS and HIPS) and Primal AC-35 on HIPS bond was strengthened. In general, the cyanoacrylate formed the strongest and Paraloid B67 the weakest bond. Most bonds were stronger on the HIPS samples when compared to adhesive bonds on the GPPS. None of the adhesives caused a cohesive break in the plastic. Adhesive breaks could be seen with the epoxies. The epoxies did not adhere as strongly to the polystyrene as it is known to adhere to other materials, such as metal, which was attributed to the non-polar quality of the polystyrene.

Most adhesives showed visible yellowing, apart from Acrifix 116 and Hxtal NYL-1, on the open layer samples. The bonds of the joint edges of the cyanoacrylate and Araldite 2020 samples showed visible yellowing. None of the tested adhesives matched the refractive index of polystyrene (1.59), which resulted in visible joints on the transparent polystyrene specimens. Deformations of the plastic were observed on the samples with an open adhesive layer of Acrifix 116 and to a lesser extant of LoctiteSAP. The Paraloids and the dispersion Primal AC-35 proofed to stay reversible and it was possible to remove the epoxies and Acrifix 116 manually. The cyanoacrylate could not be removed.

If a medium strength bond is acceptable, the non-yellowing epoxy (Hxtal NYL-1) could be chosen or, for a weaker bond, the acrylate dispersion (Primal AC-35) as these two adhesives caused the least damage to the polystyrene samples. The dispersion was also reversible, which may be a desired characteristic. Among the disadvantages are the difficulty in removing the epoxy and the slightly yellow colour of the dispersion. The dispersion might also result in unacceptably weak bonds that could pose a risk for the object. The greatest potential for damage was found in the samples using Acrifix 116 and LoctiteSAP.

THE RESULTS APPLIED TO OBJECTS

The adhesives were tested on six objects estimated to be 30 to 40 years old: a transparent water pitcher (Gelms, Sweden), a white eggcup (Gies-Plastic, W.-Germany) a red eggcup (Emsa, W.-Germany), a transparent lidded box (Perstorp), part of a toy house (no marking), and a small transparent orange part of a spoon (no marking) *(Figure 3)*. The objects were all intentionally broken by dropping them from a height of 1 meter. Based on the results from the different experiments from the two test series, four of the adhesives were chosen for further testing. Hxtal NYL-1 was chosen for its ageing stability and non-damaging properties, LoctiteSAP for its strength and fast-curing properties, Primal AC35 for its good working properties, reversibility and as a representative of a weaker adhesive, and Paraloid B72 in ethanol for its medium strength, good working properties, and reversibility.

The adhesives' performance on the objects mainly correlated with the results of the previous test series. No stress-cracking or damage was observed on the plastic when looking at the joined areas through the stereomicroscope directly after application, or when inspected seven months later.

All joints were visible on the transparent objects. Paraloid B72 was visible to a greater extent than on the test material samples due to air bubbles trapped in the adhesive layer. However, depending on how the broken edge was formed, also LoctiteSAP and Primal AC35 showed air bubbles in the joints with greater surface area. This phenomenon was not observed in the test material samples and can be attributed to the type of break, which ran diagonally through the thickness of the polystyrene and hinders the evaporation of solvents or gases from the curing adhesive. Because of its inherent pale yellow colour Primal AC35 was clearly visible on the white, but not on the red eggcup. This was also seen in the testing on the white HIPS samples, where Primal AC35 was slightly yellow which points to the fact that the colour of the original material plays a great part in the final aesthetic result. The least visible were the joints with Hxtal NYL-1.

Difficulties in achieving tight bonds were in general experienced on the white eggcup and the transparent box. Tension from the production process was probably released through breaking the objects and resulted in the distortion of the plastic, which made it difficult to align the pieces. The form of the fractured edge also affects the final result. For example, slightly ragged edges make it easier to hold the pieces in place during curing than smooth ones. A successful application of Hxtal NYL-1 was more easily achieved if the piece to be adhered was held in place by the surrounding plastic alone during the curing time without any additional manual pressure or external support. In this regard Hxtal NYL-1 was found to be easier to use on real objects than on the square test material sheets. The amount of Hxtal NYL-1 used should be kept to a minimum to avoid excessive running or spillage. A positive aspect regarding Paraloid B72's performance was the ease by which spills after curing could be removed from the surface with a wooden toothpick. For LoctiteSAP it was not possible to remove excess material after curing *(Figure 4)*.

No bond failure was experienced for any of the adhesives after curing during normal handling. However, at a later date the orange spoon was accidently subjected to some pressure, which resulted in the breaking of the Paraloid B72 joint. This did not happen with LoctiteSAP when the object was subjected to the same pressure, which reflects the results from the tensile testing in terms of its greater strength. For monitoring the objects were stored under ambient in conditions with fluctuations in the relative humidity between 20% and 65% at 20-25 °C, and 1400 to 1800 lux with some UV radiation (0.05 W/m^2 when cloudy to 0.17 W/m^2 in sunlight). After seven months (light level 2 on the blue wool scale) no visible changes could be detected by ocular inspection nor was there any evidence of stress-cracks visible under the stereomicroscope at up to 40x magnification.

APPLICATION OF THE RESULTS OR THE TREATMENT OF *TRAPPAN*

Following the experience gained from the tests on model samples and on objects, the results were applied in the conservation of an art work in the collection of Moderna Museet in Stockholm. The piece is a large sculpture made by Norwegian/Swedish artist Kjartan Slettemark (1932–2008). The sculpture is called *Trappan,* (The Stairs) was made in 1967 with the measurements 92 x 84 x 220 cm *(Figure 5)*. It was made from a variety of synthetic materials that were mounted on a partly painted wooden and metal structure.

One of the main features of the piece is a large number of letters made of polystyrene, semi-embedded in a base of synthetic resins, often covered with a layer of paint. In an earlier investigation carried out by FTIR the main component of the synthetic resin was found to be polyester. Many of the letters have broken over the years. In preparation for the artwork's exhibition in a retrospective in Oslo it was decided to re-adhere the letters. Based on the test results, an epoxy was chosen as it was considered to cause the least damage, provide enough strength and give an aesthetically pleasing result while offering reasonable working properties. In this case Araldite 2020 was used, as it was available at short notice. As the surfaces are multi-coloured the risk of yellowing was considered very low in regard to the work's aesthetic overall impression.

The first step was to determine the original position of the detached letters as well as fitting broken pieces together and to establish a plan for their fixation. There were a few pieces of letters where it was not possible to find the correct place. One of these was used as a dummy to try out the chosen procedure. After this initial test was deemed successful the surfaces of the broken letters were cleaned with distilled water and cotton swabs. Supporting structures were built with shapeable thermoplastic polyester. The adhesive was applied with a small brush and the pieces were fixated manually for about a minute. Afterwards they were held in place through the supports for at least 24 hours *(Figure 6)*. The joining of the polystyrene letters was experienced as easy. A very small amount of adhesive was used to avoid spillage as the painted surfaces of the letters could be damaged by attempts to manually remove excess material. Since the completion of the treatment the sculpture has since been transported back and forth between Oslo and Stockholm by lorry without any visible negative effect on the joined parts.

DISCUSSION

What differences in behaviour could be seen between the testing on the test samples and the naturally aged objects? For most factors, such as colour, visibility and the effect on the plastic, the joining of the objects reflected the behaviour observed on the test samples. However, there were a few aspects where there was a difference. Primarily the two sample types differed in material thickness and structure of the fractured surface. For most of the objects the surfaces to be joined were thicker (circa 2-4 millimetres) and more varied than those of the test samples. Especially the more ragged fractures were easier to hold together accurately during the initial curing phase of the adhesive. The epoxies were experienced as easier to use on the objects than on the thinner test samples with their more even fractured surfaces. On the other hand, LoctiteSAP and Primal AC35 caused more air bubbles in the joint of the objects compared to the test samples as the joint had a larger surface area.

Another important factor is that polystyrene objects are often moulded or shaped in a way that creates inner tensions that can be released when broken, as could be seen on the white eggcup and transparent box. The shapes of the objects were distorted which made them more difficult to join. A solution for this problem might be found in a treatment carried out on PMMA where PMMA pieces were slowly bent back into shape with pressures to re-shape distorted areas *(Comiotto & Egger 2009)*. Annealing, as a way to release tensions trapped in the object through the controlled use of heat, could be another method worth investigating.

The question is, in what way can testing methods be improved to be in greater congruence with three-dimensional objects? The initial pull-to-break in the tensile tester was used in an attempt to create fractures more similar to the irregularly fractured surfaces of real objects. It is debatable though how successful this approach was, as this method created a great spread in the break force values for each adhesive. For further testing more test specimens for each combination of adhesive and plastic should therefor be used to reduce this spread (standard deviation). Ideally, testing should be done on a larger number of objects from the same fabrication series to develop a more controlled way of measuring the strength of the bonds on real objects. Though there is room for improvements, it was possible to discern overall trends for the adhesives from the tests, especially as they coincided for both GPPS and HIPS.

As polystyrene is known for its sensitivity to organic solvents such as acetone which can initiate stress-cracking, it would be of interest to further develop analytical methods to track changes in and near the joints on a molecular level. In this project neither on the samples of the butt joint type nor or on the naturally aged objects stress crazing could be observed by ocular inspection or under the stereomicroscope at up to 40x magnification, though some damage was detected on the open layer samples. As solvent induced damages can emerge long after a treatment was carried out, it is important to monitor the objects and samples to assess the long-term effect of the intervention.

In this study it was assumed that light ageing is the most accurate method to mimic natural ageing like it occurs in the museum environment. Artificial light ageing cannot simulate deterioration processes, which have their origin in more physical mechanisms, caused by factors such as heat and fluctuations in relative humidity over time. Therefor the long-term monitoring of the three-dimensional objects in the museum environment is extremely important to study their natural ageing behaviour. Furthermore, the use of UV light for the artificial ageing of the samples may be misleading, given that it is not supposed to be present in the museum environment. The UV light present may initiate deterioration processes in some materials that would not occur otherwise. For instance, the weakening of the cyanoacrylate used on the transparent polystyrene is thought to have been UV triggered, as the transparent material allows the radiation to reach the adhesive *(Horie 2010)*. This theory is supported by the fact that the weakening of the cyanoacrylate on the white HIPS did not occur to the same extent as in the transparent samples. In this respect it is important to keep in mind that the results should be read as a comparison between the different adhesives and their susceptibility to certain degradation processes in relation to each other.

It is worth reflecting on how information from sample testing can be interpreted so that the results are useful in conservation practice. For instance, in the project severe damaging effects on the plastic could be seen on the samples with the acrylate in a solvent mix, Acrifix 116, and the cyanoacrylate LoctiteSAP. This damage was seen in the samples where a layer of adhesive had been spread out onto a large open surface, an unlikely application method for conservation treatments. The amount of tension caused by the curing adhesive on the open layer samples is much larger than in a joint of the butt joint type. The test however showed that this type of tension induced damage could not be observed on the other adhesives on the open layer samples, which indicates that these kinds of adhesives could potentially be more harmful to polystyrene than the other adhesives tested. The overall assessment of the results from this project provided useful information about the adhesives to be used on polystyrene that were applicable in the conservation of the art work.

CONCLUSIONS

Based on the results from the research project Joining plastics together – what happens over time? which investigated the effect of seven different adhesives on polystyrene, four adhesives were tested on objects estimated to be 30 to 40 years old. Hxtal NYL-1 was chosen for its good ageing behaviour and non-damaging properties, Primal AC35 for its good working properties, reversibility and as a representative of a weaker adhesive and Paraloid B72 in ethanol for its medium strength, good working properties and reversibility. LoctiteSAP was included as a representative of a strong and fast-curing adhesive, even though potential damage to the polystyrene had been indicated in the test results.

The behaviour of the adhesives on the objects correlated with the results from the research project, with a few exceptions. The project used test samples cut from 1 mm thick polystyrene sheets. The material thickness of actual objects is often bigger, which changes the experienced working properties for some of the adhesives. The epoxies were experienced as easier to use on the objects than on the thin fractured surfaces of the test samples. LoctiteSAP and Primal AC35 caused more air bubbles in the joints of the objects than on the test samples, when the joint had a larger surface area. Another difference was that objects are more likely to have built in tensions that may cause distortions when broken. No negative effect of the adhesives on the

Figure 5
***Trappan,* 1967, by Kjartan Slettermark.**
(see colour plate, p. 168)
Photo: Moderna Museet

objects was visible by visual inspection and under the stereomicroscope at 40x magnification but the objects will be monitored for future changes. For the conservation of a sculpture by Kjartan Slettemark from 1967 in the collection of Moderna Museet, Stockholm, an epoxy was chosen to re-attach lost polystyrene parts, which gave a satisfying result.

Ideally, in conservation practice an adhesive should be able to hold pieces together securely for the intended usage, but it should be possible to separate the pieces or reverse the treatment without damage to the object. When choosing an adhesive for an object in a heritage collection or of cultural significance one needs to consider aesthetic aspects, the history of the object, its condition, as well as future use with expected stresses. Test results gained from the laboratory environment must be evaluated carefully to assess how applicable the results are to the conservation of real life objects in museums. Although there are differences that one needs to be aware of, the material testing and ageing carried out in this project provides a useful basis for making informed choices.

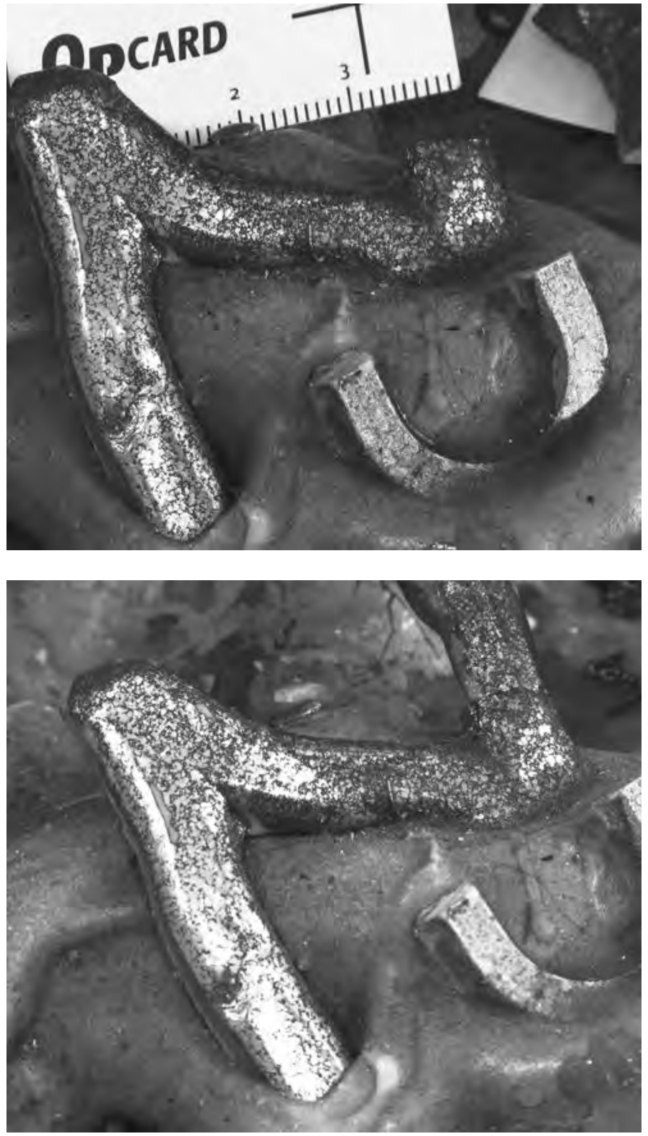


Figure 6
Letter N of *Trappan* before and after adhering.

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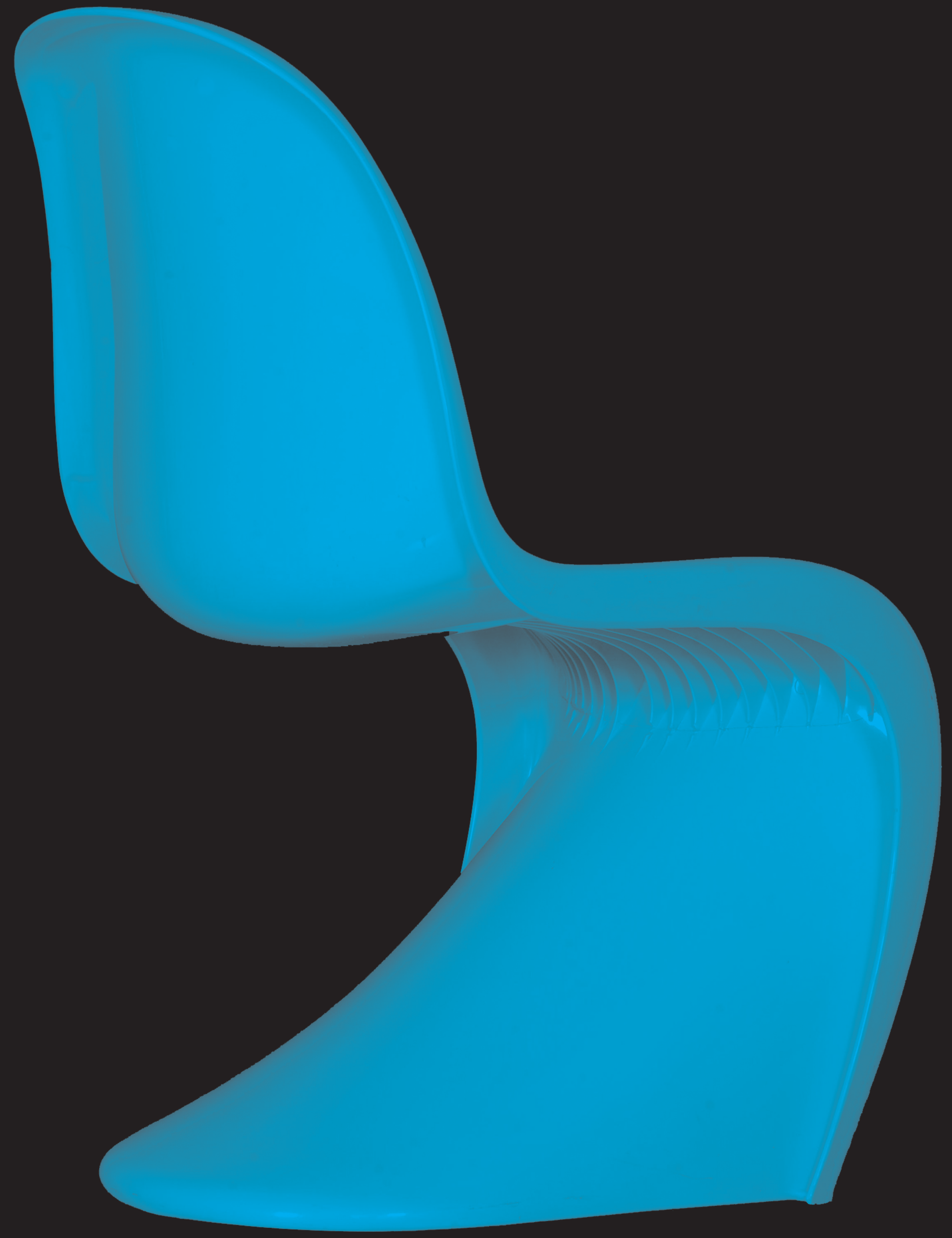


LECTURE
013
THE PANTON CHAIR MADE OF LURAN® S. CAN CRACKS IN AGED ASA BE JOINED?

BY DELIA MÜLLER-WÜSTEN

ABSTRACT

In the 1960s, the Danish designer Verner Panton developed the *Panton Chair* – a plastic chair cast in one piece. During its second production stage in the 1970s the thermoplastic acrylonitrile styrene acrylate (ASA) was used for the fabrication of the chair. Many of the chairs cracked and fractured after being in use for only a few years. A Master's thesis written at the Cologne Institute for Conservation Sciences, in cooperation with the Institut für Kunststofftechnik in Stuttgart, examined various options to restore the damaged chairs. The goal was to develop a conservation method to join the cracks in a way that would render the chairs usable again. To establish the mechanical requirements of the joined areas, the development and production of the chair, as well as typical damage patterns, were explored. A three-dimensional model of the chair was used to calculate the forces acting on the object under certain load scenarios using the finite element method (FEM). Three test series were developed to investigate eight adhesives of different mechanisms of adhesion. The main goal was to examine and evaluate the different failure patterns, the load capacity and the chance of stress cracking in the plastic material pursuant to different bonding methods.

KEYWORDS

adhesion of plastics, ASA, load capacity of adhesive joints, modern furniture, tensile testing, Verner Panton

INTRODUCTION

In the 1960s, the Danish designer Verner Panton developed the *Panton Chair* – a plastic chair cast in one piece *(Figure 1)*. In the late 1960s it was launched in a small hand-made edition using glass-fibre reinforced polyester. In the production phase of the following series, the polyester was replaced by polyurethane (PUR) rigid foam to improve the visual appearance of the chair. When the thermoplastic acrylonitrile styrene acrylate (ASA) was discovered in 1970, it seemed to be the perfect material for the *Panton Chair*. The styrene copolymer produced by BASF and sold under the trade name Luran® S could be injection-moulded, which promised a quick and cheap production of the chair, as long as the wall thickness was thin enough to allow fast cooling. Since the base material consisted of coloured ASA pellets, further treatment of the surface, such as varnishing, was not required. To keep the average material thickness as thin as possible, while guaranteeing sufficient strength, the *Panton Chair's* edges were broadened along the sides and stiffening ribs were added to the curved backside between the seat and the area below. Each chair was marked on the lower bend of the back with the month and year of production. Approximately 150,000 pieces were manufactured over an eight-year period. Many chairs became brittle, cracked or broke after being in use for only three years. As a reaction to the numerous customer complaints, production was stopped in 1979.

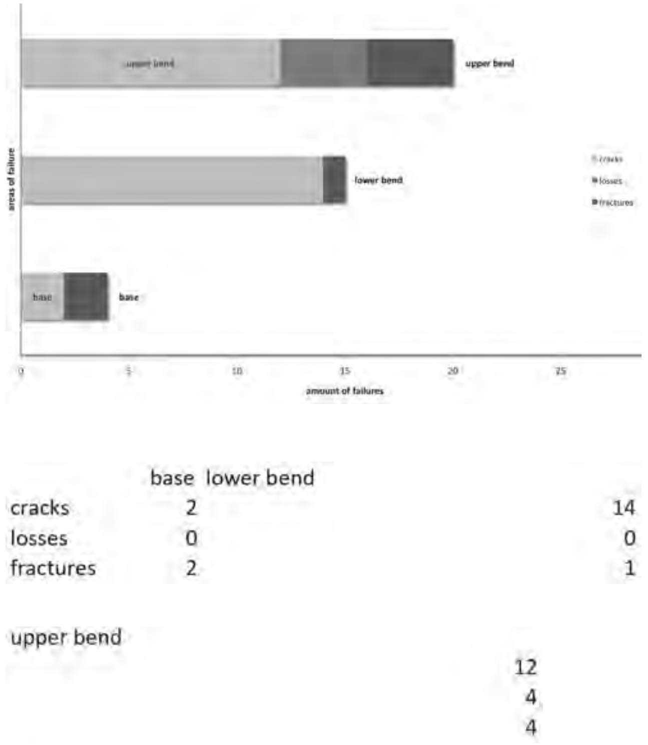
In 1983, four years after the production shutdown, the fabrication of the *Panton Chair* made of PUR was resumed. In 1999, a new version made of long glass fibre reinforced polypropylene (PP-LGF) was launched. Both versions are still being produced.

DAMAGE PATTERNS OF THE PANTON CHAIR

Private collectors, dealers in design objects, as well as museums were surveyed to analyse and evaluate the different damage patterns of the *Panton Chair* according to their frequency and the cause of damage. Furthermore, five damaged *Panton Chairs* of different colours and production years were examined. Thirty chairs were analysed in total.

On the basis of this investigation, three typical areas prone to cracks or fractures could be located: the bend between seat and back, the bend between seat and foot, as well as the foot itself. The upper bend revealed cracks, fractures and losses, of which cracks occurred more frequently. Both cracks and losses appeared along the edges. In the lower bend of all chairs examined (except for one), one common damage pattern was preva-

Figure 1
Panton Chair made of ASA named Luran® S, 1979.
(see colour plate, p. 169)



	base	lower bend	upper bend
cracks	2	14	12
losses	0	0	4
fractures	2	1	4

Figure 2
Chart visualizing the amount of failure patterns according to the failure areas of the Panton Chair.

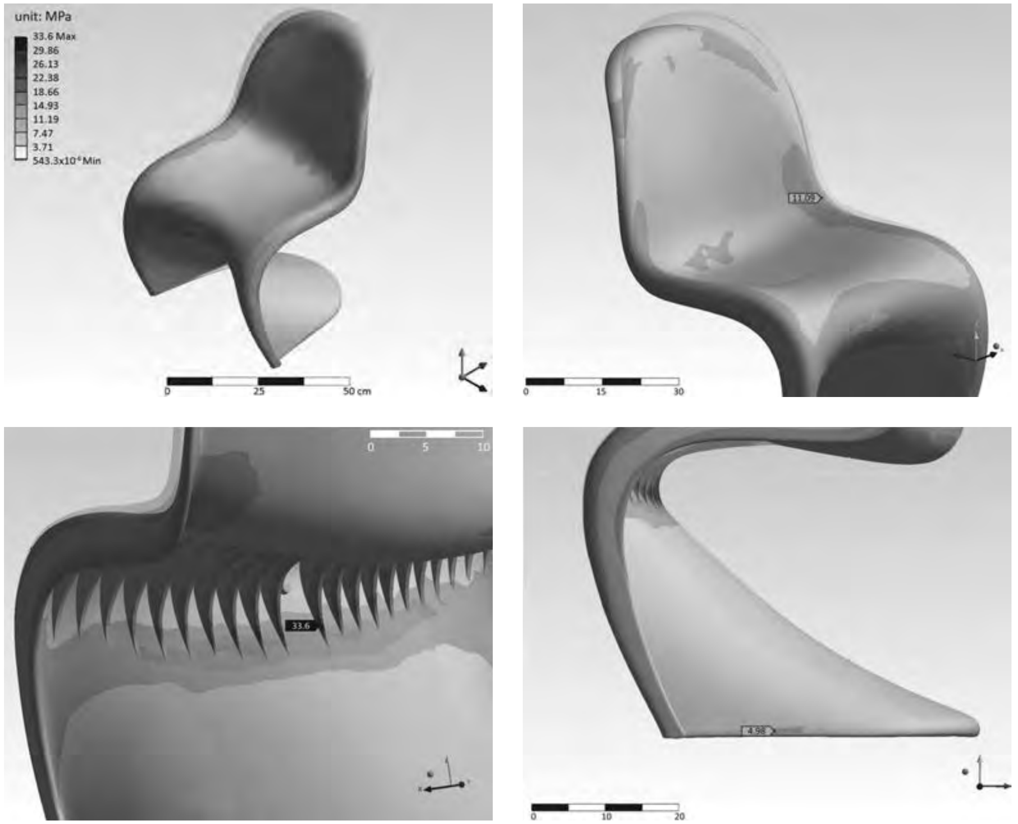


Figure 3
Four images of the digital model of the Panton Chair. Color gradients visualize the stress distribution during the second load scenario.

lent. Along the lower edge of the stiffening ribs, a fine crack of varying lengths, extended from the centre of the chair towards its sides. Some chairs showed small losses in the stiffening ribs. According to various dealers for design objects, cracks along the edges of the lower bend were also common, although only one example was broken in this area. Some chairs revealed cracks on the base, which proceeded from the sides towards the middle.

CONSERVATION CONCEPT

By developing a chair cast in one piece, Verner Panton wanted to create an industrially produced, aesthetically pleasing and affordable product. Its main purpose was to serve as furniture that could be used by everyone. When cracks and fractures appeared, the *Panton Chair* made of ASA could no longer fulfil the requirements of the designer, the producer and especially the owner.

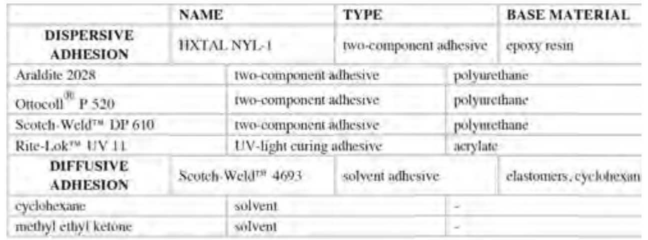
Facing the *Panton Chairs* from the 1970s, we were confronted with several questions: Should the existing chairs made of ASA be treated as sculpture with a simply decorative purpose? Or should they still function as usable furniture? Due to its innovative concept, the *Panton Chair* has certainly earned its status as a design icon. However, due to the large edition of 150,000 pieces, the *Panton Chair* made of ASA does not only exist in museum collections, but is also part of many private households.

A conservation proposal should therefore not only consider a treatment addressing preservation issues, but should also aim at restoring the chair to its original standards. The idea was thus born to develop a bonding method that would allow the chair to be presented as a uniform design object, while at the same time restoring its function as a usable piece of furniture.
part of current research work.

LOAD CAPACITY

The forces acting on the chair during use were investigated in order to determine the load capacity required in the joined areas necessary to restore the *Panton Chair's* function as seating furniture. Using the finite element method (FEM), certain load scenarios were simulated to calculate the maximum load capacity of the chairs' damaged areas under certain specific conditions of use. FEM is a calculation method commonly used in engineering to determine the mechanical properties of complex components or objects. The simulation software requires an accurate CAD-model of the piece to create a calculable FE-model. Taking into account the properties of the material as well as certain general conditions, the software provides the results as images of the digital model, visualizing the stress distribution with colour gradients. In preparation of the calculation, a digital model of the *Panton Chair* was created using a 3D laser scanner. Additionally, the conditions for the load scenarios had to be determined. Taking the chair's history into account, it did not seem appropriate to follow current standards required for seating furniture. When the *Panton Chair* was launched, the production of a chair cast in one piece was utterly innovative and the manufacturers had entered into uncharted territory. Hence, the decision was made to comply with the weight specifications assigned in the 1970s. Historic documents describing various stress tests executed in both preparation and production of the *Panton Chairs* made of ASA provided important information for the simulation of three load scenarios. The first scenario simulated a person weighing 75 kilograms sitting on the seat, while the second one considered a person sitting on the seat and leaning against the back simultaneously. The third set-up examined the forces acting on the chair while someone is sitting on the top edge of the back. The results revealed that the lower bend is under the most stress in all load scenarios with the highest tensions occurring in the eight inner ribs. At the same time the load values rated between 17.1 MPa and 48.6 MPa vary most in this area. The upper bend is also stressed significantly featuring maximum tensions up to 13.4 MPa in the second and third load scenario. It is noticeable that slightly increased tensions were calculated in an area of approximately 12 x 2 cm along the side edges of the foot. Regarding both the extensiveness of the stressed areas and the maximum tension values, the calculation revealed that the *Panton Chair* is stressed most when a person sits on the upper edge of the back. This scenario is rather uncommon, whereas leaning

Figure 4
Bent-beam method. Test specimens in the bending template coated with adhesive and covered with plastic sheet.



	NAME	TYPE	BASE MATERIAL
DISPERSIVE ADHESION	HXTAL NYL-1	two-component adhesive	epoxy resin
	Araldite 2028	two-component adhesive	polyurethane
	Ottocoll® P 520	two-component adhesive	polyurethane
	Scotch-Weld™ DP 610	two-component adhesive	polyurethane
	Rite-Lok™ UV 11	UV-light curing adhesive	acrylate
DIFFUSIVE ADHESION	Scotch-Weld™ 4693	solvent adhesive	elastomers, cyclohexan
	cyclohexane	solvent	-
	methyl ethyl ketone	solvent	-

Table 1
Adhesives examined in the test series.

against the back while sitting on the seat represents the most common way of daily use. Hence, maximum tensions of 33.6 MPa in the lower bend, 11.1 MPa in the upper bend and 4.98 MPa in the base were considered average *(Figure 3)*.

BOND REQUIREMENTS

In order to safely restore the *Panton Chair's* function as seating furniture, the joined areas must be able to bear the above-mentioned tensions. The question of reversibility was taken into consideration, but deemed subordinate to the goal of this project, where achieving sufficient load capacity in the bonded areas was of primary concern. As the original material should not be stressed more than necessary or be damaged any further, the joined areas should function as predetermined breaking joints. In order to avoid a formation of new fractures in case of overload, the tensile strength of the bonds has to be lesser than the strength of the ASA used for the *Panton Chairs*. The accelerated tensile test determined an average tensile strength of 51.4 MPa for the ASA modification of the chair. Based on these requirements, the joined areas should reach a minimum tensile strength of 33.6 MPa but should not exceed 51.4 MPa. Neither during the treatment nor in the long run should the joining method have a negative impact on the original material. Not least should the bonds correspond with the overall visual appearance of the *Panton Chair* and demonstrate acceptable aging properties such as durability and colour fastness.

BONDING METHODS

With regard to the choice of bonding methods eligible for the test series, all bonding methods common in the plastics industry were examined. Furthermore, research of literature on joining plastics in conservation was carried out. Some techniques had to be excluded from the very beginning as they were either incompatible with ASA, unsuitable for the curved shape of the chair, or they could not fulfill the requirements as stated above. The hot air welding method was preliminarily considered adequate. However, tests showed that ASA contracts when heated, so this technique proved to be ineffective for closing cracks and fractures in the *Panton Chairs*.. Hence, only adhesive joining methods were examined more closely. Case studies from conservation research projects show that both dispersive and diffusive adhesion techniques can be used to join styrene copolymers, so both mechanisms were included in the test series. Research of manufacturers' brochures showed that all kinds of adhesives common in the plastics industry were rated with regard to the following three criteria:

1 *strength level,*
2 *processing time,*
3 *applicability for ASA.*

Regarding the first criteria, all adhesives with low strength levels were excluded, as a certain load capacity has to be reached in order to restore the chair's function as seating furniture. Adhesives curing within a few seconds were also considered inappropriate, as more time is needed during treatment. Looking at the remaining adhesives, only two types creating dispersive bonds seemed suitable for ASA: UV-curing reaction adhesives and polyurethane based as well as acrylic based two-component adhesives. Examining adhesives belonging to these two curing mechanisms revealed that many of the industrially used products had to be excluded because of their colour. Although adhesives creating diffusive adhesion are classified as agents with medium adhesive strength, solvent adhesives as well as pure solvents were going to be included in the tests as the bonding technique was successfully used in previous plastic conservation treatments. One adhesive containing cyclohexane was found, which was supposed to dissolve ASA. Further solvents rated suitable to bond ASA are methyl ethyl ketone (MEK) and methylene dichloride. While methylene dichloride was excluded due to evidence of its carcinogenic effect, cyclohexane and MEK were included in the test series. According to a case study addressing the conservation of cracks in ASA, epoxy resins achieved good results adhering the styrene copolymer. Hence, this type of adhesive was tested as well. An agent featuring good ageing properties that had successfully been used to bond PMMA in former conservation treatments was chosen. Eventually a representative selection of eight adhesives was examined in the test series *(Table 1)*.

TEST METHODS

Regarding the choice of test methods, particular attention was paid to examine the bonding techniques' ability to fulfil the requirements for the joined areas. Hence, it was essential to find joining methods that provide sufficient tensile strength without damaging the original material. All industrial procedures used to test joined plastics as well as test methods used in former conservation treatments were examined. Based on various DIN and ASTM standards, three tests adapted to the devised requirements were developed.

The exposure of plastics to certain liquids tends to accelerate the crazing process caused by mechanical stress. The combined action of surface-active chemicals and low mechanical stress might initiate environmental stress cracking (ESC) in plastic materials. The first test examined the susceptibility of ASA to ESC under the influence of adhesives using the so-called bent-beam method. The short-term tensile testing is a common procedure to determine the tensile strength and the load capacity of moulded plastics. Furthermore, this method is often used to test the adhesive tensile strength of joined plastics, in example, the cohesive force between adhesive and plastic. This test method was considered adequate to investigate the mechanical properties of joined ASA. The examination of failure patterns after the tensile test can provide important information on the properties of adhesive bonds. The visual appearance of the fractures is examined and named using descriptions defined in DIN standards. This test procedure seemed to be a meaningful addition to the short-term tensile test method in order to gain more information about the behaviour of ASA under the influence of adhesives.

TEST SAMPLES

At the time the test series was carried out, according to the CAMPUS data base, BASF provided twelve modifications of ASA sold under the trade name Luran® S and distinguished using different letter and number combinations. In preparation for the production of the test samples it was necessary to find a modification that best matched the one used for the *Panton Chairs*. Several characterization techniques were carried out using samples from a chair produced in October 1971. The physical properties of the material resulting from the analyses were compared to the characteristics of the ASA modifications provided in the CAMPUS database. Important parameters were the melt volume-flow rate (MVR), the melt mass-flow rate (MFR), the flow behaviour in a plate-plate-rheometer, the glass transition temperature Tg and Young's modulus. Eventually, the ASA modification Luran® S KR 2859 turned out to be closest to the modification used for the *Panton Chair*. A total of 350 shouldered test samples of type 1A were injection moulded using black Luran® S KR 2859 pellets as a base product.

SUSCEPTIBILITY OF ASA TO ESC UNDER THE INFLUENCE OF ADHESIVES

The so-called bent-beam method was carried out following examination standards ASTM D 3929 (2003) and DIN EN ISO 22088-3 (2006-11) by using a bending template. The test samples were fixed to an evenly bent metal plate, which holds nine samples at a time. Two sets of four samples each were coated with the same adhesive, the remaining uncoated sample served as a reference *(Figure 4)*.

Immediately after the test samples had been fixed the adhesives were applied along the centre axis of the template covering approximately 20 x 25 mm of the samples. In order to imitate the curing process of an adhesive applied to cracks and fractures in *Panton Chairs*, the coated areas were then covered with a transparent plastic sheet. To simulate the joining procedure of the UV-light curing adhesive, the coated samples were irradiated with UV-light in the range between 320 nm and 400 nm seven minutes after the adhesive had been applied. The plastic's characteristics as well as potential changes were visually examined at the following time markers: one minute, five minutes, one hour, three hours, one day and finally four days after the adhesives had been applied. The samples were investigated using raking light and a stereomicroscope with two and five times magnification.

The phenomena observed during the bent-beam method revealed that adhesives caused partially severe ESC in ASA. The examination of the non-coated test samples showed that crazing occurred a few minutes after the samples had been fixed to the template. The fine cracks appeared along the edges of the samples running transversely to the loading direction in the area of maximum elongation. None of the adhesives caused ESC until after the adhesive had been applied for five minutes. The phenomena observed within one hour after the application did not expand further during the test procedure, although the adhesives had curing times of up to seven days. Hence, all tested adhesives that have an impact on ASA initiate ESC between five and sixty minutes after application. Some adhesives cause an expansion of the existing crazing along the edges of the test samples only, while others generate ESC throughout the coated area.

The test results indicate that the tested adhesives cannot be categorized according to their mechanisms of adhesion. For instance, Cyclohexane caused ESC while the solvent MEK did not have an impact on the plastic. It is remarkable to note, however, that all three polyurethane based two-component adhesives did not provoke any reaction to the ASA. Regarding dispersive adhesion, this might indicate that the polymer of an adhesive determines whether the medium is appropriate to bond ASA. The test series revealed that four of the eight tested adhesives – the epoxy resin HXTAL NY-1, the UV-light curing adhesive Rite-Lok™ UV 11, the solvent adhesive Scotch-Weld™ 4693 and the cyclohexane – are not appropriate for the conservation of the Panton Chair as they cause ESC in ASA. The polyurethane based two-component adhesives Ottocoll® P 520, Scotch-Weld™ DP 610, and Araldite® 2028 as well as the MEK were categorized as non-hazardous to ASA.

MECHANICAL PROPERTIES OF JOINED ASA

In preparation of the second test series the test samples were modified to imitate the fractures in the *Panton Chairs*. To determine the breaking point, the samples were incised in their midpoint, transversely to their axis, using a cutter knife. In order to reduce ASA's elasticity at room temperature, the samples were embrittled by first storing them in the refrigerator for twenty-four hours. Samples were then broken into two pieces alongside the incision area using flat pliers. As no standardized guidelines for adhering fractures in plastics exist to date, a standard testing method first had to be developed. In order to achieve representative and comparable results during testing, special attention was given to creating a method that allowed re-adhering of the samples under more or less equal conditions. In this case, the samples were re-adhered alongside their breakage.

The tensile testing of the re-adhered samples was carried out following the standard of DIN EN ISO 527. The samples placed in the testing machine were stretched along their main axis with a constant testing speed of 5 mm/min until they broke. Please note that the samples re-adhered with the solvent cyclohexane could not be tested as the plastic fragments had not connected. The elongation of the gauge section of the samples and the applied force were recorded during the application of tension. This provided information about various mechanical properties of the tested material. In regards to the evaluation of joined fractures in ASA, the tensile strength was of special interest in terms of its average value and standard deviation *(Figure 5)*.

Considering the standard deviation, the adhesives were classified into four categories representing no, little, medium and high average spread of the tensile strength values. The first category was comprised of the epoxy resin only, while the second group included the UV-light curing adhesive, the solvent adhesive, as well as the polyurethane-based two-component adhesive Ottocoll® P 520. The two remaining polyurethane-based adhesives constituted the third group. MEK representing the fourth category featured by far the highest average spread.

On the basis of the categories, the adhesives were judged with regard to their reliability as defined by the predictability of the tensile strength of the joints. The lower the average spread, the higher the probability that the actual tensile strength of an adhesive joint would correspond to the average value determined in the test series. Hence, the load capacity of adhesives representing the first category was considered most calculable while the potential capacity of fractures joined with adhesives featuring high average deviations was least predictable.

According to the average value of the tensile strength, the tested adhesives were classified into three categories. The first category included Rite-Lok™ UV 11 and Scotch-Weld™ 4693 representing low tensile strength. The second group describing adhesives with medium tensile strength consisted of Ottocoll® P 520, Scotch-Weld™ DP 610 and Araldite® 2028, as well as HXTAL NYL-1. MEK represented the third category of high tensile strength.

The classification allowed an evaluation according to the different types of adhesives and the mechanism of adhesion. For instance, all two-component adhesives belonging – independently of their polymer – to the middle category, indicated that the adhesive force between adhesive and plastic is similarly pronounced. In contrast, the low average value of the UV-light curing adhesive pointed out that this bonding method is not qualified to join ASA. This might have been caused by the opacity of the plastic baring the UV-rays from entering the adhesive joint and hence inhibiting the adhesive's curing process.

The low average value of the solvent adhesive corresponded with the experiences from the joining process of cyclohexane, which did not bond to the plastic. The solvent was unable to dissolve ASA and consequently neither pure cyclohexane nor the solvent adhesive were suitable for diffusive adhesion. In comparison, the high tensile strength of the samples joined with MEK pointed to the fact that the solvent was able to dissolve the plastic and affected a diffusive adhesion. Furthermore, MEK's high average value led to the general conclusion that diffusive adhered fractures in ASA bear higher mechanical tensions than dispersive adhered joints.

DAMAGE PATTERNS OF JOINED ASA

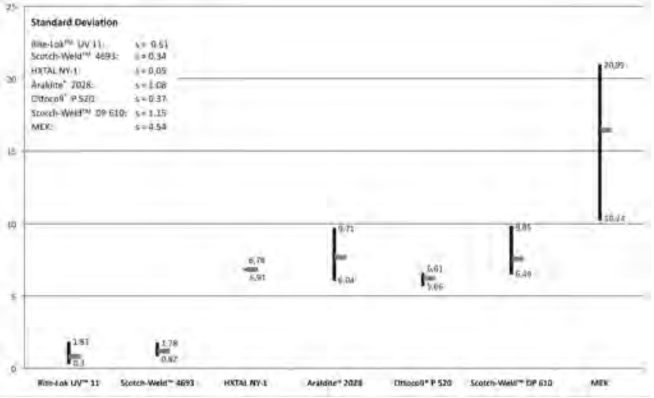
In preparation of the third test series, the test samples were cut along their cross axes using a band saw. The shouldered areas of the cut plastic samples were then glued on top of each other according to the standard DIN 53281. A device was developed to meet the exact required overlap length of 12 mm and to adhere all test samples under similar conditions. The UV-light curing reaction adhesive was not included as the overlapping adhesion method prohibited a direct irradiation of the joining area.

The tensile testing of the joined samples was carried out according to the standard DIN EN 1465. With the narrow ends fixed to the machine, the samples were then stretched along their axis with a testing speed of 5 mm/min until they fractured. Congruent with the results from the second test series, the samples adhered with cyclohexane could not be tested as no bond was achieved between the plastic fragments.

On the basis of the damage patterns caused during the tensile testing the connection between the bonding partners was visually examined according to the standard DIN EN ISO 10365. All three patterns listed in the standard – adhesive fracture, cohesive fracture and fracture in the adherent – occurred on the tested plastic samples as well as an additional pattern named adherent/cohesive fracture *(Figure 6)*.

In addition to the visual appearance revealing typical characteristics of the adhered samples, the variety of damage patterns occurring within the test series of one specific adhesive provided information about the adhesives' reliability.

All samples adhered with the solvent adhesive detached in the interface between adhesive and adherent. The adhesive stuck to only one of the plastic components, which indicated that the adhesion between ASA and Scotch-Weld™ 4693 was weaker than the forces responsible for the internal cohesion of the adhesive. Hence, a durable load transmission could not be guaranteed using this bonding method.



	Zugstab, nicht gefügt	Rite-Lok UV™ 11	Scotch-Weld™ 4693	HXTAL NY-1
Test 1	48,57	0,3	0,82	6,78
Test 2	49,2	0,46	0,92	6,79
Test 3	49,21	0,51	1,03	6,79
Test 4	49,3	0,75	1,13	6,84
Test 5	49,33	0,94	1,22	6,85
Test 6	49,35	1,02	1,52	6,88
Test 7	49,63	1,83	1,78	6,91
		0,474311531	0,315264709	0,046246897
		0,224971429	0,099391837	0,002138776
	48,57	0,3	0,82	6,78
	49,63	1,83	1,78	6,91
	49,22714286	0,83	1,202857143	6,834285714
	0,323043562	0,512315007	0,340524805	0,049952358

Araldite® 2028	Ottocoll® P 520	Scotch-Welc	MEK
6,04	5,66	6,49	10,24
7,29	5,84	6,66	10,81
7,6	6,05	6,95	14,69
7,63	6,3	7,32	18,04
7,7	6,51	7,63	19,64
7,74	6,54	8,13	20,55
9,71	6,61	9,85	20,99
0,998222911	0,344709283	1,0661527	4,20190336
0,99644898	0,11882449	1,1366816	17,6559918
6,04	5,66	6,49	10,24
9,71	6,61	9,85	20,99
7,672857143	6,215714286	7,5757143	16,4228571
1,078203974	0,37232858	1,1515766	4,53857435

Figure 5
Chart visualizing the tensile testing results.
Actual deviation and average value of the tensile strength values are shown according to the tested adhesives.

In cases of cohesive fractures, the cohesive forces in the adhesive are weaker than the attraction between the adhesive's and adherent's molecules. This phenomenon occurred on all test samples adhered with the epoxy resin breaking within the adhesive layer during the tensile testing. This type of fracture represents the ideal damage pattern, as the resin was able to build a durable connection to the ASA, while the bonding was still too weak to cause damages in the plastic when mechanical forces acted on the joint.

Two types of failure patterns were observed on the samples glued with Araldite® 2028 and Scotch-Weld™ DP 610. In addition to cohesive fractures, fractures in the adherent also occurred. Regarding this damage pattern, the forces between the adhesive and the adherent as well as the cohesive strength in the adhesive were stronger than the inner cohesion of the plastic. As it caused failures in the ASA, this kind of damage was considered unfavourable.

The samples adhered with Ottocoll® P 520 also showed two types of failure. In addition to the mainly occurring fractures in the plastic, some samples showed adherent/cohesive fractures, a pattern not mentioned in the standard DIN EN ISO 10365. One of the joining partners broke within the overlapping area with a small piece remaining on the other fragment, while the larger part separated in a cohesive fracture. This behaviour indicated that the load capacity of the adhesive joint and of the plastic corresponded, resulting in a combination of cohesive fracture and fracture in the adherent. As fractures in the plastic occurred more frequently than adherent/cohesive fractures, Ottocoll® P 520 was deemed unfavourable as it most likely would cause damage to the ASA of the *Panton Chairs* when exposed to high mechanical stress.

This appraisal also applies to MEK as all samples adhered with the solvent failed in the adherent during tensile testing. It is noticeable, though, that this method of adhesion differed from the method of the above-mentioned adhesives in regard to its bonding mechanism. During the joining process the solvent solved the ASA and then evaporated without residue. The tangled molecule chains generated in the interface between the adherent components during the diffusive bonding process were most likely so strong that they allowed a higher load transmission than the plastic. Hence, the test samples fractured outside the adhesive joint. The fact that only MEK exclusively provoked fractures in the adherent indicated that the diffusive adhesion method generally evokes stronger bonds in ASA than the dispersive adhesion method.

Regarding the reliability of the adhesive joints, the solvent adhesive causing adhesive fractures was not taken into account. HXTAL NY-1, MEK and Scotch-Weld™ DP 610 were considered reliable as they predominately caused one failure pattern. In contrast, the molecular interaction between adhesive and adherent of bonds joined with Ottocoll® P 520 and Araldite® 2028 could not be classified as steady as they alternated between two types of fractures when exposed to high mechanical load.

EVALUATION

With regard to the requirements defined for joining fractures in *Panton Chairs*, the adhesives were short-listed by means of the results of the three test series.

The bent-beam method revealed that certain adhesives pro-

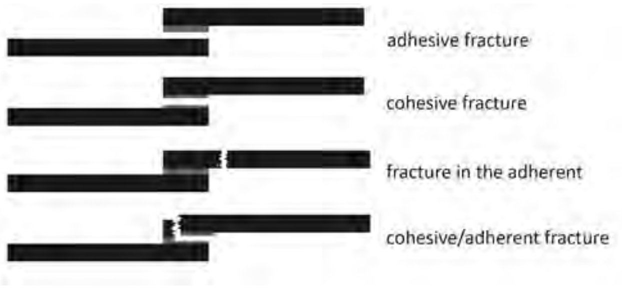


Figure 6
Schematic illustration of failure patterns

voke ESC in ASA. As this damage-causing effect should be avoided in all cases- the epoxy resin, the UV-light curing adhesive, the solvent adhesive as well as the solvent cyclohexane proved inappropriate for the conservation treatment of the *Panton Chairs*. Hence, the selection was restricted to the polyurethane based two-component adhesives as well as the solvent MEK.

The load capacity required in the joined areas necessary to restore the *Panton Chair's* function as seating furniture was established between 4.98 MPa and 33.6 MPa. In contrast, the average tensile strength values measured in the second test series went up to 16.42 MPa. This discrepancy between target value and actual value shows that the original aim to restore the usability of the chair cannot be achieved with any of the tested adhesives.

Therefore, the adhesives were re-assessed in accordance to their mechanisms of adhesion. In dispersive adhesion the fragments are held together by Van der Waals forces acting between plastic and adhesive, while the second mechanism always implies dissolving the plastic in order to interdigitate the molecule chains of two plastic fragments. Diffusive adhesion was considered less favourable than dispersive adhesion because of the changes it causes in the material. The solvent MEK was consequently excluded.

Since all remaining adhesives were polyurethane-based two-component adhesives, they featured similar properties. To maintain the treated areas as predetermined breaking joints, the pros and cons of the adhesives were discussed. Looking at the results of the third test series, it became obvious that none of the adhesives could be relied on to be the weakest link in case of an overload. While the risk of causing additional fractures in the ASA is relatively high for Ottocoll® P 520, Scotch-Weld™ DP 610 provoked considerably less, and Araldite® 2028 the least damage in the test samples.

Taking further aspects like colour and processing time of the polyurethane based adhesives into account, the following treatment methods were considered adequate: cracks and fractures in the *Panton Chair* made of ASA should be joined using either of the transparent adhesives Scotch-Weld™ DP 610 and Araldite® 2028. In the case of more complex treatments, the white adhesive Ottocoll® P 520 should be considered as an option, as it has a processing time of thirty minutes, instead of six to ten minutes, which allows more time for positioning and fixing of the fragments.

CONCLUSION

The research executed in the course of this Master's thesis revealed that until now, little attention has been paid to the conservation of broken plastics. Case studies often differ in their approach, which makes them hard to compare. A standardized testing protocol for the adhesion of plastic samples would allow for a more seamless comparison of test results from one plastic to another.

The tests carried out emphasized the importance of establishing close collaborations between plastics material scientists and conservators. Their knowledge and specialized equipment are necessary to achieve significant, reproducible and applicable test results.

Last but not least, the results from the test series revealed that the method used in this case study could not restore the *Panton Chair's* functionality as usable furniture. The need to research and find suitable treatment methods for repairing damaged design furniture is growing, as is the need to develop general guidelines for the conservation of design objects.

LECTURE
014
THE INVISIBILITY OF THE SUPPORT AND ITS RESTORATION. BONDING OF A LARGE SHEET OF PLEXIGLAS: *BULLDOZER* BY ALAIN JACQUET.

BY FRANÇOIS DUBOISSET, SYLVIE RAMEL

ABSTRACT

Bulldozer (1967) by Alain Jacquet is an object made of thermoformed Plexiglas, which is partially covered with acrylic paint. It was broken in three parts following a disaster.

A study on laser welding was initiated for treatment of this work in 2005 but unfortunately it proved unsuitable for this application. A preliminary scientific experiment was therefore carried out in the use of adhesive as a medium for restoration. This included evaluation of materials to protect the artwork's surface during bonding and assessing key characteristics of adhesives either named in conservation literature or provided by industry. The application of all four adhesives in this study was by infiltration with a syringe.

Both flat and 3D samples of similar Plexiglas as in the artwork were made. Then, several evaluation criteria were established, such as the time of cross-linking, the homogeneity of the distribution and the absence of air bubbles in the adhesive, as well as the absence of surplus, a low visibility and homogeneity of the adhesive joint, and the bond strength.

HXTAL NYL-1, a clear two-component epoxy, was chosen due to optical and mechanical characteristics.

For a proper alignment and maintaining of the three parts, clamping is required during the applying of the adhesive. The size and shape of the object presented a difficulty. A unique system with magnets was developed.

KEYWORDS

PMMA, UV-gluing, HXTAL Nyl-1, "Magnet Spider", Adhesive, Transparency

INTRODUCTION

Bulldozer, a work of art by Alain Jacquet, was realized in 1967 and belongs to the Museum of Contemporary Art of Vitry-sur-Seine, France (MACVAL) since 2001. This sculpture consists of a 3 mm sheet of Plexiglas (Polymethyl methacrylate, PMMA). The image is created using coloured dots, as in screen-printing. Due to their size, each point measuring 1 cm, they are directly painted with an acrylic paint applied with a brush *(Figure 1)*.

The PMMA features coloured surfaces: cyan and magenta colours on the front and an opaque yellow colour on the reverse. A rubber joint (U-profiled) hoops the piece. The sculpture measures 155 x 125 x 20 cm.

With his work The Lunch, Alain Jacquet plays with the dots created by the process of screen-printing. The image is split up by the points of the enlarged weft. The Museum filmed an interview of the artist. Thanks to that, we know that Jacquet had a friend who owned a factory, which made aircraft cockpit transparencies. He enjoyed producing this work with his friend. They silk-screened the sheet of Plexiglas, cut a piece so that it stayed flat and placed the other one in a steam room. Once hot, the sheet was taken out and placed on what they found. From this step it cooled down taking the shape of the support. This type of work is very rare in the work of Alain Jacquet, and *Bulldozer* is his only work of this type known in France.

In 2005, the object fell when being handled for an exhibition and broke in three pieces. Two conservators produced a first condition report. They studied solutions for repairs but stopped the project considering the treatment too dangerous. The first time I saw the artwork it was in its transit case. The breaking joint was held with adhesive tape. There were various problems caused by previous interventions. Therefore, it was felt important to initiate a study on methods of assembling other than bonding by gluing.

CONDITION REPORT

A detailed examination of the artwork was carried out. Several cracks were found, which probably occurred because of the stress during the sheet's rough cooling. The sculpture also suffered from previous interventions, some of which were undocumented and damaging. Some removable adhesive tapes were placed perpendicular to the breaking point, probably to maintain the edges of breaking joints while waiting to restore it. Two holes of about 5mm in diameter were drilled, possibly to stop the distribution of cracks. An old adhesive joint is visible, with the presence of residues and wide surplus of up to 2 cm. After some research, it turned out that this could involve Araldite Crystal, a clear two-component methacrylate adhesive. A silicone joint replaced the rubber joint during a first intervention by another team of conservators *(Figure 2)*.

FIRST STUDY: APPLIED RESEARCH IN ASSEMBLY BY LASER WELDING

With a research grant from the CNAP (Centre National des Arts Plastiques, Paris; The French national institution for contemporary art), a first study on laser welding was initiated in 2005 in collaboration with the IREPA (Institute of research and development of laser technologies, Illkirch, France), which allowed us to study the adaptation of an industrial technique to heritage conservation issues. Laser welding gave convincing and encouraging results on flat samples of Plexiglas, and proved to be reversible either mechanically, or by applying the laser again on the joint. However, before using this technique on the artwork itself, we tried it on 3D samples of PMMA and that demonstrated to be unsuccessful. The weld generated some irreversible bubbles and significant "rolls" of weld. We could have tried to adapt the technique, but it would have required a very important financial investment. The restoration would have been executed by robots and would have required an extremely complex protocol.

SECOND STUDY: APPLIED RESEARCH IN THE ASSEMBLY WITH USE OF ADHESIVES

After a discussion with the museum, it was decided to use an adhesive. The following questions remained: what about the long-term compatibility between the adhesive, its solvents and the PMMA, the latter being very sensitive to polar solvents, resulting in crazing? What is the strength of the bond? What is the reversibility of the adhesive joint? How to manage surplus of adhesive? How could we respect the visual aspect and transparency of the artwork? How could we protect the broken pieces and yet firmly and accurately secure the broken parts during the application of adhesive?

To validate a protocol of intervention before restoration, we first studied samples to answer three key issues: Firstly, the protection of the surface with the evaluation of three coating materials. The overflowing of glue might leave difficult to remove residues. That is why we started our research with the investigation of the possibility of protecting the painted PMMA surfaces during the adhesion. Secondly, four adhesives were tested for suitability featuring the following qualities: aesthetic compatibility, reversibility, mechanical compatibility and strength. Thirdly, we wanted to develop a system of tightening. The objective was to develop a system of assembling that would protect the artwork during adhesion while assuring the best edge-to-edge bonding. The idea was to limit the pressure and the tension areas while ensuring the stability.

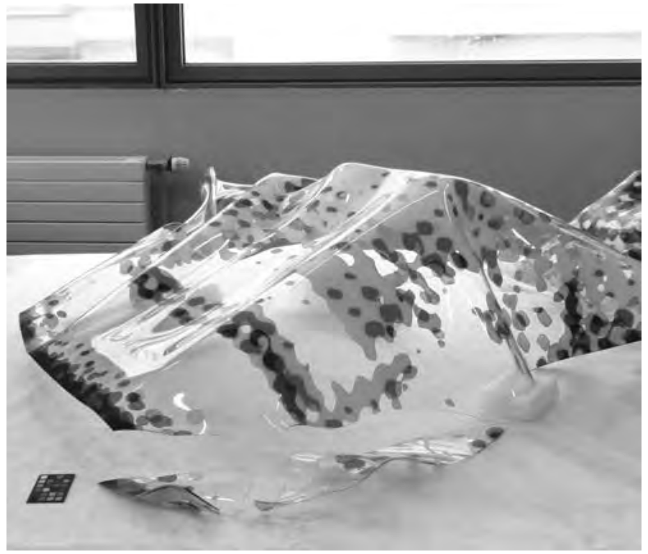


Figure 1
***Bulldozer* before intervention**

SURFACE COATING

Three film-forming substances known for their capacity to be peeled were selected: Impranil DLU (Aliphatic polycarbonate ester-polyether polyurethane dispersion), EVA (Ethylene-vinyl-acetate) and Drawing gum (latex dispersion). These films were applied with a flat spatula on PMMA sheets. The initial evaluation was to assess the qualities of the protective coating. The criteria were: the ease of application, the homogeneity of the film and the peeling. In a second step we applied the four adhesives on the artwork's coating to evaluate insulation. The best removable insulating coating was selected, and then tested on a 3D PMMA sample on each side of the break before the application of adhesive.

CHOICE OF ADHESIVES

In order to perform our tests we obtained flat samples and 3D samples of a 3mm PMMA similar to the one used for *Bulldozer.* The 3D samples were cast by heat. Once the glass transition temperature is reached, the samples are malleable. To reproduce the shape of the deformation area on the artwork an identical cast was used for all of the samples. Like the artist, we chose not to implement a progressive heating or cooling method, because induced stress inside the samples was useful for our experiment. The 2D and 3D samples were then broken.

Figure 2
Detail of the crack

At first, we listed possible adhesives for Plexiglas. We considered them because of their frequent use in the industry. From those, we selected four adhesives, which are: HXTAL NYL-1, a clear two component epoxy; Plexigum PQ611, an acrylic polymer dissolved in cyclohexane; Dymax 3099 and Vitralit 4731, both single-component acrylic adhesives which cross link through exposure to Ultra Violet light. These would be tested according to the criteria of refractive index (PMMA = 1,49).

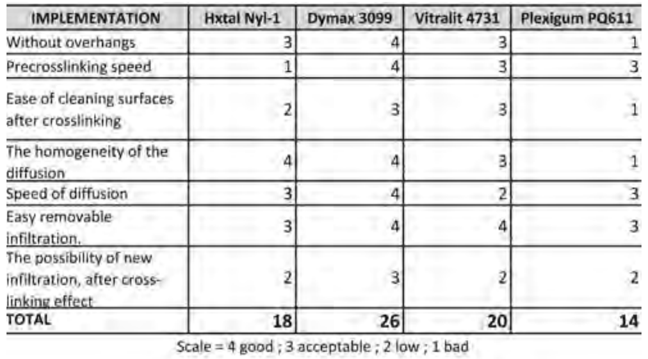
We chose adhesives that could be applied by infiltration due to their low viscosity to optimize the quality of the edge-to-edge adhesion and to limit the risks of residues on the surface.

All four adhesives had to be reversible; either chemically reversible by means of solvent use, or mechanically reversible by means of mechanical release of the adhesive.

The mechanical properties important to investigate were: brittleness of the adhesive and crack formation under pressure, the flexibility of the adhesive joint and the mechanical strength of the bond. The most important optical properties of the selected adhesives were: a refractive index similar to that of PMMA and no yellowing over time. We verified that selected adhesives were not toxic.

To assess the quality of the adhesives, several indicators were reviewed. The first was the optical result including the absence of surplus and the homogeneity of the infiltration. Then the facility of use, the easiness of cleaning surfaces after cross-linking, removing of the infiltrated adhesive and the possibility to do a new infiltration were examined. Finally we evaluated the speed parameters: the time needed for pre-crosslinking and the speed of permeation *(Figure 3)*.

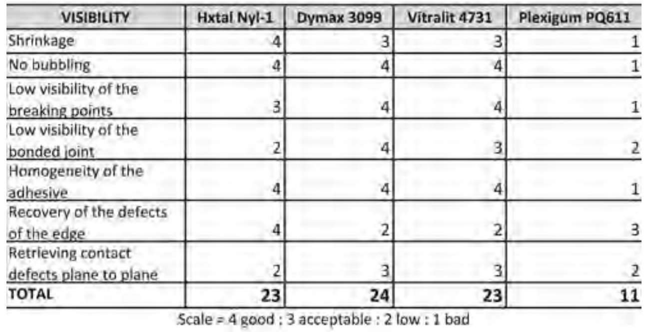
Particular attention was paid to the visibility of the joint. To compare the four adhesives raking light, a black background, and transmitted light were used. We decided to observe several details like shrinkage of the adhesive: the more pronounced the shrinkage, the more visible the adhesive joint. Finally, The ab-



IMPLEMENTATION	Hxtal Nyl-1	Dymax 3099	Vitralit 4731	Plexigum PQ611
Without overhangs	3	4	3	1
Precrosslinking speed	1	4	3	3
Ease of cleaning surfaces after crosslinking	2	3	3	1
The homogeneity of the diffusion	4	4	3	1
Speed of diffusion	3	4	2	3
Easy removable infiltration.	3	4	4	3
The possibility of new infiltration, after cross-linking effect	2	3	2	2
TOTAL	18	26	20	14

Scale = 4 good ; 3 acceptable ; 2 low ; 1 bad

Figure 3
Characteristics of adhesives_part 1 of resin



VISIBILITY	Hxtal Nyl-1	Dymax 3099	Vitralit 4731	Plexigum PQ611
Shrinkage	4	3	3	1
No bubbling	4	4	4	1
Low visibility of the breaking points	3	4	4	1
Low visibility of the bonded joint	2	4	3	2
Homogeneity of the adhesive	4	4	4	1
Recovery of the defects of the edge	4	2	2	3
Retrieving contact defects plane to plane	2	3	3	2
TOTAL	23	24	23	11

Scale = 4 good : 3 acceptable : 2 low : 1 bad

Figure 4
Characteristics of adhesives_part 2 of resin

sence of air bubbles was an important factor for the low visibility of the breaking points and of the bonded joint.

How *Bulldozer* should be handled and exhibited was also considered. Mechanical tests were therefore conducted on the bond strength. On one end of the sample a container was hung, pre-weighed. The other end was held mechanically. Adding water to it gradually increased the weight of the container. When the sample broke, the water was weighed.

RESULTS

SURFACE COATING

The protective film has a considerable impact on the observation and monitoring of the infiltration of the adhesive. It can also cause a problem for the actual penetration of adhesive into the joint. The most suitable material for our purpose was Impranil. It offers excellent surface protection and its removal is easy. It will not degrade the coating of the coloured areas.

ADHESIVES

The solutions of Plexigum PQ611 and Vitralit 4731 were excluded due to bad results, both being comparatively more visible than HXTAL and Dymax and forming weaker joints.

Of the two remaining adhesives, we knew before tests that the mechanical tensile strength of the epoxy HXTAL Nyl-1 is higher but the visual qualities of Dymax 3099 are better.
Some differences in implementation are worth noting:

- *Residues of epoxy are easy to clean because the drying time is long enough.*
- *UV crosslinking of Dymax 3099 is very fast compared to the slower cross-linking process of epoxy, which reduces the risk of movement.*

Epoxy HXTAL Nyl-1 and Dymax 3099 both provided suitable results to the visual and mechanical tests performed as described above. Thus, the choice between them was difficult. However, the differences in the application methods and the costs gave some useful keys for selection, and Epoxy HTAL Nyl-1 was finally chosen for the following reasons.

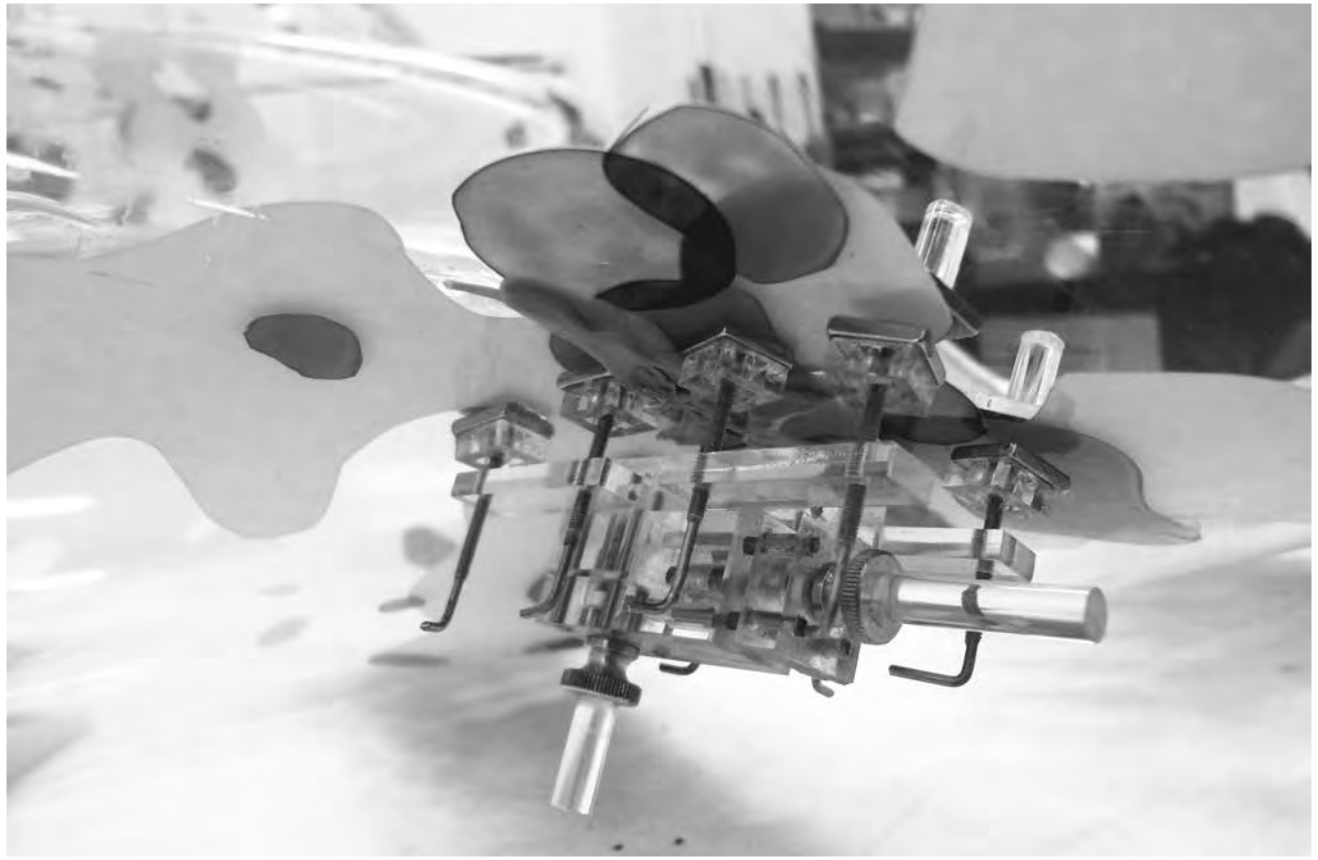


Figure 5
Magnet Spiders®
(see colour plate, p. 169)

The UV cross-linking of Dymax 3099 is a very interesting process considering the quality of the joint : strength, the time it takes and the visual qualities. However, little is known about the long-term effects of the use of UV and the stress it generates in PMMA. The adhesive is also about 10 times more expensive than epoxy.

The epoxy resin, which hardens due to addition of a catalyst, has a much longer cross-linking time. This requires a complete immobilization of the artwork for several days, and so a specific method to maintain the object while the epoxy hardens. It offers equivalent visual and slightly lowers mechanical properties than Dymax *(Figure 4)*, as the infiltration is slow and the homogeneity of the infiltration after cross-linking is not as good. However, this resin is better known from conservation studies, its long-term behaviour is better understood and so, despite being slightly less efficient than Dymax on the day of application, it was finally the one selected for long-term safety.

During intervention, *Bulldozer* needs to be safely maintained and without stress. It needs to be relieved of its own weight. For this, we placed it upside down.

"MAGNET SPIDERS"

It was important to find a clamping method. Theoretically, the clamping system should first provide the correct alignment and also maintain pressure during treatment. It needs to allow the progressive gluing of the joint, while clamping the various plans and maintaining the three parts of PMMA. The clamping should not cause additional stress or scratches. Therefore, it was not possible to rely on the piece itself for tightening or maintaining the joints. Thus, we developed an innovative system using magnets. They are isolated with a plastic film to prevent scratches, and mounted on adjustable parts through ball joints and clamping screws. Eight "Magnet Spiders" are placed on the break *(Figure 5)*. The spiders allowed us to work very accurately, adjusting as precisely as 0,05mm. We were able to work gradually, thereby checking the adjustment of the edges before applying adhesive.

Figure 6
***Bulldozer* after restoration**

INTERVENTION

Before restoration, *Bulldozer* was wedged by pieces of foam, which were now removed. We cleaned the internal and external surfaces. First, dust was removed with a microfiber and silk cloth and a mixture of water and ethanol. Then, the surface was prepared for bonding: we removed the residues of adhesives using a scalpel and micro-abrasion, with use of a micro-tool and polishing paste. The surface was protected with Impranil to limit surplus. Adhesive tape was placed perpendicularly to the break edges to strengthen the adhesive joint. Then, the resin was prepared without air bubbles and applied using a syringe. We implemented the system of tightening with “Magnet Spiders” and continued to apply the adhesive. After the adhesive had fully cured, we removed the elements of assembly and added some additional adhesive for a perfect consolidation. We removed the last elements and cleaned the piece. Finally, we adjusted the painted surface in areas with paint loss using acrylic paint. *(Figure 6)*

CONCLUSION

The trust and interest of the museum allowed us to perform essential research before the restoration of this work of art. Today, extensive research methods and intervention on plastics seem to be essential. Our approach on this project was pragmatic. Through this conservation treatment, we hope to have added to the development of research applied by conservators. Plastics are wonderful materials, which offer so many possibilities in art. They also open some new challenging fields and possibilities for restoration and conservation.

To conclude, through this work it has been possible to develop a new system for clamping complex shapes of thermoformed PMMA, which could be adapted to other plastics in similar situations. Added to this, we were able to investigate the mechanical properties of several adhesives such as PMMA, polyamide or other polyolefin, and to evaluate materials to protect the surface of PMMA during the intervention. Our best reward today is to see *Bulldozer* presented in the Museum, playing with the light and the transparency.

LECTURE 015
HOW TO RESTORE 20 PRISTINE CORIAN® SCULPTURES. A HANDS-ON APPROACH.

BY KATHARINA S. HAIDER, FRANZ-JOSEF SCHMITT

ABSTRACT

The American artist Allan McCollum produced a group of 20 *Shapes* in Corian®, a solid surface material consisting of acrylic resin and the mineral filler aluminium trihydroxide (ATH). For each sculpture 10 to 14 white Corian® boards were laminated using the matching Corian® joint adhesive. Many of these joints are now visible as white lines on the otherwise pristine sculptures. Due to these unwanted marks of manufacture the artist prohibited further exhibition or sale of the Corian® *Shapes*. Since the professional technique for repairing Corian® boards seemed not to be suitable, an efficient method to make these joints invisible was sought. The material composition of a Cameo White Corian® board and of the adhesive were confirmed by scanning electron microscopy (SEM). In addition to the elements aluminium, carbon, oxygen, titanium, calcium and sulphur some silicone was found in the adhesive. Moreover, SEM images showed a higher resin content and smaller size mineral particles in the adhesive. Various putties based on the Corian® adhesive mixed with ground Corian® boards and ATH were tried, as well as two coatings that consist of mixtures of ATH and Acrifix 2R 0190, a castable 2-component acrylic resin. No optically satisfying solution that allows efficient treatment was found so far.

KEYWORDS

Corian®, solid surface material, PMMA, aluminium trihydroxide, SEM-EDS

INTRODUCTION

Corian® is a durable and widely inert artificial stone material. It comes as boards and is used for interior fittings such as bathroom sinks, kitchen worktops, store fittings and other architectural elements. Since its development in 1967, Corian® has also been applied by architects, designers and artists such as Zaha Hadid, Ron Arad, Philippe Starck, Karim Rashid and Amanda Levente, amongst others *(purecontemporary 2006; Krumperman 2013; DesignLove 2011; Etherington 2009)*.

Conservators might know the material from display cases, like the pedestal for Nofretete's bust in the Neues Museum in Berlin, but also from architectural models. However, the conservation treatment of Corian® artefacts has hardly been an issue to date.

Since the late 1970s, Allan McCollum (born 1944 in Los Angeles) has been exploring three central themes in his oeuvre: the meaning of artworks as stand-ins for something or somebody; the influence of handicraft or mass-production on the meaning of objects and the matter of variations in large numbers of similar objects. All of these are addressed in his on-going *Shapes Project*. Starting in 2005 he developed this combinatorial, artist-designed system to produce *'a completely unique shape for every person on the planet, without repeating' (Dellinger 2013)*. The Shapes Project consists of a basic vocabulary of 300 elemental forms created as vector files. They can be combined according to the artist's guidelines in over 30 billion different ways. In 2010 the Book of Shapes was published, containing the 300 elementary parts as well as guidelines for creating all the possible combinations. Besides in print, *Shapes* have been realised in plywood, hardwoods, metals, rubber, fabric and acrylic glass.

In 2006 the group of 20 Cameo White Corian® *Shapes* was produced for McCollum in a carpenter's workshop. Their smooth surface and slight translucence evoke the impression of pristine white marble *(Figure 1)*.

After the initial exhibition in autumn 2006 the artist was dissatisfied with numerous imperfections of the surface and especially with visible joints between the laminated Corian® boards. Therefore, he prohibited further exhibition or sale in the current condition, but approved even highly invasive treatments including sand blasting or full over-painting. The involved parties, the artist, the gallery, the manufacturer and the head technician of Corian® tried to find a solution. As a trial one sculpture was coated in the cabinetmaker's workshop. An acrylic lacquer was mixed with glass lacquer (the latter was added in order to etch the surface slightly and thus facilitate adhesion) but the artist

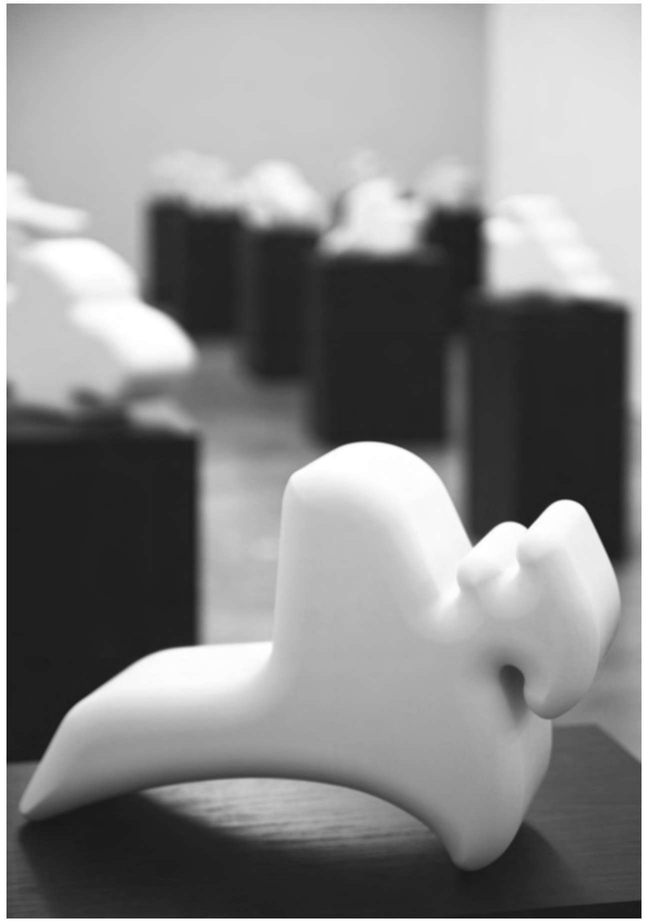


Figure 1
Exhibition view of the Corian® *Shapes* in 2006.
© The Artist.

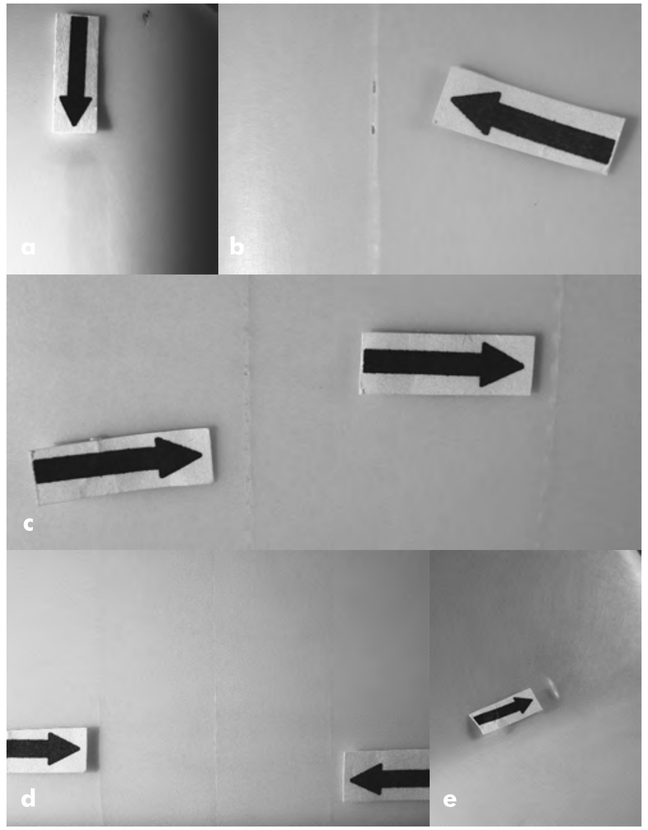


Figure 2
Marks of manufacture.
(a) Stains where levels were not on par and were filled with joint adhesive.
(b) Incompletely filled joints with air bubbles.
(c) Repairs of broken edges from milling form ridged lines.
(d) Several neighbouring joints are visible.
(e) White joints and pustule from adhesive that was pressed out right after it was filled in.

was not happy with the result. Due to the high costs for material and manufacturing, and the risk that the same problems would occur again, a remake was not a valid option. With respect to the incurred expenses for manufacturing, a cost-efficient method to make the visible joints disappear needed to be found.

THE MATERIAL CORIAN®

Corian® is DuPont's™ brand name for a solid surface material. It comes as non-porous boards made of one third acrylic resin (poly methyl methacrylate, PMMA) filled with two thirds of aluminium trihydroxide (ATH), an inert mineral extracted from the aluminium ore bauxite. The genuinely white material is also available pigmented and patterned with shredded Corian® beads. The cast boards are produced mainly in 6 and 12 mm thickness and, in limited edition, in 4 and 19 mm *(DuPont™ 2009)*.

Competitive products, all based on the ATH filler are either bound with acrylics(1) or with polyester resin(2). Some of them are also available as liquids, which allows to cast three-dimensional shapes. Some companies provide a special repair paste for their boards. Since this needs to be taken from every individual batch during board production to ensure colour fidelity, it is rather labour intensive. Therefore, Corian® is limited to sheet goods.(3) Quality differences between the various products such as orientation of material properties or thickness tolerances are due to the manufacturing techniques and not to the material composition. For Corian® boards the average thickness tolerance is ± 7 per cent.(4)

Corian® can be worked with hard woodworking tools and by thermoforming. For obtaining seamless surfaces, the separate 2-component Corian® joint adhesive is provided in 50 ml cartridges equipped with replaceable mixing nozzles. There are recommendations on which adhesive matches best to the various colours of the boards, but colour optimised adhesive does not exist for every single shade. The joint adhesive has the basic composition of the boards but contains additionally methyl methacrylate (MMA), serving as reactive solvent. When boards are adhered, the MMA softens edges and is then polymerised by the peroxide hardener to form PMMA. Therefore, the solvent does not need to evaporate and the adhesive forms a dry skin in less than five minutes. The adhesive is intended to adhere butt joints, but it is not made for adhering larger areas.

The adhered joints are generally the weak points of the otherwise robust material. This means that the low polymer density along the joint reduces mechanical stability and can increase transparency of the material. If adhered parts do not fit exactly and form a gap, the joint becomes visible due to differences in colour and transparency between the board and the adhesive. Moreover, if the parts are not cleaned thoroughly, the joints get stained. Grey staining often originates from friction wear of the aluminium edge guide of a circular saw used for cutting the boards. It was also observed that friction wear of the binding medium of some sanding papers can result in yellow staining.

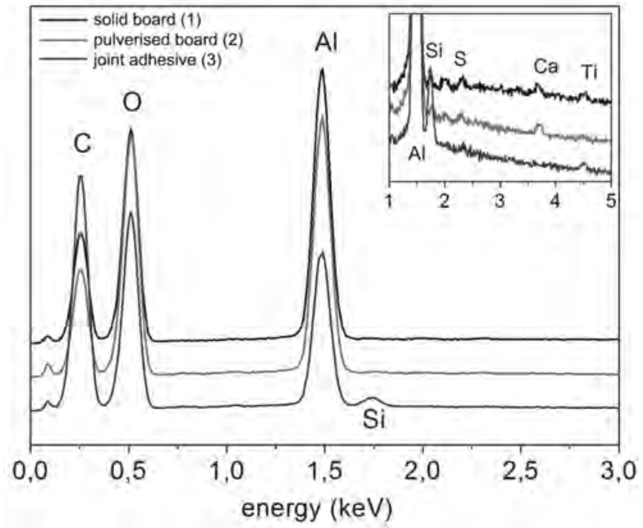


Figure 3
Elemental analysis of a solid Cameo White Corian® sample (sample 1, above line), of a powdered Cameo White Corian® sample (sample 2, middle line) and of a sample of Corian® joint adhesive for Cameo White boards (sample 3, bottom line).
The recorded area was 90 x 60 µm.

THE MANUFACTURE OF THE CORIAN® *SHAPES*

Since Allan McCollum was not contacted during the research, it is not known who initiated *Shapes* made of Corian®, but it is known that DuPontTM sponsored the material.[5] To learn more about the production of the Corian® *Shapes*, the manufacturer was visited at his workshop. By his information the *Shapes* are built of 14 layers of 12 mm thick Cameo White Corian® boards and laminated with the matching Cameo White Corian® joint adhesive.

Since the thickness tolerance for a 12 mm board is more than a millimetre, all boards needed to be double-disc surface ground in order to level them out.

Each two of the boards were adhered and cut out in a three-axis milling cutter fed with the vector files supplied by the artist. Due to limitations of the milling cutter, it was only possible to cut out two boards at once. For the inner layers the centre was cut out of the work-pieces to reduce weight and to further reduce the risk of open seams due to thickness tolerances. All seven prepared blocks of approximately 30 x 50 x 2.4 cm were then adhered using fit bores for better accuracy and were dried under pressure to reduce the width of the joints. During milling fragments of the edges were ripped off and were filled with the joint adhesive. The sculptures were sanded with an orbital sander, but due to the partially narrow curvatures not all details were accessible. In a last step the Shapes were sanded manually with dry sanding paper up to a graining of 400 to 600. No additional finish was applied.

MARKS OF MANUFACTURE

Unwanted marks of manufacture that are visible with the naked eye and under UV-light are listed as follows: repairs of the ripped-off edges from milling form ridged lines; colour deviations occur where the layers were not on par and were filled with joint adhesive; incompletely filled joints with air bubbles partially become dirty; pustules from adhesive expanded right after it was pressed into a hole with a spatula; and, most importantly, because found on nearly every sculpture, there are white lines between the boards that are whiter and less translucent than the bulk material *(Figure 2)*.

Regarding the latter, there are two possible explanations for this phenomenon. During our own experiments it was noted that the two components of the adhesive do not exit the cartridge at the same time, leading to varying ratios of resin and hardener. The less hardener, the whiter and softer the adhesive becomes. The second reason might be related to the short pot-life of the adhesive and the high volatility of the MMA, that might not have allowed spreading it fast enough on the boards. Adhesive with a dry skin cannot soften or wet the surface of the boards properly. The white colour of the joints might therefore be due to internal surfaces and air inclusions between the boards, similar to the blanching of varnishes observed on paintings.

According to the manufacturer all these defects occurred after some weeks, but it seems more likely that they formed during manufacture before all joints and fillings were fully hardened.

Figure 4
Back scattered electron microscopic images of (a) the solid Corian® surface (sample 1, left) and (b) of Corian® joint adhesive (sample 3, right). Photographs were taken at 20kV.

The visibility of the marks of manufacture depends on the lighting, which explains why they might not have been detected upon delivery.

PROFESSIONAL REPAIRS WITH INLAYS

In order to learn how Corian® sinks and worktops are repaired professionally a training for Corian® manufacturers at a DuPont™ training centre was attended.

For repairs, damaged areas are cut out as slots with a milling-cutter. The exact width of the slots is measured and sticks of the same width taken from another board, ideally from the same batch, are cut with a slightly tilted (approx. 2 °) circular saw. The ends of the wedge-shaped inlays are then sanded to match the round shape of the ends of the milled slots. When the inlays fit tightly into the slots all surfaces need to be thoroughly cleaned with acetone. Then the slots are filled with the Corain® joint adhesive and the inlay is inserted. When dry, excess material is sanded as a final step. With this technique it is possible to obtain perfect results, but it requires a lot of training. Since the hardness of Corian® requires heavy-duty machines with an edge guide on a flat surface, this technique is not applicable on the *Shapes*. Moreover, the smallest cutting heads for commercial hard wood milling cutters (e.g. tungsten carbide milling cutter, Dremel) have a diameter of 3 mm, which is too large for the max. 1 mm wide joints found on the Shapes. However, due to the brittleness of Corian® it is also not possible to cut inlays much smaller than 3 mm on a circular saw. Because of these technical difficulties the technique is not efficient.

STATE OF THE ART

During the research for possible treatments, only a single article on Corian® in the context of conservation was found. *(Krumperman 2013)* presented her investigations on *Oh Void 2*, a chair by Ron Arad that consists of red Corian® boards laminated with a black adhesive. In some areas of the chair's red surface 'small hairline cracks with no accountable cause' were observed and the black adhesive was 'locally almost blistering'. Surprisingly, in the X-ray fluorescence spectroscopy of the red Corian® board, no significant amounts of aluminium were found.

Figure 5
Putties based on Corian® adhesive modified with ATH, grinding blades and/or powdered Corian®.

SCANNING ELECTRON MICROSCOPY

Since the X-ray fluorescence spectroscopy of red Corian® boards from *Oh Void 2* reported in literature rose doubts on its composition, it was decided to perform an elemental analysis of Cameo White Corian® by scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS). Cameo White is the purest and most basic colour shade of Corian®, therefore it should clearly show the main ingredients. In addition, electron microscopic images of both materials were taken to understand the structural differences between the board material and the adhesive.

The SEM/EDS technique provides different sorts of signal: firstly, the backscattered electrons (BSE) are registered to reconstruct the microscopic picture of the sample. The brightness of a sample area correlates with its average atomic number. The higher the atomic number of a particle is, the brighter it appears on the image.

Secondly, the scanned material emits characteristic x-rays upon electron irradiation, which depend on the electronic states of the atoms in our sample. The energy of the emitted element specific x-rays is analysed with an energy dispersive system (EDS). In this way, information on the elemental composition of the sample is obtained. SEM/EDS finds broad application in micro-characterisation of materials *(Goodhew 1991)* by the comparison of the measured characteristic x-ray spectrum with a database for the specific transitions in all elements *(Reimer 1985)*.

A total of three samples of solid Cameo White Corian® and Corian® joint adhesive for Cameo White were investigated by SEM-EDS. Sample 1 is the fresh fracture face of a Corian® board, sample 2 is Corian® powder that was prepared by grinding blades in a porcelain mortar. The blades were cut with a tungsten carbide milling cutter and source from a different Corian® board than sample 1. Sample 3 is Corian® joint adhesive that was applied onto a glass plate and let dry.

The employed SEM (Hitachi S 4000, Japan) emits electrons to scan the surface and bulk material of the samples. In order to avoid charge accumulation during scanning with the electron beam, an approx. 10 nm carbon layer was evaporated onto the fresh fractures of sample 1 and 3 and onto a small amount of sample 2 to render the sample surfaces conductive. Although carbon is much less conductive than a metal plating such as sputtering with gold it was preferred because it is known that the Corian® samples contain a considerable amount of carbon anyway. Moreover, gold emits strong X-rays that would disturb the signal from the Corian® sample.

Due to a possible charge accumulation of the carbon layer fast scanning of the sample was necessary, which in turn only allowed for low-resolution imaging. Since the carbon layer is very thin, it is not visible in the BSE image and thus compensates for the loss of image quality due to the fast scanning.

In the present case quantitative information on the elemental distribution was not obtained, as the yielded X-rays in the measured signal depend on the incoming angle of the electron beam and on the angle under which the measurements are taken. For this reason, the exact sample geometry needs to be known, which is not the case for fractured samples. Moreover, a homogeneous sample would be required in order to correctly assign the elements to a component.

In the elemental analysis carbon, oxygen and aluminium from the PMMA $(C_5O_2H_8)n$ and the ATH γ-$Al(OH)_3$ were found in all three samples as expected. In the two samples of Corian® boards (sample 1 and 2) sulphur, calcium and titanium were present *(Figure 3)*. The white pigment titanium dioxide is the titanium source, which is listed in the material safety data sheet *(DuPontTM 2011: 4)*. Corian® contains a small amount of sulphates, that derive either from the application of sulphur oxide used to initiate the polymerisation of MMA *(Ghosh 1966)*, or from the use of sulphur compounds as regulator for PMMA

(Brand 2010). The calcium content in the samples probably originates from calcium carbonate $CaCO_3$. It might come from impurities in the ore or from water used for washing. Moreover, calcium is widely used as a counter ion in various technical applications.

In addition to Al, C, O and Ti the Corian® joint adhesive (sample 3) shows silicone. Since it is not present in Corian® boards, silicone may have been added to improve workability and smoothness of the adhesive. Calcium was not found in the adhesive. On the one hand, this could be due to an insufficient resolution, a measurement error or due to geometry during the measurement, as explained earlier. On the other hand it could support the thesis that calcium worked as counter ion, possibly for a polymerisation initiator in the boards. In the joint adhesive peroxides are used as initiator to harden the acrylic resin.

Figure 4 shows the electron microscopic images of the surfaces of sample 1, the solid Corian® surface, *Figure 4 (left)* and of sample 3, the Corian® joint adhesive, *Figure 4 (right)*. While the components in the board and in the adhesive are almost identical, the microscopic images show differences. In the board, big mineral particles of approximately 0.05 – 0.03 mm are embedded in a small amount of resin (which are the darker areas). In the adhesive, the particles are much smaller (approximately 0.01 mm) and there is more polymer matrix. The lower concentration of minerals in the joint adhesive correlates with its lower density of 1.6 g/cm^3 compared to a density of approx. 1.75 g/cm^3 for Corian® boards. These differences in the composition influence the optical properties and contribute to the visibility of Corian® joint adhesive in Corian® boards.

EXPERIMENTAL

For the treatment of white joints and other marks on the sculptures two approaches were tested: fillings and coatings.

PUTTIES

Putties based on Corian® joint adhesive seemed promising, since some of the repairs during manufacture, such as the ripped-of edges from milling, already showed relatively good results. Because of the structural differences between board and joint adhesive that were observed in the electron microscopic images, it was tried to increase the amount of minerals in the adhesive either with ATH (graining < 0.032 mm) or with pulverised Corian® boards.

Slots in a Cameo White Corian® board were prepared with a 3 mm diameter tungsten carbide milling cutter in a Dremel tool equipped with a funnel-shaped spacer for milling. The waste from milling was collected and powdered in a porcelain mortar. After cleaning the slot with acetone, ATH, grinding blades and /or powdered Corian® were either sparkled onto the filled-in joint adhesive and gently pressed in or the adhesive was mixed with the particles in a separate container and filled-in with a glass rod. Numbers next to the fillings written with a pencil were not removed before sanding and polishing the surface, which caused grey staining of nearly all test fields. New fields were prepared and numbers were engraved into the Corian® board to avoid staining.

For assessing the quality and appearance of the various putties independently of the application method, cubicles were cast in silicone ice cube containers. Instead of using the putties based on Cameo White joint adhesive, a self-made solid surface material was prepared. Therefore, ATH was mixed with Acrifix 2R 0190, which is a 2-component acrylate that can be pigmented and diluted and is used to adhere plexiglas. The following putties were tested: three different Corian® joint adhesives (Cameo White, Bone White and Glacier White); Cameo White joint adhesive mixed with ATH (ratio 2:1 and 1:1); Acrifix with 5% hardener and ATH (in the ratios 2:1, 1:1 and 1:2); Acrifix, Cameo White joint adhesive and ATH (1:1:1); Corian® grinding blades swollen in MMA for 6 months mixed with ATH and Acrifix.(6)

COATINGS

As mentioned before, one sculpture was spray coated with an unsatisfying result. Unfortunately, it was not accessible for assessment and could not be included in the criteria for designing a coating.

The main criteria for a coating is the preservation of the marble-like look-and-feel of Corian® with its slight translucency and smooth surface. Other requirements are durability and scratch resistance, since the Shapes are heavy and it is likely that they will be pushed into position without lifting.

Since a full coating of a whole work group cannot be seen as a conservation treatment but is rather a post-production measure, it was considered favourable to relate to the original material as much as possible, instead of obtaining reversibility.

Two paints based on the original ingredients were prepared. One consists of Acrifix 2R 0190 (with 4-5% hardener), Acrifix thinner TH 0030 (pure MMA) and ATH (2:1:1), the other one of Acrifix 2R 0190 (with 4-5% hardener), Acrifix thinner TH 0030 and powdered Cameo White Corian® (2:3:2). Both coatings were sprayed onto a hemispherical thermoformed Designer White Corian® dummy with Bone White fillings using a professional spray gun for repairs at the suggested distance of 10-20 cm with a pressure of 2.5 bar and the nozzle fully opened. The colour difference of the fillings on the dummy was chosen to test the opacity of the coatings. A hemispherical shape was chosen to mock-up the curved Shapes.

RESULTS

PUTTIES

The putties based on Corian® adhesive varied within a single treated area and were partially too grey, partially too white. Mixing the adhesive with the fillers on some parts caused air inclusions that appeared after excess material was ground down. Cut inclusions became visible as little dark holes or as white dots at the edges of the slot. Since the putties were relatively viscous, small holes had to be reworked several times *(Figure 5)*.

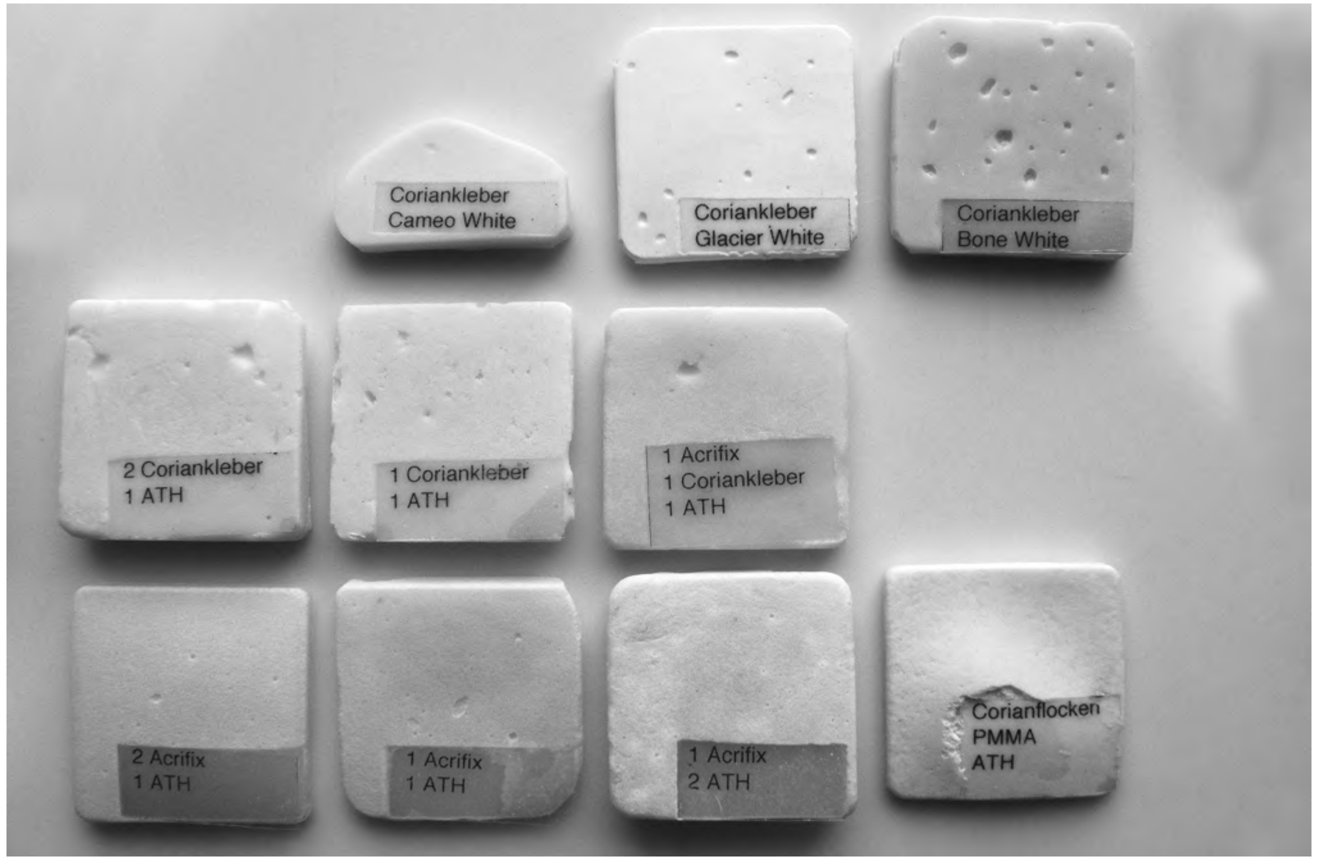


Figure 6
Cast putties placed onto a Cameo White *Shape*.
Top row: Corian® joint adhesives, from left to right: Cameo White, Glacier White, Bone White.
Middle row: Cameo White joint adhesive modified with ATH: 2:1, 1:1 and with additional Acrifix 2R 0190 (1:1:1).
Bottom row: Acrifix 2R 0190 with ATH in varying ratios (2:1, 1:1, 1:2) and Corian® flakes swollen in MMA mixed with ATH and Acrifix 2R 0190.
(see colour plate, p. 170)

Especially putties with added ATH were rough and looked slightly porous. A vacuum would have been necessary to remove air inclusions. A finer graining of the ATH could have helped improve the smoothness of the putty. After 6 months, the Corian® flakes were not dissolved in the MMA but only slightly swollen. When poured into a slot, a loose arrangement resembling coconut flakes was formed.

Figure 6 shows the cast cubicles placed onto a *Shape*. Only the cubicles based on Cameo White joint adhesive matches the colour of the sculpture. The three samples of Acrifix 2R 0190 and ATH are more translucent than the joint adhesives and show slight orange staining. When the amounts of ATH were increased, which leads to a higher viscosity, an increasing amount of air inclusions was observed that formed white dots. Moreover, their structure is slightly porous, as was observed for the putties applied into the slots of the test board. The swollen Corian® flakes remained visible when mixed with ATH and Acrifix 2R 0190, and no homogeneous putty was obtained.

COATING

Both coatings based on Acrifix 2R 0190 produced hard but rough and semi-transparent films on the hemispherical test piece. However, even several layers of coating did not cover the slots filled with Bone White joint adhesive. The coating without pulverised Corian® was glossy and slightly orange, as was observed on the cubicles containing Acrifix 2R 0190. The coating with pulverised Corian® was whiter than Cameo White boards and rough like sanding paper.

After sanding, some air bubbles became visible in the coating. Considering the feasibility on a large number of *Shapes*, an additional work step is not acceptable from a practical point of view.

During spraying at a distance of 40-60 cm, candy-cotton-like fibres were formed, indicating that the thinner evaporated and the resin in the lacquer solidified whilst on flight. In both coatings made of ATH and thinned resin, the mineral filler deposited in the mixing beaker. Therefore it seems that further dilution would not solve the fibres problem, but it may be worthwhile to try and reduce the amount of hardener.

It was possible to sand the surface and to adjust the gloss using a random orbit sander at low speed. At higher speed the resin became instantly yellow due to the heat. The commercial spray paint gave the best result and showed sufficient opacity. Since the dummy is made of Designer White, which is less translucent than Cameo White, it is difficult to decide if the coating was too opaque, but the overall impression was very close to Cameo White. However, the scratch resistance was very poor.

CONCLUSIONS

In order to find an efficient way for the removal of visible joints on the group of 20 Cameo White Corian® *Shapes* by local repairs, such as inlays and fillings and by spray coating a dummy with specially prepared lacquers was tested. However, no satisfying and efficient method was found so far. The professional technique for repairs with inlays proved not to be suitable due to the the *Shapes'* curved surface.

Filling slots with modified joint adhesive could reduce the visibility of the joints, but it requires a high degree of experience and training to obtain reproducible results. Since every joint needs individual treatment, it does not seem to be an efficient procedure. Moreover, the tested milling cutter head of 3 mm in diameter was too big for the removal of the thin visible lines. For future experiments with slots and fillers, an engraving tool for stone with a smaller head could be tested. But if the slots are too narrow, it becomes increasingly difficult to avoid air bubbles in the inserted filler.

Coating proved to be the best option, but requires professional assistance with both the scanning of the surface of the sculpture for optimizing colour, gloss and degree of translucency; and with the adjustment of the coating's workability. Even if the sculptures are coated, dirt needs to be fully removed from the joints, and all cavities need to be closed beforehand. Moreover, it generally needs to be taken into account that the Shapes can be placed in different ways, so there is no designated bottom side.

To sum up, this research shows that the visibility of the joints is not based on material quality, degradation or damage, but that it is due to unsuitable material application. Corian® joint adhesive is optimised for butt joints, but not for laminating a board material of high thickness variation. Therefore, the observed marks of manufacture are processing defects that can hardly be avoided. Using a competitive castable solid surface product would probably yield a better result.

ACKNOWLEDGEMENTS

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ENDNOTES

(1) *Solid surface materials based on ATH and acrylic resin are Himacs® by LG, Staron® by Samsung, Living Stone® and MeganiteTM from the USA and Hanex® from South Korea. (Himacs 2013; Staron 2013; Livingstonesurfaces 2013; Megnite 2013; Hanex 2013).*

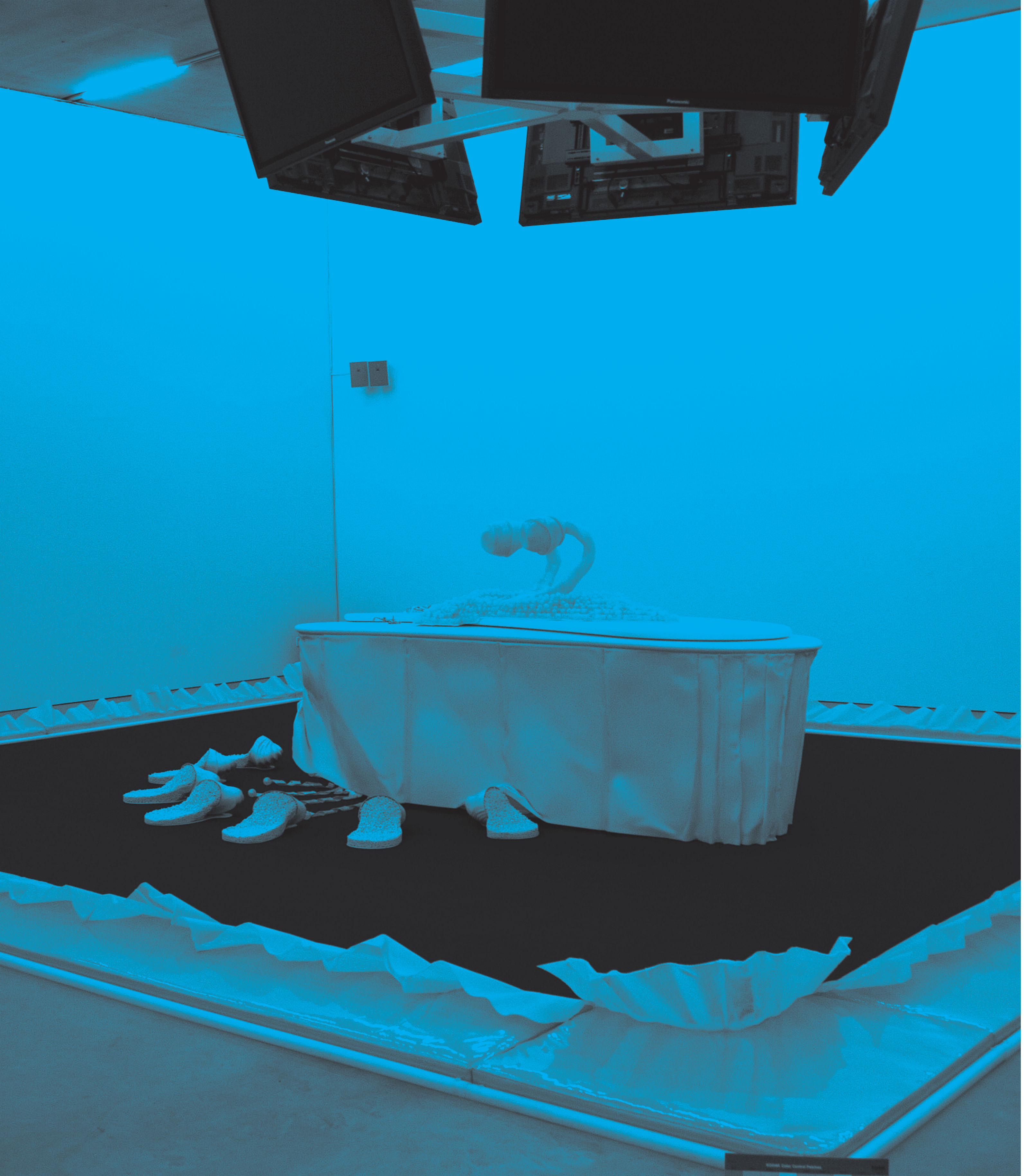
(2) *Materials based on ATH and polyester resin are Varicor® from Germany, Velstone from Ireland, Avonite® from the USA and Durat® from Finland, which contains 30% recycled polymers. Cristalplant® from Italy consists of ATH polyester and acrylic resin. (Varicor 2013; Velstone 2013; Avonitesurfaces 2013; Durat 2013; Cristalplant 2013).*

(3) *Information from Mr Wolfram, Varicor®, telephone call 16.10.2013.*

(4) *According to email communication with Jan Fischer, DuPontTM 17.10.2013.*

(5) *DuPontTM regularly posts rewards and seeks to explore innovate applications of Corian® in art and design beyond the use as interior fittings. Perhaps it is for that reason that almost every example found for the use of Corian® by renowned artists and designers is either a contract work with DuPontTM, (Krumperman 2013; Etherington 2009; purecontemporary 2006) or was created during a Corian® workshop organised by DuPontTM. (Philadelphia University 2010; DuPontTM Corian® 2007; DesignLove 2011; PUR surfaces 2011: 2, 13).*

(6) *According personal communication with Andreas Fetzer, DuPontTM 2012-2013.*



LECTURE

016

CASE STUDY *GOODYEAR FIELD* (1996): THE VERSATILE SYNTHETIC POLYMER POLYCAPROLACTONE USED BY MATTHEW BARNEY

BY GIULIANA MORETTO

ABSTRACT

The sculpture *Goodyear Field* (1996), by contemporary artist Matthew Barney, consists of a broad variety of different synthetic materials, as identified through FTIR analysis. One particular plastic present in the sculpture, which has not yet received much attention in the field of conservation science, is polycaprolactone (PCL). Barney has used PCL extensively as an artistic medium throughout his oeuvre. In Goodyear Field he used it in sheet form known under the brand name Aquaplast®, which is a cross-linked form of PCL. Aside from Matthew Barney, other contemporary artists and designers also work with this material, mainly in the form of linear PCL pellets, which are known as "Friendly Plastic®", "Polymorph" or "ShapeLock". PCL is a thermoplastic, aliphatic polyester originally used for biomedical applications and the manufacturing of orthopedic casts. The polymer's multi-faceted uses, including its low melting point, make it attractive as an artistic medium. This unique polymer was the focus of a MA thesis written at the University of Applied Sciences Bern. The main goal was to gain fundamental knowledge on its technology, material characteristics and ageing properties. In addition to a survey of available research material and test series, an interview with Matthew Barney provided valuable information about PCL as well as an understanding of the artist's motives to work with this specific material. Preliminary signs of ageing, such as yellowing, have been observed in the PCL sheets in *Goodyear Field*. This, combined with the need for research on the photo-oxidative ageing behaviors of PCL, formed the basis for this thesis, which examines PCL's ageing stability with a special focus on the photo-oxidative ageing behaviour of the polymer when stored in museums and collections. Light-ageing tests were performed by exposing both linear and cross-linked PCL samples to different kinds of light sources.

KEYWORDS

Polycaprolactone (PCL), aliphatic polyester, Matthew Barney, Cremaster 1, light-ageing test, photo-oxidative behaviour, colorimetry

INTRODUCTION

The sculpture *Goodyear Field* (1996) *(Figure 1)* was created in the context of Matthew Barney's film *Cremaster 1* (40 min, 1995), which is the second film belonging to Barney's most renowned art project the *Cremaster Cycle* (1994 - 2002). The work was first shown at the Kunsthalle Wien in 1997, together with his drawings, photographs and other sculptures made for *Cremaster 1*. Currently, the sculpture is installed in one of the viewing/storage rooms of Schaulager in Münchenstein near Basel, Switzerland.

The author's master thesis written in 2013 at the University of Applied Sciences Bern is devoted to *Goodyear Field*. This publication presents an excerpt of the paper and will focus on the investigations of one specific material used to create the sculpture: polycaprolactone (PCL). Matthew Barney and other contemporary artists and designers, have been working with this synthetic polymer extensively. So far, it has not received much attention in the field of conservation science. From a conservator's point of view the questions about the ageing properties (chemical and physical stability) of this rather unknown polymer need to be addressed. The lack of literature on the ageing of PCL under museum conditions and the artist's observation of a first yellowing of the originally white sheets in *Goodyear Field* served as a motivation to take a closer look at the photo-oxidative ageing behaviour of this synthetic polymer. Accelerated light ageing tests were performed by the author, in which different PCL products were tested, taking the artists working techniques into consideration. One of the test series presented in this publication focuses on the PCL elements in *Goodyear Field* and the possible impact of the current light situation at Schaulager upon the material.

DESCRIPTION OF THE WORK

Goodyear Field is a complex sculpture consisting of numerous elements varying in size and made of mostly synthetic materials, including: ethylene vinyl acetate (EVA), polyamide (PA), polyethylene (PE) and polyvinyl chloride (PVC), all of which were identified using ≠FTIR analysis. The entire sculpture measures about 7 × 8.2 meters (23×27 feet). The main component of the sculpture is a large table in the center, which consists of two tabletops spread apart like a pair of scissors and supported by a funnel shaped leg. The table is standing on a bright blue artificial carpet, which is enclosed by a white ruffle and a broad white border. A centerpiece is placed on the table, which resembles stylized ovaries surrounded by clusters of synthetic grapes. The stiff

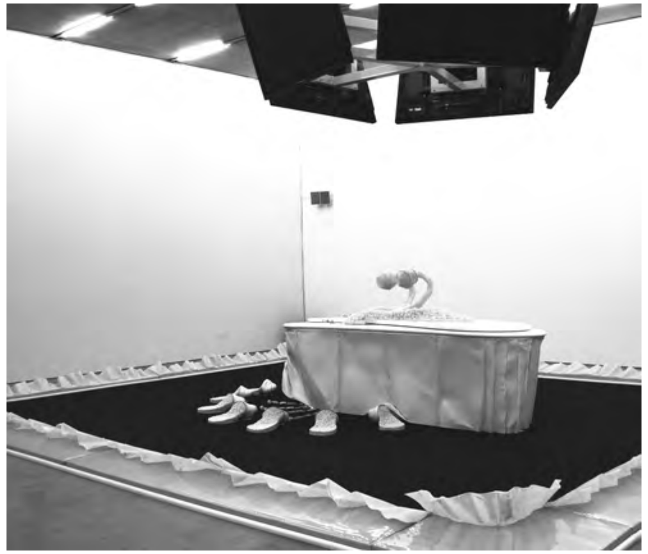


Figure 1
***Goodyear Field* (1996) by Matthew Barney.**

tablecloth drapes run along the edges of the tabletops, revealing a circle of sandals on one side. In a second, larger row, further away from the table, are thirteen long white objects resembling hats or a kind of cornucopia. Two other elements are only visible upon closer examination: A metal speculum is placed in the exact center above the circle of sandals and comes out of the hole connected to a large glass drop. A second metal speculum is seemingly superficially applied and not piercing through the tabletop. Both specula are associated with two white plastic elements.

POLYCAPROLACTONE (PCL) ELEMENTS IN *GOODYEAR FIELD*

Several elements in *Goodyear Field* consist of the synthetic polymer polycaprolactone: The white ruffles along the border, the tablecloth and the two small elements attached to the metal specula *(Figure 2)*. According to the artwork description, Barney defines PCL as prosthetic plastic. In this case he used moldable sheets known under the brand name Aquaplast®, which is a cross-linked form of PCL. These commercially available sheets are normally used for making orthopedic splints and casts. The solid and perforated sheets used in *Goodyear Field* were thermoformed and molded into shape using a heat gun.

THE SIGNIFICANCE OF PCL IN ARTWORKS MADE BY MATTHEW BARNEY(1)

Matthew Barney has been working with plastics since his early work. His usage of these materials generally originates from other application fields, such as medical-technological applications or sports medicine. In the late 1980’s and early 1990’s, Barney experimented with an orthotic sheet made of a polypropylene/ethylene copolymer with a dull fleshy color that he used for sculptural elements, including frames for his drawings and photographs. The material is referred to as prosthetic plastic in the accompanying artwork descriptions.

This commercial product had some disadvantages though and could not satisfy Barney’s desire to make elaborate shapes because it was particularly difficult to bend when heated and would not retain its formed shape:

“I was spending a lot of time with the heat gun trying to heat up big surfaces of this orthotic sheet but by the time you would get from one side to the other, the heat started to leave, it was very difficult to keep the heat even. […] Even when the orthotic sheet was well heated, it was difficult to do a complex curve. You really had to hold on to it otherwise it would want to spring back to its sheet form.” *(Interview with M. Barney, January 9, 2013.)*

After these unsatisfying experiments, his encounter with Aquaplast® moldable sheets brought to the studio by a salesman was for Barney a, “godsend”, as he describes it. In contrast to the polypropylene/ethylene sheet, Aquaplast® could be heated in water at a low temperature and had a longer working time while staying flexible. Aquaplast®, like many of the materials Barney chooses for the creation of his artworks, exists in several states. Aquaplast® becomes transparent and moldable when heated above a specific temperature, and goes back to a solid state upon cooling. This specific ability of the material appears to fit in with Barney’s interest in the transformation of the body, of objects and raw materials. *(Wittocks 2005)*. For example he uses tapioca pearls, which consist of starch that can be solid, liquid, or gelatinous. Barney's signature medium petroleum jelly, or Vaseline, changes from solid to liquid in response to a change in temperature.

Not only the thermoforming quality of the material is a concern for Barney, but also its visual appearance, namely its translucency. Furthermore, Barney is interested in materials that can be put internally and externally of the body, such as Teflon, which is used not only for implants but can also support a body from the outside, in the case of protective equipment used by football players. *(Barney 2006)*

Although he was especially interested in creating work using Teflon, Barney realized how hard it was to work with it. Therefore, he started using alternative materials instead with similar qualities, such as Aquaplast®. The first sculptural elements made of Aquaplast® moldable sheets appear in the work *Goodyear Field*. The material is described as prosthetic plastic in the artworks description, the same definition he previously used for elements made of the orthotic sheet. Barney explains his decision to invent a name for the material as following:

“I think when I started to exhibit and to make these material lists for works I didn’t really care about it chemically as much as I did conceptually. I think the notion of that material as a prosthetic material was more important to me then what it actually was.” *(Interview with M. Barney, January 9, 2013.)*

Polycaprolactone, including Aquaplast® moldable sheets, appear regularly throughout Barney’s oeuvre, not only as sculptural elements but also as props in his films and during live performances. When incorporated in the films, the material appears to be shaped, molded, and manipulated to become a character, like the other protagonists. However, for Barney it is most important that the material fulfills the following function: “When I’m using it [Aquaplast®] in a scene it is to bring a sculptural quality out of a character driven situation or one that is not particularly sculptural.” *(Interview with M. Barney, January 9, 2013.)*

During the *Cremaster* project Barney lost interest in defining PCL as prosthetic plastic and instead started to refer to it using the material’s brand name, Aquaplast®. The rather small size of the sheets had always been a disadvantage of the product for Barney and therefore restricted him in realizing larger projects. When he discovered polycaprolactone (PCL) pellets as an alternative, it almost ended Barney’s use of Aquaplast® pre-molded sheets. This product allowed him to cast larger sheets and complete large scale sculptures. Currently, Barney rarely creates artworks with Aquaplast® sheets but rather uses PCL pellets. In certain cases, Aquaplast® is still his medium of choice, especially when it needs to be applied onto a person’s body, e.g. during a performance.

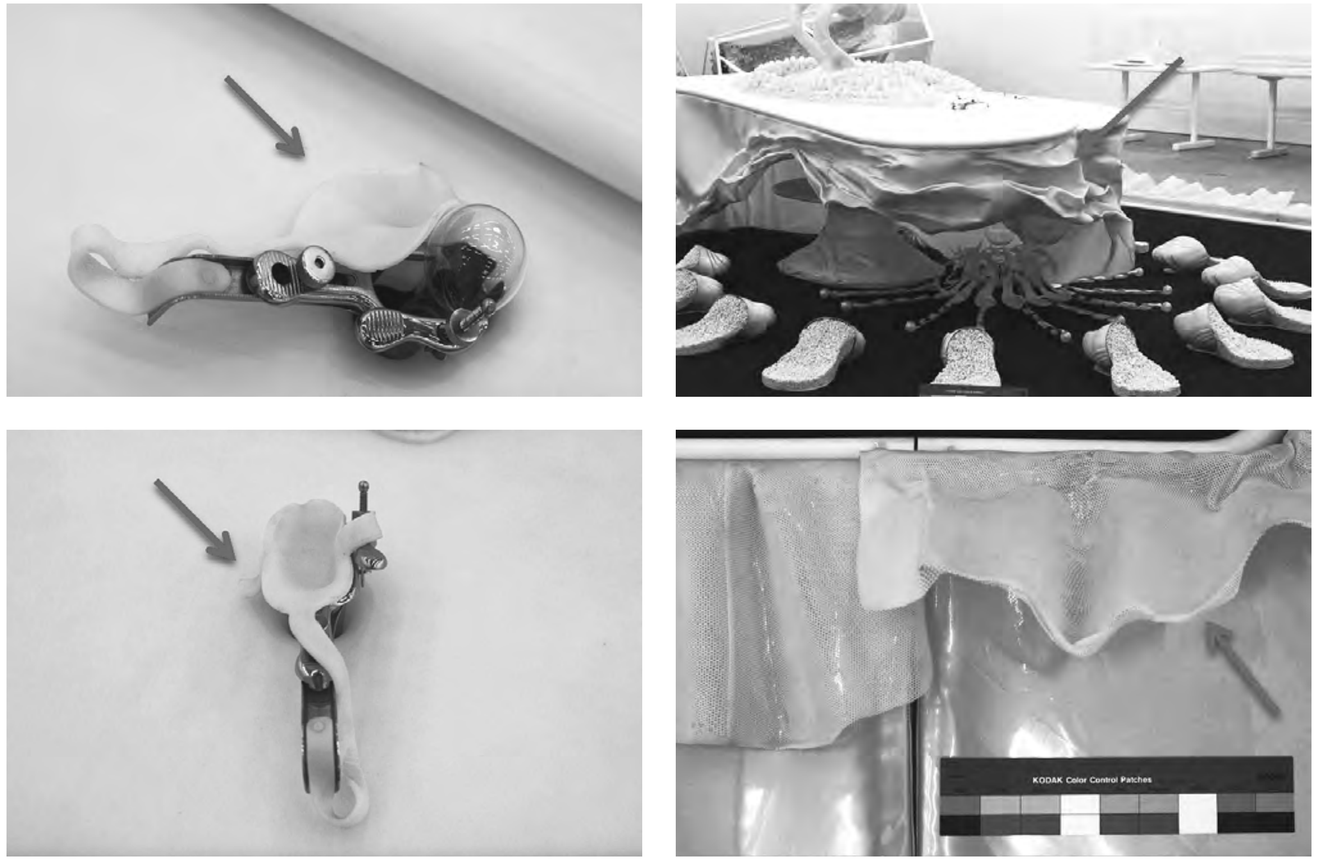


Figure 2
Polycaprolactone elements in *Goodyear Field:*
Top left and bottom left: PCL elements on the table.
Top right: Tablecloth made of PCL sheets welded together.
Bottom right: Perforated PCL sheets along the border.
(see colour plate, p. 170)

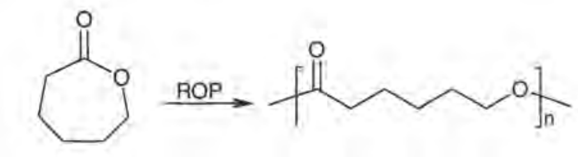


Figure 3
The chemical structure of ε-caprolactone and the resulting repeating unit by ring opening polymerization.

MATERIAL USE AND WORKING TECHNIQUE FOR PCL IN THE BARNEY STUDIO

Aquaplast® comes in different forms, each of which has different molding/shaping properties and handling characteristics. The specific product line mainly used for the creation of artworks by the Barney studio has been Aquaplast® -T (including colored and perforated sheets). These possess a non-stick coating that facilitates its handling. When the sheets need to be bonded together, the surface of the sheet is sanded down in order to remove this non-stick coating and create grit for adhesion.

Usually, several people are involved in the creation of Barney's sculptures (in the case of *Goodyear Field*, 3-4 people) and a variety of techniques have been used to thermoform Aquaplast® sheets. To make the material moldable, the sheets were either heated by immersing them in hot water, as illustrated previously, placing them in an oven, or heated locally using a heat gun. In their moldable condition, the sheets are formed by hand or draped along a negative form and as a last step, cooled down until the material solidifies. Depending on the project, one or the other method works better not least because each technique causes a certain aesthetic appearance of the end product. According to Barney, when heated in water the surface of Aquaplast® has a "rubbery" look, which can be smoothed again by warming up the surface with a heat gun.

To melt the PCL pellets(2), Barney has also used different techniques, such as placing the material under a heat lamp. However, thus far he most often places them on a Teflon pan and then heats them in an oven at 93 °C (200 °F). Halfway through the heating process, the pellets are thoroughly mixed in order to heat the material evenly. Once they have turned transparent the pellets are removed and left to cool for a few minutes. By then the pellets have a dough-like consistency, and can be either pressed into a cast or applied by hand into the mold wall before cooling down entirely.(3)

POLYCAPROLACTONE (PCL)

Polycaprolactone was first synthesized in the early 1930's and subsequently became commercially available. Because of its unique biodegradation characteristics, PCL has been extensively used in the biomaterial field and drug delivery devices (e.g. as material for drug capsules) in the 1970's and 1980's. Since the 1990's, it has also been used for tissue and bone engineering, for example as scaffolding material for tissue repair. *(Woodruff; Hutmacher 2010, p. 1218)*

Further examples for the use of PCL include biodegradable plastic bags or package material that is easily degradable by microorganisms *(Guixin 2001, p. 1639)*, as well as an environmentally friendlier alternative to phthalate plasticizer, when used for plasticizing polyvinyl chloride *(Ishigaki et al. 2004, p. 225)*. It was also used as material for rapid-prototyping, mainly for home user systems, though this has largely been replaced by acrylonitryle butadiene styrene (ABS). *(Madsack 2011, p. 51)* Furthermore, PCL has many applications in the hobby and craft market, and for these purposes it is sold in the form of pellets or sheets under different brand names such as ShapeLock or Friendly Plastic® in the United States or Polymorph in the UK. Contemporary artists and designers, such as Katie Grinnan, Claire Jackson or Jerszy Seymour have used these products to create artworks and furniture.

Most relevant for this study, polycaprolactone has been widely used as a low-temperature moldable splinting material for orthopedic devices and protective padding since the 1970's(4). The key feature of PCL splinting material is the low forming temperature (usually achieved by heating it in warm water) and the ability to reshape sheets after re-heating.

Polycaprolactone[5] a petroleum based aliphatic polyester, can be manufactured by ring-opening polymerization of the cyclic monomer-caprolactone *(see chemical structure in Figure 3)* using either anionic, cationic, or coordination catalysts or via free radial ring-opening polymerization (ROP) of 2-methylene-1-3-dioxepane. *(Woodruff; Hutmacher 2010, p. 1218)*

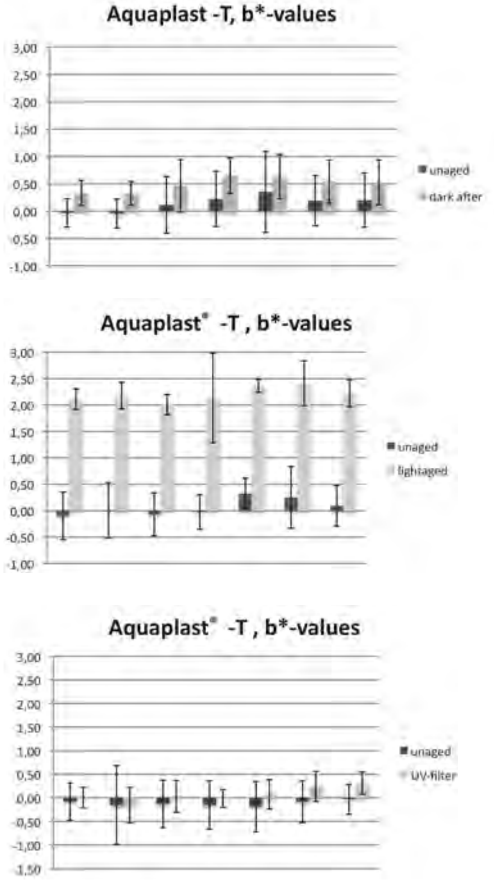


Figure 4
b*-values for Aquaplast® -T, stored in the dark, exposed to filtered simulated Schaulager light and exposed to not-filtered simulated Schaulager light. Each bar represents measurement data gained on one of seven identically treated samples.

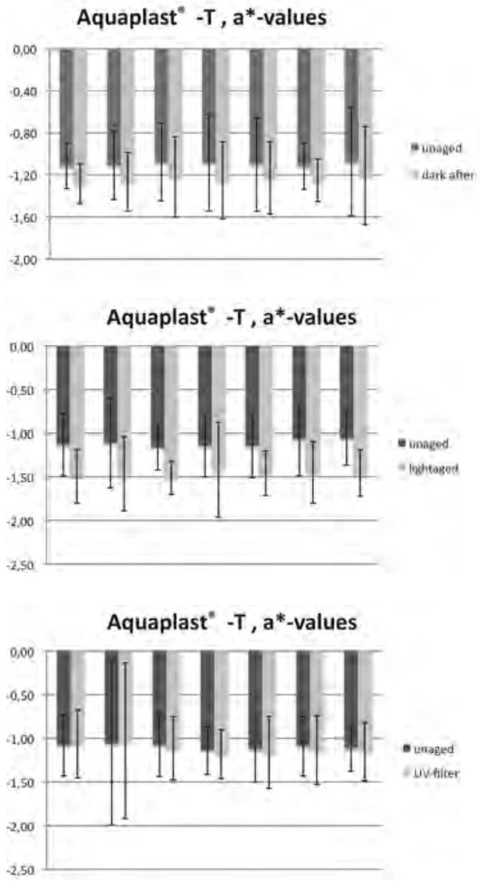


Figure 5
a*-values for Aquaplast® -T, stored in the dark, exposed to filtered simulated Schaulager light and exposed to not-filtered simulated Schaulager light. Each bar represents measurement data gained on one of seven identically treated samples.

Polycaprolactone is a thermoplastic polymer with the molecular formula $(C_6H_{10}O_2)n$. PCL is a hydrophobic, semi-crystalline polymer with a low melting point ranging from 59 - 64 °C (138 - 147 °F) and a low glass transition temperature T_G of -60 °C (-75 °F). It is also reported that PCL is soluble in chloroform, dichloromethane, carbon tetrachloride, benzene, toluene, cyclohexanone, and 2-nitropopane but has a low solubility in acetone, 2-butanone, ethyl acetate and dimethylformamide and is insoluble in alcohol, petroleum ether, and diethyl ether. *(Woodruff; Hutmacher 2010, p. 1219*. These parameters apply to new, un-aged PCL.)

Based on its molecular weight, the state of PCL varies from liquid, pasty or waxy to a semi-rigid polyethylene-like polymer. It has a relatively high modulus of elasticity and a high flexural strength at room temperature. *(Chu 1999, p. 6)*

Belonging to the family of biodegradable aliphatic polyesters, it is considered an ideal biodegradable polymer because of its flexibility and good hydrolytic (microbial and enzymatic) degradation. However, it has poor mechanical stability and a tendency to crack when stressed. *(Woodruff; Hutmacher 2010, p. 1219)* In order to compensate for these disadvantages, PCL can be modified, cross-linked or blended with inorganic fillers or other polymers. *(Han 2006, p. 593)* Aquaplast® is an example of a cross-linked PCL.

Common methods of cross-linking are the use of peroxides and ionizing irradiation, such as electron beam radiation, gamma-irradiation and x-ray-irradiation, as well as photo-cross-linking. *(Chu 1999, p. 15, p. 21)* Each of these methods induces structural changes in the molecule, mainly cross-linking and chain scission. During cross-linking, covalent C-C bonds are formed between the main polymer chains. *(Chu 1999, p. 47)*

AQUAPLAST® - A CROSS-LINKED PCL

The brand name Aquaplast®(6) indicates a low-temperature polycaprolactone in its cross-linked form, which is moldable when softened in hot water or hot air and solidifies when cooled. It is intended to be used for medical applications, such as the fabrication of custom-molded rigid splints, or protective padding for athletes. The thermoformed sheet has the ability to regain its original shape when reheated.

Today's Aquaplast® products range from pre-formed moldable casts and splints to moldable sheets. These sheets are available in a range of different thicknesses, as well as in different perforation and color options. Perforated and solid Aquaplast® -T sheets were the kinds used by Matthew Barney in *Goodyear Field*. The -T sheet is equipped with a non-stick coating consisting of an acrylic styrene compound for a temporary bond, which can be removed if needed by scraping the surface of the sheet or brushing it with acetone.

Unfortunately, today's manufacturer refuses to provide any detailed information on the actual manufacturing process of Aquaplast® moldable sheets. Based on the results of surveying patent literature, performed by the author, the PCL was radiated twice during the production of the sheets, in order to form a continuous internal network in the polymer. Electron beam and gamma radiation appear to be the two most likely methods used for the cross-linking of Aquaplast® sheets. (U.S. patent no. 4.240.415 By Lloyd H. Wartman of WFR/Aquaplast Corp.) The survey of patents also indicates the addition of a cross-linking agent, most likely thylolpropane triacrylate (TMPA). *(Wartman 1980, p. 5)*

In order to form Aquaplast® moldable sheets in the desired shape, the sheets need to be softened. The following directions are taken from the instruction sheet for Aquaplast® splinting materials provided by the manufacturer (Patterson Medical 2011). One recommended option is to soften Aquaplast® sheets by placing them in heated water. The recommended water temperature ranges from 70 - 75 ºC (160 - 170 ºF). The approximate heating time depends on the thickness of the material: 1/16” (1.6 mm) requires 30 seconds, 3/32” (2.4 mm) 60 - 70 seconds, 1/8” (3.2 mm) 1 - 2 minutes and 3/16” (4.8 mm) 2 minutes. As already mentioned, when Aquaplast® is heated to molding temperature, it turns clear.

In addition to the exposure to hot water, Aquaplast® materials can also be heated in a convection oven. The manufacturer notes that the material heated in the oven requires higher heating temperatures than when heated in water. The recommended temperature for heating Aquaplast® splinting materials in an oven ranges from 80 - 96 °C (195 - 205 °F) for up to 10 minutes or until the sheets turn transparent. The use of a heat gun, as often applied by Matthew Barney, is only recommended for spot-heating and adjustments (e.g. changes in design or form). The material is ready to form when it becomes transparent or translucent. The working time is up to 7 minutes, depending on the thickness of the material. Once the plastic cools down it loses its transparency and returns to its original color.

PHOTO-OXIDATIVE AGING OF LINEAR AND CROSS-LINKED PCL

Only little is known about the ageing properties, including the photo-oxidative ageing of PCL objects stored and exhibited in museums and collections. Due to the fact that polycaprolactone is mostly used in the biomedical field, the majority of literature on the degradation properties of PCL focuses on hydrolytic degradation by microorganisms or enzymes. Even though hydrolytic degradation occurs equally in non-cross-linked as well as in cross-linked PCL *(Darwis et al. 1998, p. 259)*, it is expected that this kind of degradation mechanism can only occur under extreme climatic conditions (high temperature and high relative humidity) where microorganisms are present (for example in the human body or in soil) and probably not in climate controlled museum environments.

Because yellowing was observed on Aquaplast® sheets in the sculpture Goodyear Field this study focuses specifically on the photo-oxidative aging of PCL as a possible ageing mechanism responsible for yellowing. In the technical literature, color changes are never mentioned as a possible degradation effect. This may be due to the fact that this kind of aesthetic change is not considered problematic in industrial applications. TSUJI et al. (2006) investigated the photo-degradation behavior of linear PCL films due to UV-radiation(7). The polymer undergoes photo-degradation by free radical formation process, which can lead to a breakdown of the polymer backbone. It is noted that the study does not mention if the photo-degradation causes any discoloration or color change of the linear polycaprolactone. Neither is known if these reactions may occur under museum conditions, where UV-A and/or UV-B radiation is often filtered. The photo-degradation mechanisms of cross-linked PCL, including Aquaplast® products, can be assumed to proceed in a similar way. In general, the oxidative ageing behavior of cross-linked polycaprolactone sheets is expected to be highly dependent on its manufacturing process (exposure to heat during sheet extrusion) and the method used for cross-linking (exposure to high energy radiation).(8)

In addition to manufacturing, the application techniques used by Matthew Barney can have an influence on the aging stability of PCL in his artworks. Thermo- and photo-oxidation of synthetic polymers can be accelerated by the impact of heat *(Scheirs 2000, p. 401)*, such as produced by a handheld heat gun to thermoform the Aquaplast® sheets in *Goodyear Field*. A commercial hand-held heat gun can produce temperatures between 100 and 550 °C depending on the model. It is to be expected that the combination of mechanical stress and exposure to high heat during the shaping of the PCL Aquaplast® sheets can cause thermo-oxidation and accelerate future oxidative aging. Furthermore, the presence of possible additives such as cross-linking agents and the non-stick coating of Aquaplast® -T products, consisting of acrylic styrene, can have an influence on the ageing stability of the synthetic polymer. In conclusion, only a rough estimation of the expected photo-oxidative ageing behavior of Aquaplast® moldable sheets can be made, based on the presence of cross-linked PCL as the main ingredient and the description of its sensitivity towards photo-oxidative degradation in literature.

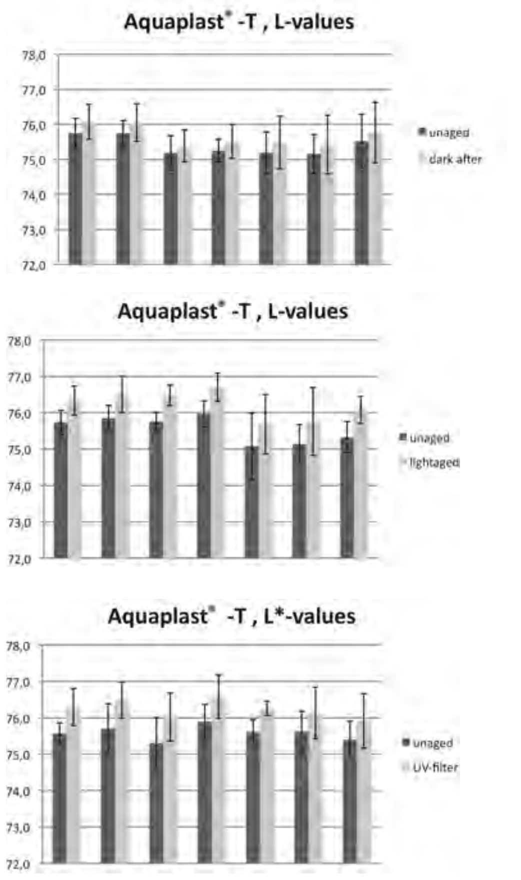


Figure 6
L*-values for Aquaplast® -T, stored in the dark, exposed to filtered simulated Schaulager light and exposed to not-filtered simulated Schaulager light. Each bar represents measurement data gained on one of seven identically treated samples.

LIGHT-AGEING TESTS ON PCL

The light stability of different commercially available PCL products under museum condition was investigated by performing accelerated-light aging tests. One test series focused on the photo-oxidative ageing behavior of samples made of linear PCL pellets melted in the oven compared to pellets melted in water. The second series investigated the light stability of Aquaplast® moldable sheets (cross-linked PCL) thereby considering the artist's working techniques and processes. Color and brightness changes of the samples were monitored colorimetrically. Furthermore, a purely visual examination (comparing samples with the naked eye in a neutral lighting situation) was performed. In this publication, the experiments regarding the photo-oxidative ageing behavior of cross-linked PCL sheets (Aquaplast® -T) used in *Goodyear Field* are presented. The investigations were performed with the following questions in mind:

1. *Is a discoloration of the Aquaplast® -T components in the work Goodyear Field to be expected due to exposure to the present light source in the storage room at Schaulager?*
2. *Is it possible to slow down a discoloration of the Aquaplast® -T components by filtering out the Ultraviolet (UV) light of this particularly light source?*

EXPERIMENTAL SET-UP

For the light-ageing experiments, Aquaplast® -T samples were exposed to high intensities of light in light-ageing chambers. Two different illumination conditions were simulated in separate light-ageing chambers:

In order to simulate Schaulager lighting conditions, eight Osram Lumilux XT T8 18W warm white fluorescent light tubes were installed in the first accelerated light-ageing chamber[9]. In order to simulate a UV-filtered Schaulager illumination, in the second light-aging chamber(10) the UV-component of these eight UV-A emitting fluorescent light tubes was filtered out using transparent sleeves consisting of polycarbonate, namely Metolight ASR UV-400 from Asmetec.

The 0.3 cm (1/8”) thick Aquaplast® sheets are cut in identical rectangular pieces of 6.4 cm (2 ½ inches) length and 2 cm (¾ inches) width. Each of the different test series includes 7 samples exposed to the same ageing conditions. The colour measurements were executed using a portable CM-2002 Spectrophotometer by Minolta with the use of SpectraMagic software.

EVALUATION OF TEST RESULTS IN REGARD TO AQUAPLAST® -T ELEMENTS IN GOODYEAR FIELD

The Aquaplast® samples were exposed for 182 days (6 months) to unfiltered and UV-filtered Schaulager lighting conditions. As a reference, a third test series consisting of the same Aquaplast® -T sample material was stored for the same span of time in the dark. The results of the colorimetric measurements are presented in the following paragraph.

Significant colour change (b* values, yellow-blue axis) of the Aquaplast® -T samples is observed after being exposed to unfiltered Schaulager light (Osram Lumilux XT). The colour values are located more on the yellow axis of the L*a*b* colour space *(Figure 4)*.

As can also be seen in the colorimetric data in *Figure 4* filtering out the UV-component in the light source prevents a significant change of the b*-values of cross-linked PCL.

Neither the a*-values (green-red axis) nor the L* -values in *Figure 5 and 6*(11) of the samples exposed to filtered and unfiltered Schaulager light changed significantly.

Furthermore, there is no significant change in L*a*b* values of the Aquaplast® -T samples that were stored in the dark for 182 days *(Figure 4, 5 and 6)*.

Based on these measurement data, it can be expected that the impact of the light source, as used for the light-aging tests and installed in the storage room at Schaulager, can influence the colour properties of the tested Aquaplast® -T material. Most importantly, it could be demonstrated that filtering out the UV-component in the light source prevents significant colour changes of cross-linked PCL. The purely visually observed colour changes of the Aquaplast® -T samples after six months of light-aging are minimal. A slight yellow discoloration of the originally white sheets can be observed, however the extent of discoloration appears to be minor, especially if compared to other photo-oxidative sensitive synthetic polymers.

These results show that the impact of light from the fluorescent light tubes illuminating the work might cause discoloration in the material over time. However, as seen in *Figure 4* filtering the UV component of the same light source prevented these changes in colour. For the preservation of Aquaplast® -T elements in *Goodyear Field,* therefore, the use of UV-filtered light at Schaulager could most certainly slow down and minimize possible light-induced damage.

CONCLUSION

The investigations of the synthetic polymer polycaprolactone elucidated the material's importance as an artistic medium for Matthew Barney, who appreciates the material's processing properties, range of design possibilities, and aesthetic effects. Due to PCL's unique characteristics and multi-faceted uses, it is foreseeable that contemporary artists will continue working with this unique material.

Although a significant body of published knowledge with regard to the technology, manufacturing, and material characteristic of linear and cross-linked polycaprolactone (including Aquaplast® products) is available, it has become obvious that there is no substantial research literature published on the ageing, including the photo-oxidative ageing behaviour of the polymer, particularly in relation to PCL used in artworks.

The question of the photo-oxidative ageing behaviour of PCL was investigated by accelerated light aging tests. The results related to Aquaplast® -T elements in *Goodyear Field* presented in this publication showed that the current light situation at Schaulager has a potential impact on the colour. The filtering of the UV-component of these fluorescent light tubes could prevent light-induced damages, such as yellowing of Aquaplast® -T components in the sculpture.

The MA thesis was undertaken to investigate an underrepresented area of study on polycaprolactone and thereby delivers a deeper understanding of PCL's technical and aesthetic properties as well as the material's degradation behaviour. Although the light-aging results show a detectable shift in colour the question of an acceptable visual threshold remains unanswered. The results of this investigation aim to provide conservators with some support when faced with the care for or conservation of this extraordinary versatile polymer in contemporary artworks.

ENDNOTES

(1) *The statements in this paragraph as well as the quotations are primarily based on an interview with the artist conducted by the author on January 9, 2013.*

(2) *Currently the studio uses the product: Capa™ 6500 by Perstorp UK, Ltd.*

(3) *M. Ryle, personal communication, production designer at Barney's studio, January 22, 2013.*

(4) *The first U.S. patent mentioning the use of PCL for the making of low temperature orthopedic casts is 3.692.023. (Philipps et al. 1972).*

(5) *Alternative spelling: poly-(-caprolactone), poly-(epyslon-caprolactone) or 2-oxepanone.*

(6) *Currently, Rolyan® Aquaplast® products are manufactured by the American company Patterson Medical Holdings Inc. (formerly Sammons Preston Rolyan) and sold by them and by large medical companies (e.g. Medline Industries, Inc.) in the United States.*

(7) *Tsuji et al. 2006 performed the light ageing experiments with Carbon Arc lamps.*

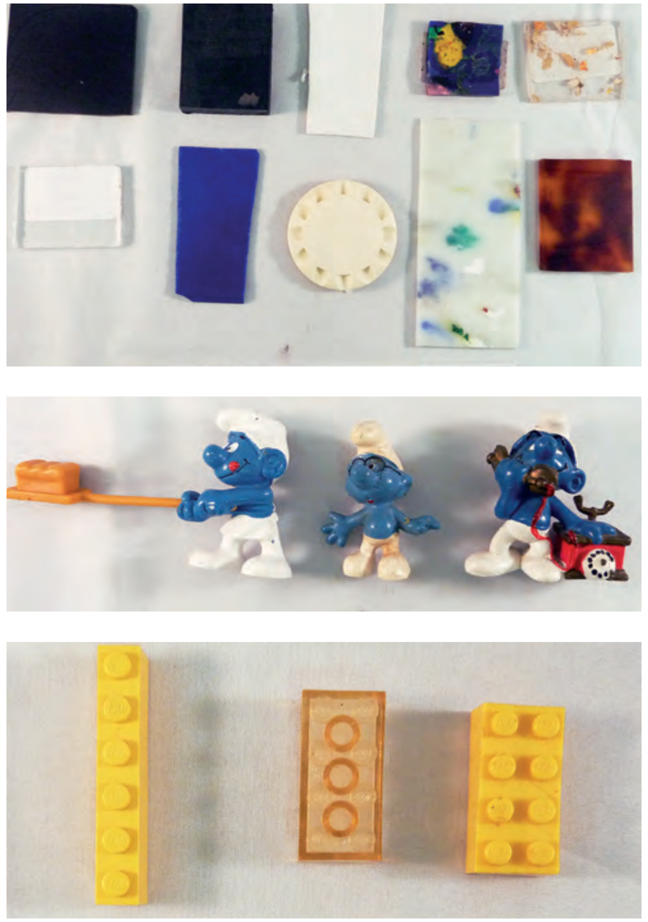
(8) *High-energy radiation, such as electron beam or gamma radiation induces polymer oxidation, leading to the generation of radicals that subsequently react with oxygen and can accelerate the auto-oxidation of the material for a long period of time after irradiation. (Zweifel 2001, p. 64).*

(9) *The total amount of light in the light-aging box with Lumilux XT T8 18W fluorescent light tubes was approximately 21,100 Lux. The lux measurement was performed in the absence of any other light source using a Gossen Mavolux 5032B. The amount of long wave UV light was 0,1589 mW/cm^2. The UV meas-urement was performed in the absence of any other light source using a Gigahertz-Optik irradiance radiome-ter X96 with a XD-9501-4 detector.*

(10) *The total amount of light in this chamber was approximately 22 200 Lux, as measured with the Gossen Mavolux 5032B. The amount of long wave UV light was 0,00211 mW/cm^2. The UV measurement was performed with the absence of any other light source using a Gigahertz-Optic irradiance radiometer X96 with a XD-9501-4 detector.*

(11) *With the exception of the L* values of one unfiltered and one filtered light-aged material sample in Figure 6.*

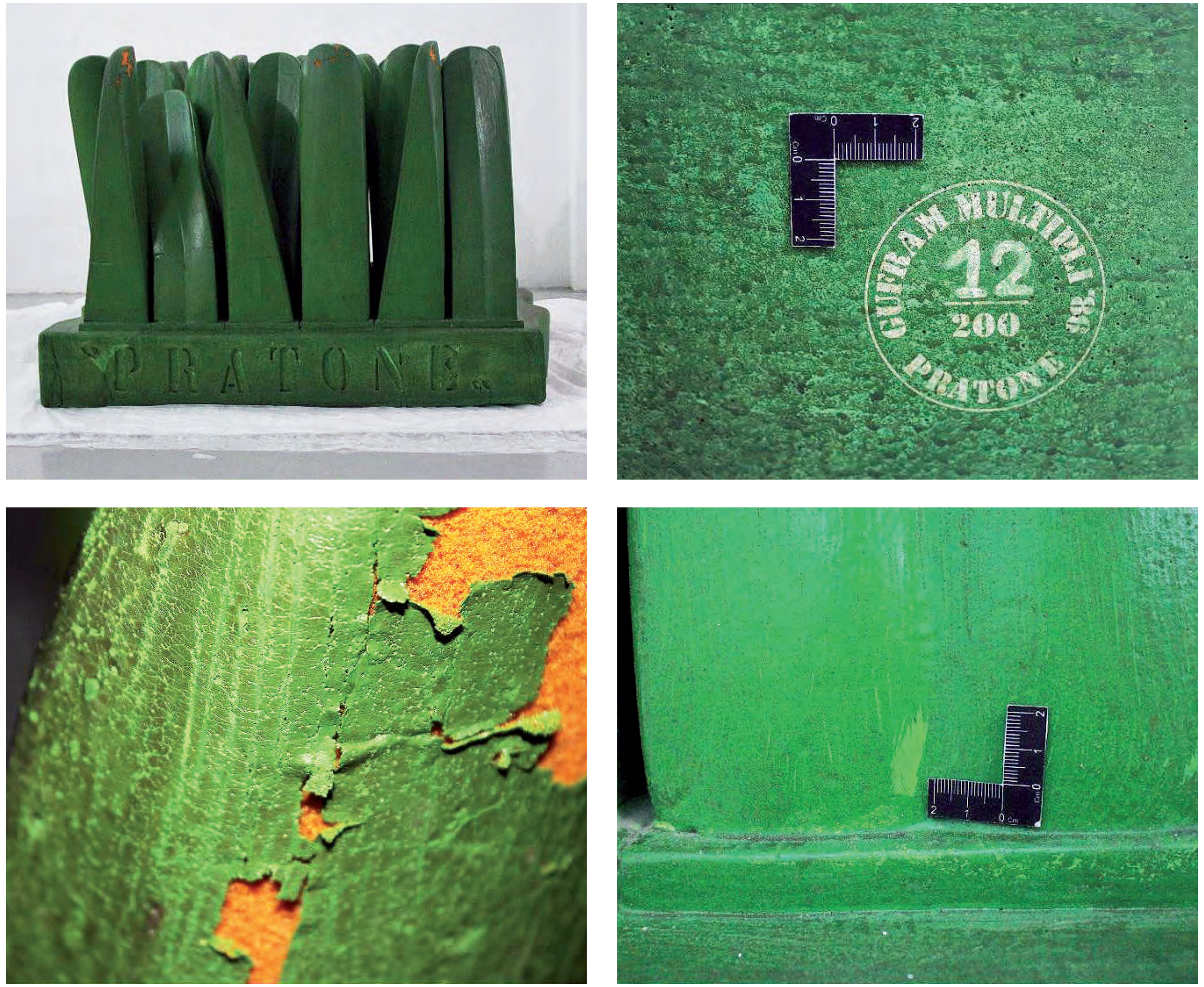
COLOUR PLATES



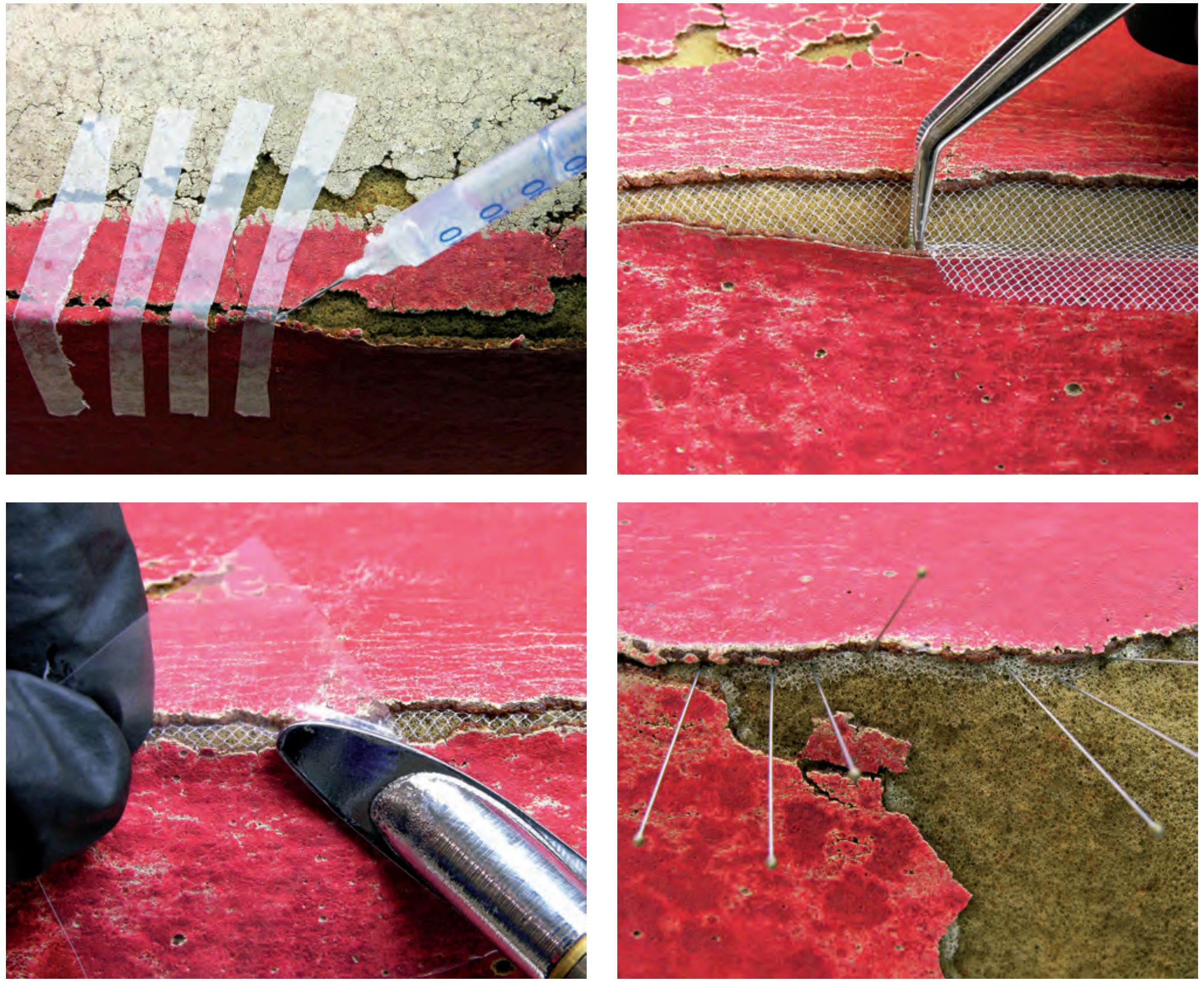
Lecture 001 / Figure 2
a) Polymeric materials provided by Collin Williamson at the POPART conference in 2012 [20]. From left to right: Vulcanite (51), High Impact Polystyrene (HIPS) (52), Urea Formaldehyde (53), PVC (54), Polycarbonate (55), Poly (methyl methaacrylate) (PMMA) (56), Melamine Formaldehyde (57), Casein Formaldehyde (58), High Density Polyethylene (HDPE) (59), and Cellulose Acetate (60).
b) PVC objects with different degree of plasticizer.
Smurf ~1980, Germany (61), Smurf ~1970, Germany (62), and Smurf ~1975, China (63).
c) Acrylonitrile (ABS) Lego brick ~1995 (64), Cellulose Acetate Lego brick ~1960 (65,66).

Lecture 002 / Figure 1
Objects from the Van Oosten reference collection showing discolouration (first 2 rows) and colour transfer from red to white plastic part (bottom row)

Lecture 003 / Figure 6
Garden lounger before (a) and after conservation treatment (b)



Lecture 004 / Figure 2
Gufram Multipli '86 – Pratone 12/200: front image and details



Lecture 005 / Figure 2
Conservation treatments – consolidation of the coating, securing the edges of the coating with synthetic netting, reshaping of the deformed edges of the coating, filling losses in the foam body with inlays

Lecture 006 / Figure 2
The Wombtomb in 2012. The photo shows how the coffin had completely lost its shape and its massive appearance compromising the artist's intention.

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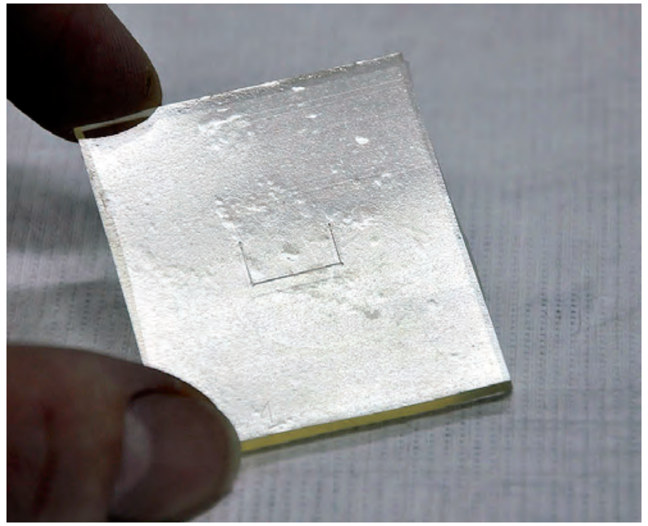
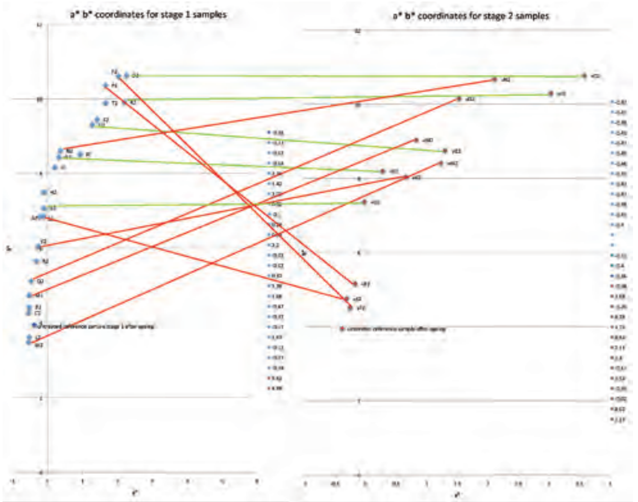
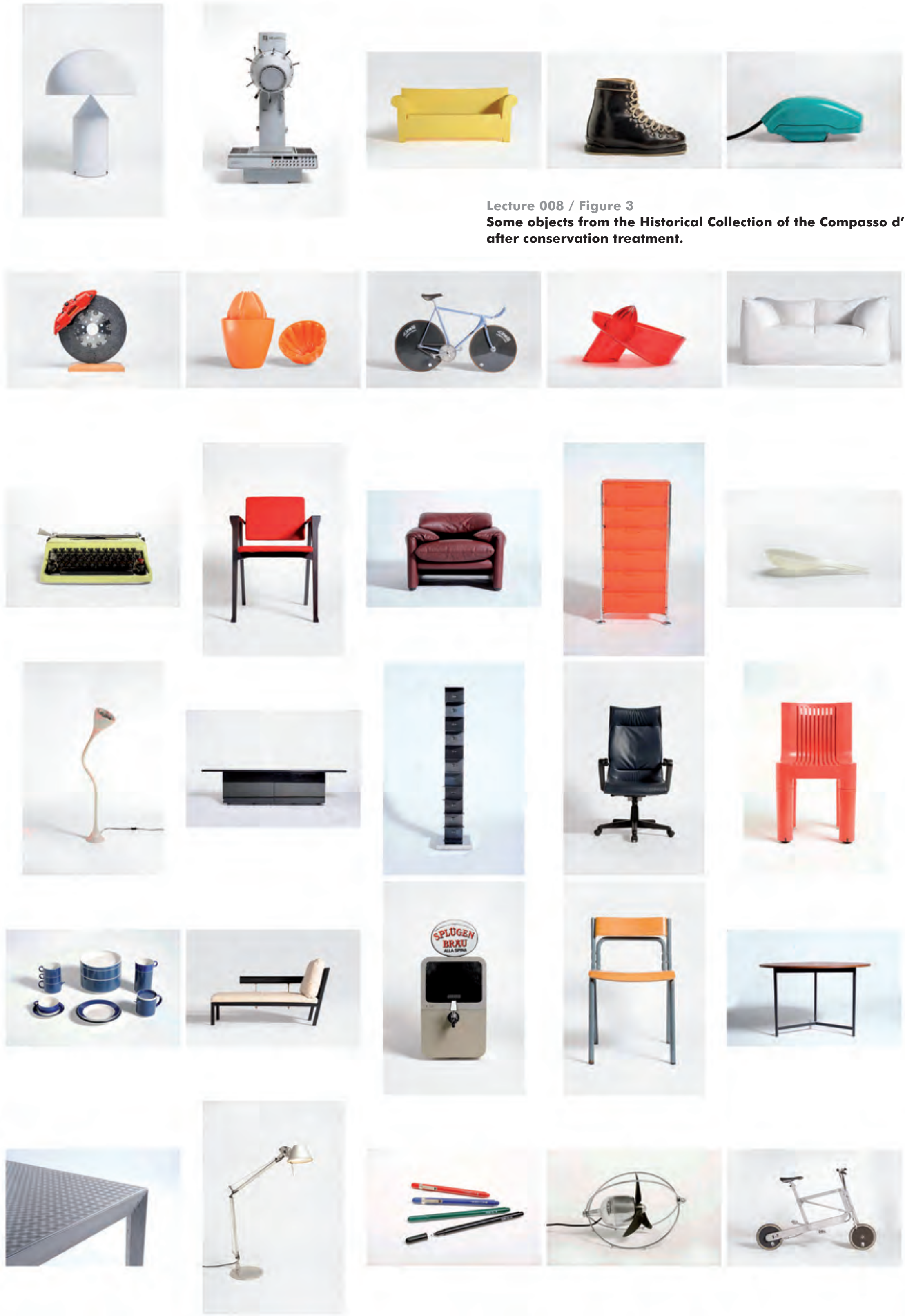


Lecture 007 / Figure 6
The shoe before (A) and after (B) conservation treatment



Lecture 007 / Figure 6
Graphs showing colorimetric data of stage 1 and 2 samples. Green lines show correspondences between stage 1 and 2 samples, red lines highlight differences.



Lecture 008 / Figure 3
Some objects from the Historical Collection of the Compasso d'Oro Award after conservation treatment.

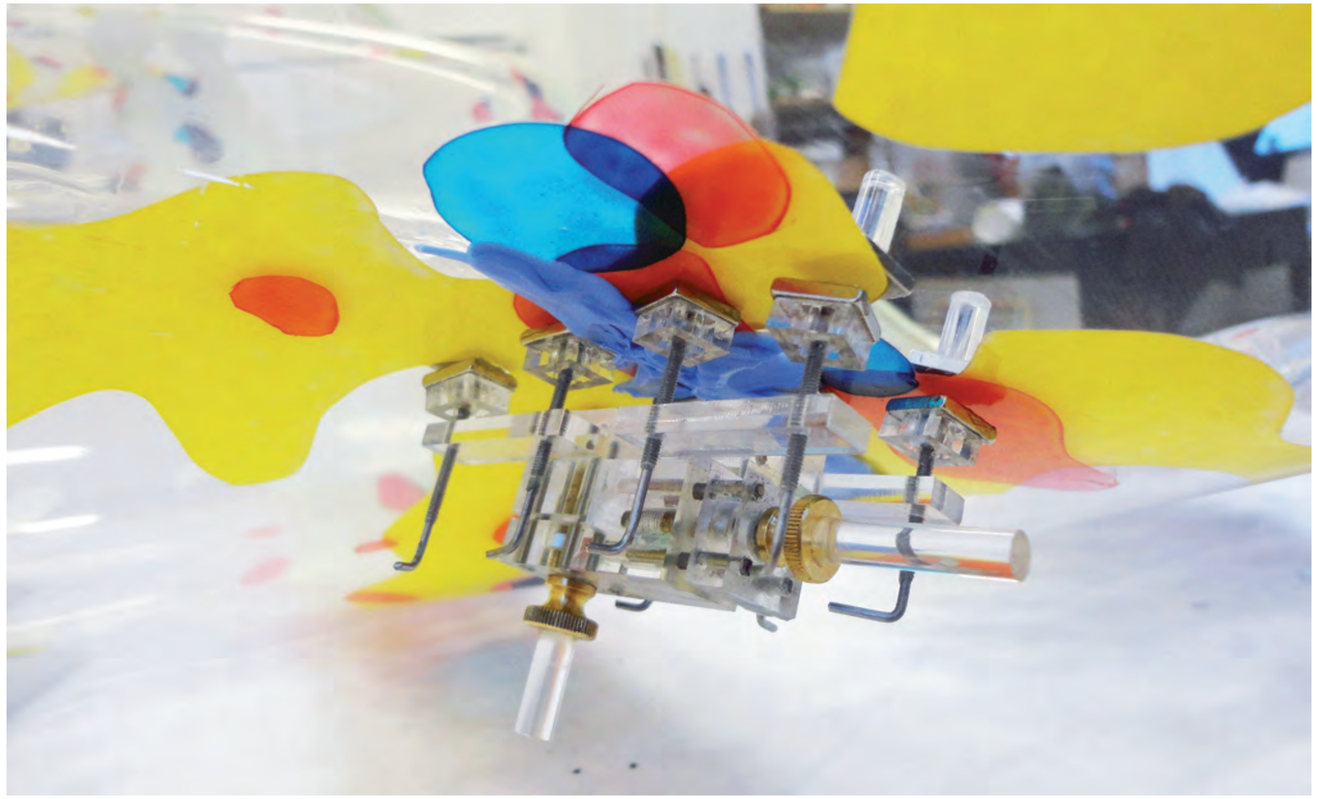
Lecture 010 / Figure 1
Car models made of industrial clay (Baron Reinhard von Koenig-Fachsenfeld, 1930s - 1940)

Lecture 011 / Figure 6
left side of the Wurlitzer 800 before and after conservation treatment

Lecture 012 / Figure 5
***Trappan,* 1967, by Kjartan Slettermark**

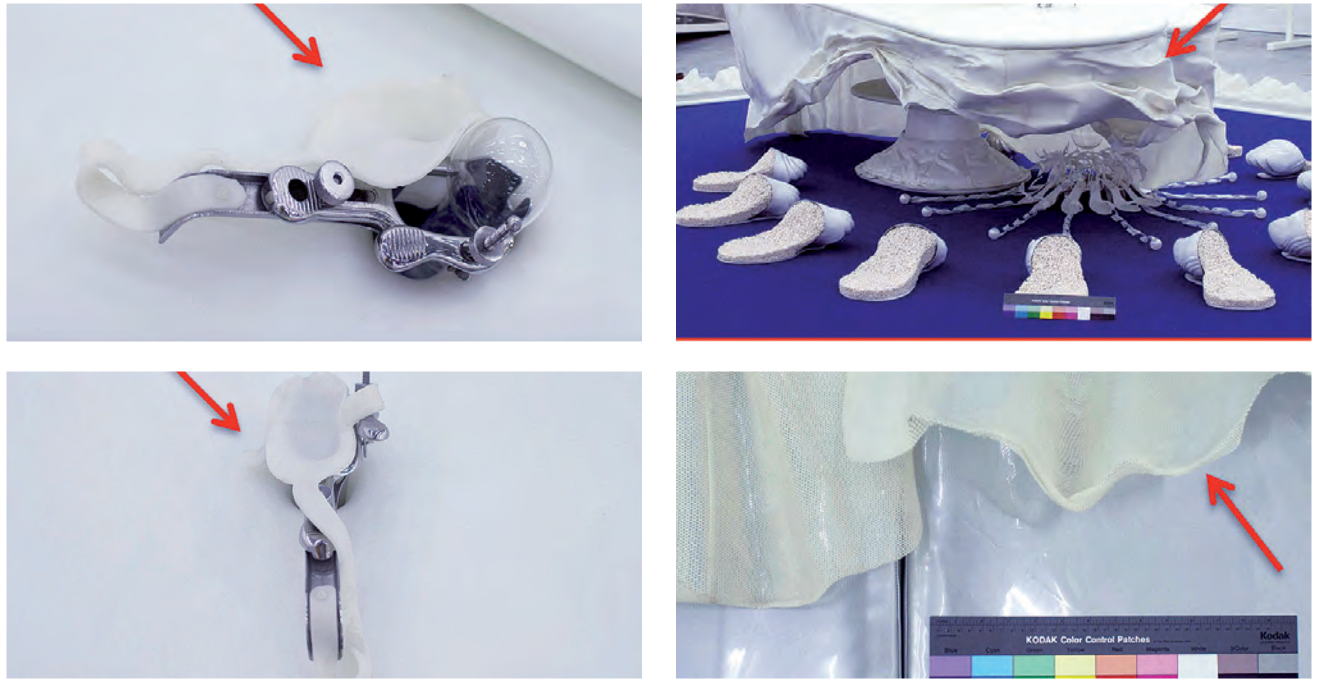
Lecture 013 / Figure 1
Panton Chair made of ASA named Luran® S, 1979

Lecture 014 / Figure 5
Magnet Spiders®



Lecture 015 / Figure 6
**Cast putties placed onto a Cameo White *Shape*.
Top row: Corian® joint adhesives,
from left to right: Cameo White, Glacier White, Bone White.
Middle row: Cameo White joint adhesive modified with ATH: 2:1, 1:1 and with additional Acrifix 2R 0190 (1:1:1).
Bottom row: Acrifix 2R 0190 with ATH in varying ratios (2:1, 1:1, 1:2) and Corian® flakes swollen in MMA mixed with ATH and Acrifix 2R 0190.**

Lecture 016 / Figure 2
**Polycaprolactone elements in *Goodyear Field:* Top left and bottom left: PCL elements on the table.
Top right: Tablecloth made of PCL sheets welded together. Bottom right: Perforated PCL sheets along the border.**



Poster 002 / Figure 1
**Norman Collins, Tattoo Flash Art (US Navy), 1964,
Ink and watercolour on thick wove cotton paper, 26 cm x 36.2 cm,
Courtesy of the Conservation Center for Art & Historic Artifacts.**

Poster 001 / Figure 1
**The PMMA slipcase belonging to
The Large Glas And Related Works (Volume 1).
Courtesy Ph. Konzett.**

Poster 003 / Figure 3
Sheila Goloborotko,
Pensamentos Comuns:
acrylic paint on cellulose acetate sheet, 2004

Poster 004 / Figure 5
a) bottom/side view of the inside of the plywood slipcase after treatment;
b) bottom view after treatment;
c) detail of polyester urethane foam with consolidated fragment.

Poster 006 / Figure 6
Detail of fading to green coat dress at the end of the exhibition run

Poster 005 / Figure 1
Wurfeisen und Zwille (Entwurf Hafenstraße), 1990 by Olaf Metzel
at the Kunstverein Hamburg in 2013.
© Hamburger Kunsthalle, VG BILD-KUNST, Bonn 2014,

Poster 003 / Figure 1
Alina Szapocznikow, Tors noyé (fragment)

PANEL DISCUSSION

PANEL DISCUSSION
FUTURE TALKS 013 OCTOBER 24, 2013
TIM BECHTHOLD, CHRISTIAN BONTEN, KONSTANTIN GRCIC, ANDREAS MAGERLEIN, NICOLA STATTMANN, FRIEDERIKE WAENTIG

MODERATION: OLIVER HERWIG

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MODERATION:
Oliver Herwig,
Journalist, Munich, Germany

OLIVER HERWIG (OH): So, there are various people here, it's a good opportunity to learn from each other and I think that's the main question: what can we learn from each other?

It's my pleasure to introduce Andreas Mägerlein from BASF, you know the big chemical country, sorry company. That was one of my running gags. The other one is 'conversation' and 'conservation'. You can be sure I will mix it up again. Andreas Maegerlein is from Ludwigshafen, he studied mechanical engineering and design and he worked as a designer before he joined BASF and is currently segment manager for engineering plastics. Please give a warm welcome to Andreas Mägerlein.

ANDREAS MÄGERLEIN (AM): Good evening, welcome to this short presentation which I will give about the creation and development of the Myto. And I will do that without having been part of the development team at that time. But nevertheless I am somehow the child of the love between BASF and industrial design because I was hired on 1 January 2008 by BASF because the company saw that there is a need for BASF to talk to engineers and industrial designers and to understand both worlds and this is exactly what I am doing and what I can do. And I will show you what the Myto is and how it came into being together with Konstantin Grcic and if anything is not right in my story please correct me because you know it much better than I do. But you will be surprised at what is coming.

BASF and product design, what does that mean? Where does this come from? If you look at BASF, it is more a town than a company. It has a site measuring 11 km2, and basically all Ludwigshafen is BASF and everybody who lives there works there. On the other hand, if you look at industrial designers, and Konstantin Grcic might know the place, it's somewhere in Munich where industrial designers work today; in this example Konstantin Grcic works close to that place. And if you look at the products, BASF just sells raw materials which are, as you can see here, granules or liquids or whatever, and industrial designers they sell ideas, they sell concepts. With those two things, the question is how do they work together, how does it fit together? And BASF sees it in the following way: you need a table. In the beginning, you always need a table even if you want to make a chair because you need a table to sit around and discuss. And you have to bring all the people to the table that are needed. An industrial designer and a chemical company are by far not enough: you need somebody who is doing the marketing, you need someone who is producing, you need a lot of people and this is what was done in the project.

In the beginning, BASF thought: let's invite industrial designers to promote a material and to promote especially engineering plastics to a world where they have not yet been used. And you can see from the pictures that Konstantin Grcic is right at that moment perhaps thinking about a product called Ultradur. He thought: What can I do with that? In the beginning, there was a workshop with those industrial designers and they went home with a bunch of ideas and Konstantin Grcic came back with the idea of making a chair out of a material called Ultradur. Ultradur is basically one of four ultra plastics that BASF sells. It is a PBT, which stands for polybutylene terephthalate. It takes quite a while to learn to pronounce it but I am five years with BASF now and I can do it. BASF has the largest PBT production plant worldwide and the plant's output equals 16 million Myto chairs per year. Just so you get an impression of the volume that we are selling. We are also the main supplier for the automotive industry, in this case electronic parts. This material has some excellent properties. And this made an industrial designer think: what else can we do apart from making parts for the automotive industry? On the other hand, you need the chemical industry because if you just start by taking a material from some producer and saying that you want to produce a chair you will get into trouble because, in the case of just this one material, PBT, you can buy 200 different types of PBT from BASF. So you need somebody who can tell you which is the right PBT to use, the amount of glass fibre you need, if you need UV stabilisers, if you need to use flowing aids. And we try to consult with industrial designers, engineers and everyone who comes to us with a project about the right material and tell people the right material to use.

So that's the first concept that Konstantin Grcic came up with. It looks quite wild but I think it was also a little bit into the process already. Basically it gives an idea of what happened then and, if you have an idea and a concept you have to think about when you want to go to market. And in this case, there was a time schedule that was very tough and extraordinary: it was one year, which was very uncommon. However, for a number of reasons the idea was to go to market at the K Fair in Düsseldorf in October 2007. I am just back from the K Fair now which only takes place every three years in Düsseldorf. And this year again, we presented another new chair from another designer and another company. But this was the starting point when BASF wanted to present a chair at the K Fair for the first time. So it started on the design side with mock-ups and raw sketches which got refined into a CAD drawing. And this CAD drawing, which was produced on the computers in Konstantin Grcic's office, was then transferred to BASF and BASF made calculations and simulations to determine whether this basic and rough chair outline would withstand the requirements and forces that are placed on a chair. And then when we found out ... above there it says you have to reinforce the chair right at this point where this arrow is ... so it got some refinement also. The surface texture of the chair was defined and with the support and consulting from BASF the texture got changed I think very often due to production limitations and mechanical constraints. But in the end we had a final texture and the final model was once again transferred to BASF where we had a look at it and checked whether it could be produced. The picture you can see there is a simulation, which is called mould flow where we show that the mould is filling properly. On the other hand, we then discuss with the producers and check whether the mould can be built and how it can be built. We support them and in the end you have a mould. And in this case the mould was very big as the chair comes out of just one mould in one shot and is produced in three minutes. And you can see here the core and cavity and that is the real value of the final product: a tool that is worth more than a house. And this is how it all looks when the tool is on a machine where it's produced and you can see one of the first Mytos which came out there.

And now, the question is what the difference is if you work together with raw materials suppliers, with engineers, with a great industrial designer? You know the Myto and the result is there. What happens if you don't do that? I think that's also a plastic chair, it's also moulded in one piece but I think there was no engineer involved, nobody told them what material would be suitable and I think nobody asked. And I think that's one of the most important things – ask. That was, in a short rush, the story of the Myto.

KONSTANTIN GRCIC (KG): Yes, the product comes out of the material and we think as far as the product and we want to make the product from the material and I would say the kind of products that we make – and this is basically furniture which is a different kind of product to a mobile phone for example – a piece of furniture like a chair can theoretically have a very long life span. We know chairs, plastic chairs, that have already lasted for 50 years and they will possibly last another 50 years. So in my field of design it is not about designing things for ever, the classics of tomorrow, none of this, but we design things with the expectation of a quality that should last and therefore my first thought is a product that will last. Of course we have to think more and more about the disposal of a product or how a product, after a certain life cycle, may be reused, recycled, there are different forms. But my answer to your question, first of all I don't think of it, I really just think of the product to begin with.

OH: Well, thank you, I guess we are in a hurry. Please take a seat, and we will move on to our next guest. I think it's more or less appropriate that after one designer we are going to grab another one. This time, Nicola Stattmann. She is a designer and materials researcher. A warm welcome to Nicola Stattmann. When she opened her studio some 11 years ago in Frankfurt, she wrote: "Our work is based on the belief that the question of material and technology must be at the beginning of product development". How many of your colleagues think likewise?

Friederike Waentig, Nicola Stattmann, Andreas Maegerlein, Tim Bechthold, Konstantin Grcic, Christian Bonten, Oliver Herwig (from left to right)

NICOLA STATTMANN (NS): I think more and more, I have to say. In those times it wasn't that usual. A designer did his sketches, developed an idea or concept then went to a company and started to think about production and engineering but times have changed in my opinion and costs are very relevant and development costs are very relevant. It's quite important that students also know which kind of material they can use. What costs does it affect? It's not that often that a company pays for a tool that costs more than a house or the same as a house or whatever. And you can explore a lot in your design and in your development. When you know it's in plastic it works like this. Or wood. What can I do with wood? What requirements do I have when working with wood? So thinking about the material at the beginning of a project is not that stupid.

OH: You're right. Well, we will now switch sides. Now that we have had designers I think it's time to step into science. I'm glad to introduce Christian Bonten. He is a professor at the University of Stuttgart at an institute whose name I have learned not to translate: Kunststofftechnologie. Welcome Christian Bonten! He studied mechanical engineering and specialised in plastic design. Your field as far as I know is biodegradable plastics. What is it?

CHRISTIAN BONTEN (CB): OK, one of my fields is biodegradation. Biodegradable means of course that the atoms of the polymer will be absorbed by microorganisms and fungi.

OH: So design eaten up by little things?

CB: By microbacteria and so on and then it will turn into CO_2 and minerals.

OH: OK, a short question, is it going to be our future? Is this kind of material changing our world?

CB: I think it might be helpful in some applications. So in some applications there is definitely a need for biodegradation. But it should not lead our society to easily get rid of waste, it should not seduce society into just throwing away plastic bags. So I hope it will not lead to that. But in some applications it is very necessary, but it will not save the world. Biodegradation will not save the world.

OH: Thank you so much. And I thought science would save the world. Friederike Waentig is professor at the Cologne Institute of Conservation Sciences and she specialises in restoring plastics. Welcome Friederike Waentig. Why do you do what you do? I mean …

FRIEDERIKE WAENTIG (FW): Good question! Then we have to start right at the beginning. I was looking for a job that had a practical and a theoretical aspect. If you work in conservation you have both. And I started with wood and I thought that wood was quite nice, it's always brown. And plastics are so nice and so colourful and you can do such nice things with plastics, more than with wood. Things like design objects fascinated me. That's how I got into plastics.

OH: Is it kind of development or is it just a shift?

FW: No, it's a kind of development. Totally.

OH: OK, wow, looking forward to hearing more from you. It's kind of awkward to introduce our host but I will do so. Tim Bechthold is head of conservation at the Neue Sammlung. He actually wrote a poem, he won't describe it that way but I thought it was a poem, as in our preliminary talks he wrote: "If you want to become a good conservator of plastics don't be afraid of plastics, of designers, of engineers, of chemical stuff, of being creative, of mistakes, of sharing your mistakes with other professionals, of interdisciplinary work, and never stop learning". I assume there must be lots of surprises in your daily work. What was the last surprise you encountered?

TIM BECHTHOLD (TB): The last surprise happened when we were preparing the glass-fibre reinforced plastics (grP) workshop for the airbrush retouching of grP and we had real problems with the materials that we got from the company. I think it was a day later or some hours later when we recognised that it didn't work and this was two weeks ago, so it was very last-minute. When we recognised this, one day later I got a phone call from our curator Dr Straßer, and he said: Okay, look Tim, over there at the auctioneer there is a globe-chair, a sunball from Rosenthal, may you have a look at it, maybe it's something where you can practise the airbrush retouching. But he didn't mean the workshop and I thought okay this was the key so this was a very positive surprise and today there were people working on it and I think it was fun for them. Yeah, it looked great.

OH: Now looking back at some 100 years of plastic design. As I mentioned before, part of it is degrading, falling apart. What are the prospects if we don't do anything?

FW: It depends what kind of plastic you have. I mean there are plastics that are a nightmare and plastics which are no problem. If you have phenol formaldehyde you're safe; if you have cellulose nitrate you have no chance. First you have to look at the type of material you have and how is it produced and then you can see if you have a chance to do something or not. The conservation of plastics is not a very well-developed field, it is just at the development stage.

OH: How do you make sure that you know everything about the stuff you are currently working with?

FW: Never. Never ever. It's like Tim said, every day it's a process of learning, every day there is something new. That's what makes it so nice.

OH: And if we were living in an ideal world what would you guys contribute to it? What would this look like? I will ask a designer maybe. Would you keep a record of all the stuff you have used, would you keep all your sketches, would you enhance your efforts in terms of science, just use one material, start at the source, at the designer?

KG: I really think, when we design things, we don't even think of that kind of afterlife, of course not. We are so engaged in the process. And I think it's important that we do not consider all the possibilities of afterlife in that process. And it's even the same for us, we only know a little bit and there is a lot we don't know while we are doing things. And we are trying things out. It is a process that needs this 'making of mistakes', it also needs our amateurish point of view. I'm not a chemist, I'm not an engineer, I'm not a plastics specialist. I work with plastics because it is one of the tools that I have to create products and I'm interested in plastics as a material and I can see a logic in plastic. As you say, some things are the right things to be made in plastic, and other things not, and some must be made in certain plastics. It is part of our work but never to the full extent of trying to understand or control everything. I don't want to sound as if we are ignorant but I think the creative process has to have a certain freedom at first and it gets narrowed down anyway and focused and specialised throughout the process. As Nicola said, as designers we have to think about materials not so much for the afterlife but performance in the first place. That chair we saw, the white chair that broke, it broke during performance so it wasn't fit for what it was made for and of course we are very concerned with that. But anything that may happen to it in its future history, we simply don't know.

NS: For my work, it is not relevant I have to say. What do museums do with the product afterwards? It's really, does it work? How does it function? Are the aesthetics all right? Can we produce it with the right tools and at the right costs? Is it ecological? How much energy do we use during production? The eco factor is becoming more and more important. And until tonight I have never really thought about what a museum will do with a product afterwards, it's not on my mind.

Nicola Stattmann:
When I'm talking to my students I say: please start thinking of biodegradable plastics. It would be so nice after a life cycle of two, three or four years – a reasonable life cycle – if it evaporates, it's gone, compostable, it doesn't exist any more. These materials are coming, I am pretty happy about that. What do you think about that?

FW: You are not the only one!

NS: I'm sure!

OH: That's kind of interesting. You mentioned the creative freedom, does it mean that you guys on the other side have to have a scientific approach to counteract it or are you forced to become an artist yourself if you restore it?

AM: Probably from a technical point of view, I can say that for me as an engineer this is really an artistic approach to say I try to conserve a plastic part, because basically I say a plastic part is a mass part and it always is because that is the soul of plastics and that's why plastics became so famous because you can produce hundreds and millions and thousands of parts and you can produce them as you like. And it's very different because you can look at the chair like the Monza here, which consists of combined materials where you have wood and plastic, compared to the Myto, which is only plastic. So in this case you can say you can't plant or grow the same tree twice but you can produce the same plastic part after 100 years because it's 100% artificial material, which is down to a chemical base that is 100% defined, so you can reproduce it whenever you want to and in the end it will be, by virtue of its chemical structure, the same as it was 100 years ago. A tree is different. And so I don't see any need to conserve plastic parts. You can just produce a new one.

OH: Good point.

TB: I think theoretically speaking it's totally right. But we already have problems. Let's take chairs for example, chairs from the 80s. If I go to the company and say can you make a new one, often it's really a problem. They've often changed the mixture of the polymers. To get the same, identical product that was made in the 80s or the 60s, from my point of view, it's not possible. And that's an issue. And also if you look at all these re-editions with new materials because they are more efficient or something like this, then for me and for the museum it's not a different design but it's a different version. If you take the first Panton which was hand-laminated, or you take the second in Baydur, in hard foam, and the third in Luran S which didn't work and so on, each version is somehow different from the sculpture and from the optical or aesthetic point of view and that is the problem or challenge that we are facing.

AM: That's true but if, at that time, if somebody had kept the mould or the recipes ...

FW: I would say no, because the task of a conservator is not only to repair but also to conserve. It's to conserve the mistakes, the historic material. It's also part of the documentation and the documentation of making mistakes and the development of the material. If I have a chair and it's just a question of repairing it I would agree, we can make a new one. But in conservation and especially in conservation in museums, the task of the conservator is to work with the curator and look back in history to see what is the history of the chair and how it was developed. What you just showed us, this is really interesting to see the development of the chair, Konstantin Grcic's first sketch is different from the chair you are sitting on. So it is a kind of development. And this chair, you couldn't have produced it 30 years ago because you wouldn't have had the materials. So this is what is interesting for conservation: to see the development of materials.

KG: The timing, when you get a historic piece of plastic and you say you will conserve it, you are freezing a moment which is already kind of old, isn't it? It just happens to be the moment when you get the chair. That is the moment you can freeze. Your conservation is therefore conditioned by the situation. You get the chair that is already 30 years old, then you can conserve it. You are not conserving it by turning it back into its original state which I think is right. Especially in plastics, I think one of the big issues in the industry is that plastic doesn't age in a nice way. A piece of wood ages really nicely. We all think that an old wooden chair is so much nicer than a new wooden chair and we would never want to bring it back into its new condition if we can have the old one as it's so much nicer. The plastics industry has not managed to produce a plastic that can age in that kind of positive way, that older means getting better, nicer, really has that kind of patina. Old plastic is scratched, it loses its colour, it may get brittle ... I'm just talking in clichés now but ...

FW: Yes, but I think if you look at the 1960s and 1970s when the first design objects emerged they had high glossy surfaces and we were really educated by the industry that this is the fine surface and you have to keep this fine glossy surface and I think it is also society which is not educated to accept a scratch on a plastic chair. I can accept a scratch on a wooden surface but I don't accept a scratch on the plastic surface. But why? What is the problem with a scratch on a plastic surface? I would accept it. I would say there IS a patina on plastics. We just have to learn to accept this.

OH: Maybe that is a good point to ask our scientists. I mean, why doesn't plastic age nicely? Or is it not so?

CB: I was really thinking about a nice plastic, I mean a nice appearance, I was really thinking about it. If I consider seeing things like Bakelite radios for example, I don't think that they don't look nice. The surface has changed a little bit but not a lot. But the surface has aged in a certain way. You can see something and it looks older. But you are right, you are totally right. Often it does not look nice. Plastic is the chameleon of materials. Usually plastic does not look like plastic, it looks like some piece of leather in your car maybe. The whole car interior is full of plastic but it looks like wood, it looks like leather. It sounds and feels good. And in this case it has to imitate something. But unfortunately oxygen, UV light etc., attack the plastic like it attacks your skin and my skin every day. In a certain way it's more organic than you think. You were saying that it's a totally artificial material. Yes, it is artificial but it‘s closer to nature than we ever thought because it's made from carbon atoms and hydrocarbon atoms so it's closer to the ageing mechanisms that we suffer from. As I said, ageing: we use the same word. When we age we usually don't look nicer afterwards. Maybe it's a question of chemistry. It's carbon atoms, hydrocarbons, maybe that is the reason, but it's not scientific.

OH: But there is no solution?

CB: I mean, we have worked together for a couple of years. Storage is an issue, to avoid UV light, avoid excessive heat, to avoid misuse of course, to reduce oxygen attack, you can somehow increase the length and lifetime and life span. From my point of view as an engineer and a materials scientist, a plastics scientist, I agree with him of course. Usually we develop a product and the lifetime might sometimes be 5 years, sometimes 10 or maybe 15 years, I don't know, whatever is calculated, and this is enough for the lifetime. And the producer does want to sell another one later and that is why we have a totally different question. We have to make sure it lasts maybe 15 years. After that we don't care any more. And this is where the guarantee is in effect for maybe15 years. So we usually forget the other side. But as long as it is real consumer products, I would say I don't care!

OH: What do we do with your 17 million Mytos every year? Is it really so?

AM: Most of it is just somewhere out on the road, in cars, definitely one of the biggest markets for engineering plastics. But the much bigger portion is not these highly sophisticated plastics, but what a lot of people recognise as the cheap plastics where we produce plastic bags or pens or whatever, plastic pieces of your daily life. And there's a big difference. That's also what I was thinking about because what you said is absolutely right. It's a lot about education. We have been educated that plastic is an artificial material while wood is not. Wood is allowed to change over time. So if you have a wooden floor and you move your furniture then you have white spots on the floor and everyone accepts that and it's OK. But if your plastic chair is out in the sun and it's getting bleached or it's yellowing and everybody says: eurggggh, plastic is crap!

OH: Is it really a question of aesthetics? Isn't it so that plastic is associated with another world, a better world? That is what people were told in the 60s. Everything is going to be bigger, better, more colourful and so it's plastic?

KG: That can be seen in the Dustin Hoffman film, The Graduate: "The future is plastic." I think this has changed .Nowadays plastic is seen as evil almost, as the fossil material that is problematic or definitely a concern. Do we continue believing in these materials or is there is an alternative, and so on. Recently I visited San Francisco and Apple, you know that great company, and they are building this new building. And I was there with a furniture company. It was like a field trip, we were talking to them, just trying to understand. These companies, they are so forward in their own world, what do they think of our world of products. And just to say that Apple, for their new offices, they want no plastic. It was like a rule for them to say: we want the best, the newest, the fittest furniture but no plastic if possible. Where we can avoid plastic, we don't want to see it.

TB: Do they lacquer their wooden surfaces?

KG: Yes, of course they lacquer their surfaces. And what you say about the wooden floor and the plastics. I know even with the company that makes this chair they have problems with the market saying this little piece of wood has a fault in it. We will send it back, it is not good enough. Even the natural material is no longer accepted as being natural and having its mistakes. Even apples have to be round and Euro standard. I think your point was really interesting saying it really is an educational shift that is needed to accept a certain form of wear or ageing, scratching, dirt, patina.

AM: I think that is a real task for industrial design because industrial design, on the one hand, is just aesthetics. But it's also trying to always transport information with a product and if you could design a product where people accept that the plastic ages and people are waiting for the plastic to age instead of throwing it away when it is aged that would be a real task for you as an industrial designer I think.

NS: But this is a question for product developers I think. You really look at the surface: is it super glossy or not glossy? How will it react to usage and so on? The thing about plastic is also that if it gets a patina, it can be really nice to have an old plastic thing from the Eames or whatever. If it's only a change in colour that's no problem, but if it breaks or if the structure is broken, then that is really bad. So this is also the idea that people have that plastics don't work for as long as wood or steel. And they are afraid of parts breaking off.

OH: And there is no solution to it?

CB: I was just thinking about saying that in this case he has a well-documented product. I mean it's a product at the moment. Maybe it's already an object but I would say it's a product you are sitting on. It's well documented. Everybody knows, I mean BASF knows the recipe. Plank I think has the moulds. You have certain knowledge as well .The issue in this case is we have a wonderful chair. I know that with PBT, which includes these UV stabilisers, this chair will last for a very long time. Maybe the colour will fade a little bit. But at the moment I think this will stand for a long time. In this case, it is a quality product, it will last longer – longer before you get it, definitely – in this case it's a totally different approach than just sitting on a cheap 5-euro chair like the one you showed us there. I don't expect that, I don't need that; if it is gone, I will throw it away. It's not good but this is what I do. I mean that's what people do. Just as a recommendation, you can bring all your knowledge together, put it in a testimonial, maybe a large envelope where BASF puts the recipe, and then put it somewhere in a neutral place so that Mrs Waentig can work with it maybe in 30 years or later when these start to get damaged. We can start it here and make it better than it is now.

FW: When you say this chair will really last a long time, what does that mean in years?

CB: I am a mechanical engineer so I think about how long it will work for, without being damaged. Of course scratches might appear ...

FW: I don't mind scratches ...

CB: It's more scratch-resistant than the current Panton chair made of PP. But of course little scratches you don't care about but I think the force transmission here, the force along we have seen, these calculations, this is properly done, the material is ageing slower than other materials. I know that. Especially these nano fillers and so on. There is high technology there. I have a good feeling that this will last for a very long time.

FW: More than 50 years?

CB: We can meet again in 50 years and I will show you my first versions of it and then we will discuss it, OK?

OH: So what would your successors in 50 years do with this kind of chair? Will they be able to repair it? Will they have a replicator like in Star Trek? Your methods are constantly expanding. As I've heard, it's getting more and more scientific. What do you think about future work in your profession? Will you be more like a scientist?

FW: Good question. I ask this every day because I also educate conservators and I ask myself what should I teach because I don't know what pieces they will be working on in 20 years. But if you look at how the conservation field is developing, there are more and more scientific elements, more and more humanities are coming in. I think we will have conservators who work more and more together with scientists, engineers, and so on, and we will have conservators working more with the humanities. So I think the specialisation in the field is getting more and more specialised.

NS: I have a question. If you have this Myto chair in a museum and it's broken all of a sudden, in 60 years let's say. And then the seat falls off, whatever, it breaks. What are you going to do? Do you glue it? For which reason? Does it just has to be connected again? Or does it has to function again? Can you sit on the chair again? What's your aim?

AM: Just buy a new one!

NS: No, it's the first series from 2008 or 2007.

FW: I would say from the historical point of view that, if it's in a museum and it's one of the first pieces in the series, then we would just try to fix it in whatever way we can develop in 60 years because if it's in a museum nobody will sit on it. So we are lucky that we can try to find a solution just to join it. What way it will be in 60 years I don't know. Maybe there will be a robot that can do this, I don't know. The question is: is it in a museum? Is it in a private collection? What is really our aim? The aim is developed together with the object and it depends on the context and the surroundings it is in. We just discussed this today. There are materials ... we were thinking of the Panton chair made out of Luran S®. We have Delia Müller-Wuesten's master's thesis, she is sitting here somewhere today. She had the task of trying to find out if she could find a solution to fix the pieces of the Panton chair so that someone can sit on it. We have to say: today, it's not possible to find a way to fix it and a way you can show it in an exhibition, bringing pieces together. So this is what we are working on, finding solutions. It always depends on what is the question you have and the object What do you want to document? What do want from the object? And if it's still in the private ... and hopefully the chair is still being produced we can buy a new one and we can compare.

AM: Just one question, just imagine the Myto will be without knowledge of anybody because we at BASF cannot tell a producer to use our material and he says from one day to the other: I'm switching materials. He has the same mould. The properties are the same, you don't feel, you don't see a difference, but in 50 years you want to do kind of a conservation. You find out it's a different material.

FW: Yes, that is why I am working together with Christian Bonten.

AM: Yes, but in this case, isn't the story more important for you than the chair itself? Such as, when did they change? Why did they change? How often did they change?

TB: I think it's both. It's the material and the story. As a museum, we always have a global view of the object or the product. We are looking for the whole documentary of the object, like moulding tools, recipes things like that. Also sketches or prototypes or models of this. In the same way, we try to keep the original. But if the original doesn't change obviously we don't spend our time just working on a broken one and indeed buying another one. That's for sure. Also we have a discussion when we are thinking about buying an object – maybe we can get an object in better condition. If it's possible. It's always the point.

FW: We have this with the changing material in the Panton chair. First it was produced in glass fibre reinforced polyester, still today in polyurethane hard foam and in in polypropylene with glass fibres. The chair changed, it's a different chair.

AM: Exactly. The properties are different, it's a different mould, it's a different process. For example, in many plastic chairs the material can be switched. The question that is interesting for me, as a material producer, is what if someone uses a PBT that does not come from BASF, does it change the value of the chair?

TB: Not the value but this is the point that we are always learning. We are never sure if the chair from today is the same as the chair that was made two weeks ago. This is why we always have to reinvent our treatments, somehow, but not totally.

KG: In the end, you are a design museum and not a technical museum or a science museum. I agree you should tell the story. For example, the Panton chair story is really interesting because the change in material was kind of caused by the fact that the early Panton chairs didn't work and technology developed and that says a lot about its time. So you have a timeline of history running in parallel with the design object and that's interesting as a design story. But I guess you don't have to educate your people here in the museum about the plastic formulas or chemistry. It's not interesting that you go that far, I guess.

FW: No, we don't go that far. And here in the museum I think you don't show chemical formulas. But as a conservator you have to have a certain amount of understanding of chemistry, otherwise I could not talk to Christian Bonten because I would not understand him.

Andreas Maegerlein:
The question that is interesting for me, as a material producer,
is what if someone uses a PBT that doesnot come from BASF, does it
change the value of the chair?

NS: We have been talking about chairs all the time. It's really nice if the life cycle of a chair is 50 years or 100 years or even longer, it's nice if it has a lifetime or life cycle like that. But what about products that do not need that life cycle? Products like consumer electronics. Very interesting also in terms of a design approach but we know that software changes every two or three years. When I'm talking to my students I say: please start thinking of biodegradable plastics. It would be so nice after a life cycle of two, three or four years – a reasonable life cycle – if it evaporates, it's gone, compostable, it doesn't exist any more. These materials are coming, I am pretty happy about that. What do you think about that? That we are going to have design products and really interesting products and the designer and the ecological people say: OK it will be air in about five years, we are happy about that.

FW: From a conservation point of view biodegradable plastics – and just what you said there about a lifetime of five years and then they are blown away – that's a nightmare for conservation. Because our task is to preserve objects. Of course if you work with designers and artists, during their development the designers are getting older and they are getting to know their objects. And sometimes they think: I want to keep these objects. So you have to think about where do I use these materials which will explode after five years and where do I not? Just now we have a master's thesis in Cologne regarding a material which is a kind of biodegradable material. It was produced in 2007 and it breaks, it doesn't wear well. We have to find a solution. We will see, it's a challenge.

NS: Do you maybe think about different methods of conserving? It's not the real product in a room. Maybe a refrigerated room or just story telling? Or a chemical code that you exhibit? Have you started thinking about things like this?

FW: Yes of course. You always have to be very open on the one hand and you also have to be very creative as a conservator. We are not artists, we are not designers but we have to understand your work. Sometimes we have to consider that we can't do anything but we can follow you and provide Sterbebegleitung, end-of-life care: if you are dying, you have someone beside you, yes you're lucky! With some objects, you know you can't do anything. But you can think about what is the best we can do for the object until it's gone away totally. Yes, that's what Tim said, we have to think about new methods, new materials and we always have to be open to think in different and new ways, we have to think provocatively to develop new things.

AM: Isn't it against the nature of a product that is meant to be biodegradable to conserve it? Wouldn't it make much more sense to show a picture and just say that it was biodegradable?

FW: Yes, and there will be a point in the future when we will only have the documentation and the picture left, but this is our task.

KG: I think this biodegradable ... it's a big myth to think that within five years this thing will dissolve into nothing. Maybe you should say ... are we talking about 100 years or how long?

CB: Under the right conditions ...Of course under the right conditions, biodegradation occurs within three months.

KG: On a kind of foil, but not ...

CB: Yes, you're right, if you have a film, a very thin film, you have to bury it underground and the microbacteria ... if it's not winter but summer they would make it within a very short time. It's very hard to control it. And now it's a telephone, it's much thicker, like a piece of wood, a branch, which would need much longer than three months of course, it is thicker, a piece of tree is thicker than maybe a phone housing and of course it would need ... but not 100, no no no.

KG: But how many years

CB: Let's say a few years, maybe, usually injection moulding is maybe 3mm or 2.5mm, this won't take that long.

AM: To answer this, some of our colleagues are now producing injection moulded coffee capsules for Nespresso systems. This has a wall thickness of 2mm and this biodegrades within one year under the right conditions. That's always the point, so if you just throw it in the forest it would take much longer so don't expect that. I think it's very funny that you are teaching students to make plastic products that are biodegradable [NS: If it makes sense for the product]. For years we worked to make woods that are not biodegradable so there are already some woods that contain more plastic than wood. So my suggestion would be just to use wood!

NS: But you can't use wood for everything. So it's really always a discussion of what makes sense, how long it will live, how long it will be usable, how much material it will take, how much it costs, and so on. And we really have to think about that if we develop products. Is it wood? Is it plastic? How much plastic and how long will it take? And that's it. Yes, and if it makes sense, like a Nespresso thing, which should evaporate even during the process, that would be wonderful.

TB: But I don't think we should be afraid of biodegradables. We just have to have a look at all these small items, which also make their way into design museums, for example, a cover for an iPhone. We have products which are four or five years old and they already have small bubbles or droplets of softener on the surface and you can't touch them anymore and they are deformed. The question is are they worth collecting but that's another point. But we already have problems with these things. And it's an issue. It's not just the biodegradables.

OH: We are just reminded to open up the discussion, your questions, your input. Looking forward to it.

AUDIENCE: Why are you so afraid of biodegradable products? Because when a biodegradable product comes into a museum and a storage area it's not degrading because the circumstances are not such that it will degrade with the water and the sun. Biodegradable plastics are made to go away because we have a lot of plastics that don't biodegrade and it's in our earth and we don't want it in our earth. Sustainability is a big thing nowadays. In China, you might have a train, where you have people going from some place to another. They eat in the train and throw away their plastic food containers. They would be biodegradable ones and not plastic ones. And for us and design, I don't think biodegradation is a big issue.

AM: Yes, you're right, it's not good that people throw away plastic things that are not biodegradable. On the other hand, if you would have biodegradable plastics, that would lead people to think they could throw away everything and it would just biodegrade. From my point of view, it makes much more sense to make the products more long-lasting and more valuable and more expensive so that people don't throw them away. It's the same with gas. People will drive cars as long as it's affordable. They will stop burning petrol in their cars as soon as it's incredibly expensive. I think it's the wrong approach to solve the problem of throwing things away with biodegradable plastics.

CB: It's an education thing, it's an education thing.

AUDIENCE: I would just like to ask a question, probably to Nicola and Andreas on the longevity of a product. When you are designing, from a business point of view, I guess you have to take the longevity into account. How strongly do you take the 'long-livedness' of the product into account when you are designing it? I'm just trying to establish how long should I be a modern materials conservator or should I just switch back to wood? Is it a strong aspect of your design – how long it is going to last? Let's just take the plastic bags that have to deteriorate. How strongly do you take it into account when you are designing the product?

Friederike Waentig:
What is the problem with a scratch on a plastic surface?
I would accept it. I would say there IS a patina on plastics.
We just have to learn to accept this.

Christian Bonten:
When we age we usually don't look nicer afterwards.
Maybe it's a question of chemistry.

NS: We take it very much into account. Furniture can last for generations, that would be wonderful, cars for about 10 to 20 years, sports equipment a maximum of 5 to 7 years, things like this. I think it's really important to think about these times. And if you have food packaging, for example, it shouldn't last longer than half a year or whatever. For me, it's a very important question in all the projects we do. And it's also a big question and a big discussion with the students. Sometimes they don't like to think about that and they want to do something with a very short life cycle in aluminium or steel or something like that. And it's always a big discussion: Is it reasonable or not? We have to think about that.

AUDIENCE: Is it dictated by a business point of view ... does it make a difference?

NS: No, it's from the user's point of view and from an ethical point of view. Absolutely. Of course, economics comes into it but I don't want to talk about these Sollbruchstellen, in English, this bad thing. It's not about making a product to shorten the life cycle because of economics. That's not in our mind. It's really about the reasonable and acceptable life cycle for the user.

OH: Would you agree?

KG: Yes, I guess I agree. I think at least it is a good question but very difficult to answer because in the end the answer is very specific to every project. Even with mobile phones. There is mobile phone A and mobile phone B with totally different producers, expectations, conditions. These discussions are very difficult to have at this very generalised level. A piece of plastic made from oil can be ecologically more sustainable than the same thing made in wood. Think of all these white plastic chairs that are everywhere in the world, think if we had to make them all from wood. There would be almost no forests left. Sorry, this is a very stupid kind of metaphor, but just to say it is very specific to each project. And as designers this is what we are dealing with, the specifics. I think as designers we have to be extremely specific and precise. We have to know a lot and go really into the depths of all the implications of a decision. Recently we were asked to design a school chair. School chairs for a company that makes them with a wooden seat shell. We started off designing this chair with a wooden seat shell because it felt just right. Yes, it's made from wood, it feels nice and also it's going to last a long time. Then we found out how much plastic is involved in the manufacture of this wooden shell and we decided to make it in plastic. And first we looked into biodegradable or eco/bio-plastics, the possibilities. It was very interesting research to find out what there is in the laboratories in the chemical companies. There is a lot. The problem in this case was we didn't get any guarantee for the life span of these plastics. They exist but if you want to use them commercially for a product like a school chair that has to have a life cycle of x years in use, the producers of the plastics would not give us the guarantee. Therefore in the end, we went for a very commercial, a very common plastic: polypropylene. But we designed the shell in such a way that we were able to use the plastic without any fibreglass reinforcement so the design of the shell, the structure of its form, created the strength. We were able to produce the shell from a very pure plastic,100% polypropylene, which performs really well but can also be recycled in a very good way. There is no downcycling and basically it is the same material you started off with. Therefore in that case I would say we were better off making it in plastic than in wood.

CB: May I make a comment on downcycling. Three days ago I had a meeting at the K Fair. It's the largest plastics exhibition in the world. It took place in Dusseldorf. So I have just come from there. I had a meeting with the largest bottler in Europe. They make sodas, mineral waters, juices, they are the largest bottling company. They told me that at the moment they achieve a rate of 60% when recycling PET bottles. SIXTY percent. They can use it as a virgin material because it is upcycled again so they increase the chain length of the polymer chain. So they can use 60% of recycled PET now. This was incredible for me. This is a very good way of doing a really closed loop in recycling. And then maybe after years and years and years when it doesn't work any more you can still bring it to downcycling and still use the energy that was kept there. I think this is a good way. I was very positively surprised.

OH: One last question, over there please.

AUDIENCE: There was a lot of discussion about educating people about the wear of plastics and the acceptance of that. I was wondering if you could comment further on how to do that since the surface quality that you talked about is so imbued in the culture.

FW: You mean how to educate people? I think Christian Bonten can say something about this because the education of people ... because Plastics Europe ... We just talked about this nice movie this morning, for example Die zwei Öltropfen. There are a lot of things happening. There is Plastics Europe ...

CB: First maybe I will make a comment. We have just talked about this. After doing research for a new chapter in a new book that will be published in six months, I received a lot of information from European industry associations. But of course I'm not sure if the information is true, they don't lie of course but I'm a bit sceptical. Then I read through all the information from Greenpeace and the BUND and other associations and I went through a lot of papers. And then I found a source. Whenever you want to find the truth I would say go to EFSA which is a European official organisation. It's not political or industry-driven. You can read a lot of publications on what has been measured with plastics and with apples and with beans and so on. You can read a lot of truth about issues and arguments here I think. I was really surprised about what I found out about plastics. I was really positively surprised. But of course some of the things were negative and I will cover them in my next book. In general, I have a very strong feeling that plastics in general provide more benefits to our society than the opposite in terms of being energy-saving, etc. We have talked about biodegradation. Maybe bio-based plastics are the key to the future. You were asking about biodegradation and I thought why didn't he ask about bio-based plastics in the future. I'm not talking about taking food from poor people. Let's talk about maybe using wood, about using grass, algae from the sea. For the post-oil era, and this will be in 30 years, I don't know how long, it will be so, so expensive we need a solution. The solutions are already in development, they are in my drawer but they are too expensive at the moment. He was asking for a polyamide, maybe a fully bio-based polyamide, I'm not sure if he thought about that. It's already there. It's maybe not the right time to decide. Maybe in five years he would trust it to use the fully bio poly-based polyamide. It might last 50 years. There are several solutions. They are coming and maybe we need another 10 years for them to be more visible.

KG: I also want to add an answer to your question. Education is not such a nice word but as designers we can help to make that shift in attitudes because we are the ones who are at the source of application. I want to come back to an interesting remark that you made in your opening speech where you pointed out that a product like the chair we did was made possible because the designer and the material company joined forces. And you just said you have something in your drawer but I just don't know about it. So we need to connect, and through my work as a designer I can be the one to apply it and bring it to market, raise awareness about it and eventually hopefully achieve acceptance. I think that's the way. Maybe at a kind of very superficial level, that kind of recycling chic has already changed some of our attitudes. Nowadays, the brilliantly perfect plastic surface is one world and another kind of attraction is in the product that shows the flaws of the material. I think, even though I call it superficial, I think there is something positive in it and something that can maybe help create a shift in the way we see plastics of different types and the way they age. Actually, I think designers are at the forefront of making this possible.

Konstantin Grcic::
I think your point was really interesting saying it really is an educational shift that is needed to accept a certain form of wear or ageing, scratching, dirt, patina.

OH: I would like to take up your notion of collaboration and formulate one final question as time is really running out. How would you see yourself, as far as new collaboration between science, design and restoration is concerned? What is your perspective on the future?

CB: I think I have shown today in three workshops that we have already done a lot of communication in the last eight years. So there is a strong connection there. And by running the designfabrik at BASF in previous years I think I have shown that I work with designers as well. So from my point of view I would only say it's a good way, we should do it. But everyone has to give more than he is used to giving, because it needs effort, you have to put energy into such a collaboration.

KG: I say what I said at the very beginning I don't really think about conservation when we design products. I mean, we think about the active life cycle of a product, we don't think about its conservation. But actually I think design museums are great because they conserve products. Really, the history of design museums is that they are study collections where we can go and learn from something that was made in the past. And we can go there and see it. Therefore I think it's fantastic that design museums conserve even the cheapest piece of plastic for some future designer who may be interested in learning something from it. Even if I say that I don't care about this, I can say that because I know you are all specialists. It is in your good hands to kind of solve all the conservation problems. I don't have to think about it as a designer but you do. I'm happy that you do because I am a visitor to a design museum and I do want to see old artefacts and I want to see them conserved as well as possible.

NS: 3D

TB: I would say we are working on this on a daily basis. I would say I feel a bit encouraged by this evening, by this round table. It's the same as working together with conservation scientists or with engineers or with designers. For our profession, it is quite important to cross over and to spread our arms and see what is behind an object or a product. In my experience, it's like kicking an open door. I am really encouraged. Don't be afraid!

AM: Basically we are working on making the products more durable. This is also something we see coming from the market. The market also wants plastics which last longer. So this is a big task for us in the future. We get requests for life cycles of 20 years, 30 years, where we can prove the life cycle for that. But I promise you will still get work in the future. Plastics will degrade and they will biodegrade definitely. That will come. Something I learned today ... you were asking about education. Education is still very, very important. I see that conserving products is also a way of educating people because if you conserve a state of patina or a state of degradation, and declare this as a value of a product, this will definitely educate people to understand that an aged product does have a value and is not just scrap.

NS: I think no scratch irritates if the product itself is really nice and fascinating. No scratch matters as long as the design and the material of the product are beautiful and as long as the function and the construction are working well. A product ages, sure. If it ages nicely it can also be seen as a new quality. As I said before, this is the first time I have thought about the conservation of products. You should work together. I think BASF can learn a lot from conservators. This durability of products is really interesting to discuss with you. Is there a finish? Is there a way of doing a restoration, a way of gluing together, of putting together, of heating the materials, of welding them together again. You should go with your experience to designers and maybe also to companies. Thank you.

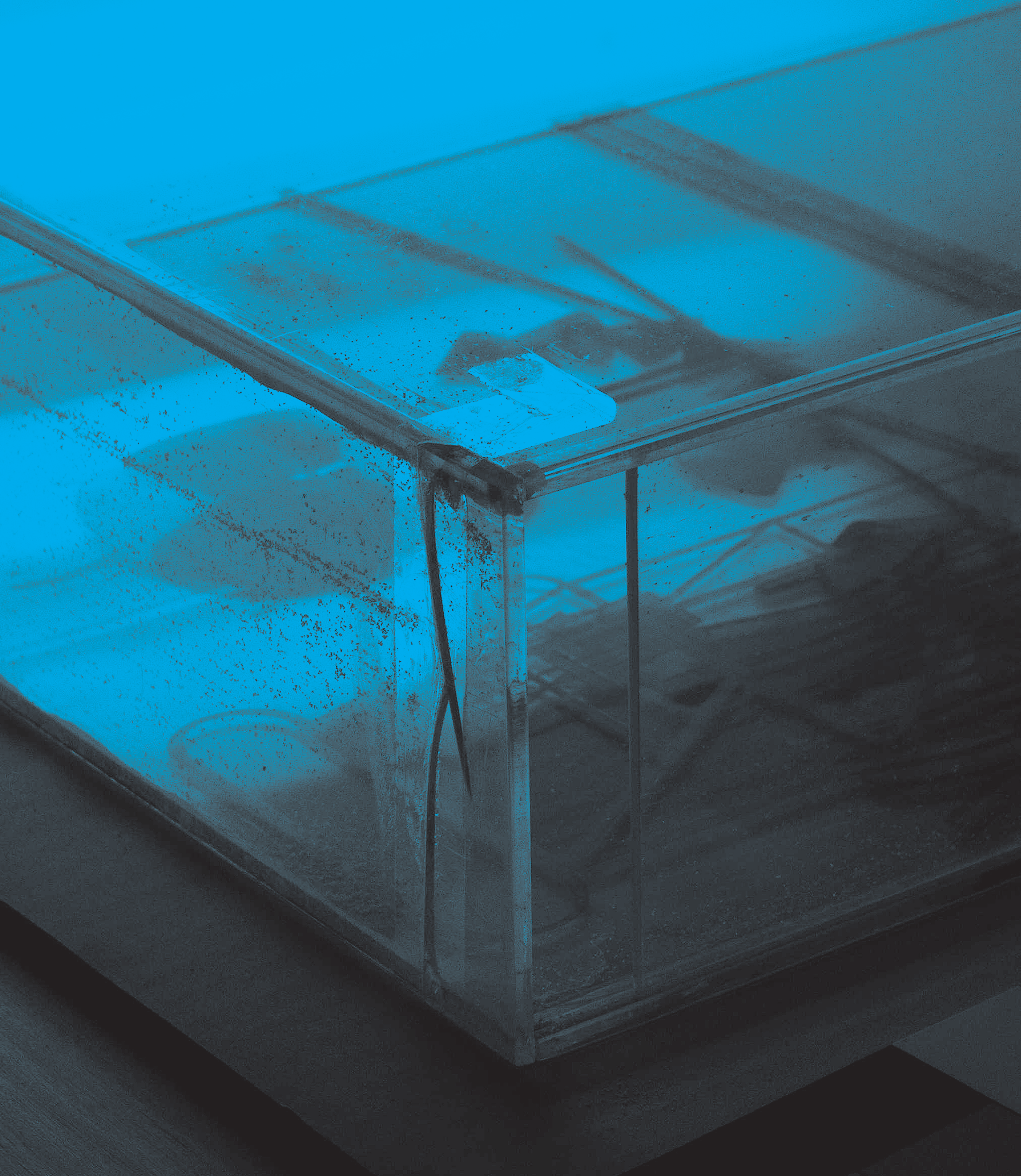
FW: What should I say now? One thing came to mind. We have a lot of plastic objects in the lab. My experience, not with BASF but with another big German plastics company, was that they don't want to look back, they don't want to talk about historic plastics, they don't want to hear that plastics can fail. For me this was quite interesting because we had an archive from the company which we were supposed to restore. We discussed whether it should go into an exhibition. And we were supposed to write an article. They said that they didn't want to hear that plastics can fail, which was quite interesting. It was in the conservation lab. We did some conservation work on it and there was a failure, so I didn't know what to write! I think it would be quite good to have the industry more open to the thinking of conservation and perhaps have a round table. The discussion this evening gives me inspiration to go on.

KG: Shouldn't you collect two of the same kind and have one deteriorate and conserve the other one so that the deterioration, which is also part of the product, is also documented, or allowed for, actually built into the product? Wouldn't it be nice to see both?

TB: We have some objects where we really discussed this kind of perspective. It would be great to have both. To have something that is aged from use or whatever, and another piece that is brand new. To see that one has a life cycle used by hundreds of people, is overpainted, and things like that. That would be brilliant, but it's not common. Yeah, we have to think about this.

OH: Well, I guess I'm not able to sum it up. We have heard so many interesting things. As an outsider I was really puzzled to know that plastic is more or less just human. We talked about funerals, we talked about the way to fade away. I think that was just wonderful. Thank you guys, you've been great, big applause.

POSTERS



POSTER
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THE CHALLENGE OF CONSERVING A MECHANICALLY DAMAGED POLY(METHYL METHACRYLATE) (PMMA) OBJECT – ADHERING AND FILLING. THE CONSERVATION OF A MULTIPLE BY ARTURO SCHWARZ AND MARCEL DUCHAMP, PART II

BY JONATHAN DEBIK, GERDA KALTENBRUNER, KARIN STEINER

ABSTRACT

The subject of this paper is a slipcase made of poly(methyl methacrylate) (PMMA) that belongs to *The large glass and related works (Volume 1)*, a boxed edition by Arturo Schwarz and Marcel Duchamp from 1967. The bottom of the slipcase was broken resulting in three different types of damages: open adhesive joints, an open fracture, and a crack, each of which required different adhesives and modes of application. In order to restore the mechanical functionality of the object it was necessary to readhere the open joints with the 2-component epoxy resin HXTAL NYL-1 due to its high tensile strength. Degalan PQ 611 N on the other hand was chosen to adhere the open fracture and for filling the crack to meet the aim of retreatability and/or reversibility to the greatest possible extent.

KEYWORDS

Poly (methyl methacrylate), PMMA, adhering, filling, Degalan PQ 611 N, HXTAL NYL-1

INTRODUCTION

The following case study focuses on the conservation of a PMMA slipcase belonging to *The large glass and related works (Volume 1)*, a boxed edition by Arturo Schwarz and Marcel Duchamp from 1967. Each of the 150 published multiples is composed of a box made of plywood that contains a slipcase made of PMMA that again contains a set of etchings reproducing motives and notes relating to *The Large Glass*, one of Duchamp's major works.

This paper focuses on the conservation treatment of the breakage in the bottom of the PMMA sheet, although the entire conservation of this object involved further treatment steps, which are omitted from this paper.

The graphic reproductions of the edition and the silkscreen print on one side of the PMMA slipcase refer to *The Large Glass* (original title: la mariée mise à nu par ses célibataires, même), one of the major works of Duchamp. Many years after he had stopped working on *The Large Glass* Duchamp published most of the notes and sketches he had made in preparation for the artwork in the form of an edition of facsimiles called *The Green Box*. Because these notes are essential for the work's reception, the Green Box can be considered as “a part” of *The Large Glass (Tomkins 1987: 10). The large glass and related works (Volume 1)* also includes graphic works referring to *The Large Glass*, which were exclusively printed for this edition by Duchamp *(Schwarz 1997: 245)*. Therefore *The large glass and related works (Volume 1)* may also be understood as an extension of *The Large Glass*, given the fact that Duchamp declared it as “unfinished” in 1923 *(Tomkins 1987: 10)*.

The large glass and related works (Volume 1) in its materialized form could stand for the idea of Duchamp's Boîte-en-valise, since it contains various motives from *The Large Glass* inside the slipcase that itself may represent a smaller version of *The Large Glass*, hence forming together with the plywood box a box-in-a-box-system. In this sense the purpose of the plywood box and the PMMA slipcase is not only to hold and protect the set of etchings, but also they must be considered as an integral part of the artwork.

THE PMMA SLIPCASE

The slipcase (h/w/d: 42.2×7×25 cm) is constructed of five PMMA sheets of 3 mm thickness and bonded with an adhesive based on PMMA. Both acrylic materials were identified by Attenuated

Figure 1
The PMMA slipcase belonging to
The Large Glas And Related Works (Volume 1).
Courtesy Ph. Konzett.
(see colour plate, p. 171)

Total Reflectance Infrared Spectroscopy (ATR-IR). A sixth sheet of PMMA is vertically inserted at one of the narrow sides to close the slipcase. Considering the date of the work it can be assumed that the PMMA sheets were cell cast, given the fact that extruded PMMA in plate form did not emerge before 1978 *(Sale 1993: 326)*. On the inner side of all adhesive joints a thin and even, 1 mm wide layer of adhesive was deposited during the joining process. Under high magnification a fine network of mainly parallel oriented cracks is visible which is causing a slight hazy appearance of the adhesive layer.

BREAKAGE AND PREVIOUS TREATMENTS

At the location where the inserted PMMA sheet meets the bottom of the slipcase a section of the bottom sheet was broken. The breakage had occurred due to a vertically induced force, presumably caused by inserting the front sheet or the graphic reproductions with too much impact. The loose fragment had previously been repaired twice, having left two generously applied adhesive layers on the surface. After loosening again, this fragment was subsequently temporarily attached by the current owner with a pressure sensitive tape.

ATR-IR analysis indicated that the upper adhesive layer consists of an ethyl acrylate-methyl methacrylate copolymer. It is spread in a narrow area following the course of the fracture edges. ATR-IR analysis of the second, bottom adhesive layer identified PMMA to be the main component. It was applied rather thinly except for the area near the fracture edges, where the thickness of the film partially increases. The adhesive was smeared with a finger after application as can easily be seen in raking light.

ATR-IR analysis of the tape revealed that the adhesive layer mainly consists of poly(-2-methyl butyl acrylate) with a polypropylene film serving as the carrier.

DEVELOPMENT OF A CONSERVATION STRATEGY

In the current state it was impossible to close the slipcase properly and the original purpose of this component of the artwork was no longer served. As the usage of the slipcase is an intended feature of the edition, this function was to be restored by reattaching the loose fragment in a manner that the adhesive joint should be able to withstand any stresses that might occur during future handling. In addition, the transparency of the damaged area should be re-established as far as possible.

For a good optical result a transparent, colourless adhesive with a refractive index (RI) close to that of PMMA *(RI = 1,492; Domininghaus 2008: 522)* was needed. The ideal adhesive should already have been long-term tested for the use on PMMA and have proven not to promote crazing or undergo noticeable discolouration. Furthermore, the reversibility of the added material as well as the retreatability of the damaged area should remain possible on a mid- to long-term scale. The newly established joint should act as predetermined breaking point, hence it should have a lower tensile strength than that of PMMA with 80 N/mm^2 *(Domininghaus 2008: 521)*.

With these goals in mind it soon became clear that one single adhesive could not fulfil all requirements. Therefore, the damaged area was divided into three sections *(Figure 3)*, each representing a different category of damage and hence necessitating an individual choice of adhesive and mode of application:

a) *Open adhesive joints:*
The original joints between the loose fragment on the bottom and the adjacent side sheets were broken.
Each fracture started at the front side of the slipcase and extended with a length of 2 cm.

b) *Open fracture in the bottom sheet:*
The fracture had developed as two arcuate break lines, which extended through the full width of the bottom sheet and met approximately in its middle.

c) *Crack through the loose fragment:*
Where the two arcuate break lines met, a crack of 2 cm in length continued through the loose fragment, following the direction of the shorter arcuate line. The crack had a maximum depth of 1,5 mm as it did not penetrate through the entire thickness of the sheet and was merely open on its upper side.

In order to ensure a strong and preferably invisible glue joint, the tape and all residues of the former adhering processes that covered the fracture surface as well as the surface near the fracture edges had to be removed.

Figure 2
Breakage in the bottom sheet (here on the left side)
with attached self adhesive tape.

REMOVAL OF ADHESIVE RESIDUES

The tape was detached by peeling it off slowly and consistently in a flat angle. As expected, it could not be removed without leaving small residues of the adhesive film on the surface.

For all three different types of adhesive residues tests for their removal were carried out. Both mechanical removal, the use of solvents and a combination of these two methods were taken into account. Solvents considered safe for treating PMMA are mainly deionized water and aliphatic, non-aromatic hydrocarbons *(Rapoport 2009: 36)*. The duration of contact of such solvents and PMMA should be kept as short as possible, as crazing could even be caused by prolonged exposure to aliphatic hydrocarbons *(Sale 1993: 328)*. For the planned treatment the use of deionized water, 2,2,4-Tripenthane (isooctane) and ShellSol D40 was considered. The best results for removing the still viscoelastic residues of the adhesive film from the tape were achieved by swelling with ShellSol D40. The adhesive increased in flexibility and after a few seconds could be peeled off with the tip of a wooden stick. The residues were removed entirely using this method.

The ethyl acrylate-methyl methacrylate copolymer based adhesive could also not be removed without the use of a solvent. As a slight increase in the flexibility of this adhesive was observed after contact with deionized water, a solution of 5% Tylose MH1000 in deionized water was applied and covered with a polyester sheet. Thinner parts of the adhesive layer were peeled off with the tip of a wooden stick after an exposure time of eight minutes, while the thicker parts still showed no signs of increased flexibility. However, some delamination between this upper and the underlying adhesive layer took place, visible as a slightly blue haze between the two layers. After an exposure time of 15 minutes the upper layer could easily be lifted with the tip of a scalpel.

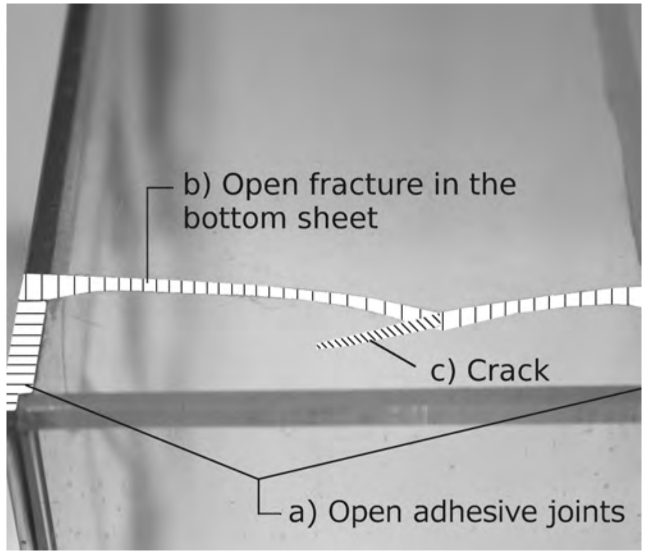

Figure 3
Detail of the slipcase upside down.
Division of the breakage into three sections.

The lowermost adhesive layer, based on PMMA, showed no signs of swelling in any of the tested solvents even after one hour of contact. Therefore, the possibilities were limited to mechanical removal. A blunt scalpel blade was used as a tool and in order to prevent scratching of the PMMA surface this step was carried out under 100-times magnification. On the fracture surfaces the adhesive layer was too thin to be clearly distinguished from the original material, which is why its removal was omitted in these areas.

EVALUATION OF POTENTIAL ADHESIVES FOR THE THREE DIFFERENT TYPES OF DAMAGE

According to current conservation literature there are only three adhesives, respectively resin-solvent systems that have undergone long-term testing and proved to cause no crazing or cracking on PMMA under the tested conditions:

HXTAL NYL-1

HXTAL NYL-1 is a two-component epoxy resin, which has a relatively high tensile strength with an average of 2.26 MN/m^2. During polymerisation almost no volume shrinkage occurs. After artificial thermal and light-induced ageing and the combination of both it shows only a slight yellowing *(Sale 1993: 334)*. Although the RI of 1.52 is not exactly matching the RI of PMMA, the visible result is satisfactory. Laganá and Van Oosten suggest this adhesive for the filling of cracks because of its low viscosity *(Laganá and Van Oosten 2011: 6)*. According to Sale HXTAL NYL-1 could be a suitable adhesive for PMMA. Even if the adhesive is not reversible with solvents the retreatability of the joint is possible in case it should fail *(Sale 2011: 13)*. Because of the very high loading capacity of the adhesive joint, its only slight yellowing on ageing *(Wanner 2009: 393)* and the fact that it has already been long-term tested, HXTAL NYL-1 has been taken into consideration for this project. Due to the fact that it can only be removed mechanically which means that removing the film from the crack would be impossible, a potential use of the epoxy resin is limited to the open adhesive joint and the open fracture.

PARALOID B 67: PARALOID F 10 (1:1)

The (1:1) mixture of Paraloid B67 and Paraloid F 10 dissolved in mineral spirit 60-140 °C seems to be a suitable medium for adhering PMMA, as it is reversible, not subject to yellowing on ageing *(Sale 2011: 10)* and has been successfully used for this purpose *(Lorne 1999; Wolf 2005)*. An average tensile strength of 0.34 MN/m^2 had been determined *(Sale 1993: 334)* and the refractive index of 1.48 is very close to that of PMMA, which provides a very good optical result *(Laganá and Van Oosten 2011: 5)*. The use of the resin mixture could theoretically be considered for this project however, Paraloid F 10 is no longer available on the European market.

DEGALAN PQ 611 N (FORMERLY KNOWN AS PLEXIGUM PQ 611)

Degalan PQ 611 N used as a solution in isooctane has already been long-term tested for the use on stress loaded PMMA and has been shown to cause no damage over an observation period of three years *(Comiotto and Egger 2009: 66)*. Although in comparison the RI of 1.45 is much lower than that of PMMA, the joint provides a good visual result for the treated objects in a case study undertaken by Laganá and Van Oosten *(2011: 6)*. The tensile strength seems to be very low at an average of 0.006 MN/m^2 *(Varchmin 2010: 109)*. Since Degalan PQ 611 N is a buthyl methacrylate, it may cross-link during ageing under the influence of light and may become less soluble over time *(Varchmin 2010: 117)*. The use of Degalan PQ 611 N was taken into consideration for the filling of the crack and the open fracture in the front area of the bottom sheet. It does not seem advisable to use it on joints that are exposed to high mechanical stresses as the tensile strength of the adhesive film seems much too low.

Based on this evaluation it was decided to use two different adhesives taking into account the different categories of damage and the special requirements related to them.

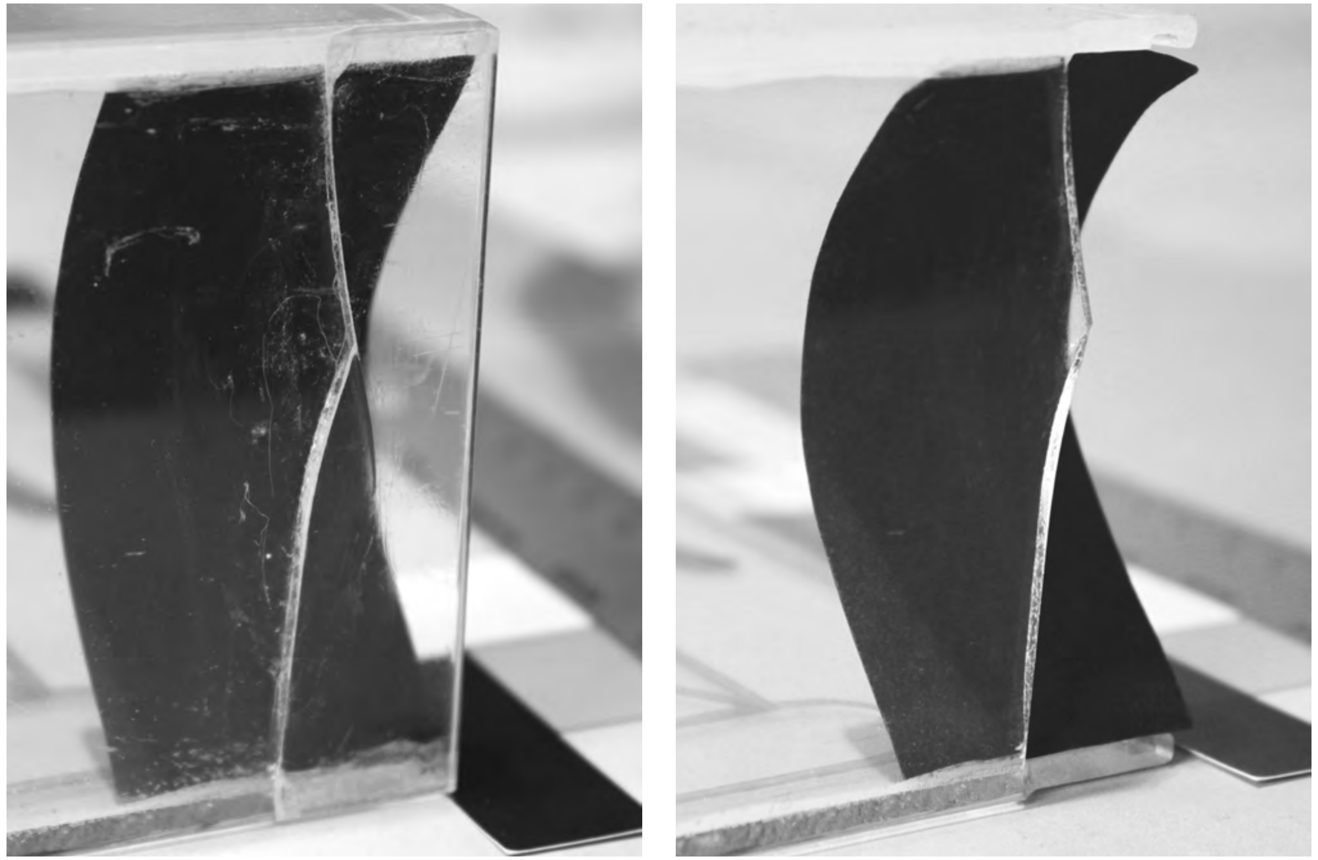

Figure 4
Area around the breakage before and after the removal of the adhesive layers.

OPEN ADHESIVE JOINTS

In this area the highest stresses are expected during any future handling of the slipcase, demanding an adequate loading capacity of the readhered joint. Due to the location of the fracture the visual quality was not as important as the stability of the joint since the original joints do not appear to have been absolutely transparent anyway. Moreover, the glue joints of the reattached fragment will be best visible only from below. The epoxy resin HXTAL NYL-1 was chosen for this purpose, primarily because of its high tensile strength. Its tendency to slightly yellow during ageing seemed acceptable in this particular case.

OPEN FRACTURE OF THE BOTTOM SHEET

Assuming that sufficient stability is reached in the reattached open adhesive joints, the treatment of the open fracture on the bottom sheet mainly had an aesthetic function as it served to restore the transparency of the area. In this case the best possible optical properties of the adhesive film had greater priority than a high stability of the joint. Since the fracture extended all the way through the PMMA sheet any discolouration of the used adhesive could become noticeable over time. As some of the old adhesive residues could not be removed completely and remained covering the fracture surface the visual result of the treatment could not be predicted in advance. Hence it seemed important that the joint could be opened easily in case a correction was necessary. For both reasons it was decided to use Degalan PQ 611 N to fill the void which the open fracture had caused, providing that an even and continuous film could be achieved after drying. The poor tensile strength was acceptable since the stability was expected to be provided by the areas adhered with HXTAL NYL-1.

CRACK THROUGH THE LOOSE FRAGMENT

The crack will barely be exposed to mechanical stress, so the filling of the crack primarily aimed to restore transparency. Since accessibility was limited, the adhesive had to have an appropriate viscosity that allowed it to be drawn into the crack by capillary force and gravity. Degalan PQ 611 N dissolved in aliphatic hy-

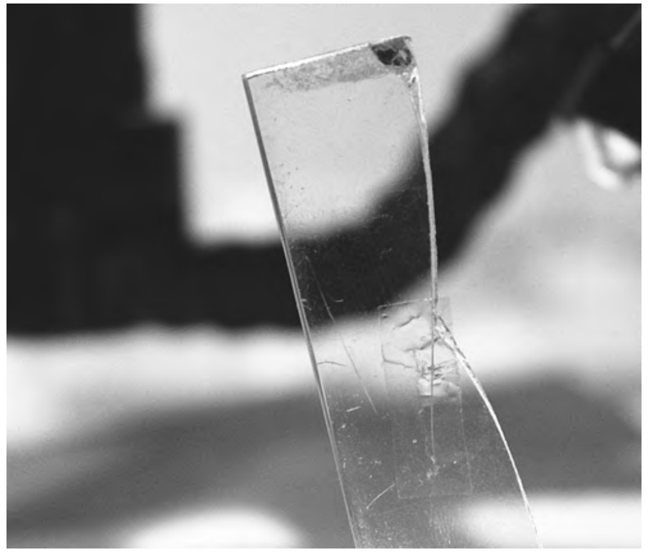

Figure 5
Upright position of the crack during the drying process of the adhesive. The edge of the filled crack is sealed with a polyester sheet.

drocarbons and used under specific conditions of application, is considered to be one of the "safer" adhesives for adhering PMMA. If an even and continuous film can be achieved after drying Degalan PQ 611 N would seem to be the best choice to fill the crack.

Adhering and filling of the different sections of the breakage had been carried out in three stages that were scheduled in the following order:

1.) *Filling the crack with Degalan PQ 611 N as its accessibility was best at the beginning of the treatment.*
2.) *Adhering open adhesive joints with HXTAL NYL-1 to establish a stable joint.*
3.) *Filling the open fracture in the front of the bottom sheet with Degalan PQ 611 N to regain the transparency of the sheet material.*

FILLING OF THE CRACK WITH DEGALAN PQ 611 N

To successfully use Degalan PQ 611 N to fill the crack it was necessary to find a suitable solvent, an ideal concentration and an optimal application technique. Tests were carried out beforehand on strips of new PMMA sheets with a thickness of 3 mm that had been purposely damaged by mechanical impact to create cracks. Aliphatic hydrocarbons isooctane and Shellsol D40 were chosen as solvents for the resin.

For application a small brush and a syringe with two different needles were tested. Experiments with Degalan PQ 611 N in isooctane in a concentration of 20% and 30% showed that application by brush was unsuitable because most of the solvent evaporated on the way from the jar to the crack. Using a syringe and a needle with a diameter of 0.5 mm worked best. In all tests an extreme shrinkage of the adhesive film became apparent during the drying process, resulting in a fine network of vesicular voids inside the joint. Those voids were inaccessible for any corrections because the adhesive had already formed a solid film at the edge of the filled crack.

To study the effect of a solvent with a lower evaporation rate, tests were carried out with Degalan PQ 611 N dissolved in Shellsol D40 at concentrations ranging from 20% to 33%. However, except for a prolonged drying time, no significant differences in film formation were noticed.

As a next step it was tested whether the distribution of the medium could be positively influenced by means of gravity, i.e. by putting the crack in an upright position during the drying process. In order to extend the drying time the surface along the crack was covered with a polyester sheet, which was applied to the small excess amount of adhesive along the edge of the crack. As a result of the upright position and the extended drying time the adhesive formed a more or less continuous film at the lower part of the crack whereas a network of voids mainly appeared in the upper area.

Further tests showed that by reintroducing more adhesive at regular intervals and before drying set in, the amount of voids in the adhesive film could be reduced. Filling was here carried out in a horizontal position, drying took place in the upright position of the crack.

A promising result was achieved by starting at the pointed end of the crack, filling one third of its length with 25% Degalan PQ 611 N in Shellsol D40 and covering the side with polyester sheet afterwards. After an hour a small amount of adhesive was applied on top of the already treated area, followed by sealing the side again. Filling the whole crack was carried out using this method.

The same procedure was then used for the treatment of the loose PMMA fragment. A first phase of filling took about eight hours. After pausing for 12 hours more adhesive was applied four times in two hours on the upper end of the crack where voids started to build up. After this phase of filling no change in the formation of some remaining voids was visible, which hence seemed unavoidable. The excess material along the edge of the crack was mechanically removed under 100-times magnification with the tip of a scalpel after one to three days of drying time.

ADHERING OPEN ADHESIVE JOINTS WITH HXTAL NYL-1

The two-component epoxy resin HXTAL NYL-1 was applied to each of the open adhesive joints of the loose fragment in the shape of a narrow line using a syringe. The amount needed to completely cover the fracture surfaces without too much excess material had previously been determined empirically on mock-ups. The fragment was adhered under slight pressure and fixed in this position with clamps. After a drying time of three weeks the removal of the excess adhesive was carried out under 100-times magnification using a scalpel. The glue joints appeared slightly more transparent than the adjacent original joints because the epoxy resin had formed a homogeneous film without the fine cracks that could be observed in the original one. Nevertheless, this result was acceptable because the emphasis was here placed on the stability. Moreover, the great transparency of this new joint in contrast to the original one is only perceivable when the slipcase is turned upside down.

FILLING THE OPEN FRACTURE IN THE BOTTOM SHEET WITH DEGALAN PQ 611 N

The filling of the open fracture was carried out following the same method used for filling the crack. After 30 days the polyester sheet was removed, however it turned out that the adhesive had not dried and remained tacky on the inside of the sheet. Such slow drying process was unexpected and had neither occurred in any of the test series, nor in the filling of the crack. Within 48 hours following the removal of the polyester sheet several vesicular voids formed in the filled fracture.

However, the voids that formed inside the crack during the drying process of its filling were now almost completely filled with additional adhesive, probably due to the long exposure time to the solvent vapours.

A set of additional tests on mock-ups showed, that the film quality of an already dried adhesive film with voids could be positively influenced by the exposure to ShellSol D40. The solvent was applied directly onto a small area that contained voids in the filled fracture and was subsequently covered with a polyester sheet. After around 16 hours the adhesive film sagged down slightly and some of the voids were now accessible for filling with additional adhesive. In the mock-ups of this test series an almost continuous film could be created this way, so it was decided to carry out this step on the filled open fracture of the slipcase, starting with a small area. Once a day a small amount of solvent was added and three days later a few of the voids were accessible for filling with more adhesive. Due to the promising result the procedure was carried out simultaneously on further areas along the open fracture, which showed numerous voids. After 36 hours a change in the formation of the voids was observed. During the next three days, the accessible voids were filled with adhesive and in the following covered with polyester sheets. However, finally the treatment caused an unexpected change: after complete drying smaller voids appeared, covering the whole length of the open fracture. The differing outcome compared with the mock-ups could probably be explained by differences in the texture of the fracture surfaces, which were still covered with adhesive residues. Also, it is likely that the solvent had penetrated the entire width of the fracture and hence had an intense effect.

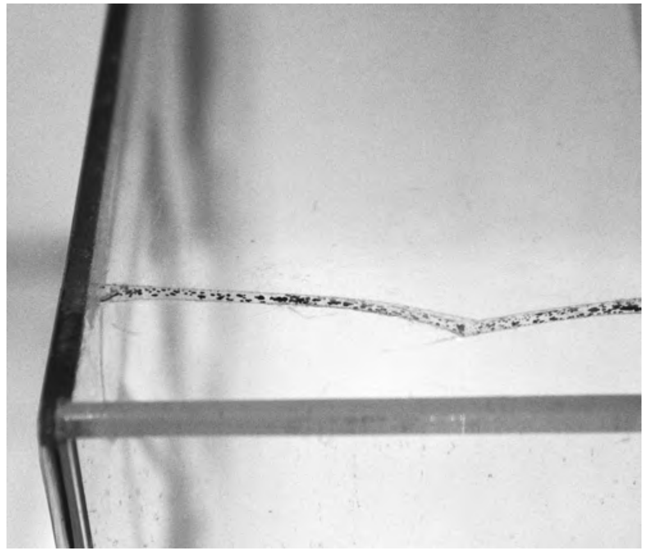

Figure 6
The breakage after the conservation treatment.

As each removal of the adhesive and the new filling implied additional long contact of solvent and PMMA and as it was uncertain whether a better visual result could be obtained, no further steps were taken.

RESULT

The crack was filled with Degalan PQ 611 N as a first treatment step, with only developed a few and hence acceptable voids in the film. However, after filling of the adjacent open fracture these voids disappeared completely presumably because of a process of redissolving and rearrangement of the adhesive film and the crack was barely visible. Despite successful results on mock-ups, redissolving the adhesive in the treated fracture did not lead to an improved outcome. The conservation treatment of the open adhesive joints, performed with HXTAL NYL-1, lead to a load-bearing joint with an acceptable visual result.

Taking into account the position of the damaged and treated area on the bottom of the object and considering the visual appearance of the object as a whole, the final results of the adhering and filling seemed satisfactory.

CONCLUSION

Mechanically damaged PMMA can show diverse types of damage which require different conservation approaches that one material alone – regarding the choice of adhesives – is unlikely to fulfil. Hence, the first steps could be to classify the different areas of any breakage and selectively use different adhesives, in this case HXTAL NYL-1 and Degalan PQ 611 N, in combination. The shrinking of the Degalan PQ 611 N film due to solvent evaporation and hence the formation of voids in the centre of the adhesive layer was the reason for developing an alternative mode of application and additional measures to be taken during drying time. Although satisfactory results could be achieved, the requirement of minimizing contact time between PMMA and solvent could not be fulfilled and the formation of a continuous film could not be guaranteed. Therefore, a further step will be an investigation into the drying process of this adhesive in order to find a successful way of creating a continuous film without prolonging the exposure time of PMMA to a solvent. This research is currently being carried out by the corresponding author in the context of a diploma thesis.

ACKNOWLEDGEMENTS

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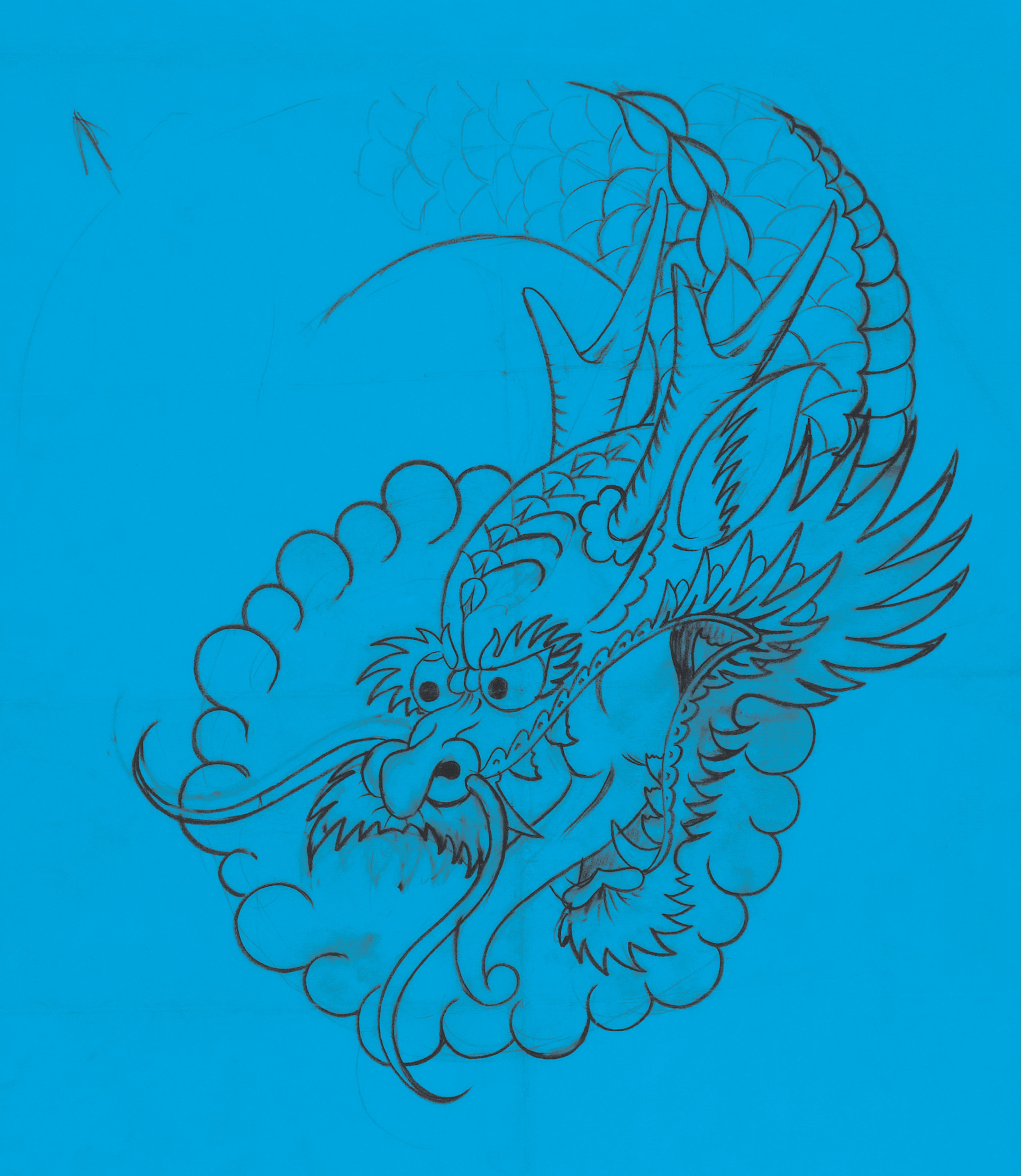


POSTER
002
THE LINK BETWEEN FLASH AND FLESH: THE PRESERVATION OF SAILOR JERRY'S TATTOO STENCILS

BY SAMANTHA SHEESLEY

ABSTRACT

Norman Keith Collins, known as Sailor Jerry, elevated the status of tattoos to fine art. He built a reputation for quality work, which attracted customers in spite of the cost. His studies culminated in a style that combined bold colors and designs with iconic Americana imagery.

Sailor Jerry's original tattoo flash, acetate stencils, sketches, and rubbings were examined, treated, housed, and framed at CCAHA to the highest standards for long-term preservation and exhibition.

The collection as a whole illustrates the progression of a tattoo design. However, the acetate stencils were of particular interest. Stencils had been used to transfer designs from the flash sheets onto the customer's body. The designs were inscribed in pieces of acetate with a stylus, tracing the outlines from the flash through the transparent acetate. Charcoal was then rubbed into the inscribed lines, and then transferred onto the customer's body. Having been replaced by modern digital technology, they are artefacts of a lost tattoo craft. Exhibiting discoloration, embrittlement and planar deformations, the stencils presented significant challenges due to their composition and inherent vice. Understanding their significance to the collection and their need to travel for exhibition prompted investigations into physical and chemical stabilization and secure housing.

KEYWORDS

tattoos, stencils, cellulose acetate, mending plastic, Lascaux acrylic adhesive, sealed packages

NORMAN "SAILOR JERRY" COLLINS

Norman Keith Collins, known as Sailor Jerry, has helped to elevate the status of tattoos to fine art. A renaissance man of his time, Jerry was interested in art, electronics, politics, and business. Early in his career, he travelled the globe with the Navy, eventually landing in Honolulu to set up a tattoo shop on historic Hotel Street in Chinatown. He built a reputation for quality work, which attracted customers in spite of the cost. During a time when trade secrets were guarded, he befriended the most talented tattoo artists in the world, corresponding only with those whom he tested and deemed worthy of his attention. His studies culminated in a style that combined the bold colours and designs seen in Japanese tattoos with iconic Americana imagery *(Hardy 2007)*. Sailor Jerry, who longed for the day when tattooing would be seen as fine art, would be pleased to learn that his flash, stencils, rubbings, and sketches underwent full conservation treatment at the Conservation Center for Art & Historic Artifacts in Philadelphia, Pennsylvania.

THE SAILOR JERRY ART COLLECTION

Twenty-six sheets of Sailor Jerry's original flash, 148 acetate stencils, and nineteen preliminary sketches were examined, treated, housed, and framed to the highest standards for long-term preservation and exhibition. The colourants used to create the bold flash art found on the walls of Sailor Jerry's shop remain brilliant, mainly due to the conscious decision of the artist to invest in quality materials. The acetate stencils, yellowed, brittle and distorted, are artefacts of a tattoo craft made obsolete by technological advancements. The sketches illustrate the confidence and control Jerry had over his hand and tools.

THE ACETATE TATTOO STENCILS

This collection reveals the progression of the artist's idea as seen in sketch form, its realization in full colour flash, the translation onto the acetate stencil, and the rubbings taken from the stencils. However, the acetate stencils were of particular interest. Stencil cutting was one of the first trades learned during a tattoo apprenticeship. Using a 78 rpm phonograph needle in a pin vice, designs were engraved into acetate supports, carefully following the underlying contours of a drawing *(Hellenbrand 2002)*. It was a way for aspiring tattooists to familiarize themselves with designs, and to develop a steady hand. Charcoal was then rubbed into the inscribed lines so that the design could be transferred to the customer's body. The stencils could be cleaned and reused, making the tattoo process more efficient. Crayon rubbings of

Figure 1
Norman Collins, Tattoo Flash Art (US Navy), 1964, Ink and watercolour on thick wove cotton paper, 26 cm x 36.2 cm, Courtesy of the Conservation Center for Art & Historic Artifacts. *(see colour plate, p. 171)*

Figure 2
Norman Collins, Tattoo Stencil (Sailor's Grave), Mid 20th Century, Charcoal on Acetate, 15.2 cm x 11.4 cm, Courtesy of the Conservation Center for Art & Historic Artifacts.

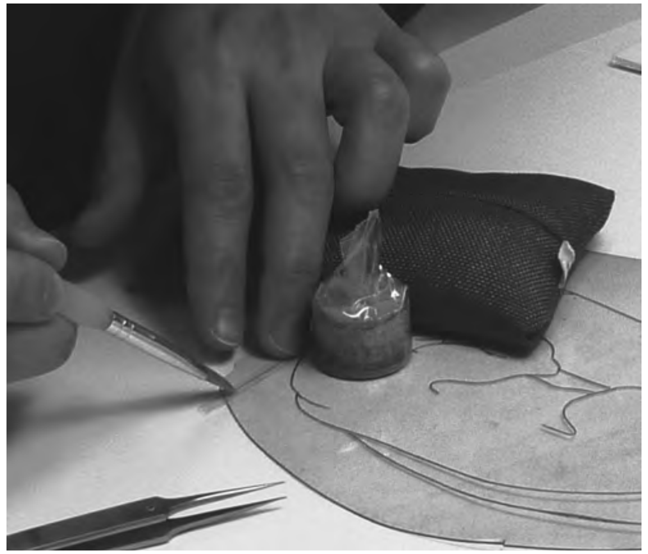


Figure 3
Mending an acetate stencil with Tengujo and Lascaux 498 HV reactivated with ethanol

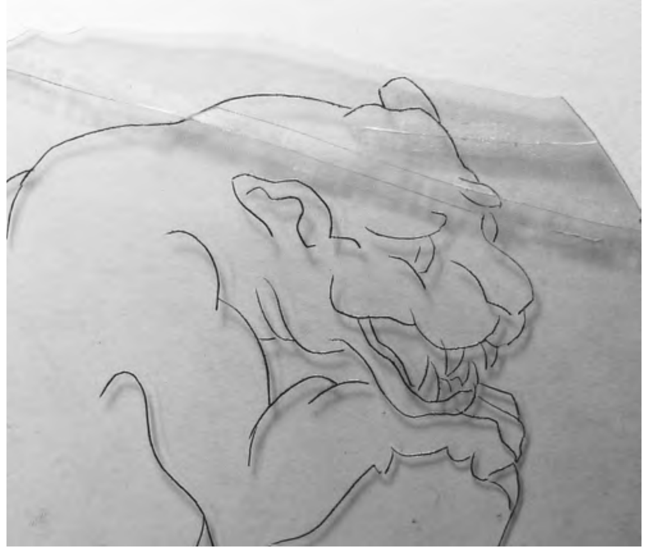


Figure 4
Broken acetate stencil after mending

stencils allowed tattoo artists to share designs between shops. Replaced by modern technology, such as thermographic prints, these acetate stencils are true artefacts of a lost tattoo craft *(Hellenbrand 2002)*.

CONSERVATION TREATMENT

Exhibiting characteristic deterioration in the form of discolouration, embrittlement and planar deformations, the acetate stencils presented significant challenges due to their composition and inherent vice. Understanding their significance to the collection and their need to travel for exhibition prompted investigations into stabilisation and secure housing.

Decisions regarding the degree of surface cleaning were carefully weighed. Because the charcoal rubbed into the incised lines is evidence of history and use, the inscribed side of each stencil was gently cleaned with a soft brush so as to remove extraneous dirt that could transfer during handling or while housed without disturbing the charcoal medium. The smooth side was cleaned with a soft polyurethane sponge to remove dirt and grime, revealing as much detail as possible in each design.

Breaks caused by handling and manipulation of the brittle stencils were mended with a non-aqueous adhesive and visually unobtrusive reinforcement strips. Tengujo, a fine mulberry paper, was coated with Lascaux 498 HV acrylic adhesive and dried. Narrow mending strips were cut from the coated Tengujo and positioned over the realigned breaks. The adhesive was reactivated with a minimal amount of ethanol on a fine brush and gently burnished into contact. The result was a strong, flexible, nearly invisible mend to the deformed, transparent and hydrophobic supports.

HOUSING

Once cleaned and mended, special considerations were required to house the stencils. The stencils needed to be secure for travel, handling and display. Challenges bought forth by the hydrophobic nature of the transparent supports were compounded by the stencils' extreme fragility and severe distortions.

Due to exhibition and storage space limitations, the stencils were divided into thematic groups. As was done for the flash art and drawings on transparent paper, each group of stencils was housed in a sealed package consisting of: window mats and backboards cut from 8ply ArtCare paperboards, ultraviolet filtering acrylic glazing, and Marvelseal 360 (University Products). When sealed to the acrylic glazing with Scotch Brand #415 tape and heat, the Marvelseal 360 provides protection against pollution and mitigates damages caused by changes in relative humidity, which is known to promote acid hydrolysis in cellulose acetate *(Mills and White 1994)*. The ArtCare paper products are made from lignin-free and sulfur-free alpha cellulose that include zeolites to capture and neutralise acids, pollutants and degradation products, such as acetic acid (Conservation Resources).

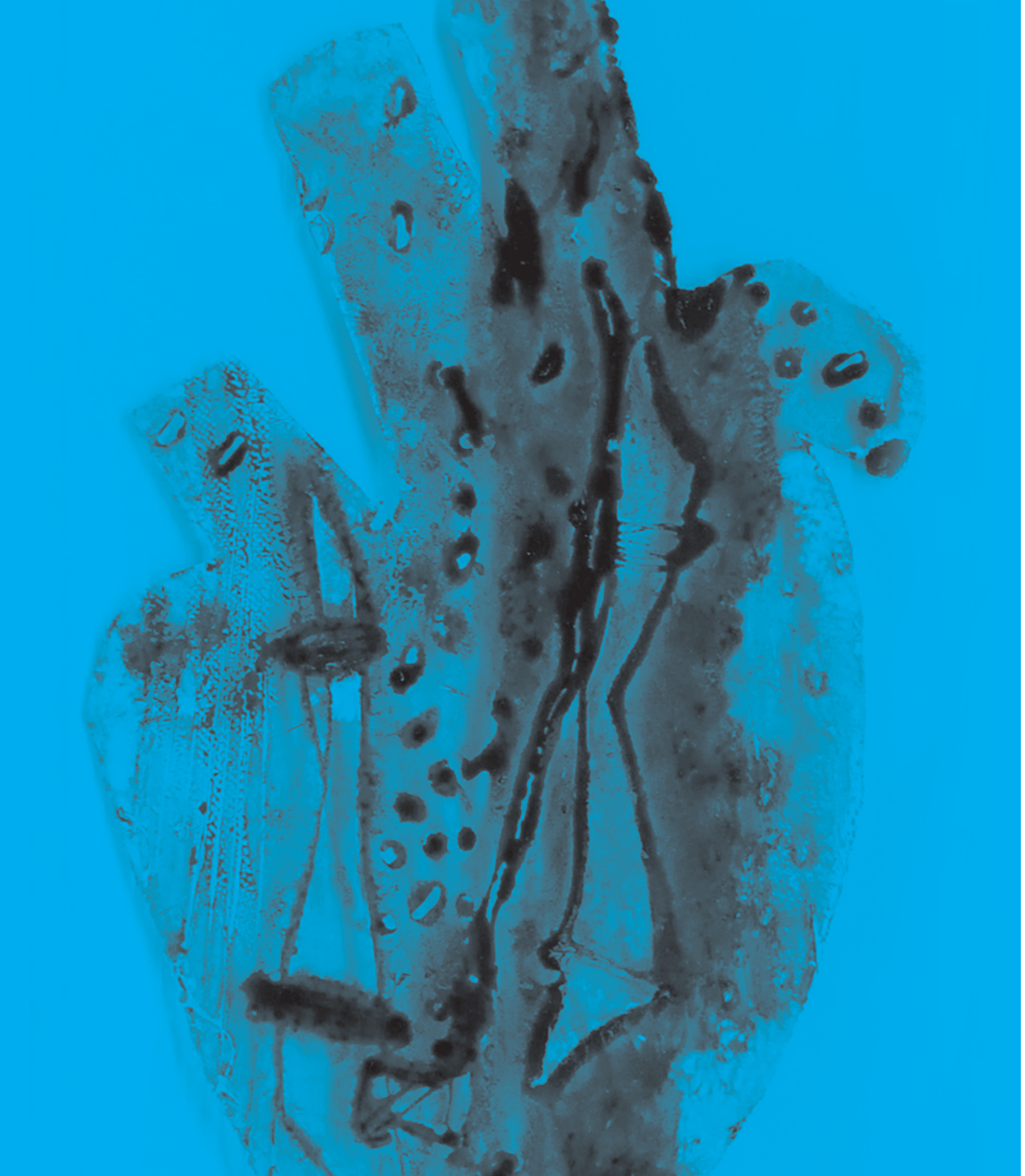
A visually unobtrusive, non-adhesive, system was devised to secure the stencils in the mats using perimeter "clips" made from narrow strips of polyester film. The polyester film strips were threaded through slits in the backing boards around the perimeter of each stencil. The strips were gently curled down by the acrylic glazing when placed on top of the window mats, cradling the edges of stencils with minimal pressure and maximum stability.

RESULTS

The result was a display of acetate stencils, which were cleaned and stabilized without compromising the contextual and historical significance as trade tools. Their presentation is aesthetically pleasing for exhibition, their mounts are secure for handling and transport, and the use of ArtCare matboards and Marvelseal will mitigate degradation.

Figure 5
Securing a stencil to ArtCare backing board with polyester film clips

Figure 6
Group of acetate stencils in a sealed package and new frame



POSTER
003
CONSERVATION OF PLASTICS AT THE PINACOTECA DO ESTADO DE SAO PAULO, BRAZIL

BY PATRICIA SCHOSSLER, CAMILLA VITTI MARIANO, TEODORA CAMARGO CARNEIRO, VALÉRIA DE MENDONÇA

ABSTRACT

This paper presents the results of a survey conducted in the collections of the Pinacoteca do Estado de São Paulo, which aimed at identifying the plastics used within objects and developing ways of conserving those. A total of 71 objects were identified, which were either made entirely of (semi) synthetic polymers, or in which plastics had been used together with other materials in the object's creation. Although most of the objects surveyed were in good condition, it was possible to observe differences between the plastics most susceptible to degradation (cellulose nitrate, polyvinyl chloride, poly(methyl methacrylate), rubber, and polypropylene) and the more stable synthetic polymers. In addition to the survey's results, this paper discusses three case studies in which inhibitive conservation procedures were carried out as an attempt to slow down the degradation of objects made from or containing unstable plastics.

KEYWORDS

Plastics, identification, conservation, cellulose esters, polyvinyl chloride

INTRODUCTION

Over the course of the last twenty years, scientists and conservators have become increasingly interested in the processes that lead to the deterioration of synthetic polymers within artworks and conservation treatments for these materials. Surveys conducted in various European museums have concluded that certain plastics and mixed media objects show signs of severe degradation in spite of being rather new. In a study conducted at the British Museum, most of the plastic objects examined were considered to be relatively stable, but around 0.5 per cent showed signs of active degradation *(Shashoua and Ward 1995)*.

At the Stedelijk Museum in Amsterdam the condition of synthetic polymers was found to be more worrying: around 20 per cent of the objects examined in 1995 required conservation treatments or were in an unacceptable condition *(Keneghan, van Oosten, Lagana et al. 2012)*. When the Stedelijk Museum conducted a new survey in 2010, which included the re-examination of objects that had previously been examined in 1995, the results revealed that 35 per cent of the objects had deteriorated over the last 15 years, but that the condition of some (15 per cent) had actually improved due to conservation actions *(ibidem)*. Recent surveys have also revealed dramatic changes in the condition of some polymeric materials in collections at the Victoria & Albert Museum and at three public museums in France *(ibidem)*.

The rapid and irreversible degradation of some synthetic polymers, and the lack of established restoration procedures available for many of these materials, is a cause for concern. At present, the active conservation treatment utilised on objects made from polyurethane foam stands out from other active treatments available for plastics, since it is the result of a systematic scientific research. The treatment retards the rapid oxidation of the polyurethane ester based foam and prolongs its lifetime *(van Oosten 2011)*.

A considerable number of publications regarding the conservation of plastics therefore stress the necessity to control degradation causing factors (light, oxygen, acids, relative humidity) to slow down the deterioration of objects in storage or on display. The advantage of such procedures is that they can be employed at relatively low costs and are easy to implement, though they do not address the issue of active conservation.

The advantage of such procedures is that they can be employed at relatively low costs and are easy to implement, but they do not address the issue of active conservation.

In addition to the known instability of many historic synthetic polymers the ever-expanding range of plastics and rubbers

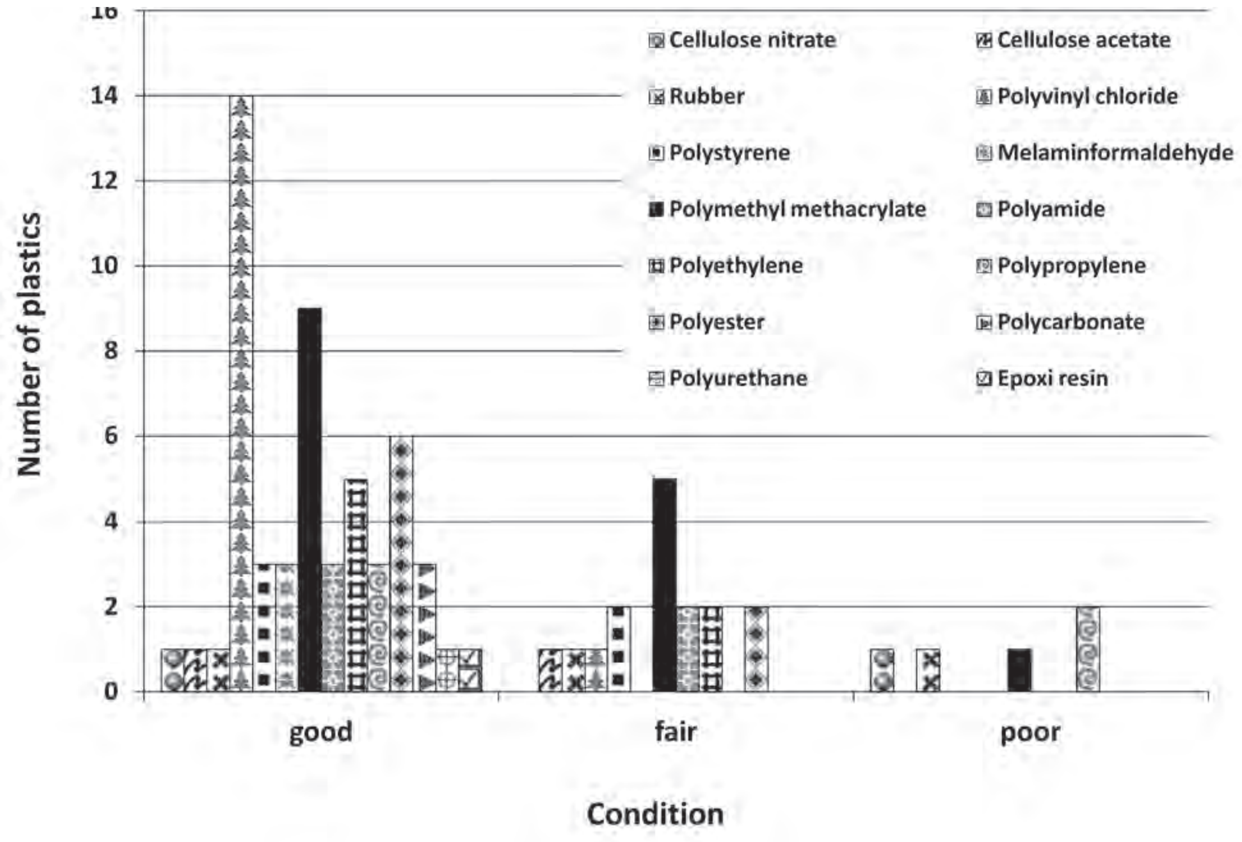


Figure 1
(a) Number and condition of plastic-containing objects identified at the Pinacoteca do Estado de São Paulo.

(Plastics Europe 2012) poses a considerable challenge for conservators. Treating plastic or rubber objects can get even more complex when other materials are involved. For example, some materials like glass, paper, textiles, and metals can react negatively with the acidic degradation products of cellulose nitrate and cellulose acetate. Ideally, all components of the work must be considered equally in the preparation of a conservation strategy. As this is not always possible, adjustments must be made to suit the material or part of the object considered to be the most unstable or susceptible.

These points underline that an examination, if not a regular survey of all plastic-containing objects in collections, is an indispensable tool to develop suitable conservation strategies for plastic-containing objects in collections.

This paper presents the results of a survey conducted at the Pinacoteca do Estado de São Paulo. Its aim was to identify all plastic objects, document their condition, and, if necessary and possible, carry out conservation treatments. Special attention is given to three case studies, in which the complexity of the object and the instability of the (semi) synthetic polymer were considered as important factors to develop a suitable preventive conservation strategy.

BACKGROUND

The Pinacoteca do Estado de São Paulo is one of the most important art museums in Brazil and the oldest of its kind in São Paulo. It was founded on December 24, 1905, and turned into a state museum in 1911. After passing through a reform in the 1990s, the museum developed into one of the most dynamic cultural institutions in the country, hosting important international exhibitions and cultural events. Today, it is an important presence in Brazil's contemporary artistic landscape.

The museum is mainly noted for its extensive collection of 19th century paintings and sculptures, as well as for its significant collection of Brazilian art, including a number of iconic Brazilian Modernist masterpieces. Over time, the Pinacoteca has gradually taken on the role as a museum of contemporary art, as it committed itself more and more to present-day artworks. With the increase in modern art works came a growing number of plastics materials into the collection. Although the number of objects made of or made with plastics is still small, the museum decided to develop a strategy for their long-term preservation and conservation.

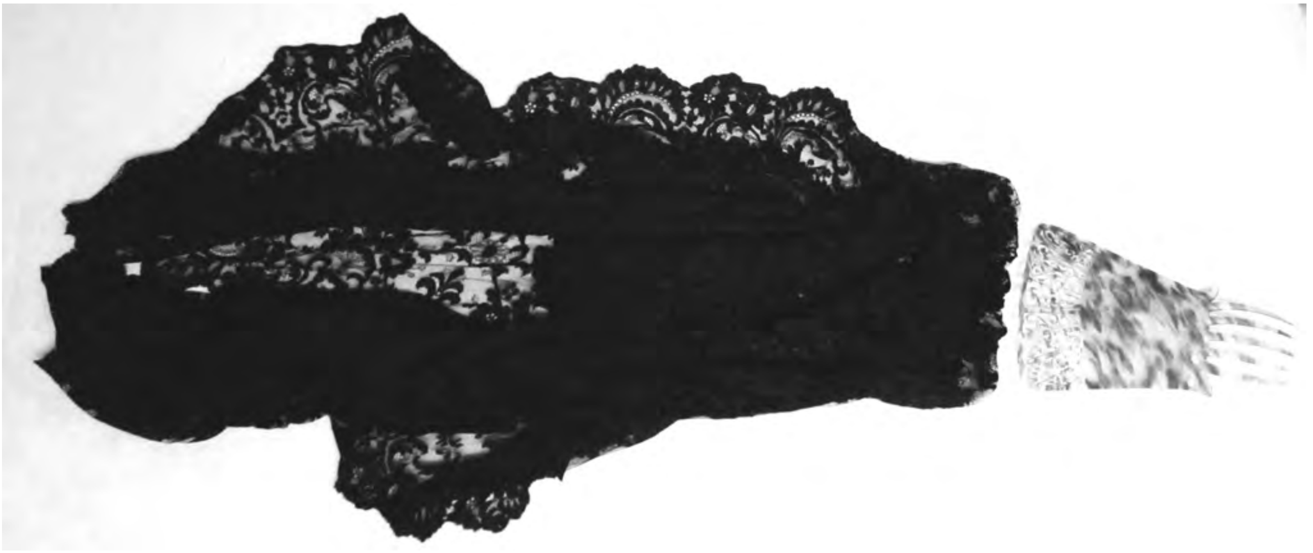


Figure 2
Object *Véu de Tecido:* cellulose nitrate hair comb and textile.
(©Pinacoteca do Estado de São Paulo, photo Antônio Carlos Timaco).

IDENTIFICATION AND CONDITION SURVEY

The methodology used for the identification of synthetic polymers in the collection was based on a literature research for techniques and methods commonly used for this purpose *(Coxon 1993; Derrick, Stulik and Landry 1999; Waentig 2008; Shashoua 2008; França 2010)*. The methods of investigation were classified into the following categories:

1) *literature review about the artist/artwork*
2) *visual examination of the object*
3) *destructive analyses employing a sample removal (microchemical, solubility, and flame tests) and*
4) *laboratory analyses (Fourier transform infrared spectroscopy - FTIR).*

As it was deemed necessary to obtain a maximum of information from a minimal amount of sample material, the identification procedure began with a literature research on the respective artwork. This step also included, if possible, an interview with the artist. In some cases this procedure enabled us to narrow down the list of materials possibly used by the artist, whereby the next step could be determined: destructive tests or spectroscopic analysis. Plastic samples from the Resin Kit™ were used as reference for the identification of polymers using both FTIR analysis and destructive tests. Due to costs associated to the FTIR analyses, these were only carried out when it was not possible to identify the (semi) synthetic polymer using the destructive tests described above.

A total of 67 artworks (0.2 per cent of the collection) made from plastic, or containing plastics elements, were identified in various categories: sculpture, relief, print, collage, and installation art. In addition to the 67 artworks, the museum's bibliographic collection also holds four personal objects, which belonged to the Brazilian artist Tarsila do Amaral. The results revealed an interesting range of synthetic materials used *(Figure 1)*, including some semi-synthetic polymers (vulcanised rubber and cellulose esters), followed by commodities plastics produced on a large scale since the 1950s. According to the records of the institution's database, the most recent work dates back to 2012 and the oldest to 1954.

After identifying the main components of each plastic containing object, a report on the condition of each object was compiled, based on the museum´s records and on information gathered from the Surveying Collections workshop held at the POPART Conference *(Keneghan 2012)*. The data collected consisted mainly of:

1) *Information about the object*
2) *Storage and housing*
3) *Overall condition of the object*
4) *Detailed condition of the object*
5) *Destructive tests and FTIR analysis.*

The assessment of the general condition of the artwork started with a visual examination to identify and document any signs of degradation, such as changes in flexibility, form, colour, or brightness, residues, stains, and surface dirt. Once the initial analysis was completed, a more detailed examination of the object was carried out with the help of a stereomicroscope. In doing so, signs of change noticed during the initial examination could be observed in more detail and recorded using microphotographs. The photographs helped to facilitate an identification of the degradation, by comparing the phenomena observed with reference images found in specialised literature. The microphotographs will also be used to monitor the degradation process and are therefore attached to the condition report of the artwork/object. Based on the findings the examined objects were classified into different condition categories *(Figure 1)*.

The survey results show that 75 per cent of the plastics were identified as being in good condition without any need for conservation treatment. 18 per cent of the objects were identified as being stable (in fair condition), but minor actions, such as cleaning, were considered necessary. Approximately 7 per cent of the objects examined were considered to be in poor condition, showing signs of deterioration and requiring consolidation, cleaning, and repair.

The objects identified as being in either fair or poor condition showed the typical degradation signs for the respective material: sticky or darkened surfaces on plasticised PVC objects, stress crazing and cracks on PMMA artworks, and yellowing and stiffening of a cellulose acetate object.

Comparing the outcomes of our survey with the results of surveys recently carried out at European museums *(Lavédrine, Fournier and Martin 2012)*, it becomes evident how important the examination of plastic objects in collections is. Conservation priority should be given to complex artworks (composed of different materials) and to unstable synthetic polymers. To illustrate these points, three case studies are presented in the following section.

Figure 3
Sheila Goloborotko, *Pensamentos Comuns*: acrylic paint on cellulose acetate sheet, 2004. (©Pinacoteca do Estado de São Paulo, photo Antônio Carlos Timaco).
(see colour plate, p. 172)

CASE STUDIES

CASE STUDY 1 – OBJECT *PENTE* (COMB)

The comb is one of the personal items that belonged to the Brazilian artist Tarsila do Amaral *(Saturni 2008)*. The object was donated to the Pinacoteca do Estado de São Paulo by the artist´s family and is part of the museum's bibliographic collection. It was stored wrapped in paper in a standard storage box with other personal items from Tarsila do Amaral.

The object consists of a cellulose nitrate hair comb, to which a black textile had been attached *(Figure 2)*. A diphenylamine test *(Waentig 2008)* confirmed the presence of nitrates and supports the assumption that the comb is made of cellulose nitrate.

Cellulose nitrate is considered to be one of the least stable plastics in collections *(Bützer and Keßler 2001; Shashoua 2008)*. The degradation of cellulose nitrate involves hydrolytic, thermal, and photochemical reactions that produce reactive nitrogen oxide. Under humid conditions nitrogen oxide can react with water in the air to form nitric acid. Nitric acid is a strong oxidising agent that can seriously damage objects close by or in contact with the degrading material *(Brimblecombe 1990)*. Since the breakdown of cellulose nitrate is an autocatalytic reaction, the degradation products themselves accelerate the chemical reaction, leading to an increasingly faster and more extensive degradation process *(Shashoua 2006)*. As a result, characteristic signs of degradation, such as yellowing of the polymer and cracks appearing internally and on the outside surface, are frequently observed on objects made of cellulose nitrate. In the final stage, crazing becomes so extensive that the cellulose nitrate disintegrates *(Bützer and Keßler 2001)*.

Figure 4
Jorge Menna Barreto, *Feliso:* made from soft-PVC, 2011. (©Pinacoteca do Estado de São Paulo, photo Antônio Carlos Timaco).

The comb in the museum's collection was categorised – according to the grading system – as being in good condition. This categorisation led to a series of preventive conservation measures to prolong the lifetime of the object and to control the emission of chemically active degradation products into the surroundings. The first step was to remove the object from the storage box, since the other objects stored in the same box were partly made of textiles, paper, and glass – all materials that can be damaged by nitrogen oxides *(Hatchfield 2005)*. The black textile, attached to the hair comb was also considered to be at risk from the nitrogen oxide. Separating the black textile from the comb was one possible solution discussed by the museum's conservation staff to protect the fabric from the emissions. This procedure would not cause damage to either the cellulose nitrate comb or to the dark textile, since the textile was only inter-laced with the comb and could easily be separated from it. After discussion with the directors of the museum, it was decided to store the two materials separately and to re-attach the fabric solely for exhibition purposes. The entire process was registered and documented in the documentation sector of the museum *(de Mendonça 2012)*.

To slow down the degradation of the cellulose nitrate object, and to consequently prolong its useful lifetime, the comb was stored in a (hand-made) box covered with buffered paper that was not completely closed to allow some airflow. A small piece of paper impregnated with cresol purple *(Fenn 1995)* was positioned close to (but not touching) the object, to monitor the progress of deterioration. If a change in colour is observed on the indicator (from purple to red), it indicates that the cellulose nitrate is actively degrading and that the acid-free paper requires changing.

CASE STUDY 2 – ARTWORK *PENSAMENTOS COMUNS*, REGISTRATION NUMBER 6676

The artwork *Pensamentos Comuns* is another example of a highly unstable polymer in the collection of the museum. Created in 2004 by the artist Sheila Goloborotko, and donated to the museum by the artist in 2006, the object consists of a cellulose acetate sheet (32 cm x 16 cm) serving as a support for the acrylic painting *(Figure 3)*. FTIR analysis *(Shashoua 2008)* confirmed that the artwork *Pensamentos Comuns* is made of cellulose acetate. The object was kept in a closed paper box in the museum's storage area. The paper covering the object had yellowed. However, as is visible in *Figure 3*, the artwork was in good condition.

The degradation mechanism of cellulose acetate is similar to that of cellulose nitrate and involves the replacement of acetyl groups on the cellulose rings by hydroxyl groups. The reaction is a denominate deacetylation that is accelerated by water (moisture in air) and acids, resulting in an autocatalytic reaction *(Shashoua 2006)*. As the hydrolysis of the acetyl groups leads to the formation of acetic acid, a typical vinegar odour is detectable in the advanced stages of the degradation of cellulose acetate objects. For this reason the process is also known as 'Vinegar Syndrome'. When dealing with this substance, it is necessary to observe special conservation protocols, as the dangerous corrosive effect of acetic acid within a museum environment is well documented *(Hatchfield 2005)*. The degradation of the plastic material is further a result of the loss of additives, such as plasticisers and flame-retardants, attached to the cellulose acetate polymer by weak physical bonds, through diffusion and evaporation processes. Visible effects are shrinkage, tackiness, and an increased brittleness of the material *(Shashoua 2008)*.

As a preventive conservation treatment the artwork *Pensamentos Comuns* stored in a ventilated box made of alkaline paper. Acetic acid that cannot be neutralised by the alkaline paper can dissipate through the openings of the box, whereby an acidic environment in the storage container can be controlled. To avoid direct contact of the object with the alkaline paper, the lower side of the box was covered with acid-free paper. The object will be monitored with the help of an acid indicator (A-D Strip). This indicator is positioned near the object and will be frequently checked. If the colour of the A-D Strip changes from blue to yellow, it indicates a critical rise in the concentration of acetic acid inside the container as result of the degradation of the object. At this point increased ventilation and a change of the alkaline paper box will be necessary. Specialised literature also suggests the use of activated charcoal or zeolites in storage containers to absorb acetic acid vapours generated by the degradation of the cellulose acetate object *(Shashoua 2006)*. However, recent studies *(Shashoua 2012)* conclude that additives present in the plastic formulation (plasticisers and flame-retardants) could also be strongly adsorbed by activated charcoal or zeolites, which would contribute to the degradation of the cellulose acetate material. In consideration of this recent research, it was decided to store the artwork *Pensamentos Comuns* without the use of any adsorbent.

CASE STUDY 3 – ARTWORK *FELISO*, REGISTRATION NUMBER 9085

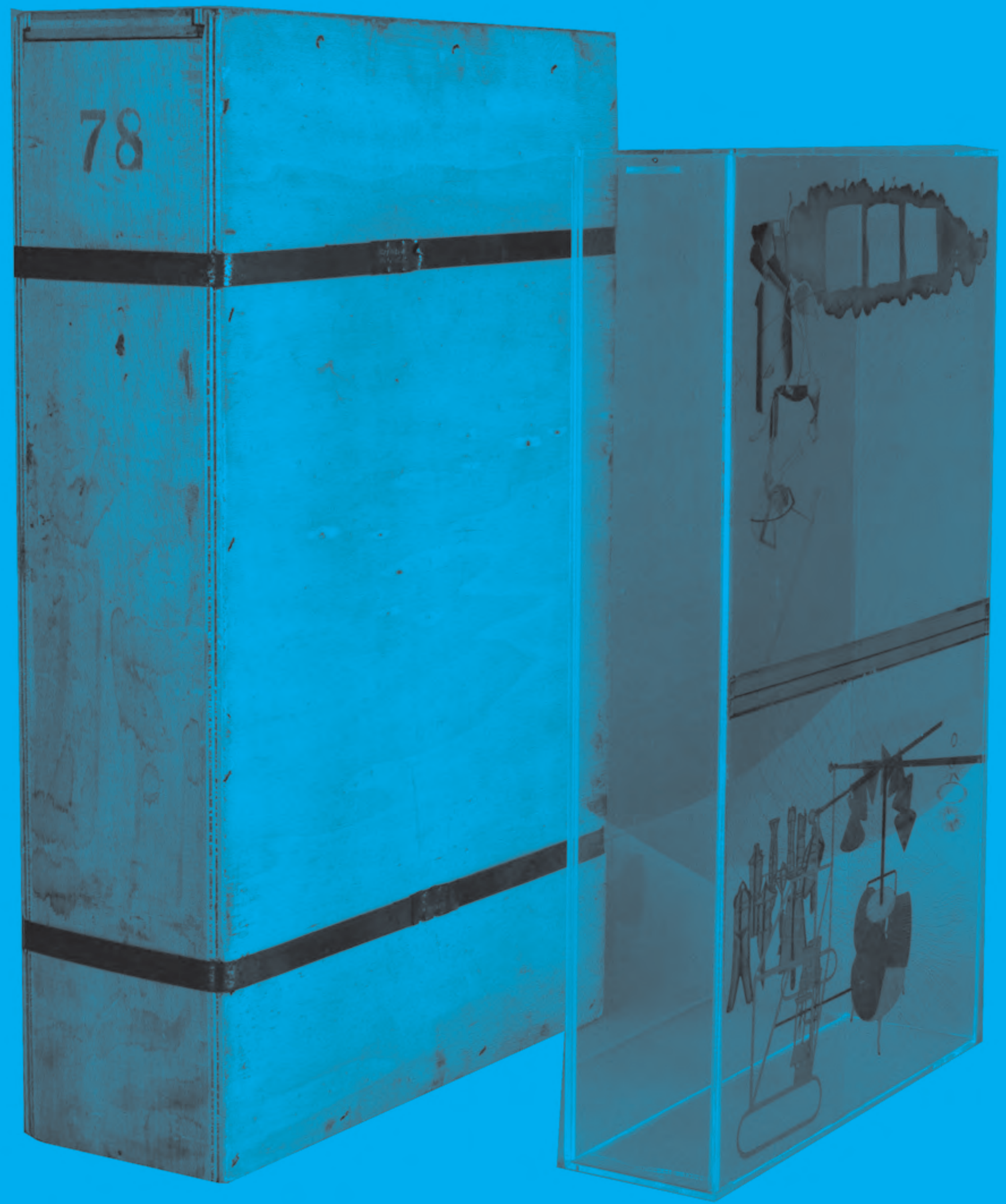
The artwork *Feliso,* by the Brazilian artist Jorge Menna Barreto *(Figure 4)*, was industrially produced in 2010 and donated to the museum by the Associação Pinacoteca Arte e Cultura (APAC) in 2012. The object was made from soft-PVC and is part of an artistic series in which different words are 'printed' on soft-PVC doormats (dimensions: 70 cm x 90 cm). The museum also holds three other works from the same series: *Fomiliar* (registration number 9087), *Eulogio* (registration number 9086), and *Deusejo* (registration number 9084). The Beilstein test *(Waentig 2008)* and FTIR analyses *(Shashoua 2008)* confirmed that all four works were made of PVC.

The degradation of plasticised PVC is directly related to the diffusion of the plasticiser from the inside of the polymer to the surface of the object, and further into the surrounding environment. The emission of plasticisers is the dominating step in the degradation process of soft-PVC and is controlled by the physicochemical properties of the additive as well as by external factors like temperature, ventilation rate and dust concentration in the vicinity of the object. The loss of plasticisers from soft-PVC objects results in a tacky surface, loss of flexibility, tearing, and embrittlement of the material *(Shashoua 2001)*. Discolouration is often caused by a reaction known as dehydrochlorination, which involves thermal or photochemical reactions and the production of hydrogen chloride (HCl). The acidic environment, generated by the presence of HCl, contributes to the hydrolysis of some plasticisers, such as di-2-ethylhexyl phthalate (DEHP), resulting in the formation of crystalline phthalic acids on the surface of the object *(Shashoua 2001)*. Due to its chemical structure, DEHP functions as an anti-ageing additive protecting the PVC polymer from dehydrochlorination *(Shashoua 2001)*. For soft-PVC objects it is therefore most important to prevent the loss of the plasticiser by minimizing ventilation. This is most easily achieved by enclosing the objects in an impermeable material, such as a glass box or a heat-sealed polyester bag *(Shashoua 2006)*. The latter option is under discussion at the museum, as it is an inexpensive and relatively simple procedure, requiring little equipping. However, its drawback is that, after a certain time period, it is difficult to monitor the object enclosed in the polyester bag due to the emission of plasticisers from the artwork. The emission of plasticizers from one object onto another object's surface is a well-known phenomenon. In the conservation field glazings can be affected by so-called "ghost images" from prints or paints *(Schilling, Carson and Khanjian 1999)*, but every encasement or display case can be affected, if plasticiser-containing materials are stored inside.

The museum´s conservation staff has been informed about the toxicology of some of the plasticisers such as DEHP *(Heudorf, Mersch-Sundermann and Angerer 2007)*. It is necessary to handle all objects identified as containing (or made entirely from) PVC or cellulose acetate with caution: the use of gloves is mandatory to avoid direct contact with the plasticisers or flame-retardants.

CONCLUSION

A systematic approach to the care of plastic objects in museum collections should start with the identification of all materials present in the object and an evaluation of their condition. This procedure requires professional experience and interdisciplinary collaborations between conservators and conservation scientists. In this study, the correct identification of materials provided useful information for the registration of the collection, and for the documentation of its condition. In addition, the results of the survey allowed the museum to develop practical solutions for the proper monitoring of the objects in a targeted manner, and to plan strategies for their safe handling and storage. This project is ongoing and the objects will be surveyed again within a period of five years. All new plastic-containing objects, that are acquired by or donated to the museum, will also undergo the same surveying described in this paper.



POSTER
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CONSOLIDATION OF A POLYESTER URETHANE FOAM CUSHIONING WITH LIMITED ACCESSIBILITY USING ULTRASONIC MISTING. WORKING METHOD, RESULTS AND POSSIBLE IMPROVEMENTS. THE CONSERVATION OF A MULTIPLE BY MARCEL DUCHAMP, PART I

BY STEFANIE ILLI, GERDA KALTENBRUNNER, MARTINA PFENNINGER LEPAGE, KARIN STEINER

ABSTRACT

This article discusses the consolidation of a polyester urethane foam cushioning in one example of the multiple *The large glass and related works (Volume 1)* by Marcel Duchamp and Arturo Schwarz. Since the polyester urethane foam was in an advanced state of deterioration a non-intrusive consolidation method was chosen using an ultrasonic mister "AGS 2000" distributed by the Zentrum für Bucherhaltung Leipzig. This paper focuses on the choice of a consolidant and the challenge of finding an application technique adapted to the limited accessibility. Possible improvements for the work method are listed and discussed including a critical review of the results.

KEYWORDS

polyester urethane foam; consolidation; ultrasonic mister; Impranil DLV/1; aerosol; access

INTRODUCTION

The treatment described here was part of the overall conservation of one of two nestable boxing-elements of *The large glass and related works (Volume 1)*, an edition of multiples created by Marcel Duchamp and Arturo Schwarz in 1967. The edition consists of two volumes, each comprising 150 published copies. Volume I and Volume II differ in terms of boxing design and choice of materials. Volume I consists of a cushioned plywood box (h/w/d: 49.0 x 12.0 x 31.7 cm) and an insertable poly(methyl methacrylate) (PMMA) slipcase (h/w/d: 42.2 x 7.0 x 25.0 cm) which contains the publication with etchings of motives and notes for Duchamp`s *The Large Glass* (1915-1923) *(Figure 1)*.(1)

This paper focuses on the treatment of a polyester urethane foam cushioning of the plywood box with the edition No 78, Volume I.(2) The conservation treatment was performed at the Academy of Fine Arts Vienna, Institute for Conservation-Restoration, as a student project.

The polyester urethane foam cushioning was in an advanced state of deterioration and showed intense crumbling, loose fragments, compressed areas as well as a powdery surface *(Figure 2)*. A strategy to treat this highly sensitive surface was developed taking into account ethical as well as technical and material-specific challenges.(3)

ETHICAL ASPECTS

Having a functioning nestable structure is one of the most important aspects of the artwork's integrity. Due to the advanced deterioration of the polyester urethane foam cushioning it was no longer possible to insert the PMMA slipcase into the cushioned plywood box.

The polyester urethane foam no longer fulfils its original function of cushioning and does not appear to hold any specific artistic intention or meaning besides its function,. Nevertheless, the fact that in this case the polyester urethane foam is a part of the artwork, as well as a historical material, should certainly be taken into account in light of professional ethics.

After discussing different scenarios including replacing the foam or storing the PMMA slipcase separately, it was decided to consolidate the remaining parts of the polyester urethane foam with Impranil DLV/1 (BAYER©). Additionally, a slipcase made of cardboard was mounted to protect the consolidated polyester urethane foam as well as the PMMA slipcase and to compensate for the difference in space caused by the loss of cushioning material

Figure 1
The Large Glass And Related Works (Vol. I);
plywood slipcase and PMMA slipcase (the publication is not pictured as it was not subject of any treatment and therefore was not transferred to the Academy of Fine Arts).
© Photo: Stefanie Illi/Jonathan Debik; Courtesy of Ph. Konzett

(Figure 3). As a result the nesting property of the boxing elements was restored.

The main guiding criteria for the treatment were:

- *The decision to preserve the present condition of the polyester urethane foam as "documentation" inside the object and as a part of the artwork's biography.*
- *An interest in collecting experiences regarding the consolidation of polyester urethane foam as this is still a fairly new area of research. Since the deterioration was in an advanced state, it was assumed that hydrolysis, being the main factor for degradation of polyester urethane, was already proceeding auto-catalytically. There is a foreseeable risk that the foam will further degrade in the future and will have to be consolidated again. Nevertheless, it is expected to gain further insights by future monitoring of the materials' behaviour during ageing for both the consolidated polyester urethane foam and the consolidant Impranil DLV/1, as well as into their interaction.*
- *Taking the approach of using reversible materials (such as the cardboard slipcase) and a medium that will not inhibit further treatment in the future. The guide strips holding the cardboard slipcase in place were mounted with Japanese paper straps and attached with wheat starch paste. The use of an ultrasonic mister allows the consolidation medium to be applied as extremely fine particulate material to prevent clogging of the porous structure of the foam. Thus, the options for future successful consolidation treatments are kept as open as possible.[4] The opportunity for replacing the polyester urethane foam cushioning in the future is not inhibited by the present consolidation. It can be replaced any time, with all the advantages, disadvantages and challenges that come with this decision.*

COMPARISON OF VOLUME I AND VOLUME II

As mentioned previously, the edition *The large glass and related works* consists of two volumes (I and II, each comprising 150 published copies) differing in terms of boxing design and choice of materials. Volume I consists of a cushioned plywood box and an insertable poly(methyl methacrylate) slipcase which contains the publication with a selection of etchings of motives and notes for Duchamp`s *The Large Glass*. Volume II consists also of a cushioned plywood box but with an insertable slipcase made of cardboard wrapped in textile, which contains a second publication with a selection of etchings of motives and notes for Duchamp`s *The Large Glass*.(5)

Fortunately, the owner of the conserved copy No. 78 of the edition *The large glass and related works (Volume 1)* also owns the corresponding second copy of the edition Volume II. Both these objects were stored under similar conditions for at least the past twelve years. It is highly probable that they have been stored together since their creation, but this cannot be known with certainty due to changes in ownership. However, whereas the cushioning of Volume I was in a highly deteriorated condition, the cushioning of Volume II was in pristine condition. The foam showed neither visible degradation, nor powdery or crumbling areas. FTIR-analysis identified the foam-padding of Volume II as polyether urethane, a material primarily prone to photo-degradation mechanisms. Contrary to this, the polyester urethane foam used in Volume I is prone to hydrolysis. This impressive difference in ageing behaviour of both polyester and polyether urethane foam in two objects of the same age, apparently stored under the same conditions for a long time, also contributed to the decision to consolidate the strongly deteriorated polyester urethane foam in Volume I.

CHOICE OF CONSOLIDANT

Due to the fragile, powdery surface of the foam a non-intrusive application technique was required. The use of a non water-based consolidant (regarding the polyester urethane foam's sensitivity to hydrolysis and the partial surrounding hydrophilic materials) was initially favoured but proved difficult to achieve because of the high vulnerability of polyester urethane foam to organic solvents. Nevertheless, this option introduced by *Pataki-Hundt (2011)* was taken into consideration as well.

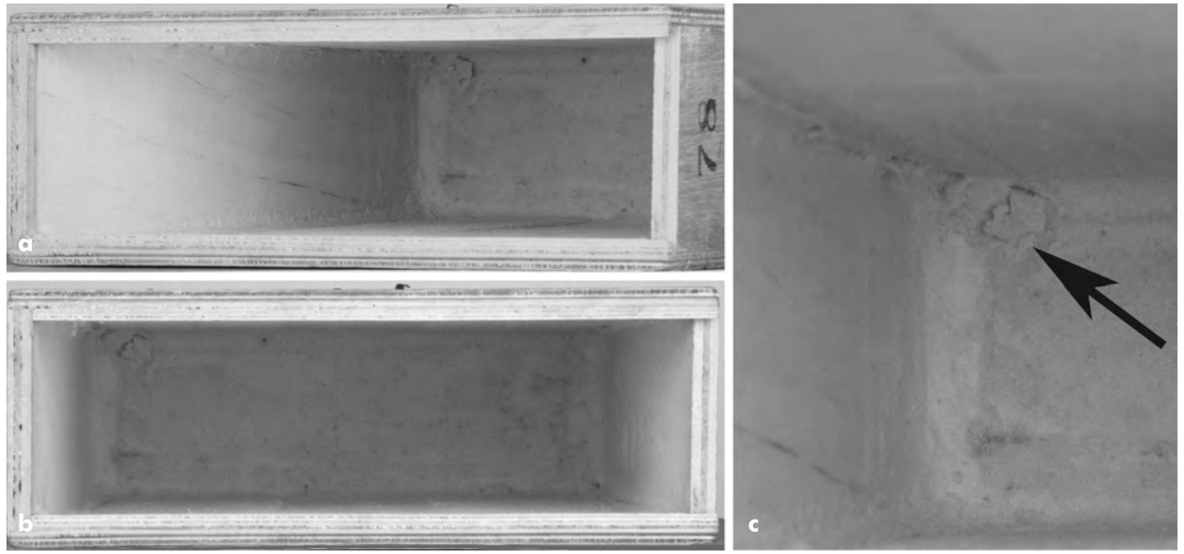

Figure 2
a) bottom/side view of the plywood slipcase before treatment showing its deteriorated cushioning;
b) bottom view before treatment;
c) detail of polyester urethane foam with loose fragments.
© Photo: Stefanie Illi; Academy of Fine Arts Vienna
(see colour plate, p. 173)

The following list of criteria for a possible consolidant was compiled in advance:

- *suitable chemical/physical characteristics (solubility, adhensive strength, pH value, toxicity, etc.)*
- *suitable processing quality (e.g. application possibilities)*
- *good ageing qualities*
- *compatibility with polyester urethane*
- *no optical changes of the polyester urethane foam*
- *formation of a flexible structure (regarding the strong deterioration and pressure sensitivity of the material)*
- *introduction of no or as little water as possible – both during consolidation process and through formation of a hygroscopic film*
- *ability to thinly coat the foam's cell structure without blocking its pores*

SOLVENT SENSITIVITY OF POLYESTER URETHANE FOAM

First of all, the solvent sensitivity of the deteriorated polyester urethane was tested on small amounts of original, dislocated foam particles. For this purpose, a particle was placed on a depression microscope slide and covered with a cover slip. One drop of solvent each was put on the left and right side of the cover slip. Photo-micrographs (40x optical magnification) were taken at given intervals (pre-state, after five and 30 seconds, one and five minutes). The following results were obtained: The material was affected by ethanol and acetone and slightly affected by isopropyl alcohol whereas it seemed unaltered by deionised water, ethyl acetate as well as white spirit 60-95°C / 140-200°C.

CONSOLIDANTS TESTED

Based on results from solvent tests and a literature survey, the following consolidants were tested (mixture ratios are given in amounts by weight):

- *Paraloid B72 (ethyl methacrylate copolymer), 20% in ethyl acetate*

Figure 3
Slipcase made of acid-free cardboard (front), mounted after consolidation by means of guide rails and Japanese paper straps attached with wheat starch paste.
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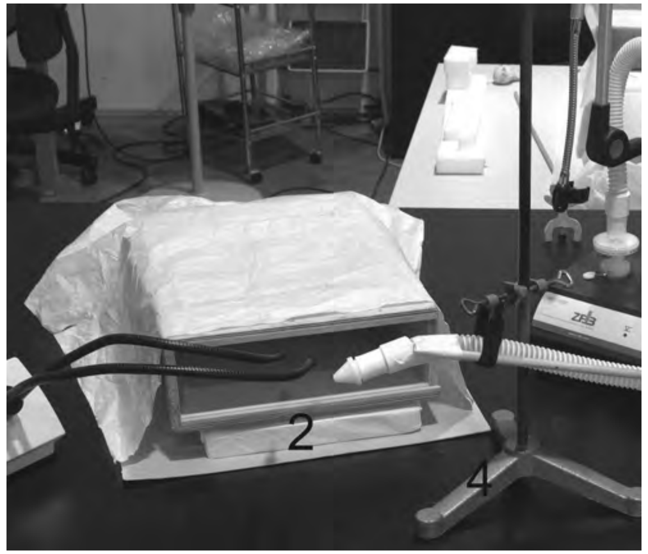

Figure 4
Improved working situation:
1) gooseneck lamp;
2) Ethafoam block for diagonal positioning of the box;
3) wooden stick;
4) laboratory stand with textile loop;
5) ultrasonic mister "AGS 2000".
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- *Plexigum PQ611 (acrylic polymer based on isobutyl methacrylate), 20% in Shellsol D*
- *Tylose MH 50 (methyl hydroxyethyl cellulose), 1,25% in deionised water*
- *Klucel E (hydroxypropyl cellulose), 4% in deionised water*
- *Methocel A4C (methyl cellulose), 1% in deionised water*
- *Polyethylene glycol, 7,5% in deionised water*
- *Mowilith DMC 2 (polyvinyl acetate dispersion), diluted with deionised water at a ratio of 2:5*
- *Plextol B500 (dispersion based on ethyl acrylate and methyl methacrylate), diluted with deionised water at a ratio of 1:5*
- *Primal SF 016 (aqueous acrylic dispersion, formaldehyde and ammonia free), diluted with deionised water at a ratio of 1:4*
- *Lascaux medium for consolidation (aqueous acrylic copolymer dispersion), undiluted*
- *Mowiol 4-88 (polyvinyl alcohol), diluted with deionised water at a ratio of 1:8*
- *Impranil© DLV/1 (anionic aliphatic polycarbonate-polyether polyurethane dispersion), diluted with deionised water at a ratio of 1:5 / 1:10 / 1:20*
- *Kremer PUR-Dispersion (aqueous, solvent free, low-viscosity dispersion based on aliphatic polycarbonate-polyurethane without free isocyanate groups), undiluted*

These consolidants were tested on a polyester urethane foam pad which was available in the studio as a mock-up. To get a general sense of their application properties, the consolidants were applied by brush to observe penetration behaviour and optical appearance after drying. Almost all consolidants exhibited a highly glossy appearance on the impregnated areas. Only solutions of Klucel E as well as Impranil DLV/1 showed satisfactory results and were further tested on the degraded polyester urethane foam pad.

Solutions of different concentrations were tested and applied with the ultrasonic mister, aiming for the highest possible concentration possible using the ultrasonic mister "AGS 2000". Finally, a "test body" made of detached particles (the original location of which could not be identified), collected from *The large glass and related works (Volume 1)* was used for the final test of a consolidation medium. Both consolidants showed similar results in regard to the consolidation strength and their handling properties. Nevertheless, differences were discernible: after drying the foam impregnated by Impranil DLV/1 showed a highly flexible structure, whereas the foam treated with Klucel E produced a rigid, stiff structure. Areas consolidated with Impranil DLV/1 showed elastic behaviour – returning to their initial shape after pressure impact without breakage of the cell walls. As the polyester urethane foam pads were originally intended as a cushioning, it was decided to use Impranil DLV/1 diluted with deionised water at a ratio of 1:5 as a consolidant.

Figure 5
a) bottom/side view of the inside of the plywood slipcase after treatment;
b) bottom view after treatment;
c) detail of polyester urethane foam with consolidated fragment.
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Since Impranil DLV/1 is a relatively new product, there is little long-term experience with its use in conservation. Nevertheless, the lightfastness of Impranil DLV/1 was rated 5 (good) in a test series by *(Winkelmeyer 2000: 106)*. Regarding discolouration and resilience, Impranil DLV/1 was rated better than the more commonly used conservation product Plextol B500 (a dispersion based on ethyl acrylate and methyl acrylate) in test series by van Oosten and co-workers *(van Oosten 2011: 68)*. Besides, BAYER claims in its product description that Impranil DLV/1 has excellent resistance to hydrolysis (according to DIN 53504) which seemed an important piece of information in the project`s context *(BAYER, n.y.)*.

ACCESS

Since access to the plywood-box was very limited whilst using the ultrasonic mister – due to the aperture dimensions of the slipcase – and a proper application of the consolidation medium was therefore difficult, some improvements for the procedure were designed *(Figure 4):*

- *The tube of the mister was taped to a wooden stick for stabilisation and to facilitate controlled access to less accessible areas and corners in the plywood-box.*
- *The tube attached to the stick was further hooked into a textile loop and fixed on a laboratory stand. The loop helped carry the weight and facilitated the precise circling*

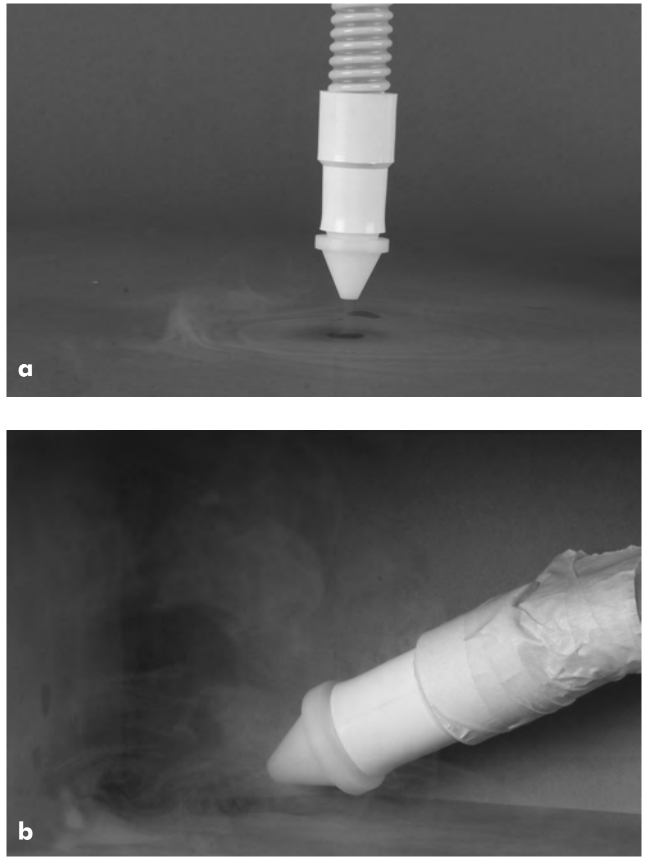


Figure 6
a) in an upright position the nozzle causes a small aerosol whirl and surplus moisture evaporates;
b) in an angular position there is an aerosol whirl and, the closed slipcase inhibits moisture evaporation. Hence, aerosol moisture accumulates during treatment.
© Photo: Stefanie Illi; Academy of Fine Arts Vienna

above small sections of the cushioning to be consolidated.

- *For consolidation with the ultrasonic mister an application with a vertically held nozzle (ideally at a 90° angle to the surface) is recommended. In our case, an application perpendicular to the surface was not possible due to the limited access. To improve the application angle the nozzle was slightly bent and also taped to the stick. In the upper areas of the slipcase it was possible to consolidate the foam by guiding the nozzle by hand. However, this adaptation caused a modification of the aerosol flow in the tube, which led to drop formation. Therefore, the tube had to be emptied approximately every 20 minutes to avoid uncontrolled dripping of the consolidant onto the cushion.*
- *The plywood box was fixed in a tilted position using two polyethylene foam (Ethafoam©) blocks in order to improve accessibility during the consolidation treatment.*
- *Areas of exposed wood between the sections cushioned by polyester urethane foam were protected with cardboard strips from unwanted contact with the consolidant. The cardboard was weighted down with two sandbags against slipping. Additionally, the cardboard strips as well as the sandbags were wrapped in silicone film to prevent them from sticking to the wooden board and from taking up any consolidant.*

TREATMENT METHODOLOGY

The different stages of the treatment can be summarised as followed:

- *First areas of the foam in danger of becoming loose were re-attached with the consolidant applied by brush.. .*
- *Dislocated foam particles were removed and the areas of exposed wood were cleaned using a small vacuum cleaner.*
- *The exposed wood was covered with cardboard strips to prevent it from pollution with consolidant.*
- *To reach a sufficient consolidation effect without clogging the foam's porous structure, the consolidation was executed in sequential stages:*
- *pre-consolidation phase without nozzle (two consolidation stages, according to Pataki 2005)*
- *first consolidation phase with nozzle (one consolidation stage)*
- *second consolidation phase with nozzle (one consolidation stage)*
- *consolidation phase using a syringe*
- *Finally, the cardboard slipcase was fitted to protect the cushioning and restore object's integrity.*

CONSOLIDATION BY ULTRASONIC MISTER

Since the polyester urethane foam was in extremely deteriorated condition and had become powdery, it was affected by the aerosol's airflow. Therefore, consolidation was started without nozzle. Due to the bigger orifice of the tube without nozzle the airflow velocity could be further reduced as recommended by Pataki *(Pataki 2005: 225)*. The airflow velocity at the device was set to the minimum as well, whereas the regulation for aerosol quantity was increased to the maximum in order to obtain as much consolidation medium as possible. To perform the consolidation, the tube was circled for about five seconds above a small part of cushioning (approximately 3 cm^2) before moving on to the next part. With this procedure the cushioning pads were overall consolidated twice. In between the two consolidation stages, the cushioning was left to dry overnight.

The cushioning pre-consolidated with this method was then sound enough to continue the process with the nozzle on. During the first phase with nozzle, the settings of the mister were held on minimal airflow velocity whilst the wheel for the quantity regulation of aerosol was on a two o'clock position to avoid unnecessarily intense exposure of the still sensitive polyester urethane foam cell structure. The nozzle with the smallest aperture was chosen for this and the following consolidation phases. Again, the tube was circled for about five seconds above a small part of cushioning (approximately 1.5 cm^2)

Using these settings all polyester urethane foam pads were consolidated once. The thickest foam areas in the bottom corners of the slipcase were treated repeatedly, with drying times in between. The consolidation of all polyester urethane foam pads with attached nozzle took nearly two working days.

The strengthening effect of the consolidation was checked with a fine brush between each of the individual steps. The results showed that the polyester urethane foam pads were stabilised to a degree where the surface withstood light mechanical stress without cell walls breaking immediately or polyester urethane foam particles crumbling. Nevertheless, areas with greater material thickness showed stable microstructures on their surfaces and flexible cells, but still a high pressure sensitivity inside the cell structure. It was therefore decided to consolidate areas of greater thickness additionally with a syringe. A small amount of consolidant (Impranil DLV/1,1:5 diluted with deionised water) was applied with the syringe underneath the polyester urethane foam particles and lightly pressed with a metal spatula to the wood to adhere them properly.

Subsequently, a further consolidation phase with attached nozzle and optimised settings was performed so as to make the consolidation more efficient.

The surface of the polyester urethane foam pads showed small foam flakes sticking out of the surface in certain areas that were still associated with the polyester urethane foam pads ground. Since the nozzle could not be directed vertically above the polyester urethane foam pads, these flakes threatened to break away if an increased air flow rate was used. Therefore, the air flow rate was set again to the minimum in this consolidation phase, whilst the amount of aerosol was maximised to further increase the stabilisation of the polyester urethane foam pads. With these settings, all polyester urethane foam pads were consolidated one more time.

After sufficient drying time overnight the consolidation effect was again evaluated with a fine brush. Polyester urethane layers of a thickness of up to 1 mm showed sufficient stability. Areas thicker than that and the polyester urethane foam flakes mentioned above indeed showed a good surface stability, whereas the stability inside the cell structure and the adhesion to the ground still needed improvement.

The results of prior consolidation stages showed that consolidation via ultrasonic mister is achieved primarily on the surface. For this reason the application method was modified in order to reach areas below the surface too.

To consolidate these areas, again, a syringe was used. A small area was moistened with deionised water using the ultrasonic mister. Afterwards the consolidation medium (Impranil DLV/1 diluted 1:5 with deionised water) was applied in small droplets to the surface and the treated area was moistened again with deionised water by the ultrasonic mister. It appeared that moistening prior to and after application of the consolidation medium was conducive to regular spreading of the consolidation medium in the polyester urethane foam structure.

With this method the polyester urethane foam pads were once more consolidated. Any difference in the thickness of the foam was accounted for by applying droplets at varying distance from each other. In areas where the foam thickness exceeded 2 mm the consolidation medium was applied twice in a row. Additionally, the consolidation medium was injected after selectively moistening the polyester urethane foam areas thicker than 5 mm at the bottom of the slipcase. This final treatment step was taken in order to consolidate the inner cell structure and to avoid a possible loss of foam patches due to insufficient inner stability. Towards termination of consolidation, minor changes in colour of the foam were observed. But these were deemed acceptable as the yellowish colour of the polyester urethane foam pads was most likely caused by degradation and hence does not represent the original colour of the foam *(Figure 5)*.

EVALUATION AND POSSIBLE IMPROVEMENTS

One effect was the formation of a thin, bright whitish-grey film of consolidant on the foam's surface. Most probably, this was caused by undirected aerosol mist. The effect was likely furthered by the nozzle position and by the fact that the slipcase is closed on three sides, which prevents the undirected aerosol mist from escaping into the environment *(Figure 6)*.

By suctioning the undirected flow and deposition of the aerosol mist, a build-up of consolidant on the surface could probably be avoided. A suction device close to the nozzle would be necessary,. The suction would have to be strong enough to avoid undirected mist but should not affect the controlled deposition of consolidant required for an effective consolidation.

A suctioning device placed outside the slipcase near its aperture on the other hand would have to produce strong suction and would most likely not stop the mist floating near the foam surfaces and its deposition.

There would be also the difficulty of placing a suctioning device – be it near the nozzle or outside – since the space conditions are highly limited anyway. Every additional device contains the danger of touching the fragile surface during consolidation. Further testing is therefore necessary to gain experience.

As an additional effect, dark tidemarks near the thick polyester urethane foam cushioning areas along the side edges of the plywood slipcase have appeared. This was possibly caused by the difficulty to control the amount of applied consolidant using a syringe. The consolidant was applied underneath the polyester urethane foam particles to adhere them properly.

The authors suggest to directly apply the consolidant in even smaller amounts using a brush, rather than a syringe for similar treatment situations. An application of Impranil DLV/1 at a higher viscosity could be another improvement too and should be tested.

The tidemarks in this case were removed mechanically with a scalpel and reduced with deionised water.

As a third effect yellowish tidemarks on the exposed areas of wood on the bottom of the slipcase were detected.

Degradation products or colourants in the polyester urethane foam cushioning might have caused this phenomenon when in contact with moisture. Another possible reason is the corner position of these areas – they are exposed to a higher amount of moisture combined with slower drying rates.

Suctioning methods as described above or the use of an ultrasonic nebuliser would possibly reduce the amount of moisture and could help to avoid these kind of tidemarks. An ultrasonic nebuliser uses compressed air to generate the aerosol and therefore reaches an airflow velocity about six times higher than an ultrasonic mister with approximately 1200 ml/min. Additionally, the aerosol particles of a nebuliser are smaller than those of the "AGS 2000", having a particle size of 1-2 µm, respectively 5 µm *(Pataki-Hundt 2011: 66)*. Therefore, it is easier to reach areas underneath the surface with an ultrasonic nebuliser than with an ultrasonic mister. The last consolidation phase with the syringe in combination with moistening prior and after consolidation could then be dispensed with.

Nevertheless, there is a risk that the polyester urethane foam pads would not withstand the high airflow velocity of a nebuliser. Even with the ultrasonic moisture "AGS 2000" the airflow velocity was reduced to the minimum.

The yellowish tidemarks described above were unfortunately irreversible.

Finally, tidemarks around metal staples were detected too. These metal staples are embedded in the polyester urethane foam pads. Due to degradation processes, small brownish tidemarks were already visible around the metal staples before the consolidation treatment. Small corrosion particles might have been washed out into the foam areas next to the staples with the introduction of moisture during the consolidation treatment, hence amplifying the already existing tidemarks.

Applying a protective coating (e.g. wax or Paraloid B72) prior to the consolidation was considered but could not be done without harming the polyester urethane foam, because of the solvents that would have to be used. Moreover, only the exposed parts of the staples could have been covered by this protective layer whereas the parts of the staples in the foam structure would remain fully exposed to moisture.

Even though the metal staples were dried thoroughly using cotton-swabs immediately after consolidation, the formation of tidemarks could not be prevented entirely.

CONCLUSION

The consolidation of the polyester urethane foam cushioning of *The large glass and related works (Volume 1)* was a complex and difficult treatment. The padding was in an advanced state of deterioration, exhibited a high sensitivity to a variety of solvents, and could not be subjected to any mechanical stress. Direct contact was impossible. The concentration of the consolidant and numbers of applications proved crucial while the limited access to the inside of the plywood slipcase was an additional challenge.Taking these factors into account the consolidation treatment can nevertheless be regarded as a success-. It is hoped that this case study introduces an approach for a possible treatment method for polyester urethane foam which can be further optimised and discussed.

ACKNOWLEDGEMENTS

Many thanks to Dr. Kyujin Ahn, Academy of Fine Arts Vienna, for interpretation and explanation of the FTIR analysis results as well as to Dr. Nanke Schellmann, Academy of Fine Arts Vienna, for her attentive proofreading of this article. Thanks are given also to MA Cons. Christa Haiml, Academy of Fine Arts Vienna, for her friendly support. The owner has supported our work with vital source material and a great sensitivity to the conservation approach as well. Also many thanks to Jonathan Debik for great collaboration.

ENDNOTES

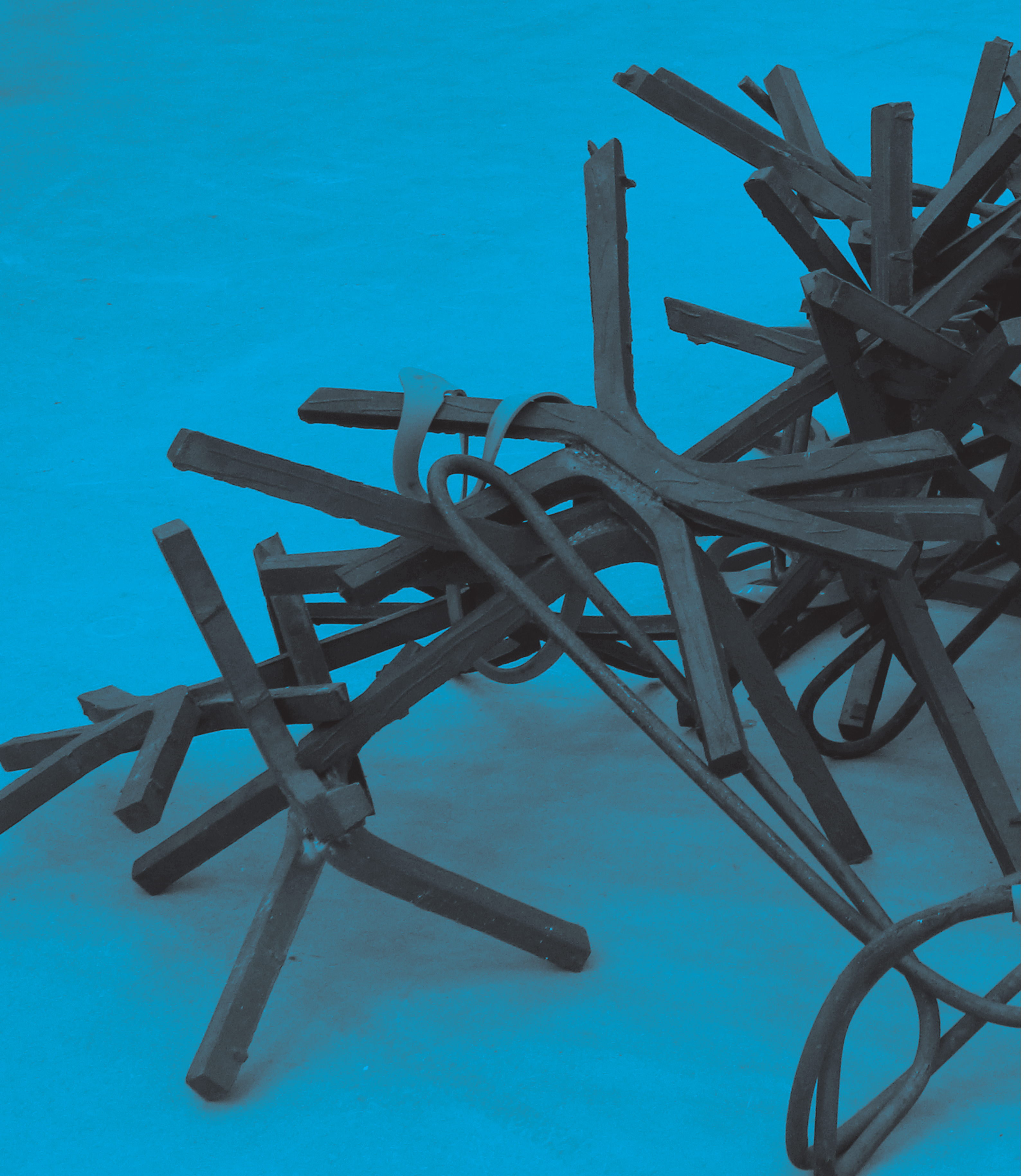
(1) One of Marcel Duchamp's main works entitled "The Bride Stripped Bare by Her Bachelors, Even" (1915-1923) is composed of two glass panels (277.5 x 177.8 x 8.6 cm) mounted in an aluminium frame, presented freely standing in the room. The glass panels contain over 25 motives executed in different materials/techniques (e.g. varnish, lead foil or dust), whereby the majority of the glasses' surface remain transparent. The work often is referred to as "The Large Glass" and is owned by the Philadelphia Museum of Art as component of the Bequest of Katherine S. Dreier (see: Philadelphia Museum of Art 2015).

(2) The material was identified as polyester urethane in FTIR analysis. A detailed explanation including illustrations for the evaluation and differentiation of FTIR spectra for both polyester- as well as polyether urethane can be found in van Oosten et al. (2011: 62-67).

(3) Besides other Socrates (2008: 270) as well as van Oosten et al. (2011: 11) classify polyester urethane primarily prone to hydrolysis, whereas polyether urethane is declared as vulnerable by photodegradation mechanisms.

(4) Pataki-Hundt (2011: 64-5) describes the ideal conception of ultrasonic consolidation initially developed for consolidation of powdery paint layers in the following way: "[...]: As soon as aerosols are generated by ultrasonic or compressed air, they should impinge on the surface, moisten each pigment particle, penetrate into the porous pigment structure and form stable, meniscus-shaped adhesive bridges."

(5) For more information about the different volumes of The large glass and related works (Volume 1) see Schwarz (1972: 90,101).



POSTER 005

MATERIAL REVERSION: INVESTIGATION INTO DEGRADATION MECHANISMS OF POLYURETHANE ELASTOMERS

BY JULIA LANGENBACHER, BARBARA SOMMERMEYER

ABSTRACT

The sculpture *Wurfeisen und Zwille (Entwurf Hafenstraße)*, 1990 by Olaf Metzel is part of the collection of the Hamburger Kunsthalle. Made of multiple components, the artwork features abstracted and oversized caltrops as well as very large slingshots with matching red bands. These bands are made from a cold-curing two-component casting system based on a polyurethane ester. They presently show signs of significant material deterioration, initially becoming soft and tacky before ultimately liquefying with additional migration of plasticisers.

The material characterisation using Fourier Transform Infrared Spectroscopy (FTIR), Pyrolysis-Gas Chromatography / Mass Spectrometry (Py-GC / MS) and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) will be outlined in the present paper. Test series of different casting systems were used to examine the physical properties and the degradation mechanisms of polyurethane (PUR) elastomers.

The research also included interviews with the artist and coworkers, as well as ethical considerations concerning a reconstruction.

KEYWORDS

Polyurethane (PUR), elastomer, material deterioration, reconstruction, Olaf Metzel

INTRODUCTION

Polyurethanes (PUR) became commercially available in the 1950s and are popular nowadays for commodities and industrial products. PUR foam is the most common use, for example as upholstery material, while the production of elastomers, coatings and fibres based on polyurethane has grown within the last decades *(Oertel 1993: 11)*. The opportunities to modify the raw materials of PUR elastomers and use different production technologies in order to gain specific material properties has led to great versatility, for example in strength and flexibility. As a result, elastomers have increasingly become a popular choice not only for mass-produced items, but also for design and artistic applications.

The majority of PUR foams demonstrate poor ageing behaviour *(Kerr and Batcheller 1993; Van Oosten 2011)*, but some protective coatings with a PUR composition have proven highly stable in outdoor conditions and are used as automotive paints and finishes *(Oertel 1993: 606f.)*. Several contemporary works of art made from PUR elastomers have shown strong ageing phenomena related to their composition *(Kessler and Van Oosten 2005; López et al. 2007; De Groot et al. 2013)*. Industrial and mass-produced items, for example gaskets, are only meant to last for a certain period of time and can generally be replaced easily. However, in contemporary art, the irreversible material degradation entails slow alteration or even the complete destruction of objects. In such instances of complete decay, replacements are seldom an acceptable solution.

Today, the elastic rings of Olaf Metzel's sculpture *Wurfeisen und Zwille (Entwurf Hafenstraße)* already exhibit severe material deterioration. Therefore, investigations into the ageing behaviour of the material were carried out and the possibilities of a replacement were discussed as part of the research study. The related conservation issues and ethical considerations are beyond the scope of the present paper and are discussed separately *(Langenbacher and Sommermeyer 2015)*.

WURFEISEN UND ZWILLE (ENTWURF HAFENSTRASSE)

Wurfeisen und Zwille (Entwurf Hafenstraße) (Figure 1) reflects the topics of housing shortage and real estate speculations, as well as the related demonstrations and clashes around the squats on Hafenstraße in Hamburg in the 1980s and 1990s. The sculpture was planned as a model for a large-scale outdoor sculpture as part of the public art programme Kunst im öffentlichen Raum, but was never realised as such *(Metzel and Waldvogel 2013)*. Instead, the Hamburger Kunsthalle purchased the model version for their collection in 1991.

Figure 1
***Wurfeisen und Zwille (Entwurf Hafenstraße)*, 1990 by Olaf Metzel at the Kunstverein Hamburg in 2013.**
© Hamburger Kunsthalle, VG BILD-KUNST, Bonn 2014, photo: Julia Langenbacher.
(see colour plate, p. 174)

Made of 48 cast iron, 12 steel and 18 elastomer components, the sculpture features abstracted and oversized caltrops, as well as very large slingshots with matching red bands. The caltrops are made of cast iron and are up to 50 cm high and weigh approximately 43 kg. After casting, they were exposed to outdoor weather conditions in order to develop an irregular surface corrosion. The artist welded the single cast parts in different variations, thereby leaving the weld seams intentionally rough and unpolished. The slingshots were formed by steel bars of 2.5 cm in diameter. Each bar was heated and bent in an irregular and unique form. The polyurethane bands imitate the form of rubber gaskets used for preserving jars and, with an inner diameter of 42 cm, are also oversized. The art mould maker Ulrich Wolff(1) made the casts in 1990 from a relatively solid polyurethane elastomer.

For each installation of *Wurfeisen und Zwille (Entwurf Hafenstraße),* the caltrops and slingshots are piled up in the exhibition space. The elastomeric rings are loosely looped or partially tied around the steel parts and some are randomly thrown onto the sculpture.

CONDITION

The iron and steel components of the sculpture are in fairly good condition, but the polyurethane rings are badly degraded *(Figure 2)*. In 2009, limited material deterioration was observed. The degradation process started underneath the intact surface and was at early stages only visible within tears. The performance of the PUR slowly changed from elastic to soft. A few areas showed strong material deterioration and a migration of plasticisers *(Figure 3, 4)*. Today, all 18 bands have lost their elastic properties and large proportions have become liquid and tacky.

Additionally, deformations and stress cracks have emerged in oxidised areas, where the material was exposed to exceeding stress due to high tension or nodal points.

POLYURETHANE ELASTOMERS

Based on information given by the mould maker, the gaskets of Olaf Metzel's sculpture were cast by hand applying the product Ebaflex N2K. It is a cold-curing two-component casting system based on a PUR ester. The term polyurethane generally describes plastics formed by an addition reaction with multiple modification possibilities, where a urethane link presents the characteristic elemental structure within the organic molecular chain. Most commonly, they are formed by the reaction of a diisocyanate with a polyol in the presence of chain extenders.

Polyols are long-chain, high molecular-weight components with several hydroxyl groups, which built the soft segments of the cured PUR. The industry provides two main types for the production of PUR: polyester and polyether.

The diisocyanate represents the second basic component for the formation of polyurethanes. They are highly reactive and enter easily into exothermic reactions with groups containing active hydrogen. Today, mainly aromatic diisocyanates like methylene diphenylene diisocyanate (MDI) and less often naphthalene diisocyanate (NDI) are used to produce polyurethane elastomers, whereas toluene diisocyanate (TDI) is the standard type for flexible PUR foams. Several other diisocyanates are used for specific applications *(Oertel 1993)*.

The usual formulation of a urethane elastomer proceeds via the prepolymer method, where the final product is formed in two steps. In general, prepolymers consist of diisocyanate, polyol and often stabiliser. Together they form an intermediate polymer with free isocyanate groups, the so-called prepolymer. In a second step chain extenders are added to obtain a slightly crosslinked PUR *(Hepburn 1992: 125)*. Furthermore, plasticisers, antioxidants, fillers and pigments are added in order to control the curing process and to improve performance properties.

The final PUR block copolymer presents a characteristic morphological structure of hard and soft segments, which is responsible for the physical properties such as hardness and flexibility. This combination of rigid and flexible segments results in a very high elasticity and enormous ductility of PUR elastomers in comparison to other rubbers *(Hepburn 1992: 51; Oertel 1993: 44)*.

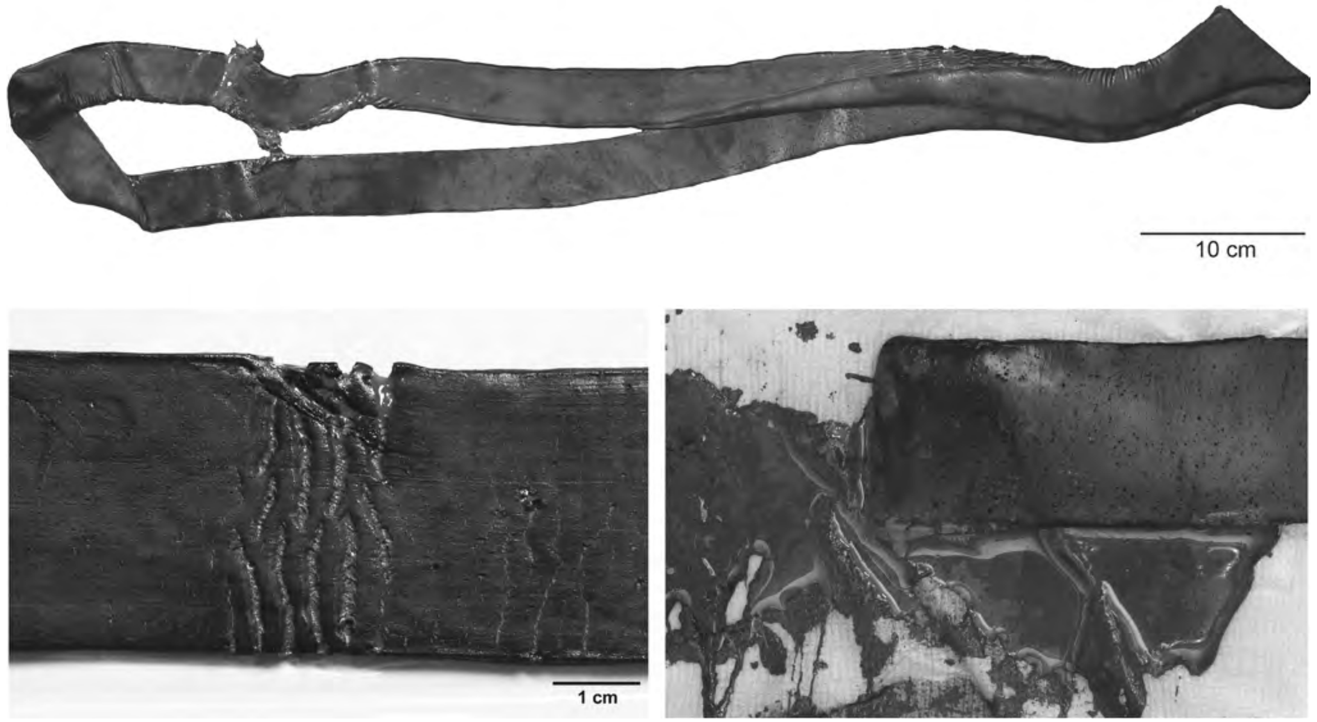


Figure 2
Details of PUR elastomer rings with signs of material deterioration and loss of plasticisers.
© Hamburger Kunsthalle, photo: Julia Langenbacher.

EXPERIMENTAL

In order to identify and understand the material degradation, samples were taken from the elastomeric rings and analysed using FTIR(2) and Py-GC/MS(3). The FTIR spectra indicate a polyester based polyurethane by absorption bands at 3346 cm^{-1} (urethane N-H stretching), 1724 cm^{-1} (C=O stretching), 1218 cm^{-1} and 1164 cm^{-1}. Unfortunately, some of the characteristic features are masked by the peaks of the accompanied phthalate ester plasticisers and fillers (hydrated aluminium silicate (kaolin) and silica), as seen in *Figure 4*.

Thereupon, Py-GC/MS analyses confirmed the presence of a PUR elastomer based on ethylene glycol, adipic acid, 1,4-Butanediol (as chain extender) and a derivate of methylene diphenylene diisocyanate (MDI). The plasticisers could be specified as mainly benzyl butyl phthalate (BBP), accompanied by dibutyl phthalate (DBP) and dibenzyl phthalate. In addition to the morphological structure, these plasticisers are responsible for the elastic nature of the polyurethane, but they are prone to migration as the present case of *Wurfeisen und Zwille (Entwurf Hafenstraße)* shows(4). In addition, fillers and pigments were analysed by means of SEM-EDS(5), showing a homogeneous distribution within the polyurethane samples. Several silicates, sulphates and metal oxides (e. g. titanium dioxide, mercury) were incorporated in order to increase the hardness, improve material properties, and generate the slight grey colour of the product Ebaflex N2K. Also red ferric oxide and lead-chrome based pigments were detected, presumably mixed into the casting system post hoc. According to the mould maker, he intermixed the two primary components of Ebaflex N2K first and incrementally added dry pigments in order to obtain the light red colour typical for rubber gaskets of preserving jars.

DEGRADATION OF PUR ELASTOMERS

The performance of elastomeric PUR is highly dependent on its morphological structure and individual components, its additives, fillers and impurities, as well as the production process. Hence, several internal and external factors affect the degradation. Because of their chemical composition and different reactive groups,

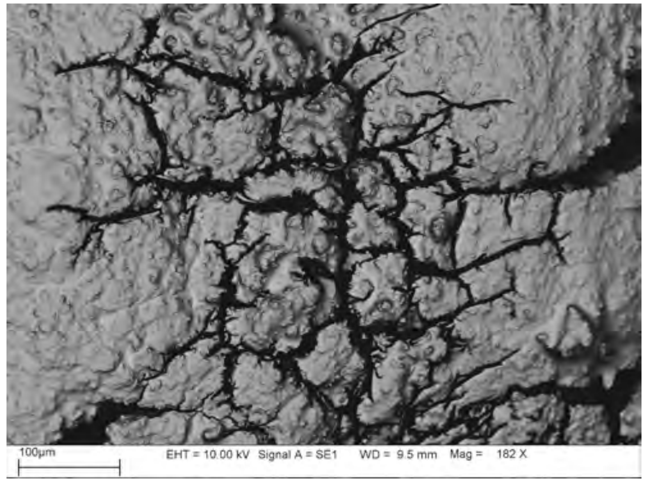


Figure 3
SEM image of a PUR sample. Single filler particles are visible. Formation of a membrane on the surface and strong cracks due to loss of plasticisers. © Stuttgart State Academy of Art and Design, photo: Dr. Christoph Krekel.

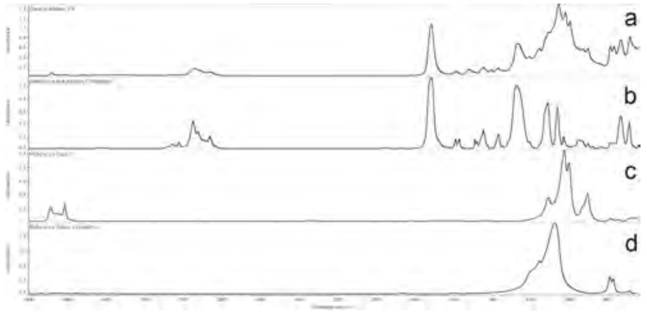


Figure 4
FTIR spectra of a PUR sample taken from (a) *Wurfeisen und Zwille (Entwurf Hafenstraße)*, compared to references of (b) butyl benzyl phthalate, (c) kaolin and (d) silica.

polyurethanes can be affected by a wide range of external factors, such as visible light and UV radiation, temperature, moisture, pollutants and microorganisms. Furthermore, the degradation can be intensified significantly by parallel impact of mechanical strain *(Kerr and Batcheller 1993)*. The ageing of PUR elastomers is mainly caused by oxidation and hydrolysis. In general, light radiation induces an oxidative material degradation accompanied by brittleness and discolouration. Instead, moisture commonly leads to a softening of the PUR due to a hydrolytic cleavage, where an increased temperature above 80°C can intensify the hydrolysis and promote thermal degradation[6]. Especially PUR esters are prone to hydrolysis. On the other hand, polyether based elastomers are more vulnerable to photo-oxidation and thermal degradation. *(Hepburn 1992: 376f.)*. Additives play an important, but sometimes opposing part in the ageing of PUR: for example, light stabilisers and antihydrolysis agents stabilise the composition, whereas on the contrary metal ions can catalyse further material breakdown *(Rånby and Rabek 1975)*.

As described above, the morphological structure of hard and soft segments is responsible for physical properties, but also influences the deterioration. Internally plasticised elastomers, for example, contain plasticisers which are copolymerised with the polyurethane. They present more soft segments and therefore show a higher flexibility. Instead, external plasticisers are only embedded in the structure rather than bound chemically to the elastomer. As a result they can migrate easier. For commercially available two-component PUR systems, the accurate proportion of the mixture and an even stirring of its parts, as well as an adequate temperature and the exclusion of humidity are critical for the curing process. Disregard can result in material failure and a tacky or brittle final product. In the present case, the quantitative ratio of the mixture was compromised by adding dry pigments, which, most likely, caused the elastomer to undercure. Secondly, the added pigments (ferric oxide, lead chromates) could have accelerated the degradation. Insufficient curing and inappropriate storage led to a hydrolytic cleavage of the polymer chain and the migration of plasticisers, which was confirmed by means of FTIR. The chain breakage resulted in a decrease in molecular weight and the loss of mechanical properties as outlined above.

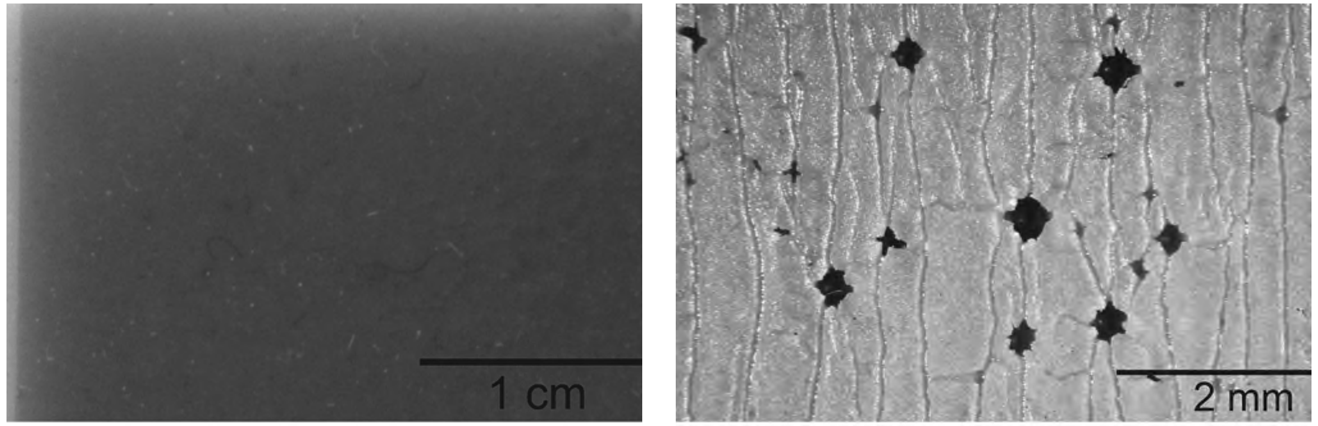


Figure 5
Details of test specimens after accelerated ageing.
(a) VytaFlex 60 after 24 hours of artificial light ageing with considerable discolouration. Left side covered during light exposure.
(b) Reckli PUR-Elastomer A55 after accelerated ageing showing cracks and discolouration.
© Julia Langenbacher.

TEST SERIES

The research included a test series on various PUR elastomers in order to reproduce the material degradation and to compare different casting systems with regard to their stability and similarity with the original. For the purpose of a reconstruction, it was necessary to find a more durable elastomer system which could be cast by hand in individual moulds, and was commercially available in small batches. Finally, the following six cold-curing systems were chosen considering hardness, tear strength, colour and stability of the cured elastomer, as well as viscosity, pot life, shrinkage, toxicity and availability of the casting compounds: Biresin U 1404, Ebaflex N2K mould making compound, GM 26, Neukadur ProtoFlex 165-05, Reckli PUR-Elastomer A55 (Type N) and VytaFlex 60 *(Table 1)*.

Besides monochrome grey test pieces, also coloured PUR samples were cast in different red hues using AltroColor colour pastes(7). The latter contain light fast pigments and are especially made for applications with PUR elastomers. They were stirred into the prepolymer, in proportion by weight up to three per cent. Then, the two-component PUR systems were mixed according to the manufacturers' recommendations and poured onto Melinex film. Following the appearance of the original material, an open mould was chosen and air bubbles that formed during stirring were aspired. The fully cured elastomer plates were cut into test samples, with a dimension of 10 x 3 cm and a thickness of 2 - 4 mm, in order to be comparable to the elastic rings of the sculpture.

ARTIFICIAL AGEING

Visible light and UV radiation, moisture and temperature significantly influence the degradation of PUR elastomers. Therefore, different climate conditions were simulated during accelerated ageing tests using a light chamber, alternating relative humidity and increased temperature.

The test samples were subjected to artificial light ageing in a Q-SUN Xenon test chamber(8) with an irradiance of 0.51 W/m^2 at 340 nm following the practice of standard DIN EN ISO 4892-2. Alteration was evaluated after eight and 24 hours. Some of the test

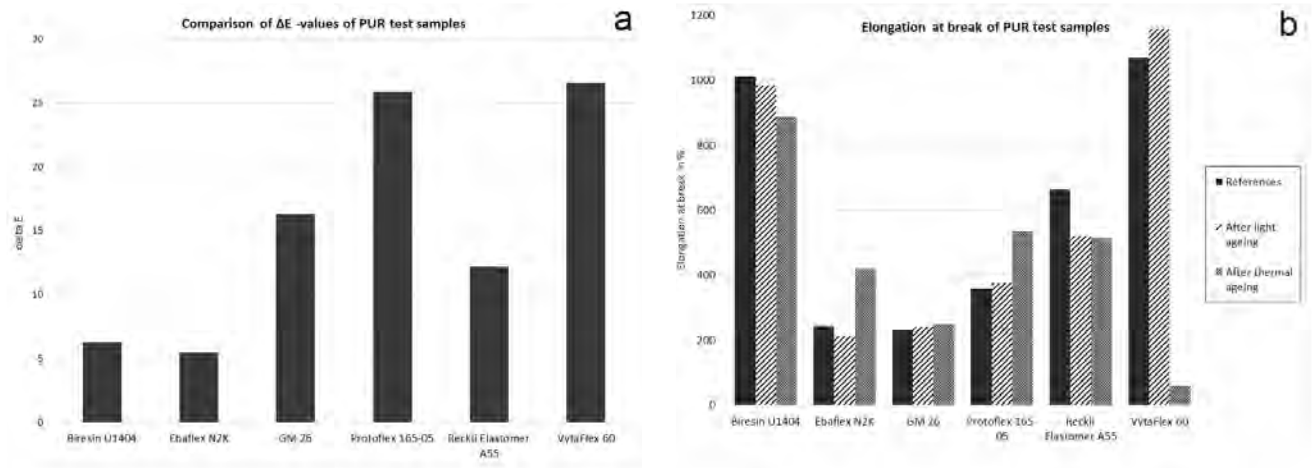


Figure 6

(a) Evaluation of colour alteration of monochrome grey test pieces expressed in ΔE (overall colour change) after 24 hours of artificial light ageing.
(b) Results of tensile tests before and after accelerated ageing.
References are compared to test samples exposed in a light chamber for 24 hours and to test pieces aged in a climate chamber for 21 days.

specimens were then exposed to accelerated thermal ageing in a Vötsch VC0020 climate chamber. In order to provoke hydrolysis, various cycles with changing relative humidity between 25 and 90 % and a temperature range of 15 to 100 °C were performed for 21 days referring to DIN standard 53508.

As a reference, non-aged test samples of each elastomer were kept in the dark at standard conditions of 20 °C and 55 % RH.

EVALUATION

The evaluation was made with regard to optical, mechanical and chemical alteration, while the results also had to meet the required material properties for a reconstruction.

Changes in surface structure and gloss were assessed microscopically and all test pieces were photographed consistently. Samples of each PUR elastomer were taken for additional surface observation using SEM.

Induced colour shifts could be determined with a Konica Minolta CM-2600d spectrophotometer[9] applying the CIELAB colour space. The results are expressed in terms of L*, a* and b*, where L* represents the lightness, a* the red - green and b* the yellow - blue scale. For each test piece, multiple measurements were taken and averaged before and after the ageing procedure. Colour difference was calculated between the averaged values and expressed in terms of ΔE 76.

Changes in mass were captured by weighing the test samples before, during and after several artificial ageing steps.

Tensile tests were subsequently performed to measure elongation, tensile strength and stress values, by using a Zwick Z2.5/TN1S materials test machine. Each sample was clamped and elongated until break following the practice of DIN 5350420.

RESULTS AND DISCUSSION

During the accelerated ageing tests major differences between the evaluated elastomers were detected *(Figure 6)*. The casting resin Biresin U1404 exhibited good ageing properties, and only small colour changes occurred after removal from the light chamber when compared to the other polyurethanes. Nevertheless, slight deformation and increase in weight were observed after thermal ageing. Unfortunately, the mechanical properties, for example the abrasion resistance, were not comparable to the original elastomer. As seen in *Figure 6* Biresin demonstrated a very high elongation (even before the artificial ageing) as opposed to Ebaflex N2K. Therefore, it wasn't considered a suitable reconstruction material in this specific case.

The coloured test pieces of Ebaflex N2K showed only slight changes after the accelerated light ageing, mainly a decrease in surface gloss became visible. The test specimens which were artificially aged at a high relative humidity became rather soft and more flexible due to hydrolysis. An additionally increased temperature above 90 °C intensified the hydrolytic cleavage and promoted thermal degradation. Although high temperature and relative humidity lead to a softening of the test specimens, these conditions were not sufficient to provoke a material reversion linked to hydrolysis and a migration of plasticisers comparable to the original rings. Furthermore, no visible alterations could be detected after artificial ageing at moderate conditions below 70 °C. In summary Ebaflex N2K showed relatively good test results.

Product	Composition		Mixing ratio by weight	Shore Hardness A	Colour
	A	B			
Biresin U1404	Aromatic polyisocyanate-Prepolymere TDI	Polyol formulation 2,6-diamino-3,5-diethyltoluene	80 : 100	40	Yellow translucent
Ebaflex N2K	Polyester polyol Fillers (kaolin, silica, titanium dioxide)	p-MDI BBP	100 : 10	55 – 60	Grey
GM 26	Polyether blend	p-MDI	100 : 28	59	Beige
NEUKADUR ProtoFlex 165-05	Formulated polyether-polyesterpolyol Alkylated aromatic hydrocarbon Tetramethylenglycol	p-MDI Alkylated aromatic hydrocarbon	100 : 33	65	White
RECKLI PUR-Elastomer A55, Type N	Polyol formulation	p-MDI	8 : 1	55	Grey
VytaFlex 60	TDI Diisononylphthalate	Polyether polyol Diethyltoluenediamine Di(methylthio)toluene diamine	1 : 1	60	White

Table 1

Material properties of selected PUR elastomers.
Information based on technical data sheets by manufacturers.

Colour measurements of the PUR ether elastomer GM 26 exhibited variations mainly in b* and L* values after 24 hours light radiation, which represents a shift into yellow and darkness. Cracks and embrittlement occurred and led to low tear strength during tensile tests.

The test specimens of Neukadur ProtoFlex 165-05, made from a polyether-polyester-polyol blend, displayed distinct colour alteration within only one hour of artificial light ageing. Additionally, considerable shrinkage up to 19 per cent and deformations were detected on all test pieces.

The Reckli PUR-Elastomer A55 was the only tested polyurethane that exhibited similar physical properties as the original Ebaflex N2K, which could be accounted for by the included fillers. However, its ageing stability was inferior, because noticeable changes in colour and gloss, and severe cracks occurred during accelerated ageing *(Figure 5b)*.

The VytaFlex 60 elastomer, based on PUR ether, exhibited a very poor ageing behaviour *(Figure 5a)*. Distinct discolouration after eight respectively 24 hours light radiation was measured whereby the photo-induced oxidation even continued afterwards in dark storage(10). Furthermore, the material lost its elastic behaviour during thermal ageing and showed a tacky surface with formation of wrinkles, most likely due to the migration of plasticisers and other additives.

In summary, the products GM 26, Protoflex 165-05, Reckli PUR-Elastomer A55 and VytaFlex 60 exhibited insufficient ageing properties, such as discolouration and cracks, or did not yield acceptable mechanical strength. As explained above Biresin U1404, although showing good test results, was not suitable as a replacement material in this case. Ebaflex N2K yielded good chemical and physical stability in moderate conditions (not exceeding 70 °C and no highly increased humidity). These findings support the assumption that an insufficient curing of the original elastomer has induced the degradation initially, aggravated by catalysing pigments.

CONCLUSION

The test series demonstrated that the various ageing properties of PUR elastomers are strongly related to their complex composition. A differentiation was made mainly between polyester and polyether types, but also the contained diisocyanates, catalysts, and plasticisers played an important part.

In the case of *Wurfeisen und Zwille (Entwurf Hafenstraße)*, the reinforced elastomers were more suitable for a reconstruction than products without fillers. In addition to the bright colour, a specific strength, hardness and elongation were required in order to mimic the material properties of the original elastic rings. It necessitated an elastomer with a certain amount of rigid as well as flexible components. In addition, the selection of a suitable material was limited by the requirement to use a cold curing system, which is supposed to be applied by hand in a custom-made open mould. An elastomer that fully met all demands and at the same time had excellent ageing properties could not be found within the scope of this research study. Despite the materials' intrinsic disadvantage of external plasticisers and their migration being problematic, Ebaflex N2K showed a good performance during the accelerated ageing tests. This is most likely due to its strong rigidity and filler content and its relatively low amount of plasticisers compared to more flexible PUR elastomers. By ensuring the appropriate mixing ratio of the two-component system, as well as applying compatible colouring products instead of dry pigments, it is assumed to result in a more durable elastomer.

Following the test results, Ebaflex N2K and AltroColor colour pastes were chosen to cast new elastomeric rings for the sculpture. The art mould maker Ulrich Wolff carried out the reconstruction in agreement with the artist. Finally, preventive conservation arrangements were made, like establishing dry and cold storage conditions in order to minimize the degradation of the polyurethane ester elastomers.

ACKNOWLEDGEMENTS

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ENDNOTES

(1) *Ulrich Wolff, Atelier für Kunstformung, Karlsruhe.*

(2) *Perkin Elmer Spectrum One, universal ATR diamond Zn/Se, spectra recorded from 4000 to 650 cm^{-1}, Software: Spectrum V3.02.*

(3) *Gas chromatograph-mass spectrometer QP-2010 Ultra with pyrolyser 2020id (Shimadzu Deutschland GmbH). Pyrolysis temperature 540 °C / 15 s. XLB-HT column (Zebron), 30 m x 0.25 mm x 0.25 µm. GC/MS were performed with the following parameters: Split 120:1 at 280 °C, He 40 cm/s, 40 °C, 2 min, 20 K/min up to 340 °C, El with 70 eV from 15 to 550 m/z, 15 scans/s. Software: F-Search (Shimadzu) and NIST08 (The National Institute of Standards and Technology). Analyses and interpretation by Dr. Ulrich Jäger (State Criminal Police Office Baden-Wuerttemberg).*

(4) *The PUR industry provides high resistant elastomers made by specific modifications of the soft and hard segments within the morphological structure. De facto, the use of phthalates as plasticisers is often preferred, because of their comparable low prices. Hepburn 1992: 65.*

(5) *Scanning Electron Microscope EVO 60 by Carl Zeiss AG, Energy-Dispersive X-ray Spectroscopy (EDS) in variable pressure mode (VP), 10kV accelerating voltage. Analyses performed by Dr. Christoph Krekel (Stuttgart State Academy of Art and Design).*

(6) *In general, there is a permanent decrease in the properties of PUR elastomers, such as hardness, strength and elasticity above 80 °C caused by an oxidative cleavage. However, only above 210 °C a considerable decomposition takes place and the elastomer releases degradation products. Hepburn 1992: 377. Grassie et al. 1980.*

(7) *The AltroColor colour pastes are polyol formulations, which contain the following pigments: PR 48:3 (Monoazo Sr lake), PY 74 (Monoazo yellow), PW 6 (Titanium oxide).*

(8) *Q-SUN Xenon test chamber XE-1-BC, Daylight Q filter, irradiance: 0.51 W/m^2 at 340 nm, black panel temperature: 63 °C.*

(9) *Konica Minolta 2600d Spectrophotometer, used relative to a magnesium oxide white standard, geometry: 0/45°, illumination: D65, area SAV Ø 3 mm, observer: 10°, standard deviation ± 0,04, software: SpectraMagic. The data was collected regardless surface gloss.*

(10) *Besides the primary process of photon absorption and release activated by visible and UV radiation, secondary reactions might also take place due to an energy transfer to other molecules. This process is called post-irradiation effect and can start a chain of various further events. Cf. Feller 1994: 51 f.*

POSTER
006
DESIGNED FOR CONSERVATION? THE IMPACT OF EXHIBITION DESIGN ON MODERN MATERIALS

BY SARAH GLENN

ABSTRACT

The Victoria and Albert Museum (V&A), London, is committed to exhibiting contemporary displays featuring artists, designers, photographers and craftspeople currently producing work in the UK and worldwide. The recent Yohji Yamamoto exhibition reflected this commitment. A major retrospective of the Japanese designer's work was held from 12th March to 10th July 2011, featuring over eighty garments and accessories from the designer's archives and was the first to show Yamamoto's designs for womenswear and menswear together. The design of the single room exhibition included a large light installation in the centre of the space, creating challenging and unusual conditions in which to exhibit garments on open display. Several garments contained potentially unstable materials, including PVC [poly(vinyl chloride].

This paper explores the challenges faced by the conservator in displaying contemporary fashion designs, some containing synthetic materials, and the impact of the exhibition design on these materials. Also discussed are the ethical considerations of mounting a display with unusual and challenging environmental conditions and the conservation issues that arise from displaying costume containing modern materials and the role of the conservator in communicating potential issues to lenders, curators, designers and others.

KEYWORDS

PVC, exhibition design, open-display, contemporary, fashion, ethics

INTRODUCTION

The Yohji Yamamoto exhibition at the V&A opened between 12th March – 10th July 2011, the first major retrospective of the Japanese designer's womenswear and menswear collections and featuring over 80 garments from his archives. Ligaya Salazar, the exhibition curator, wanted to showcase the variety of Yamamoto's designs from the 30 years of his career in several spaces throughout the museum; a large exhibition space featuring 65 outfits and several 'satellite' spaces containing 3 to 5 outfits, placed in galleries throughout the South Kensington site. The main exhibition space also featured accessories, 2D items and a multimedia timeline highlighting aspects of Yamamoto's wider creative output and design collaborations.

Yohji Yamamoto became internationally known as an avant-garde fashion designer in the 1980s. He is known for challenging traditional ideas of fashion by designing clothes that are often oversized, unfinished and created using unusual pattern cutting techniques. He is also known for his use of fabrics such as felt, neoprene, wood and PVC, using a fairly limited colour palette throughout his designs. He describes the colour black, the colour most associated with his collections as 'modest and arrogant at the same time'. Textiles are central to his work and each fabric used in his collections are made in Kyoto, Japan to his specifications. 'Fabric is everything' he once said, 'the material will probably teach you something if you listen to it' *(Salazar, 2010)*.

THE EXHIBITION DESIGN

The exhibition space was designed by Yamamoto's long-term collaborator in set and lighting design, Mr. Nihei. The aim of the V&A show was intended to have a design aesthetic in keeping with his previous smaller exhibitions, which featured bright, open exhibition spaces and to facilitate the visitor to get as close to the costumes as possible *(Figure 1)*.

In some previous exhibitions, it was possible for the visitor to try on the outfits. Yamamoto's aim for visitors to the V&A show to have a strong sense of feeling physically close to the outfits and this was to be achieved in several ways:

1. *A bright exhibition space, with white walls, floor and ceiling*
2. *Mannequins standing on the floor of the gallery*
3. *No plinths or barriers, enabling visitors to have close-up views of the objects*
4. *Touching the objects not to be discouraged*

THE IMPLICATIONS OF EXHIBITION DESIGN ON THE GARMENTS

The design of the main exhibition space contained a large fluorescent light installation, which dominated the middle of the gallery. The Yamamoto team wanted to include this feature as it enhanced the clean and bright ambience of the gallery and had continuity with designs of other Yamamoto exhibitions. The likely risks to unprotected objects underneath this kind of light were highlighted by V&A conservation to the Yamamoto team at the design stage of the process.

After installation, the light levels of the design feature were measured at over 12000 lux (the light meter used was not capable of showing values higher than this). It was strongly recommended that the lux levels should be reduced as the likelihood of damage to objects situated directly underneath and in the local area was extremely high.

The V&A conservators felt very strongly that the lux levels were not acceptable and indeed, were far out of the range normally recommended for textiles on open display, usually below 50 lux. During subsequent discussions with Yamamoto and his design team, the risk factors to the objects were reiterated by conservators. However, the design team felt strongly that the light was integral to the design and it was decided to leave the installation as it was intended.

OTHER RISKS POSED TO OBJECTS

The other direct consequences of the open display exhibition design were also explained to the Yamamoto team. This included the risks of open display, such as security and repeated handling by the public.

The V&A usually recommends a one metre distance between the visitor and the object to prevent unnecessary touching and handling by the visitors. The Yamamoto design featured the mannequins to be standing on the gallery floor with no plinths or barriers, and no distance between the object and the visitor to enable greater understanding of the garments. The opportunity to touch the objects by visitors was also to not be discouraged. Again, the risk to the objects was strongly explained to the Yamamoto team, who again decided that this close-up opportunity was part of the visitor experience. To that end, all objects that could be easily removed from mannequins, including broaches, pins, belts, ties, scarves and hats had to be stitched to the mannequin for security purposes.

SECURITY

There was some concern about the safety and security of the objects, especially those in the satellite spaces where there was no specific invigilation. The nature of the open display was also a concern and the level of invigilation in the main gallery was discussed. The conclusion was reached that as the V&A conservators could not check the outfits as regularly as was required, a host system could be set up. The idea was to employ local students from fashion and textile courses who would be trained as special temporary gallery assistants who would undertake the following daily:

1) *Check the condition of all objects at each change of shift and record any minor findings that could be dealt with by conservation*
2) *Alert exhibitions coordinators and conservation immediately should any major damage occur*
3) *Be able to carry out very minor alterations to the clothes if they were mis-handled or moved by the visitors*
4) *Be able to talk to visitors about the garments on show*

Figure 1
The main gallery space with fluorescent light installation in the gallery; note also the stark white walls and floor and lack of plinths and barriers

As part of the gallery host's training, the lead conservator organised several training sessions on basic handling and condition checking. Detailed guidance documents were drawn up for the hosts to study including condition ratings, condition description words and phrases, insect and pest identification, and handling guidelines, as well as specific instructions for each garment on display. It was hoped that this programme would enable the hosts to carry out everyday checks and visual assessments without the need for a conservator. The scheme required the hosts to produce good documentation and communication to relay any possible problems with the garments as soon as possible so that suitable adjustments could be made in a timely fashion. This proved to be vital in monitoring the more potentially unstable materials in the exhibition.

Figure 2
The black cotton gabardine and PVC appliqué skirt is situated directly underneath the light (during installation)

MEMORANDUM OF UNDERSTANDING

Since the exhibition contained no objects owned by the V&A or other lenders, it was vital for all stakeholders in the exhibition to be in agreement about the level of care given to the objects. The exhibition and conservation department insisted that the risks and subsequent responsibilities were understood by the Yamamoto archive, having had the risks explained to them fully. Therefore a memorandum of understanding, explaining the likelihood of damage to objects as a direct result of the exhibition design during the display period, was drawn up.

To clarify terminology, a number of appendices defining descriptions of wear and tear were also included. The role of the conservation department before, during and after the exhibition was set out as well as the systems put in place to reduce the risks to the objects whilst in the V&A's care.

This document was agreed on and signed by all the relevant parties; lender, archive, curator and conservation department.

BLACK COTTON GABARDINE SKIRT WITH PVC APPLIQUÉ

A small number of objects in the exhibition contained some elements of synthetic and semi-synthetic materials, which were flagged as being potentially unstable on open display.

One outfit was a black cotton gabardine skirt with black polyvinyl chloride (PVC) appliqué and tulle underskirt (W17 YY216) made for Autumn/ Winter 1995-6. Black liquid PVC had been brushed, splattered and dripped to the cotton gabardine skirt, applied to various locations and in a variety of thicknesses *(Figure 2)*.

On arrival at the V&A the condition of the garment was assessed and found to be in a good condition. The PVC appliqué had a coherent structure with no cracking, bloom, crazing or evidence of other degradation. No odour was detected, and the surface was not tacky to touch. Therefore it was considered that the object would be suitable for display.

A daily visual assessment of the object was planned for the duration of the exhibition to ensure that the condition remained consistent. This object, along with several other garments considered at high risk, was highlighted to the gallery hosts due to the vulnerable nature of the materials used. The hosts were told to look for the following on the PVC elements during their daily inspection;

1) *surface tackiness (dust adhering to the surface of the PVC)*
2) *discolouration*
3) *white bloom or chalk-like substance appearing on surface*
4) *changes in the structural integrity of the PVC (splits, lifting surfaces)*
5) *any unusual or change in odour*

The object was situated almost directly underneath the light installation and therefore required frequent checking. After weeks one and two of the exhibition, the PVC appliqué was found to be in a similar condition as the initial assessment. However, week three brought a significant change to the appearance of the PVC surface.

The plastic appliqué was found to be lifting from the surface of the cotton skirt and deep cracks were appearing in several places. The surface was becoming very fragile *(Figures 3-5)*.

The surface felt slightly tacky and warm to the touch, which may have been due to the plasticizers leaching out due to the heat of the gallery, produced mainly by the fluorescent light installation in the centre of the gallery. Temperatures were recorded at over 35°C directly under the installation. The general ambient temperature of the gallery increased from usual ranges of 18-25°C to 27-28°C, most likely due to the white, reflective walls and floor of the space. In order to help to reduce the temperature, it was suggested that the air flow in the gallery was increased and where possible, the airflow should be uninhibited by

Figure 3
**Detail of damage to PVC appliqué:
large splits occurring in surface**

Figure 4
**Detail of damage to PVC appliqué:
surface lifting and adhesion to cotton surface failing,
leaving areas of loss**

Figure 5
**Detail of damage to PVC appliqué:
surface becomes tackier and 'flowing', causing distortions**

Figure 6
**Detail of fading to green coat dress
at the end of the exhibition run
*(see colour plate, p. 173)***

removing barriers from vents within the gallery. Unfortunately this was only possible to a certain extent due to the design of the exhibition hall itself, so the temperature had to remain higher than usual parameters for textile objects.

It is likely that the cracks in the surface were caused by the loss of plasticizer from the material resulting in brittleness. The high temperature caused the loosening of the adhesive bond and so has made the possibility of mechanical stress much more likely to occur. In addition, the general gallery dust caused by the flow of visitors despite regular cleaning was beginning to stick to the tacky surface and there was concern that this would eventually become impossible to remove.

After discussion with Brenda Keneghan, the polymer specialist at the V&A, and the Yamamoto team, it was agreed to remove the outfit from display due to this rapid rate of deterioration after only three weeks of display. It was suggested that it was most likely that the polymer would continue to become tackier, begin to adhere together and cracks continue to occur throughout the polymer surface.

OTHER OBJECTS IN THE EXHIBITION

The strong light levels had an adverse effect on other objects in the exhibition. A green dress coat was situated at the beginning of the gallery space, and was one of the objects furthest from the light installation. Light levels in this area of the exhibition space were measured at 500 lux, considerably lower than elsewhere in the gallery, yet still a great deal over the usual recommended level. Despite its location, fading was noticed by the hosts one month into the duration of the exhibition and continued to worsen throughout *(Figure 6)*.

An inspection of all the of the garments in the gallery at this point revealed fading to a greater or lesser extent on all of the objects. The Yamamoto team was informed of the damage to this object at the earliest opportunity, but after understanding the explanation of the cumulative effects of light damage and subsequent discussions, were happy to keep the object on open display for the rest of the exhibition's duration.

ETHICAL CONSIDERATIONS

The issues of mounting a major display with such unusual and challenging conditions to be part of a major exhibition provoked much discussion in the textile conservation studio. On one hand, it sets an unhelpful precedent for future exhibitions where designers may want to recreate a similar environment of the exhibition. There was concern that the Yamamoto exhibition should be an exception rather than becoming the norm for exhibition design at the V&A. Indeed, the damage sustained during the exhibition to objects has somewhat set a benchmark for future displays and is used as an example provided to curators, exhibition designers and conservators as a guide for avoiding similar conditions. Simply because the objects are not part of the V&A collection does not mean that a design for an exhibition can include an 'anything goes' approach; it was strongly felt by the V&A project team, including curators, conservators and the exhibitions department, that any object displayed in the museum and under the 'umbrella' of the V&A, should be treated just as an object in the collection itself; as conservators we have a duty of care to any object under our responsibilty, regardless of the owner. However, if the owner or lender still wants to display the object after the risks have been fully explained, then the conservator must work within the parameters of the design brief to the best of their ability.

CONCLUSION

It was no surprise to the V&A conservators that the extreme conditions of the Yamamoto exhibition had an effect on the conditions of objects, especially to those modern materials which are known to be susceptible to fluctuations to or conditions outside of the recommended environmental parameters. It was however, unprecedented that the damage occurred in such a short space of time. The rate of deterioration could not have been anticipated or indeed prevented, given the environmental conditions, but the frequent checks on the garment prevented further unecessary damage from ocurring unnoticed.

The host system proved to be vital during the exhibition. The system relies on good communication and documentation and the hosts were excellent in carrying out their duties. The damage to the PVC applique was reported and dealt with within the same day, limiting the potential for further issues to arise. Although a great deal of time was taken in interviewing, selecting and training the hosts, the system was invaluaable to conservators who were unable to check the objects daily.

The ethical considerations of the project were perhaps the most challenging for the V&A team, and for both conservators and exhibition co-ordinators. Working within parameters where it is almost certain that damage will occur is difficult, especially as it is in direct conflict with conservation ethical guidelines and training to safeguard objects under our care. Although perhaps not a satisfactory outcome for best practice, the success came when all the systems put in place by conservation worked correctly and efficiently to prevent a greater deal of damage occurring. At the least, the Yohji Yamamoto exhibition provided an invaluable example and reminder of how modern materials are susceptible and that irreversible damage can be caused by such conditions. It also highlighted the essential role of the conservator in safeguarding objects to the best of their ability, within challenging working parameters.

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COMPLEX CARE FOR CONTEMPORARY ART HERITAGE: RESEARCH PROJECT: PLASTICS IN ART IN POLAND.

BY MONIKA JADZINSKA, PAWEL PARZUCHOWSKI

ABSTRACT

This paper introduces the first in-depth project focused on plastics in art and conservation in Poland. The research projects aims to compile a body of knowledge to further research, identification and methodology in the field. Conceived as an innovative, interdisciplinary research project (initiated by the National Science Centre, 2012-15), its findings are of scientific, artistic, cultural and social importance. Fifteen works of art by some of the most important Polish artists working from the 1960s to 2013 were chosen as case studies to determine the role of new scientific technologies in conservation science with the further possibility of application in museum practice, as well as the public and private space. Three of the case studies by artists Alina Szapocznikow, Tadeusz Kantor and Paweł Althamer will be featured in this article.

KEYWORDS

Plastics in Poland, Szapocznikow, Kantor, Althamer, FTIR, NMR, Raman spectroscopy

INTRODUCTION

The lifespan of a modern and contemporary work of art is defined by its exceptional character. Plastic is a miraculous substance, 'a stuff of alchemy' as Roland Barthes put it in his famous essay *(Barthes 1956 (1972): 97)*, but in order to keep its magic, we need to recognise it properly, identify its needs, and then maintain properly.

Plastics have been a part of our cultural heritage for over a hundred years. Artists of different disciplines employ them as a means of expression in their work, sometimes as the featured component, whether newly forged or as ready-mades, or as part of larger structures. The choice of material, and the way in which it is used encode the object, and together with external factors, determine its entire subsequent life. To ascertain the best forms of maintenance and conservation measures, the artist's intention in creating the work of art (the authenticity of the image, idea and substance) and in particular the meaning of the use of plastics should be taken into account together with an analysis of the material. While this issue has been examined in the Western European countries and the USA since the 1990s, that body of knowledge cannot be easily extrapolated to the Polish region because of different cultural, social, economic situation, and specific differences in materials that were used. The history of plastics in Poland should be regarded as 'exceptional' case. Compared to Western European countries it suffered from a 'delay' in the initial availability and production of plastics. However, once introduced this delay seems to have boosted the creativity of its use by artists and designers, making each work of art even more personalised.

WHY A COMPLEX APPROACH IS NECESSARY

Let us imagine the situation when the material of the work of art is known, but there is no broad knowledge and deeper awareness of other aspects of the work of art, and as a result, its proper maintenance is affected. An example is Caprice (1967), an experimental sculpture made of plastics by Alina Szapocznikow. The sculpture was made by shaping polyurethane soft foam around a steel frame. It was then immersed in a rigid layer of red-dyed saturated polyester resin solution and reinforced by a fibreglass cloth. Since the piece was created as a kind of lampshade with an operating electrical lighting system inside, the plastic sculpture should be semi-transparent.

The conservation-related problems started soon after the piece left the artist's studio, probably because of extensive travels in the years 1967-73 (galleries in Paris, Sweden and Poland)

Figure 1
Alina Szapocznikow, Tors noyé (fragment).
(see colour plate, p. 175)

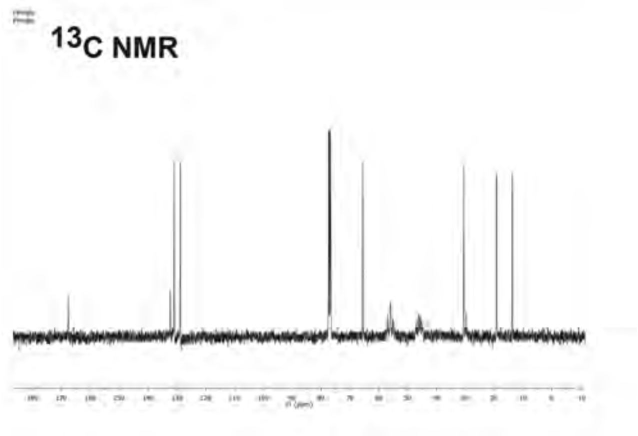

Figure 2
FTIR spectra (KBr) of *Tors noyé*.

and the fragility of the object. Huge amount of cracks all over the surface of the object started appearing *(Kusz 2006: 38)*. In 1975, on request of the Museum of Art in Łódź, the piece was restored by the chemist Dr. Janusz Lehman, who knew the material and technology very well, but did not reflect on other aspects and the author's intent. He used a thick layer of epoxy resin and red chiffon, covering the polyester, and changing the form, dimensions and character of the original. The different properties of the new materials resulted in a milky-yellow, brittle and cracked, visible layer of resin. In this case, the lack of complex recognition of the individual iconography of the material resulted in a substantial transformation of the work of art.

TRYING TO SOLVE THE PROBLEM. METHODOLOGY

In Poland, even among those directly involved in collecting, protecting and taking care of works of art made of plastics, special knowledge of plastics in terms of the properties, character and history of use is rather scarce. As a relatively young material, plastics are generally expected to be durable and, as a result, the involvement of conservators only comes into play when the degradation process is in an advanced state and becomes visible.

The project, initiated by the National Science Centre and called *Innovations and new technologies devoted to the conservation of artworks of plastic. Sustainability through building of knowledge for identification, research and methodologies of conservation in the collections and public space* is supposed to fill this gap. The project will result in a study that presents plastics in a broad, but coherent and synthetic way, together with methods of identification and historical use in works of art based on case studies. To begin the project, the current state of knowledge was ascertained and methods of identifying the presence of plastics were selected. An important objective of the project is to analyse aging processes, and propose solutions to preserve objects (storage, climate, transportation, exhibition, conservation), which will be synthesized in a kind of short practical guide, aimed at various users from museum professionals to ordinary people who would like to preserve family keepsakes. The final section of this guide will specifically refer to the protection of works of art.

Due to their infinite variety and extreme personalisation modern artworks remain difficult objects to research in a comprehensive manner. Therefore, the selection of the examined objects in the guide and project as a whole was not based on their 'universality', but principally on the status of the artists, the period in which the works were created, and the interested of the individual works of art.

In addition to the guide, we also plan to issue a monograph. The objective of this project is to extract knowledge of polymers and plastics from broad areas of the industry, design and conservation, to produce a publication focused on preservation of works of art and objects made of plastics.
Below we present a part of our research on plastics in art in Poland, including case studies: sculptures by Alina Szapocznikow (1960s), Tadeusz Kantor (1970s and 1980s) and Paweł Althamer (twenty-first century).

Figure 3
Tadeusz Kantor, Mannequine no 98 from The dead class.

EXCEPTIONAL CASE – PLASTICS IN POLAND

(Wojciechowski 1956; Łuczak-Surówka 2012; Demska, Frackiewicz, Maga 2011)

Before and during World War I there were no possibilities for development of the plastics industry in Poland. New materials appeared in the 1920s in the industry and later on in art and design. In the 1930s Tomofan (cellophane) (1931), Galalith (1934) and phenolic resins were obtained. After World War II intensive development in production of several kinds of plastics took place: polystyrene (the Smoleński method), polyurethane, epoxy resins, polyesters, silicone, polyethylene, polypropylene, melamine, urea resins, formaldehydes and others. It was the time when socialist realism became the obligatory style in Poland and Central-Eastern Europe, which was very conservative and prevented any form of experimentation in the field of material, forms and content. Works of art had to be legible to all viewers, and at the same time as solid and durable as the conveyed ideology. Social realists therefore used historical styles and traditional materials like marble, bronze or traditional painting techniques. In the mid-1950s political changes made it possible to abandon the doctrine of socialist realism bringing with it the promise of all things new. 'Modern times' followed. Modernity was understood as 'leaning out into the future and turning away from the past' *(Demska, Frackiewicz, Maga 2011: 34)*. It was the time when the famous Polish film school and the Polish school of poster were shaped, the first International Festival of Contemporary Music and the first Jazz Jamboree Festival took place. The feeling of the turning point was closely connected with the new aesthetics, corresponding to new materials and technologies in visual arts, architecture and design. New materials provided new possibilities, with the potential to be formed into various shapes. Aleksander Wojciechowski, an art critic, wrote in 1957: 'it is only the modern materials combined with a modern production method that can create the form which can barely be foreseen by our artists in their wildest dreams' *(Wojciechowski 1956: 2)*. In 1950 the Institute of Industrial Design was opened to deliver 'the beauty on a daily basis, for everybody'. At the turn of the 1950s and 1960s, plastic became the main popular material in all areas of life, because of low production costs, great ductility and its aura of modernity. The fascination with organic forms and abstraction resulted in the search for new formal and material solutions in design and art. Plastics were the best materials for experiments. In furniture making, plywood was replaced by plastics – Igelit, Winidur, Bakelite or epoxy resins. Seats were woven from plastic cords, formed from polyvinyl chloride or synthetic resins reinforced with a glass mat and metal frame. One of the most original, unique, called 'an icon of Polish design', was the RM58 armchair, designed and produced by Professor Roman Modzelewski in 1958, as a prototype for serial industrial production. He used rotational moulding technology, in which an aluminium form was spinning in a furnace, while polyethylene powder covered the exterior of the form provid-

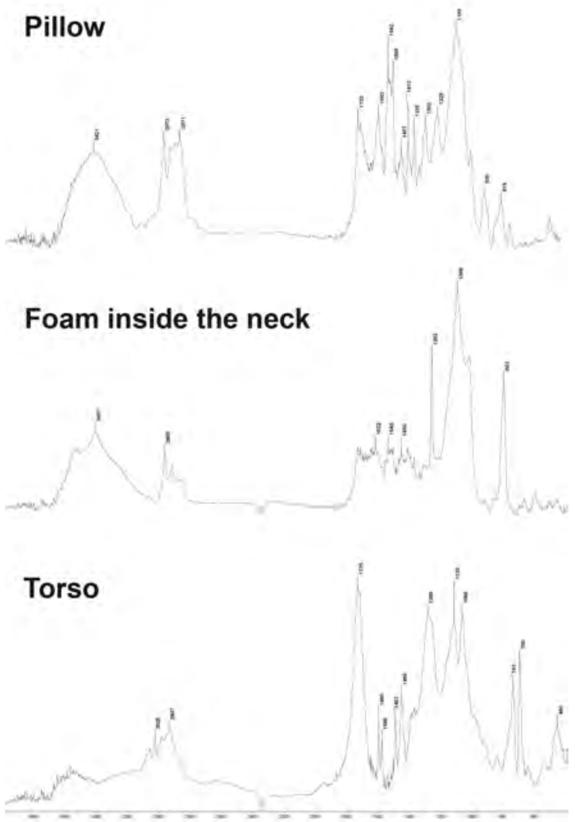

Figure 4
^{1}H and ^{13}C NMR spectra of PVC used for construction of Tadeusz Kantor's marionettes.

ing a kind of organic shell-and conch-like shape, to the monolith seat. Le Corbusier was very interested in the production of this model in France, but this was never realized. Because of the political and economic situation many prototypes designed by Polish designers were only displayed in exhibitions, without a chance to enter mass production. The lack of support from the state chemical industries (which was a strategic branch, hugely controlled by the USSR) forced people to work on their own. Paradoxically, artists and designers were themselves creative enough to produce unique forms, sometimes with the support of certain artist associations and studios that sold the finished products to cultural and public institutions and citizens.

In the 1960s the role of design and demand for consumer goods soared. Centres of research – development, trades, new faculties at the academies and universities, and design associations were working with new materials. In spite of the fact that there were still problems with accessibility of materials as well as technology, modern objects, household goods, furniture, cars, machines, equipment and other objects were made of plastics (think of the Ramona and Ewa radio, Bambino gramophone, System MK 'Kowalski segment furniture' and others). New trends and visible change in aesthetics were introduced (among others by the Ulm School of Design). Synthetics became a fertile field of experimentation for artists. This moment forms the point of departure for the objects and plastics, which form the focus for our research project.

MATERIAL ANALYSIS OF CASE STUDIES

Within the research project, the implementation through analytical tests and broad research has been carried out based on case studies of leading Polish artists working with plastics in different periods of time (from the 1960s until the present): Paweł Althamer (b. 1967), Julian Antonisz (1941-1987), Mirosław Bałka (b. 1958), Włodzimierz Borowski (1930-2008), Stanisław Drózdz (1939-2009), Tadeusz Kantor (1915-1990), Edward Krasinski (1925-2004), Zbigniew Libera (b. 1959), Alina Szapocznikow (1926-1973), Leon Tarasewicz (b. 1957), Jan Tarasin (1926-2009), JulitaWójcik (b. 1971), and Krzysztof Zarebski (b. 1939). We have selected case studies from the 1960s, 1980s, and 2011 for further treatment in this article, which highlight various idiosyncrasies, and problems found in Polish artworks that are made out of or include plastics.

METHODS OF RESEARCH

The research project on plastics in Poland is based on a holistic approach focused on plastics in their historical and cultural context in Poland, intentions of artists (obtained by interviews with artists, family, and assistants), technology, production processes in the region etc. The care of objects has begun with the identification of materials and techniques based on, among others, various instrumental techniques, oral testimony in documentation of intangible values, wide research in archives, publications, films, maintenance documentation. In addition, precise information has been gathered about technical rules and derogations, methods of past interventions as well as about the way of storage, transport and exhibitions.

While non-invasive tests are preferred during the project, in certain cases it is necessary to carry out invasive, traditional micro-chemical analysis and cross-sections. Analytical techniques such as UV, VIS analysis, X-ray microanalysis in the scanning microscope SEM-EDS, Raman, GPC, IR-RS, GC/MS, FTIR-ATR, HPLC, NMR, ASM, TGA and DSC have been done for all case studies selected for the project. Instrumental examination are carried out as a cooperative effort between the Faculty of Conservation and Restoration of the Works of Art of the Academy of Fine Arts in Warsaw, and the Faculties of Chemistry of the Warsaw University of Technology and University of Warsaw. We describe some of them here.

IDENTIFICATION OF THE MATERIALS

Figure 5
FTIR and Raman spectra of sculptures by Paweł Althamer.

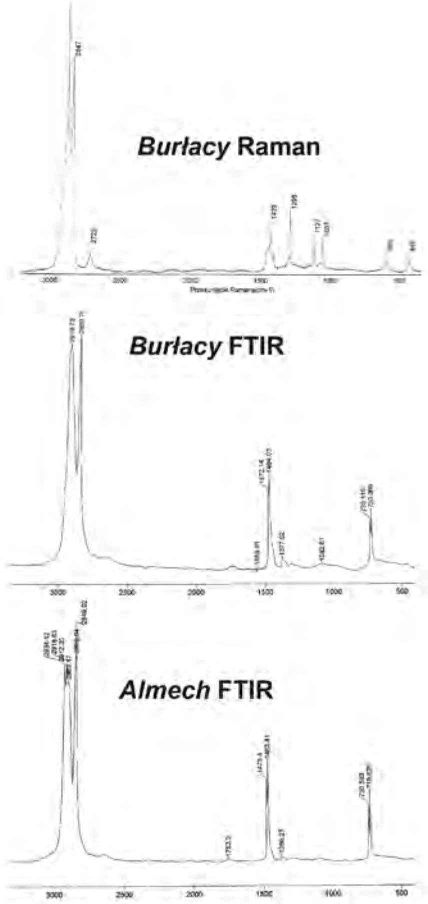

Figure 6
Paweł Althamer, Witold form Almech.

Before the conservation of any of the objects can start, it is mandatory to identify all the materials used for preparation of original sculptures. In this section we concentrate on the analysis of materials used by the three artists mentioned above. Preliminary tests were performed with use of FTIR, FTIR-ATR and Raman spectroscopies. In addition DSC, GPC and NMR measurements were done.

FTIR spectra were recorded on a Biorad FTS-165 FTIR spectrometer (as KBr pellets or thin films) or Bruker ALPHA FTIR spectrometer equipped with Platinum ATR single reflection diamond ATR module. Raman spectra were collected using a Nicolet Almega Raman dispersive spectrometer, equipped with a confocal Raman microscope, an 1800 lines mm^{-1} holographic grating and a CCD camera. A diode laser operating at 780 nm was used as the excitation source and spectral resolution was about 2 cm^{-1} for high resolution spectra. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian VXR 400 MHz spectrometer using tetramethylsilane as an internal standard and deuterated solvents ($CDCl_3$) and analysed with MestReNova v.6.2.0-7238 (Mestrelab Research S.L) software. The molecular weight and weight distribution were determined by a GPC on a Viscotek system comprising GPCmax and TDA 305 unit equipped with one guard and two DVB Jordi gel columns (102-107, linear, mix bed) in CH_2Cl_2 as an eluent at 35 °C at a flow rate of 1.0 mL/min using the RI and UV detectors and PS calibration. DSC data were obtained between -110 and 150 °C using a UNIPAN 605M scanning calorimeter with a low-temperature measuring head and a liquid-nitrogen-cooled heating element. Samples in aluminium pans were stabilized by slow cooling to -110 °C and then heated at 10 °C/min to 150 °C. An empty aluminium pan was used as a reference.

ALINA SZAPOCZNIKOW (1926-1973)

Alina Szapocznikow was one of the first female sculptors in post-war Poland who related her work directly to materiality and mystery of the human, and especially the female body. From 1963, she began to create sculptures using revolutionary sculpting materials, including polyester and polyurethane. This technical innovation allowed her to immortalise an artistic language of her own -

which was informed by her early exposure to death in childhood, her traumatic memories of the Holocaust, and the awareness of the premature collapse of her own body due to tuberculosis and breast cancer - while, at the same time, capturing the volatility of life. *Tors noyé* (1968), naked woman torso on the black 'pillow' is an excellent illustration of that thought. Her last work was a group of sculptures called *Tumour* (1969) was made with resin, gauze, crumpled newspapers and photographs and intended to preserve the impermanence of the body that is a source of pain, trauma and truth. The sculptures are very fragile. The first conservation treatment was conducted on some of the sculptures 15 years ago. However, the challenge that remains is to find a suitable method for continual preservation, to maintain a constant state of remission.

Samples of two sculptures *Tors noyé* (1968) and *Tumour* (1969) by Alina Szpocznikow were obtained. The *Tors noyé* samples consisted of two types of foams and colourless resin. In case of *Tumour* the set of samples consisted of printed paper, polymeric resin, gauze and fibres.

Both groups of samples showed no solubility in common solvents: aliphatic, aromatic and chlorinated carbohydrates, esters (ethyl acetate), ketones (acetone) and alcohols (methanol, ethanol, 2-propanol). In case of polymeric materials the lack of solubility is usually associated with cross-linking of the polymeric chains. The lack of solubility also limits the number of possible methods of analysis.

The *Tors noyé* samples were first examined by means of FTIR spectroscopy. *Figure 4* shows spectra of samples of a pillow, foam from inside the neck and the material of a torso. Through comparison of the recorded spectra with the Atlas of Polymer and Plastics Analysis by Dieter O. Hummel and Friedrich Scholl it was possible to identify the materials.

The first sample (the pillow) was made of polyurethane. The polyurethanes are usually prepared by mixing two components: polyisocyanates and polyols. There is only a limited number of polyisocyanates while polyols can vary in chemical structure and molecular weight. Their number is almost unlimited. They are responsible for the final properties of polyurethanes. In the investigated case the strong absorption band at 1109 cm^{-1} suggests that a polyether-based polyurethane was used. In case of this kind of polyurethanes the most possible degradation process is oxidation of polyether chains.

The second sample – a foam from inside the neck was most probably a mixture of two types of polymers: a mentioned above polyurethane and a polysiloxane. Strong absorption bands at 1262, 1098 and 803 cm^{-1} are characteristic for poly(dimethylsiloxane) - PDMS. The spectrum was measured from the whole sample (average composition), so further investigations are necessary to determine whether the PDMS was located on the outer surface or not.

The third spectrum in *Figure 4* shows that the material of the main body of the sculpture was a styrenic polyester resin (most probably alkyd resin Alkydal V 10). The bands at 3100-3000, 1600 and 1580 cm^{-1} are characteristic for phthalic acid esters, which is a main compound of this type of materials. The sample also showed a strong ester band at 1730 cm^{-1}.

The Raman spectrum of the 'torso' is characteristic for copolymers of styrene with monomers containing ester bonds. Two possibilities of such materials were taken into consideration: a copolymer of styrene with methyl methacrylate or a styrenic polyester resin. The second possibility is in agreement with former FTIR results.

The materials used by Alina Szapocznikow for the preparation of the *Tumour* group sculptures are in general very similar to those used for the preparation of *Tors noyé.*

Another similarity of those samples was observed on DSC thermograms. Both samples showed small endothermic peaks (approx. 10 J/g) at 68V́C.

Even though the base material of the sculptures was the same, the FTIR spectra of *Tumour* samples showed a varying concentration of inorganic carbonate salt (1426, 875, 711 cm^{-1}). Calcium carbonate is a commonly used filler for unsaturated polyester resins. However, in this case, varying concentrations of carbonate in different samples suggested that it was present mainly on the outer surface of the sculptures.

The newspaper material was identified as lignin-containing cellulose, which is characteristic for paper samples.

TADEUSZ KANTOR (1915-1990)

Tadeusz Kantor, one of the best known Polish artists of the twentieth century who worked as a painter, theatre producer, set designer, author of assemblages and first happenings in Poland, created marionettes (latex, polyurethane) which played a fundamental role in his most widely known revolutionary theatrical performances, such as *The dead class* (1975) among others. In the spectacle, which can be understood as a type of danse macabre, an absurd compilation of performance, poetry and sculptural installation, he experimented with the juxtaposition of life-size latex mannequins and living actors. A class of dead characters were confronted by mannequins representing their younger selves, and were carried by actors on their backs as well as pushed, floated and thrown on the old wooden desks over and over again. After 2.000 performances over a period of 17 years, and hundreds exhibitions in museums and galleries in Poland and abroad (most recently in the exhibition: *Beuys and Kantor:* Remembering, Israel Museum, Jerusalem, May - October 2012), where the sculptural props were presented as autonomous artworks in various constellations, their state of preservation was in serious decline. Some plastic elements (heads, feet, hands) had to be repaired, glued and changed, or replaced by new ones, developed using different plastic materials and new technologies. In the end, only one, seriously damaged mannequin remained from the original set. The rest (made of PVC and polyurethane in 1989) are in various stages of preservation, with particularly significant differences in colour. Little information was known about them both related to the original materials and other aspects of their making. Kantor's intent regarding the matter was ambivalent – on the one hand he accepted destruction and change of mannequins, treating the ephemeral materials as recurring messengers of death and signifiers of repression. On the other hand, he wanted them to be autonomous objects: material fingerprints of theatrical performance, with the status of works of art.

In studying these objects, the main challenge was to determine how and why the objects' appearance had changed so significantly (outside the obvious damages incurred during the performances). The most important cause of the visible changes, most apparent in the colours, was found in the chosen manufacturing techniques for the replacements, the discretionary choice of proportions for individual components, as well as subsequent significant changes of climate, experienced by the objects over their lifecycle.

Multiple samples of two sets of marionettes from *The dead class,* both the original ones and the newer ones (1975, 1989), were collected. The two sets appeared to be prepared with different materials. The FTIR spectroscopy revealed that the main construction material of the original marionettes was a styrene-butadiene rubber. Some spectra suggested that natural caoutchouc rubber was also used. Besides, polyether based polyurethanes, human hair and cotton-polyester (most probably poly(ethylene terephthalate) fabrics were applied.

In contrary, the newer set of marionettes was constructed of plasticized poly(vinyl chloride) - PVC. Since this material was soluble in organic solvents (cyclohexanone, chlorinated hydrocarbons etc.) we had an opportunity to investigate it in more detail.

The FTIR showed characteristic absorption bands of phthalate plasticizer at 1730, 1580 and 1600 cm^{-1}. The 'fingerprint' region was again compared with the Atlas of Polymer and Plastics Analysis revealing that the material was in fact phthalate plasticized PVC. This was further confirmed with a Raman spectrum. Other materials used for construction were similar to those used in the original set of marionettes.

To determine the type of the plasticizer NMR spectroscopy was applied. The spectra *(see Figure 4)* confirmed that the plasticizer was dibuthyl phthalate. The ^{13}C NMR spectrum of material dissolved in deuterated chloroform consisted of eight sharp peaks coming from low molecular weight compound - dibutyl phthalate (1 ester carbonyl carbon, 3 types of aromatic carbons and 4 aliphatic carbons) and two sets of signals at approx. 56 and 46 ppm of poly(vinyl chloride) chains. The ^{1}H NMR spectrum showed three groups of signals. A presence of separated signals of aromatic protons made it is possible to calculate the polymer to plasticizer ratio. For the investigated samples the ratio varied from 7 to 8 molar parts of polymer repeating units per one mole of a plasticizer. This can be converted to 1.6-1.8 weight part of the polymer per 1 weight part of the plasticizer.

Decomposition of PVC is usually accompanied by formation of conjugated unsaturated carbon-carbon bonds. No signals of such structures were visible in the NMR spectra.

The molecular weight of several samples of PVC with varying colours (from colourless to slightly red) were investigated by means of GPC. The M_n varied from 41000 to 44000, the M_w from 89000 to 95000 with the PDI equal 2 to 2.3. No correlation between colour of the samples and their molecular weight was found.

The DSC thermogram showed no phase transitions confirming that the material was mostly amorphic. No glass temperature was detected for investigated samples.

PAWEL ALTHAMER (B. 1967)

Pawel Althamer is one of the most important contemporary Polish artists, active as a performer, sculptor, social activist, and creator of video art and installations. Since 2008, he creates sculptures out of polyethylene, applying technology used by his father who ran a small plastic processing plant called *Almech*. *Almech* is also the title of the commissioned work that Pawel Althamer created for the Deutsche Guggenheim (DG) in 2011. He transformed the museum into an art factory by moving machines and other equipment from his father's plant in Wesoła, Poland to Berlin.

During this exhibition-in-progress and public performance, Althamer contrived face casts of employees, exhibition visitors, artists, and curators and then attached bodies to them; thereby creating a unique collective work of art that everyone could participate in. A similar idea, material and technology was used in his artwork *Burlaks* (2012). In this case, the artist invited employees of the Museum of Modern Art in Warsaw to participate. Another consistent implementation of the same series is a sculptural group *Venetians* made for the 2013 Venice Biennial and presenting portraits of dozens of residents of the host city.

Issues arising in the first set of sculptures include the cracking of the plastic in many places and the formation of wide gaps in those places.

Samples of the two works *Burłacy* (2012) and *Almech* (2011) by Paweł Althamer were obtained. The samples showed no solubility in common solvents. FTIR and Raman spectra *(Figure 6)* revealed that the material of the sculptures was polyethylene. The Raman spectrum also suggested that the polymers contained a rutile filler. Rutile is the most common natural form of TiO_2. DSC thermograms of the samples showed strong endothermic peaks at 110°C (186 J/g), which can be associated with melting of the crystalline phase of polyethylene. To determine the type of polyethylene, the density of the polymer was investigated by means of a helium picknometer. However, due to the relatively small size of the sample taken results were not reliable. It is clear that the density of the samples was lower than 1g/cm^3 but further investigations are necessary.

CONCLUSION

In spite of the fact that conservation treatments on plastics have been carried out at least since the 90s in Poland, systematic, interdisciplinary and comprehensive studies in this area are still lacking. This research project was a necessary step to fill the gap through collecting data and stimulating further research. The huge interest in this subject by institutions linked to contemporary art confirms the value and importance of this work. The complex care of the plastic legacy in Poland through research, identification and establishing the methodology of maintenance, conservation, preservation and exhibition is the main aim of the project presented here. The essence of it is to gather the knowledge of the artistic heritage on the basis of extensive interdisciplinary research (chemical, physical and cultural history). The indication of guiding rules will have a practical and essential purpose for the conservation of artworks. The project results will be the basis for a monograph and pro vide guidelines for stakeholders.

‘Plastics are materials devised by the mind of man’ *(Pendry 1962)*. And now the mind of man must find the way to preserve them – we hope the project will contribute to that challenge.

ACKNOWLEDGEMENTS

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APPENDIX

SUPPLIERS AND REFERENCES

LECTURE 001

NON-INVASIVE INVESTIGATION OF POLYMERIC MATERIALS USING UNILATERAL NUCLEAR MAGNETIC RESONANCE

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LECTURE 002

DISCOLOURATION OF PLASTIC OBJECTS: INVESTIGATION INTO COMPOSITION USING VARIOUS ANALYTICAL TECHNIQUES

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LECTURE 003

REVERSIBLE AIRBRUSH RETOUCHING ON FADED GLASS FIBRE REINFORCED PLASTIC OBJECTS

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LECTURE 004

THE USE OF POLYURETHANE FOAM IN CONTEMPORARY ITALIAN DESIGN: CASE STUDIES FROM THE TRIENNALE DESIGN MUSEUM IN MILAN, ITALY

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LECTURE 005

WAVING THE FLAG
THE CONSERVATION AND EXHIBITION OF THE SEATING COMBINATION LEONARDO BY STUDIO 65

MATERIALS AND SUPPLIERS

Polyurethane foam RG20, open-pored:
W. Dimer GmbH, Laufenburg, Germany (www.dimer.com)

Fine tulle Michele 300, white, 100% Polyamid:
Fucotex GmbH & CO. KG, Friedberg, Germany (www.fucotex.de)

Polyurethane-Dispersion PU 52, Nr.: 76805:
Kremer Pigmente GmbH & Co. KG, Aichstetten, Germany (www.kremer-pigmente.com)

3mesh spacer fabric:
Müller Textil GmbH, Wiehl-Drabenderhöhe, Germany (www.mueller-textil.de)

LECTURE 006

IT'S NEVER TOO LATE TO GET IN SHAPE!
THE CONSERVATION OF WOMBTOMB BY FERDI. APPROACHING THE REPLACEMENT OF DETERIORATED POLYURETHANE FOAM PADDING

MATERIALS AND SUPPLIERS

Handy Rubber brush:
BLOKKER, The Netherlands.

Polyurethane ether flexible foam 95/50 and 95/30:
ABC Schuim Plastic Huis, Amsterdam, The Netherlands.

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LECTURE 007

CONSERVATION TREATMENT OF A POLYURETHANE ESTER SHOE SOLE FROM A BEN VAUTIER'S WORK OF ART

MATERIALS AND SUPPLIERS

N-(2-Aminoethyl)-3-aminopropylmethyldimethoxysilane; 95%.
Abcr-Speciality Chemicals for research, developments and production. Product no. AB110805.

Hexamethyldisiloxane, 98%.
Abcr-Speciality Chemicals for research, developments and production. Product no. AB117016.

Polyurethane ester reference samples:
Elastogran®, BASF branch.

Plextol® B500:
Aqueous emulsion of a thermoplastic, pure acrylic resine.

CTS:
products, equipment and systems for art restoration service.

Lascaux®360 HV:
Dispersion of a thermoplastic acrylic polymer on the basis of methyl methacrylate and butyl acrylate. Lascaux Colours & Restauro.

Plastazote® foam:
Closed cell cross-linked polyethylene foam. Atlantis France.

Bondina:
Non woven polyester. CTS: products, equipment and systems for art restoration service.

Mylar®:
Polyester film. CTS: products, equipment and systems for art restoration service.

Silicagel type E spherical beads. Long Life for Art.

ANALYTICAL METHODS AND EXPERIMENTAL CONDITIONS

Aging chamber:
Vötsch Industrietechnik VC0020. This chamber can control temperature and humidity with an accuracy of ±0.3°C for the temperature and of ±1 to 3% RH for relative humidity.

Visible spectrophotometry:
X-Rite SP64 spectrophotometer. Set-up parameters: 4 mm measurement area (6.5 mm target window), illuminant type D65, 10° standard observer angle and specular component included (SPIN). The measurements were repeated on the surface at 5 different locations on each sample.

Fourier Transform Infrared Spectroscopy:
Nicolet 6700 – Smart Endurance ATR device. Analysis were carried out scanning from 600 to 4000 cm^{-1}, 36 scans were recorded for each spectrum at a resolution of 8 cm^{-1}.

Scanning Electron Microscopy imaging and elemental analysis:
SEM Jeol JSM-5410LV equipped with an Oxford Link Isis - Energy Dispersive X-ray Spectrometer (EDS). Samples were mounted on aluminium sample holders with double-sided carbon tape (NEM tape, Nisshin EM Co. Ltd.). The following experimental conditions were kept constant for both backscattered images and elemental analysis: high vacuum, 20 mm working distance, 20 kV accelerating voltage.

Pyrolysis – Gas Chromatography – Mass Spectrometry:
Gas chromatograph Shimadzu GC2010 coupled to a mass spectrometer Shimadzu GCMS-QP2010 Plus with a pyrolyzer Frontier Lab PY-2020iD. The pyrolysis temperature was set at 610 °C. The carrier gas used was He with a constant flow rate of 1 mL/min. A capillary column Frontier Lab UA-5 (95% dimethylpolysiloxane, 5% phenyl) was used. The final column temperature was of 300°C. Mass spectra were acquired in electron impact mode at 70 eV with m/z scanned between 40 and 500.

Mechanical test:
Buchholz Hardness Indentation Test. The calibrated weight with a sharp-edged metal wheel is positioned on the sample for 30 seconds. The length of the indentation mark is recorded and used to define the hardness of the surface according to the following formula:
Hardness (cm^{-1}) = 100/mark length (cm).

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LECTURE 008

EFFECTS OF CLEANING GEL SYSTEMS ON PLASTICISED POLY(VINYL CHLORIDE): NEW INSIGHTS

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MATERIALS

Plasticised PVC
Weber Métaux, Paris France

Water ultrapure
Direct Q5 Water Purification System, Millipore

Triethanol amine
CTS France, CAS 102-71-6

Pemulen™ TR2 (
Noveon, purchased at CTS France)

Citric acid
monohydrate, 99,5-101%, analytical grade, ChemLab, CAS 5949-29-1

Cyclohexane
for analysis ACS, 99,5%, Merck, CAS 110-82-7

EXPERIMENTAL DETAILS

Artificial ageing:
Centre de Recherche sur la Conservation des Collections (CRCC): Light unit Atlas Solar constant 2500 equipped with a 2500 watts Hydrargyrum medium-arc iodide OSRAM lamp. The light energy was 1300W/m^2, UV filter at 350nm, illumination of the samples was 180klux. Climate unit Servathin connected to Sirpac 2000 software.
Centre de Recherche et de Restauration des Musées de France (C2RMF): Atlas Suntest XXL equipped with 3 xenon lamps NXE1700. The light energy was 60W/m^2, UV filter at 320nm, illumination of the samples was 140klux.

Stereo microscope:
Nikon SMZ10A, ocular lenses SMZ-U UW (10XA/24), objective lens ED plan (0,5X).
Magnification x 10 and x 24,5.

Confocal white light microtopography:
MicroMesure CHR, STIL, non-contact device based on Chromatic Confocal Sensing and MoutainsMap software. Measurement parameters: sensor size 300 µm, measurement rate 1000 Hz, step of 10 µm, measured area 11000 x 5000 µm.

Digital microscope:
HIROX KH-7700, objective lens "High Range". Magnification x 350, diaphragm aperture 1/7.5, J mode, direct light, black background.

FTIR-ATR spectroscopy:
Spectra of the two to four first microns of the surface were recorded on a Nicolet 6700 spectrophotometer, equipped with the diamond ATR macro-system Smart Endurance scanning from 600 to 4000 cm^{-1}.

LCMS:
A Hewlett-Packard 6890 GC equipped with a Hewlett-Packard 5973 mass selective detector (MSD),a Hewlett-Packard 7683 autosampler and a 30 m x 0.25 mm x 25 µm HP-5 MS column were used. Oven temperature was raised from 55 °C to 325 °C at a rate of 10 °C/minute then held at 325 °C for 10.5 minutes. The injection port and transfer line temperatures were 300 °C. A 1 µL volume was injected in the splitless mode at a flow rate of 2.3 ml/minute.

Colorimetry:
Spectrophotometer Minolta CM-2600d. Measurement parameters: D65 illuminant, 10° observer, 0.8 mm opening, UV 100 %. Data recorded with included specular reflection mode. L*a*b* color space (1976 CIELAB).

Raman spectroscopy:
Laser 785 nm, grating 1200 l/mm, Detector CCD 1024, spectral range 670-1770 cm^{-1}, exposure time 3 s, laser power ~30 mW, image 34.000 points, 1 scan/pixel.

LECTURE 009

THE HISTORICAL COLLECTION OF THE ADI COMPASSO D'ORO AWARD: TWO CASE STUDIES FOR THE RECONSTRUCTION OF VOLUMETRIC AND INDUSTRIAL SURFACE LOSSES

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MATERIALS AND SUPPLIERS

Araldite® 2020:
Bresciani Srl, Via Breda 142 - 20126 Milano, Italy, www.brescianisrl.it/newsite/ita/xprodotto.php ?id=2741&hash=1ac4233ca0411c7b8c1c539e1dbfd7f9 (last accessed in January 2015)

Cyclododecane spray:
Kremer, http://www.kremer-pigmente.com/media/ files_public/87099e.pdf (last accessed in January in 2015)

Debypon LS 45:
Conservation by Design Limited, Bedford, UK, http://www.conservation-by-design.com/pdf/ datasheets/Dehyphon%20LS45%20Technical% 20Data%20Sheet.pdf (last accessed in January 2015)

Dental Plaster, calcium sulphate hemihydrate ($Ca_SO_4 \cdot ½ H_20$):
C.T.S, Via A.F. Stella n. 5
20125 Milano, Italy, http://www.ctseurope.com/en/ scheda-prodotto.php?id=646 (last accessed in March 2015)

E-30 water effect:
Prochima s.r.l, Via G. Agnelli 6, Calcinelli di Saltara, 61030 Puglia, Italy. + 39 0721.897635, www.prochima.com/public/eng/ E%2030%20ing.pdf (last accessed in January 2015)

Espak polyurethane systems:
Prochima, www.prochima.it/pages/res_poliure.htm (last accessed in January 2015)

Hxtal NYL^{-1}:
Conservation Support Systems, P.O. Box 91746, Santa Barbara, CA 93190-1746, USA, http://www.conservation supportsystems.com/product/show/hxtal-nyl-1-epoxy/ clear-epoxies (last accessed in January 2015)

Lascaux 360 HV:
Kremer Pigmente, Dr. G. Kremer, Farbmühle, D-88317 Aichstetten, Germany, http://www.kremer-pigmente.com/media/files_public/ 81000e.pdf (last accessed in January 2015)

Orasol® dyes:
Kremer Pigmente, www.kremerpigmente.com/media/ files_public/94400-94416e.pdf (last accessed in January 2015)

Plexigum® PQ 611:
Kremer Pigmente, www.kremer-pigmente.com/media/ files_public/67380e.pdf (last ac-cessed in January 2015)

Pentasol Un colour pastes:
Prochima, http://www.prochima.it/pages/coloranti.htm (last accessed in March 2015)

GLS-50 Liquid rubber for casting:
Prochima, http://www.prochima.com/eng/product.asp?id=1 (last accessed in January 2015)

Silical 110 Kneadable Silicone Rubber:
C.T.S http://www.ctseurope.com/en/scheda-prodotto.php?id=624 (last accessed in March 2015)

Silical 100 Release Agent:
C.T.S http://www.ctseurope.com/en/scheda-prodotto.php?id=623 (last accessed in March 2015)

Sintagom Neutro:
Prochima http://www.prochima.com/eng/product.asp? id=11 (last accessed in January 2015)

LECTURE 010

INDUSTRIAL CLAY AS A DESIGN MATERIAL. TECHNICAL INVESTIGATION AND SUITABLE CONSERVATION TREATMENTS

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LECTURE 011

CATALIN – A THERMOSETTING PLASTIC USED FOR VINTAGE JUKEBOXES

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SUPPLIERS

Surfynol 61:
Kremer Pigmente GmbH & Co. KG, Germany

LECTURE 012

PRACTICAL ASPECTS ON THE TESTING AND USE OF ADHESIVES ON POLYSTYRENE

MATERIALS AND SUPPLIERS

Paraloid® B72, Paraloid® B67, Primal® AC35, Hxtal® Nyl-1:
http://www.kremer-pigmente.com

Loctite® Super Attack Precision:
Henkel technologies, http://www.henkel.com

Araldite® 2020:
Huntsman Advanced Materials, http://www.huntsman.com

Acrifix® 116:
Evonik Industries AG, http://corporate.evonik.com

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Winther, Thea; Judith Banner, Hilde Skogstad; Mats KG Johansson; Karin Jacobson; Johan Samuelsson.
Joining plastics together-what happens over time? A comparative study of seven adhesives for adhering polystyrene and their long-term effect. Research report Swedish National Heritage Board. 2013.

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LECTURE 013

THE PANTON CHAIR MADE OF LURAN® S. CAN CRACKS IN AGED ASA BE JOINED?

MATERIALS AND SUPPLIERS

Araldite® 2028 (Huntsman):
Ruderer Klebetechnik GmbH, Zorneding

Cyclohexane, HXTAL NYL-^{1} (HXTAL Adhesive LLC):
Kremer Pigmente GmbH & Co. KG, Aichstetten

Luran® S KR 2859:
BASF, Ludwigshafen

Methyl ethyl ketone:
Merck KGaA, Darmstadt

Ottocoll® P 520 (Otto-Chemie):
Daniel Maas Dichtstoffhandel u. Co., Kevelaer

Rite-Lok™ UV 11, Scotch-Weld™ 4693, Scotch-Weld™ DP 610:
3M Deutschland GmbH, Neuss

LECTURE 014

THE INVISIBILITY OF THE SUPPORT AND ITS RESTORATION. BONDING OF A LARGE SHEET OF PLEXIGLAS: *BULLDOZER* BY ALAIN JACQUET

LECTURE 015

HOW TO RESTORE 20 PRISTINE CORIAN® SCULPTURES. A HANDS-ON APPROACH

MATERIALS AND SUPPLIERS

Acrifix 2R 0190 (resin and hardener) and thinner Acrifix TH 0030.
Evonik Röhm GmbH, D-64293 Darmstadt

Aluminiumtrihydroxide white, dust-free powder, graining 0 – 0.032 mm, density 2.4 g/cm^3, mean density 1.2 g/cm^3.
Modulor GmbH, D-10969 Berlin

Corian® joint adhesive colours Cameo White, Bone White and Glacier White.
DuPont™

Dupli Color spray paint white mat RAL 9010.
Motip Dupli GmbH, D-74855 Hassmersheim

SATA minijet® 300 B HVLP, nozzle 1.0.
SATA GmbH & Co. KG, D-70806 Kornwestheim

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Art from the World’s Top Designers Auctioned at DesignLove. Exhibit: November 28 – December 6, 2011 http://www.dupont.com/products-and-services/construction-materials/surface-design-materials/press-releases/corian-designlove.html, retrieved 14-10-2013

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Corian® Press Information: 40 Years - 40 Designers - DuPont celebrates 40 years of successes of Corian® through the multi-cultural creativity of 40 designers. Milan, April 2007, http://rapidlibrary.com, retrieved 14-10-2013

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http://purecontemporary.blogs.com/behind_the_curtains/2006/04/fire_island_in_.html, retrieved 14-10-2013

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http://www.hanex.de/fileadmin/pdf/de/Hanex_Technische_Datenblatt.pdf, retrieved 15-10-2013.

http://www.himacs.eu/dynamo/files/user_uploads/LGCH_Fabr-Manual_Update2012_DE_Health+Safety.pdf, retrieved 15-10-2013.

http://www.livingstonesurfaces.com/www/pdf/material_safety.pdf, retrieved 15-10-2013.

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http://www.staron.com/staron/ger/techsupport/technicaldata.do, retrieved 15-10-2013.

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LECTURE 016

CASE STUDY GOODYEAR FIELD (1996): THE VERSATILE SYNTHETIC POLYMER POLYCAPROLACTONE USED BY MATTHEW BARNEY

MATERIALS AND SUPPLIERS

Rolyan® Aquaplast® products, Splinting Material,
Patterson Medical Holdings, Inc., Corporate Headquarters, 1000 Remington Blvd. Suite 210, Bolingbrook, IL 60440-5117, U.S.A, www.pattersonmedical.com

Capa™ 6500 PCL pellets,
Perstorp UK, Ltd., Baronet Road, Warrington, Cheshire,, WA4 6HA, UK, www.perstorp.com

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POSTER 001

THE CHALLENGE OF CONSERVING A MECHANICALLY DAMAGED POLY(METHYL METHACRYLATE) (PMMA) OBJECT – ADHERING AND FILLING.

THE CONSERVATION OF A MULTIPLE BY ARTURO SCHWARZ AND MARCEL DUCHAMP, PART II

SUPPLIERS

Degalan PQ 611 N®:
Coating & Adhesive Resins,
Evonik Degussa International AG, Germany

HXTAL NYL-1®, Isooctane, Shellsol D40:
Kremer Pigmente GmbH & Co. KG, Germany

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'Das Verfüllen von Rissen in Plexiglas, am Beispiel der Arbeit „Strahlenfall“ von Gerhard Hoehme' [journal article], VDR Beiträge zur Erhaltung von Kunst und Kulturgut, 1/2005:99-106.

POSTER 002

THE LINK BETWEEN FLASH AND FLESH: THE PRESERVATION OF SAILOR JERRY'S TATTOO STENCILS

MATERIALS AND SUPPLIERS

ArtCare matboards:
Conservation Resources International LLC, 5532 Port Royal Road, Springfield, Virginia 22151,
Email: sales@conservationresources.com

Marvelseal 360 and polyester film:
University Products, Inc., 517 Main Street, Holyoke, Massachusetts 01040, Email: info@universityproducts.com

Lascaux 498 HV and Tengujo:
Talas, 330 Morgan Ave, Brooklyn, NY 11211

Conservation Clear Acrylic:
TruVue, Inc., 9400 W. 55th Street, McCook, Illinios 60525

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American Tattoo Master. San Francisco: Hardy Marks Publications, 2007.

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Mills, John S., and Raymond White.
The Organic Chemistry of Museum Objects Second Edition. Oxford: Butterworth-Heinemann, 1994.

POSTER 003

CONSERVATION OF PLASTICS AT THE PINACOTECA DO ESTADO DE SÃO PAULO, BRAZIL

MATERIALS AND SUPPLIERS

Resin Kit™:
The Plastics Group of America, Resin Kit™ Company, 1112 River Street, Po Box 509, Woonsocket, RI 02895 - 0509, http://www.plasticsgroup.com/resin_kit/

A-D STRIPS:
Image Permanence Institute, Rochester Institute of Technology, 70 Lomb Memorial Drive, Rochester, NY 14623-5604 USA, www.imagepermanenceinstitute.org

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'Plastics: modern resins with ageing problems'. Paper presented at the Scottish Society for Conservation and Restoration Conference on Resins Ancient and Modern. Aberdeen, 13-15 September 1995.

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POSTER 004

CONSOLIDATION OF A POLYESTER URETHANE FOAM CUSHIONING WITH LIMITED ACCESSIBILITY USING ULTRASONIC MISTING. WORKING METHOD, RESULTS AND POSSIBLE IMPROVEMENTS. THE CONSERVATION OF A MULTIPLE BY MARCEL DUCHAMP, PART I

MATERIALS AND SUPPLIERS

"AGS 2000" Ultrasonic Mister:
ZFB - Zentrum für Bucherhaltung GmbH ,
Amazonstraße 4, 04347 Leipzig
Germany, http://www.zfb.com/en/products

Impranil DLV/1,
Bayer Material Science AG, Kaiser-Wilhelm-Allee, 51368 Leverkusen, Germany, www.bayercoatings.com and www.impranil.com

Klucel E / Kremer PUR-Dispersion / Mowiol 4-88 / Paraloid B72 / Plexigum PQ611 / Polyethylene glycol:
Kremer Pigmente GmbH & Co. KG, Hauptstrasse 41-47, 88317 Aichstetten, Germany, http://kremer-pigmente.de

Lascaux medium for consolidation / Mowilith DMC2 / Plextol B500:
Lascaux Colours & Restauro, Barbara Diethelm AG, Zürichstrasse 42, 8360 Brüttisellen, Switzerland, http://lascaux.ch

Primal SF 016 / Tylose MH 50,

Deffner & Johann GmbH, Mühläcker Strasse 13, 97520 Röthlein, Germany, http://www.deffner-johann.de

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http://www.impranil.com/BMS/DBRSC/BMS_RSC_CAS.nsf/id/CODE_Produkte_nach_Handelsname?open&line=Impranil%C2%AE (last access 01.09.2013).

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POSTER 005

MATERIAL REVERSION: INVESTIGATION INTO DEGRADATION MECHANISMS OF POLYURETHANE ELASTOMERS

MATERIALS AND SUPPLIERS

AltroColor colour pastes (flame red, white, lemon yellow):
Altropol Kunststoff GmbH, Stockelsdorf

Biresin U 1404:
Sika Deutschland GmbH, Stuttgart, Germany

Ebaflex N2K Formbaumasse:
GFK-Tech, Bergisch-Gladbach, Germany

GM 26:
ebalta Kunststoff GmbH, Rothenburg ob der Tauber, Germany

Neukadur ProtoFlex 165-05:
Altropol Kunststoff GmbH, Stockelsdorf, Germany

Reckli PUR-Elastomer A55, Type N:
Reckli GmbH, Herne, Germany

VytaFlex 60:
KauPo Plankenhorn e.K., Spaichingen, Germany

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Plastics -- Methods of exposure to laboratory light sources -- Part 2: Xenon-arc lamps. DIN Deutsches Institut für Normung e.V. June 2006.

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'From rubber to liquid: Alterungsphänomene und Rekonstruktion von Polyurethan - Elastomeren bei einer Skulptur von Olaf Metzel'. In Die Vergänglichkeit des Materials – Künstlerintention versus Restaurierbarkeit. Ed. Verband der Restauratoren e. V. (VDR). p. 50 - 63.

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'Stage Evidence, Loris Cecchini: Ejemplo de deterioro de materiales industriales en el arte'. In Conservación de arte contemporáneo 8. Ed. Museo Nacional Centro de Arte Reina Sofía. Madrid. p. 103 - 108.

Metzel, O., Waldvogel, F. 2013.
'Easy Alter – Ein Gespräch zwischen Olaf Metzel und Florian Waldvogel‘. In Olaf Metzel: Gegenwartsgesellschaft. Ed. Florin Waldvogel. DISTANZ Verlag GmbH. Berlin. p. 33 – 92.

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POSTER 006

DESIGNED FOR CONSERVATION? THE IMPACT OF EXHIBITION DESIGN ON MODERN MATERIALS

REFERENCES

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Mention POPArt project- talk to Brenda about this
'Touch Me' exhibition 16 June - 29 August 2005
This uniquely touchable exhibition explored the pleasures, sensations and future of touch, bringing us closer to each other and the designed world around us – from site specific art and design commission to games, live science experiments and a fantastical petting zoo. Touch Me was a collaboration between the V&A and the Wellcome Trust

POSTER 007

COMPLEX CARE FOR CONTEMPORARY ART HERITAGE: RESEARCH PROJECT: PLASTICS IN ART IN POLAND

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Dep. of Conservation and Restoration of Works of Arts, Master Thesis no. 7428.

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Warsaw:
Muzeum Narodowe w Warszawie.

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Wojciechowski, A. 1956.
‘Drogi i bezdro a plastyki polskiej’. Projekt, 2: 2-13.

BIOGRAPHIES

BIOGRAPHIES

SILVANA ANNICHIARICO

Director Triennale Design Museum.
A trained architect, Silvana Annichiarico works in the fields of research, critical study, education and media. Between 1998 and 2007 she acted as Head Conservator for the Permanent Collection of Italian Design at the Triennale in Milan and became Director of the Triennale Design Museum in 2007. As a member of the Scientific Committee for the design sector since 2002, between 1998 and 2004 she taught as Professor of Industrial Design at the Politecnico di Milano. From 1998 to 2001 she acted as Vice Director to the design journal «Modo». She currently collaborates with various publications (eg. «Wired») and radio programs.
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NATHALIE BALCAR

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ELENA BOZZO

Elena Bozzo earned her degree in Restoration and Enhancement at the Politecnico in Turin (Italy) with a dissertation on the protection of cultural heritage in Bosnia. She attended a master's degree in 'Management, marketing and multimedia for cultural heritage'. Since 2009, she has worked with many architectural firms of urban planning (5+1AA in Milan, AI Studio, Studio Andrea Bruno and Studio Mellano and Associates, Turin). Since 2010, she has worked with the CCR 'La Venaria Reale', being in charge of supervising and organising the acquisition of works and the status of the operations. She has also supported the team for the ADI project.

TIM BECHTHOLD

Tim Bechthold trained as a cabinet-maker in Bad Tölz, Germany from 1991 to 1993. The following three years he studied conservation at the College Goering-Institute, Munich, Germany, where he graduated in 1996 as a state-approved conservator for furniture and wooden sculptures. The following year he worked as a freelance furniture conservator in Munich, Germany. From 1997 to 2002 he proceeded to study at the Chair of Conservation, Arts Technology and Conservation Science, Technical University Munich, Germany, focusing on modern materials. At that time he completed several conservation projects on the degradation of plastics, among others at the Museum of Applied Arts (MAK) in Vienna, Austria, and at the Vitra Design Museum in Weil am Rhein, Germany. In 2002 he graduated with a diploma thesis on "Polyurethane in 1960's furniture design". Since 2002 he is Head of Conservation at Die Neue Sammlung, Germany. He set up the Conservation Department which has become an important hub for the conservation and maintenance of modern design objects, through research into the deterioration and preservation of the collections, the development of new conservation processes and the knowledge of its original technology. Tim initiated and organized the FUTURE TALKS conferences and is editor of the post prints:
FUTURE TALKS 009.
The Conservation of Modern Materials
in Applied Arts and Design
FUTURE TALKS 011. Technology and Conservation of Modern Materials in Design
FUTURE TALKS 013. Lectures and Workshops on the Conservation of Modern Materials in Design
Tim Bechthold has given numerous lectures on the conservation of plastics.
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PAOLA BIOCCA

Paola Biocca graduated in "Chemical Sciences and Technologies for the Conservation of Cultural Heritage" at Ca' Foscari University of Venice in 2012 with a master thesis on polyurethane foams and the study of Pratoni from Triennale Design Museum in Milan. From 2013 she works as a scientific consultant at the Central Institute of Restoration in Rome and collaborates with Italian institutions for the study of cultural heritage materials such as metals, paper, gilded and painted leather, archaeological objects, paintings on wood and canvas. She is currently involved in a laser cleaning test at the Central Institute of Restoration.

CLÉMENTINE BOLLARD

After a master 1 of art history completed in 2003, she graduated from the master of conservation of cultural heritage at Paris I Panthéon-Sorbonne University in 2007.
She is now working as a freelance conservator specialised in design objects and modern/contemporary art. Besides working for museums, art galleries and private collectors, she has been involved in research projects on the conservation of plastics (E.U funded project POPART, grant of the Centre National des Arts Plastiques for the research on modern and contemporary art conservation).
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ULRIKA BRYNNEL

Ulrika Brynnel is a conservation scientist at the Swedish National Heritage Board with degrees in chemistry and archeology.

TEODORA CAMARGO CARNEIRO

Teodora graduated in the conservation/restoration of easel paintings in 1996. From 1999-2005, she attended workshops organised by the British Council and VITAE in Brazil. In 2001 she participated in a one-year internship as a restorer in the Tate Gallery (UK) conservation studios (Tate Britain, Tate Modern, Tate Liverpool, and Tate St. Ives). Since 2004 she has been coordinator of the storages at Pinacoteca do Estado de São Paulo. Teodora also runs her own conservation studio in São Paulo, Brazil.
tcarneiro@pinacoteca.org.br

JONATHAN DEBIK

After a one-year internship at the Hamburger Bahnhof – Museum für Gegenwart in Berlin, Jonathan Debik started his studies at the Institute for Conservation and Restoration at the Academy of Fine Arts Vienna, specialising in the field of Conservation of Modern and Contemporary Art. Additionally he completed different internships at museums as well as at private conservation workshops in the fields of modern and contemporary art and paintings. Currently he is writing his diploma thesis on the conservation of a work of the American artist Jim Dine with a focus on adhering and filling PMMA.
Jonathan.Debik@gmx.de

FRANÇOIS DUBOISSET

Francois Duboisset is a French conservator, who graduated in 2010 from the Institut national du patrimoine in Paris (National Institute of Heritage) and is originally an industrial designer. He operates in the field of industrial heritage, design objects, contemporary art and specializes in plastics and rubber.
francois.duboisset@gmail.com

BARBARA FERRIANI

Barbara Ferriani has worked as a conservator, specialized in the conservation of contemporary art, in Milan since 1983. As a founding member of INCCA Italy, together with Marina Pugliese, (co-author of the recently published book "Monumenti Effimeri – Storia e conservazione delle installazioni"), she is currently co-ordinating a research project on the preventative conservation of contemporary art installations. Since 2010 she has headed up the conservation laboratory at the Triennale Design Museum of Milan and lectures at the Università Cattolica in Milan and Ca' Foscari University in Venice
barbaraferriani@virgilio.it

SARAH GLENN

Sarah holds a BA Fashion Illustration and a Postgraduate Diploma in the History of Art from the Courtauld Institute and studied for an MA Textile Conservation course at the Textile Conservation Centre, during which she was supported by the Clothworkers' Foundation. Since graduating in 2008, she has been employed on a full time permanent basis at the V&A in London.

Recent projects for the museum have included Hollywood Costume (2012), David Bowie Is (2013), La Moda: The Glamour of Italian Fashion (2014) and Horst: Photographer of Style (2014). Research interests include wax objects in textile conservation, modern materials and composite objects.

s.glenn@vam.ac.uk

SILVIA DI GIORGIO

Silvia Di Giorgio is a conservation scientist, currently working in Bolzano (Italy) for a private collection of contemporary art.

She graduated from Turin University with a dissertation work concerning x-ray tomography of big-sized cultural goods.

In 2011 she collaborated with the Italian Research Foundation Bruno Kessler (FBK) on the archeological applications of 3D laser scanners, rendering and mapping the frescos of an Etruscan grave. In 2012 she got a postdegreespecialization in Restoration and Conservation for the Cultural Heritage in Florence,collaborating with Editech s.r.l., the first art diagnostic center in Italy, on multispectral imaging and analytical diagnostics. In 2013 she collaborated with the International Design Museum Die Neue Sammlung in Munich, investigating a collection of industrial clay car prototypes from the 1930s. In 2014 she interned for the Conservation Department of Museion - Museum for contemporary art in Bolzano.

silviadigiorgio10@gmail.com

SUSANNE GRANER

Susanne Graner was trained as a cabinet-maker in Munich from 1992 to 1995. After two years of internship(s) she studied Conservation, Art Technology and Conservation Science at the Technical University Munich (1997-2002). The topic of her diploma thesis was the conservation of “The Lemon Room by Bruno Paul in Faber-Castell Castle in Stein near Nuremberg”. Upon completing her degree she worked as a Furniture Conservator in the Restoration Department of the Bavarian State Conservation Office (2002-2004) and in the Studio for Furniture Conservation at the Bavarian Palace Administration (2004-2005) in Munich. She joined the Conservation Department of Die Neue Sammlung as an Object Conservator in 2006, specializing in the conservation of early twentieth-century furniture. Since October 2010 she has served as Head of the Collection Department at the Vitra Design Museum.

susanne.graner@design-museum.de

JULIA GREDEL

After finishing a three-year cabinet making apprenticeship in 2001, Julia Gredel began a three-year training in conservation of furniture and wooden objects at the Goering Institute in Munich. She completed her training in 2004 and was awarded the title “Master Craftsman of the Year”. Since then, she worked as a freelancer for several conservation studios as well as her own projects. In 2010, Julia Gredel established her own conservation studio in Munich. Together with her husband, their passion is to collect and conserve jukeboxes from the 30s to the 50s.

julia.gredel@gmx.de

SUZAN DE GROOT

Suzan de Groot studied analytical chemistry at the Hogeschool Amsterdam and graduated in 1996. She is employed by the Cultural Heritage Agency of the Netherlands (RCE), Movable Heritage Department since 1996.

She is currently engaged in Fourier Transform Infrared Spectroscopy (FTIR) and Raman spectroscopy analyses of organic materials, especially plastics in objects of cultural heritage and modern materials in modern and contemporary art objects. She is also involved in testing physical and mechanical properties of various types of materials and carrying out artificial ageing experiments.

s.de.groot@cultureelerfgoed.nl

KATHARINA HAIDER

Katharina Haider studied conservation, art technology and conservation science at the Technical University Munich. Her final thesis was about the conservation of plastic bags. Focusing on modern and contemporary art and design she worked as an intern at the Neue Sammlung – The International Design Museum Munich and for the New National Gallery Berlin. She has been Senior Time-based Media Conservator at Tate Gallery and worked for museums such as the Museum of Modern Art MMK. Currently she graduates in Polymer Science at the Technical University Berlin, works as a chemistry tutor and runs her atelier in Berlin.

kathihaider@hotmail.com

STEFANIE ILLI

Following a carpenter apprenticeship, Stefanie Illi received a Bachelor degree in Conservation from Bern University of the Arts, which included several internships.

In 2012 she worked as a conservator at the Museum Moderner Kunst Stiftung Ludwig in Vienna. In 2014 she completed her Master's degree at Bern University of the Arts in Conservation-Restoration of Modern Materials and Media. The case study published here was undertaken during her ERASMUS exchange semester at the Academy of Fine Arts Vienna in 2012.

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