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Adhesives for Stained Glass Windows – Development of a New System for Wide Cracks

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Abstract

To improve the adhesives used for restoring stained glass windows, various adhesives were tested and modified. Stained glass windows often show gaps that are too wide to be glued with conventional adhesives, and complementing the gap with spare glass is very time-consuming. To solve this problem, a filler with improved adhesive strength was developed to bridge wider gaps and cracks. The new filler combines glass adhesives with specially treated glass powder. Three different glass adhesives were selected and mixed with the specially treated glass powder. The adhesive – glass powder mixture developed was then subjected to accelerated aging and analysed with Fourier transform infrared analysis, scanning electron microscopy, colourimetry, and bending and tensile tests. The results were excellent and the mixture was subsequently used to restore glass windows from four 19th-century churches and chapels. The restoration process was described in conjunction with the advantages of using this approach. This new adhesive – glass powder mixture provides an adhesive process that can be adapted to the special needs of any object being restored and thus provides a ready answer to the specific damage of each object.

Titre et Résumé

Adhésifs pour vitraux – Nouveau système mis au point pour combler les larges fissures

Divers adhésifs ont été modifiés et mis à l'essai afin d'améliorer les adhésifs utilisés pour restaurer les vitraux. Les vitraux présentent souvent des fissures ou des lacunes qui sont trop larges pour pouvoir les combler adéquatement avec des adhésifs courants. Le remplacement à l'aide d'autres morceaux de verre exige, quant à lui, beaucoup de temps. Pour résoudre ce problème, un matériau ayant une force d'adhérence supérieure a été mis au point afin de combler les lacunes et les fissures plus larges présentes dans les vitraux. Ce nouveau matériau est composé d'un adhésif pour vitraux et de poudre de verre ayant subi un traitement spécial. Trois adhésifs pour vitraux ont été sélectionnés et mélangés avec la poudre de verre traitée. Le mélange mis au point a ensuite été soumis à un vieillissement accéléré et a été analysé par spectroscopie infrarouge à transformée de Fourier et microscopie électronique à balayage et soumis à des essais de colorimétrie et de résistance à la flexion et à la traction. Les résultats obtenus sont excellents et le mélange a par la suite été utilisé pour restaurer des vitraux situés dans quatre églises et chapelles du XIX^e siècle. L'article comporte la description du procédé de restauration et les avantages de l'approche adoptée. Ce nouveau mélange d'adhésif et de poudre de verre constitue un matériau polyvalent qui peut répondre aux besoins particuliers de différents objets devant être restaurés, ainsi qu'une solution facile aux problèmes de dommages particuliers subis par des vitraux.

Introduction

The size of the panes of glass produced over the years has become larger due to increased technological capabilities. That is why we find considerably larger panes in 19th century churches compared to mediaeval churches, as Wolff (2000) describes. As a result the web of lead (called came) which frames the glass got larger. When damage such as cracks and gaps in the panes occur they span wider areas and thus, in particular, endanger the stability. Repair leads were used for temporary bonding (as shown in Figure 1) and if they were removed further instabilities occur. In cooperation with a Restoration Studio, the Federal Institute for Materials Research and Testing carried out a research project for the restoration of stained glass windows from 19th and 20th century churches. The aim of the project was to develop an adhesive which guarantees the bridging of wider cracks as well as being adapted for coloured bonding.

Adhesives for restoring historic glass objects have been the subject of various studies, (Koob 2006; Davison 2003; Marschner 1996). Well known problems in bonding glass are the poor ageing behaviour with yellowing and embrittlement and unachievable reversibility as Sander-



Figure 1: Knights Hospitaller Window, German, 19th century, pane with repair leads and thus reduced legibility.

Cornwell and Schmitt-Ott (1993) described. Glass adhesives developed for restoration with an improved ageing behaviour are often complicated to apply and not suitable for economical use (Davison 2003, p. 212).

Adhesives normally used for restoration are only suitable for gaps of 2 mm wide maximum due to limited adhesion; the maximum gap width is specified by the manufacturers of the adhesives. Clear and transparent adhesives are usually used for these purposes which are afterwards coloured with an adapted and reversible inpainting. Where yellowing of the adhesive occurs, the inpainting can be removed and the colouring process can be corrected by a newly applied inpainting. Another possibility is colouring the adhesive with pigments or dyes. The applications are described by Jordan (1999) and Burck (2001). However the bonding of wide gaps does not usually achieve the brilliance of coloured glass and even after colour matching the gaps are clearly visible.

Therefore the basic idea of the project was to colour the adhesive and to use this material at the same time as a filler material for bridging wider gaps. The use of filler materials is well known from wood conservation (Mintrop 1997). Glass powder seems to be well suited because of its similar physical and chemical properties to the glass objects that have to be restored (coefficient of thermal expansion, refractive index, gloss level etc.).

The project described in this paper examines three glass adhesives (epoxy resin, silicone, and UV-cure) with a glass powder filler for colour changes, chemical changes [Fourier transform Infrared microscopy (FTIR)], and physical changes (bending and tensile changes) before and

after various ageing techniques, and also examines samples by scanning electron microscopy (SEM). The test methods were selected due to their ability to describe relevant changes like ageing behaviour, yellowing and embrittlement and the tests were performed to determine the best possible adhesive to use with the glass powder filler.

During the course of a pilot study, cracks and gaps with widths up to 5 mm were restored in coloured stained glass windows from several churches and chapels of the 19th century in the Berlin area.

Experimental

Material and processing

Glass powder

The colours of the glass powder were selected to match the glasses selected for the pilot study. Commercially available glass powder from Kremer Pigments, Germany was used as well as Artista Glass powder from Schott, Germany. Additional glass powder was made in the lab of the Federal Institute of Materials Research and Testing. The idea being to use a glass powder with a similar composition to the original glass, e.g. having the same refractive index as the original glass. Therefore the original glass was analyzed and the colouring agents were determined by using EDX-analyses. Glass samples according to the original composition were melted in the lab, ground and then fractionated in different particle size ranges from <56 up to 200 µm. The particle size distribution from all of the applied glass powder was determined with the analyzer “Mastersizer S” and allowed conclusions to be drawn concerning the homogeneity of the fractions. The homogeneity of the glass powder is important to achieve a uniform distribution in the adhesive during the mixing process.

Adhesives

The selection of the adhesives was based on a survey of more than 50 glass restoration studios. Following preliminary setting time, ageing resistance and yellowing tests (the tests were conducted in a previous study), three adhesives were selected: Araldite 2020 two-component epoxy resin, CAF3 silicone adhesive, and UV- and daylight-reactive Conloc 684. The adhesives harden chemically and belong to various adhesive classes: the epoxy resin Araldite is a polyaddition adhesive with a reaction between the resin and hardener components, CAF3 silicone adhesive ranks among the polycondensation adhesives and cross-links due to humidity, and finally, Conloc UV 684 - a light-hardening adhesive, belongs to the polymerization adhesives where cross-linking is triggered by light.

Mixing the components

The first step is processing the glass powder. This included a slurring procedure followed by a 24-hour drying process at 60°C in the climate chamber. The glass powder was then mixed with the selected dispersing agent using ethanol as a carrier in the ultrasonic homogenizer for 2 minutes. After a one-hour rest period the ethanol was decanted and the remaining residual

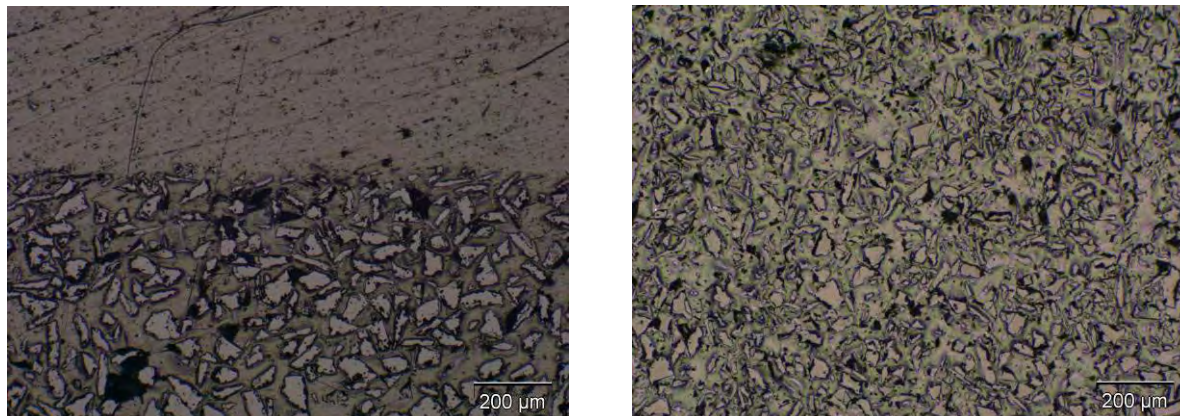


Figure 2: Cross section of the adhesive-glass-powder mixture without (left) and with dispersion process (right), SEM image.

moisture was evaporated at 60°C. The adhesive and glass powder were mixed with a magnetic stirrer combined with a vacuum pump at an absolute pressure of 1 mbar. In Figure 2 the effect of the dispersing agent is shown.

Sample preparation

Samples with clear adhesive and with the “adhesive-glass-powder mixture” 1:2 (adhesive:glass powder) were prepared. Since it is easier to observe the mixing process, coloured (green) glass powder with a grain size of 56-80 µm was used. For evaluation purposes the “adhesive-glass-powder mixture” was compared to the standard application of clear and black pigmented adhesive. Black pigmented adhesives are often used in restoration, because no change in colour will be visible, even if ageing occurs. A very small amount (less than 1 mg) of the black pigment was used to colour the adhesives. To enable a statistically firm mean value of strength to be calculated, an appropriate amount of samples for the bending and tensile tests was prepared with thirty (30) samples for each application. All samples were tested before and after artificial ageing, so it comes up to 540 samples (three adhesives, each with glass-powder, black pigment and clear, before and after ageing).

Adhesive application

The bonding was carried out on float-glass samples (modern window glass) with 3-mm thickness. The samples were cut in two similar parts and were glued together in a butt joint with a defined gap of 2 mm width. To control the width of the gap as well as the spread of adhesive the two glass parts were fixed with adhesive tape. The adhesive was applied on the horizontal lying glass. For colorimetry the sample material was spread on microscope slides with a thickness of approximately 1 mm. For the FTIR measurements thin dried films of pure Araldite and Araldite-glass-powder mixture were placed on part of a calcium fluoride disk and the other, empty part, served as the background.

Methods of analysis

Environmental scanning electron microscopy (ESEM/SEM) analysis

Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) were used to characterize the glass powder and observe grain structure and grain size. The analyses were carried out in a high vacuum using a FEI (Philips)-XL-30 ESEM. The effect and stability of the dispersion were assessed using SEM images.

Artificial ageing

Ageing of the sample specimens was performed in two weathering periods. The first period covered 4 weeks (summer and winter cycle were repeated four times) and simulated the Central European summer and winter climate and integrated Sulphur Dioxide pollutant levels. The pollutant was only added during the summer cycle.

Summer cycle:

4 ½ days, Day cycle - 12 hours at 40°C, 50% relative humidity (RH). Night cycle - 12 hours at 10°C, 80% RH.

Sulphur dioxide pollutant supply: concentration 1 ppm = 2860 µg/m³, the 2009 mean value in Brandenburg was 2.8 µg/m³ (Landesamt für Umwelt, Air Quality Report 2009).

Winter cycle:

2 ½ days, day and night: -10°C, without adjusted humidity.

The second weathering period covered a 4-week UV irradiation in the weathering equipment “Global UV test type 200 BAM”. The irradiance in the UV range was 27 W/m². The spectral distributions corresponded to ISO standard 4892-3 (ISO 4892-3 2011). The weathering was performed at a constant temperature of 40 ± 2 °C and unregulated humidity. In the second weathering period some of the samples selected for colorimetry were placed behind a protective glazing, which is used for the protection of stained glass windows in churches. The intention was to prove the benefit of protective glazing not only for the stained glass but for the adhesives too.

The samples were characterized before and after weathering both macroscopically and microscopically, using colorimetry, IR spectroscopy and bending and tensile tests.

Colorimetry

Colorimetry was used for assessing colour changes in, or yellowing of, the samples before and after artificial ageing. Transmission to CIELAB colour space enabled the pigments to be described by their colour values L*, a* and b*, where L* indicates luminosity, a* gives the red-green colour values and b* the yellow-blue colour values (DIN 6174). The quantity of colour difference is given by ΔE^*_{ab} and indicates how strong the change is.

Colorimetry was performed using a spectrometer with a MM 20 prism-type two-monochromator (Zeiss DMC 25). The measurement conditions are specified in DIN 5033, on which the colorimetric analysis was also based (5033-3 1992).

FTIR spectroscopy

The FTIR uses infrared light and is a helpful instrument to detect ageing changes as Lopez-Ballester et al. (1999) showed in their comparative study of glass adhesives. Thus the method was used for recording and analysing the structural changes before and after artificial ageing. The tests were performed using an IR-Scope II microscope. The measurement condition at the microscope was a 15x objective, with a 100 μm test spot, in transmission mode. This was coupled with the Bruker AXS Company's Equinox 55 FTIR spectrometer, with a nitrogen-cooled MCT detector and a resolution of 2 cm^{-1} , recording 100 scans. The detected measurement ranges between 4000 and 600 cm^{-1} .

Bending and tensile tests

A 4-point bending test was used to determine the flexural strength of the adhesive bond. The bending tests were performed on Araldite and Conloc adhesive samples using an Instron 8562 servo-mechanical testing machine. The test speed was 2 mm/min without initial load. A tensile test was used for the silicone glue since the 4-point bending test is not suitable for elastic joints. The tensile tests of the CAF3 adhesive samples were carried out by a Zwick 010 universal testing machine, the test speed here was also 2 mm/min without initial load. To obtain an appropriate contact area for the testing machines, the samples size was defined with a dimension of 6 x 2 cm. The tests were carried out before and after the artificial ageing.

Results

ESEM/SEM

The first bonding tests indicated clumping of the glass powder independent of its grain size. SEM images showed that glass particles < 20 μm , produced by the grinding process, adhered to the glass grains. The fine fraction (glass dust) was removed by slurring the glass powder in distilled water and decanting, and thus clumping was substantially eliminated (see Figure 3).

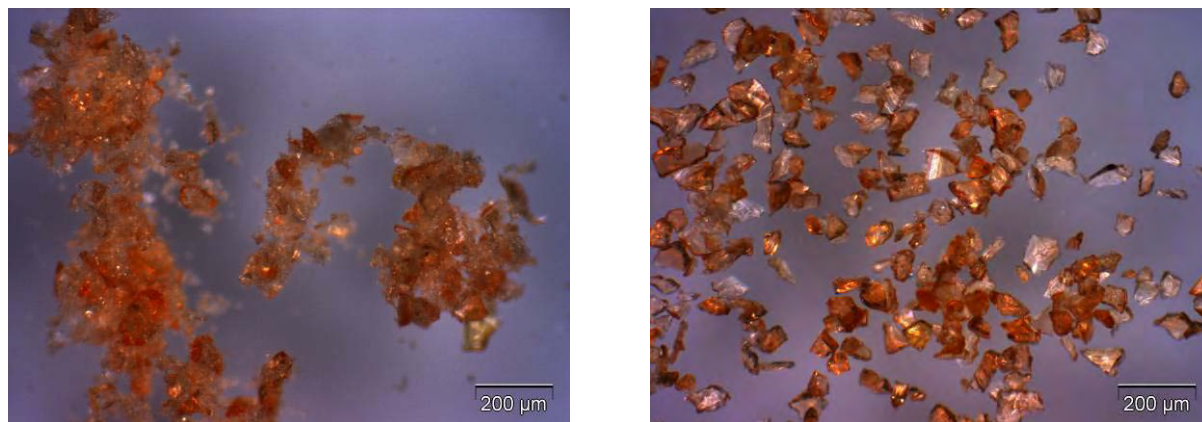


Figure 3: Pure dried red glass powder before (left) and after slurring/decanting (right), SEM image.

Viewing the samples with various dispersing agents (e.g. terpineol or triolein) and glass powders of various grain sizes in the SEM enabled the dispersing effect and homogeneous

distribution to be assessed. Smaller grain sizes showed a better dispersal effect and homogeneous distribution. A further test series determined the optimum mixing ratio of glass powder and adhesive, and the prevention of separation of the two components. SEM images indicated a substantially lower separation in the mixture at higher glass powder fractions, probably due to the increased viscosity of the mixture.

Colorimetry

Colorimetry was performed before and after each weathering period, the results of colorimetry are listed in Table 1. Colour changes up to ΔE^*_{ab} values of 0.5 are hardly seen by eye, while a ΔE^*_{ab} value >1.0 is significant. After both weathering cycles the colour values of the CAF3 silicone adhesive remained constant (ΔE^*_{ab} : 0.3 clear/ 0.2 with glass-powder), Conloc 684 samples with and without glass powder exhibited a small colour change (ΔE^*_{ab} : 0.4 clear/ 0.7 with glass-powder), while colour values of pure epoxy resin Araldite 2020 changed the most (ΔE^*_{ab} : 6, see Figure 4 top). The Araldite-glass-powder mixture however, hardly changed (ΔE^*_{ab} : 0.6, see Figure 4 bottom). This agrees with the results of the FTIR test (see below). In agreement with the visual observation, colorimetry assessment of the pure adhesive Araldite 2020 showed a considerable change which occurred mainly after the second weathering period with UV irradiation without protective glazing. The benefits of protective glazing are widely examined e.g. by Godoi et al. (2006). After the first weathering period (with pollutant but without UV irradiation), however, hardly any colour change occurred. Samples which were illuminated with UV light under protective glazing, exhibited no change in the colour values: the UV protection afforded by a cover glass was fully effective.

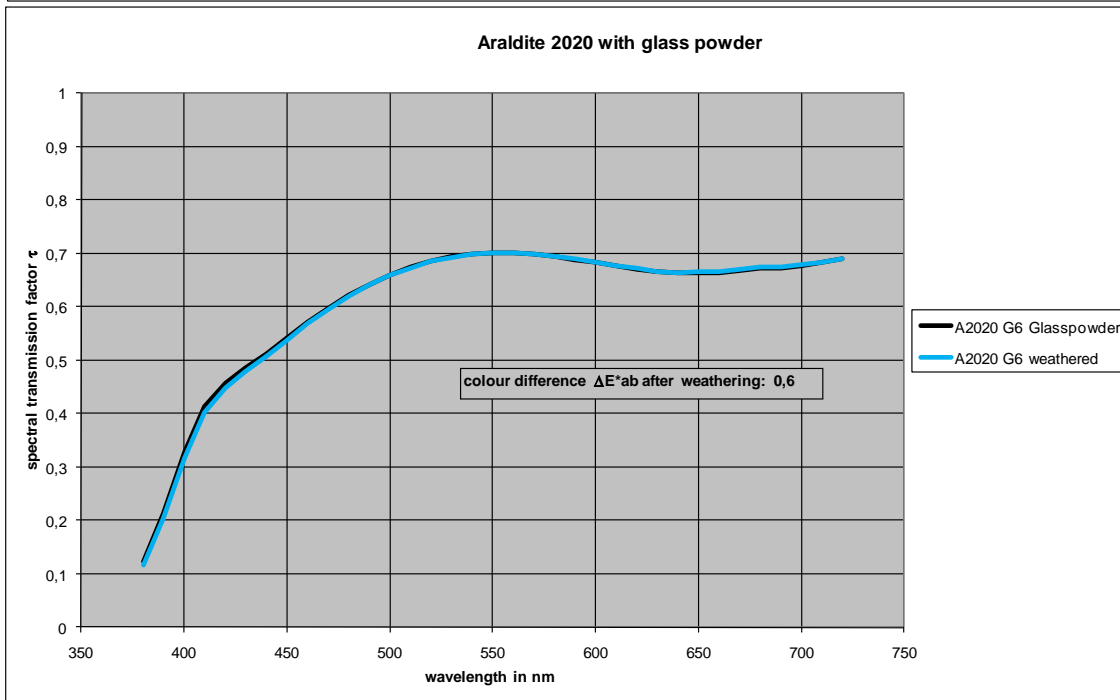
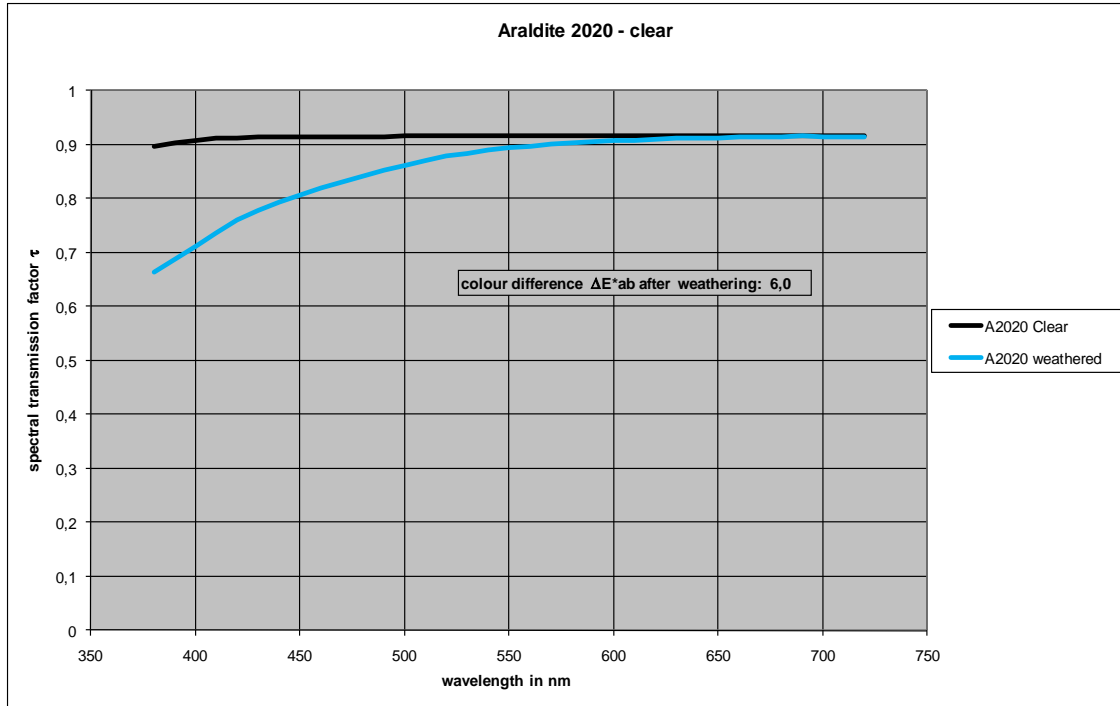


Figure 4: Colour assessment before and after the two weathering periods. The colorimetry of the pure Araldite 2020 adhesive shows considerable differences before and after UV irradiation (top) while the Araldite-glass-powder mixture shows no discoloration (bottom).

Table 1: Results of colorimetry after the first and second weathering period without protective glazing, the ΔE^*_{ab} -values show the colour changing after each weathering period.

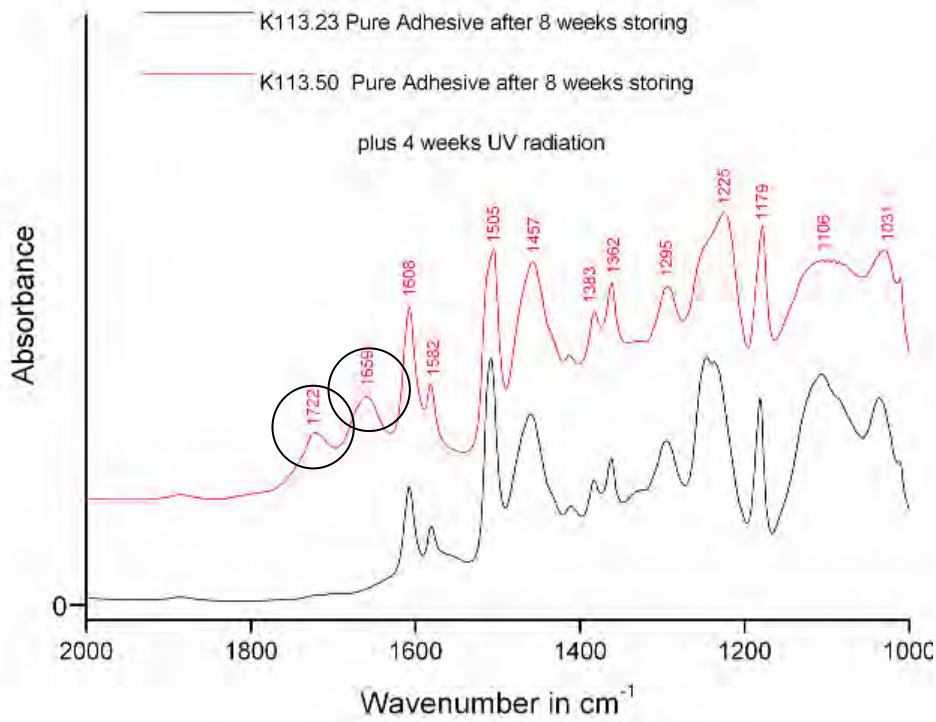
The colorimetry was calculated according to the CIELAB colour space 1976, for 2° angle standard observer, reference illuminant D65 in transmission, the spectral data range from 380 to 720 nm, interval 10 nm.

CODE	X	Y	Z	x	y	L*	a*	b*	ΔE^*_{ab}
CAF3 clear	86.46	91.01	98.67	0.3131	0.3296	96.41	-0.06	0.28	
1 weathering	86.52	91.07	98.83	0.313	0.3295	0.03	-0.01	-0.05	0.06
2 weathering	86.33	90.88	98.15	0.3135	0.33	-0.05	-0.02	0.25	0.26
CAF3 pigmented	0.18	0.19	0.2	0.3174	0.3272	1,70	0.15	0.01	
1 weathering	0.16	0.17	0.18	0.3168	0.3263	-0.17	-0.01	-0.02	0.17
2 weathering	0.14	0.15	0.16	0.3214	0.3285	-0.37	0.02	0.04	0.37
CAF3 glass-powder	68.12	73.26	71.11	0.3206	0.3448	88.57	-3.29	6,78	
1 weathering	68.25	73.41	71.28	0.3205	0.3448	0.07	-0.03	-0.02	0.08
2 weathering	68.07	73.22	70.81	0.3209	0.3452	-0.02	-0.02	0.21	0.21
Conloc clear	87.29	91.89	99.72	0.313	0.3295	96.78	-0.08	0.22	
1 weathering	87.34	91.96	99.83	0.3129	0.3295	0.03	-0.04	-0.02	0.05
2 weathering	87.07	91.69	98.94	0.3135	0.3302	-0.08	-0.06	0.37	0.39
Conloc pigmented	14.14	14.76	15,70	0.3171	0.3309	45.3	0.72	0.82	
1 weathering	14,05	14.66	15,60	0.317	0.3309	-0.14	-0.01	-0.01	0.14
2 weathering	13.99	14.63	15.64	0.3161	0.3305	-0.18	-0.17	-0.19	0.31
Conloc glass-powder	74.26	79.05	81.06	0.3169	0.3373	91.26	-1.8	3,67	
1 weathering	74.22	79.02	81.02	0.3168	0.3373	-0.01	-0.03	0,00	0.03
2 weathering	73.35	78.1	79.42	0.3177	0.3383	-0.43	-0.03	0.49	0.65
A2020 clear	87.05	91.63	99.55	0.3129	0.3293	96.67	-0.06	0.15	
1 weathering	87.09	91.66	99.59	0.3129	0.3293	0.01	0,00	0,00	0.01
2 weathering	84.21	89.13	88.75	0.3213	0.3401	-1.03	-0.89	5,51	5,67
A2020 pigmented	28,01	29.39	31.73	0.3142	0.3298	61.13	0.27	0.39	
1 weathering	28,10	29,50	31.87	0.3141	0.3297	0.1	-0.03	-0.04	0.11
2 weathering	26,50	28,06	25.81	0.3297	0.3491	-1.19	-0.97	6,77	6,94
A2020 glass-powder	62.4	68.41	60.31	0.3265	0.358	86.21	-6,00	11,98	
1 weathering	62.06	68.06	59.98	0.3264	0.358	-0.17	-0.04	0,00	0.18
2 weathering	62.02	68.06	59.37	0.3274	0.3592	-0.18	-0.11	0.55	0.59

FTIR

The adhesive Araldite 2020 was tested solely, due to the well known yellowing behaviour of epoxies, as Down (1986) has reported. Two IR measurement series were carried out on thin films of pure adhesive and “adhesive-glass-powder mixture” and analyzed by comparing the spectra. The IR-spectroscopy tests showed new bands around wave numbers 1725 cm^{-1} and 1660 cm^{-1} after UV-radiation which were pronounced in both pure and glass containing spectra. These bands indicate the presence of C=O double bonds, i.e. carbonyl bonds. At 1725 cm^{-1} a carbonyl stretching vibration was observed which can be interpreted as the beginning of photo oxidation and indicated the degradation of long-chain molecules (Hilbert 2002). As shown in Figure 5 bottom the spectra of the “adhesive-glass-powder mixture” exhibits a smaller band change than those of the pure Araldite adhesive. This shows that glass powder offers protection from UV beams and prevents degradation reactions of the polymer network due to photo-oxidative processes. This might be due to fewer parts of adhesive in the “adhesive-glass-powder in colorimetry. The bottom line is that the addition of glass powder to Araldite 2020 provides an improved resistance to yellowing, as stated previously in colorimetry.

86/07 Sample Pure Adhesive, Detail of Spectra



86/07 Sample Adhesive with Glass Powder, Detail of Spectra

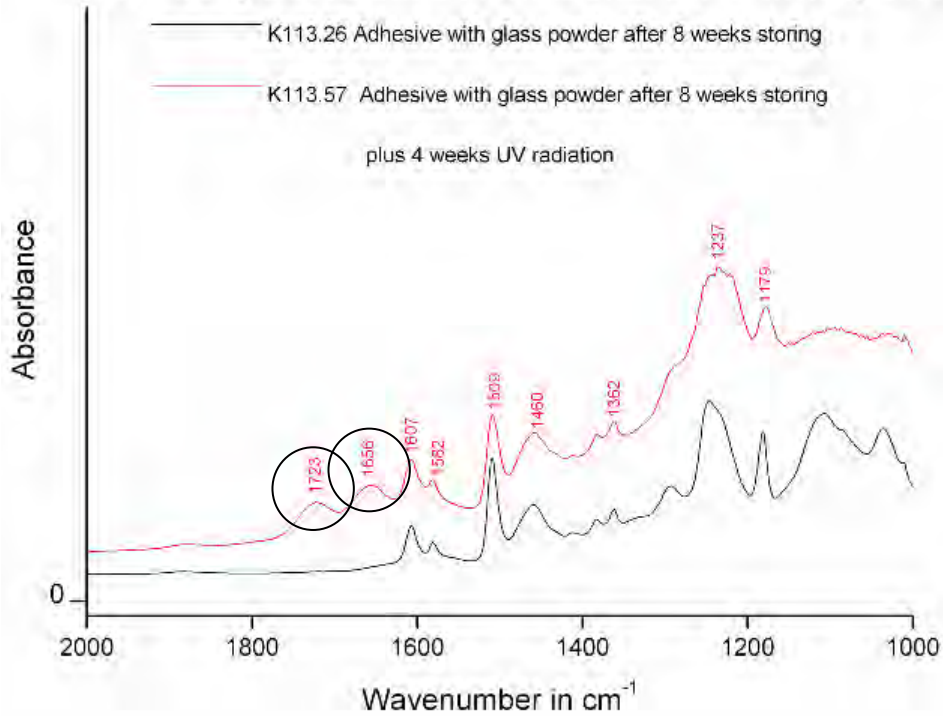


Figure 5: Comparative spectra of pure Araldite 2020 adhesive (top) and the Araldite-glass powder mixture (bottom): before UV irradiation (black), and after UV irradiation (red).

Bending and tensile tests

Samples with an “adhesive-glass-powder mixture” ratio of 1:2 (adhesive:glass powder) were tested and compared to clear and black pigmented adhesive. All of the three adhesives with glass powder had higher strength values than samples without glass powder added as shown in Figure 6. Samples of Araldite 2020 and Conloc 684 containing glass powder exhibited a higher strength even after ageing than did samples without glass powder addition. Here the strength after ageing is still sufficient, without being too strong to provoke new breakage of the glass substrate in case of stress.

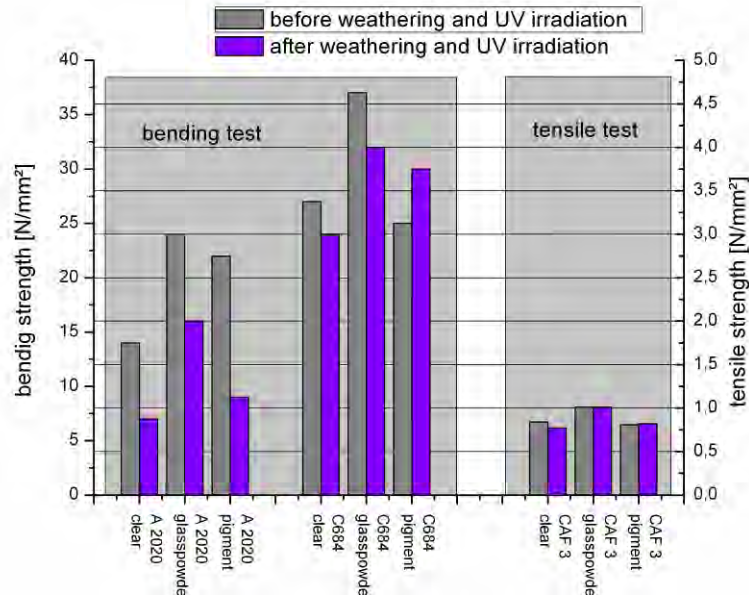


Figure 6: Results of the bending and tensile tests, carried out on samples with a mixing ratio of 1:2 of adhesive : glass powder.

Adhesion and strength of the glued joints could be adjusted by changing the content of glass powder in the mixture. This is important for fragile glass windows. A decrease in the amount of glass powder in the mixture decreased the joint strength. Further tests were carried out with adhesive to glass powder mixing ratios of 3:5 and 1:1. In all tests, when the joints broke, they broke in the cured “adhesive-glass-powder mixture” and not in the substrate (e.g. the original glass). It is important for the restoration of objects that in case of stress the joint will break but no further breakage in the original glass will occur.

Treatments

The stained glasses to be restored in the example treatments given below were in very different states of preservation. Individual windows were selected for restoration in agreement with the State Monument Protection Offices, as the responsible institution. An important aspect of these example treatments was to demonstrate the versatility of the “adhesive-glass-powder mixture” developed in our pilot study. Araldite 2020 was chosen for these example treatments because in Germany it is the most frequently used adhesive for stained glass windows and did fairly well in

the above tests. The following examples give the reader an idea of how the “adhesive-glass-powder mixture” can be used.

Colour adjustment

The ability to add glass powder enables an optimum colour match to the original glasses to be made. Colour-intensive glasses required more glass powder than lightly coloured glasses, to achieve the desired colour. A design pallet of various original glass colours was established using the “adhesive-glass-powder mixture” and thus the preliminary determination of the most suitable colour was ensured by using the relevant mixing ratio as shown in Figure 7.



Figure 7: Samples to match the colour of medieval glass fragments, cooperation with the workshop of the Cologne Cathedral.

Adjusting the colour to the red flashed glass of a choir window of the St. Matthew and Marc Church in Rohrshelm/ Saxony-Anhalt built in 1888, required two work phases (see Figure 8). Flashed glass usually consists of a colourless base glass on which a thin coloured coat is melted. The flashed glass had shell-shaped chips at the point of fracture and showed multiple fissures (Figure 8 left). The repair was achieved by applying a transparent adhesive (Figure 8 middle) and a thin layer of “adhesive-glass-powder mixture” containing a high portion of red glass powder and a red wax (Figure 8 right), i.e. a wax colourant to intensify the red colour.



Figure 8: Broken red flashed glass (left), first work phase with transparent adhesive (middle), second work phase with adhesive-glass-powder mixture with red glass powder and red wax (right).

Transparency

To achieve a glass-like transparency, a multi-layer arrangement was recommended even if wider joints had to be glued. First, a layer of coloured “adhesive-glass-powder mixture” was applied and a layer of clear Araldite 2020 was placed on top. The layer thickness of mixture and

clear adhesive required was determined by trials. Particularly lightly coloured glasses achieved a good glass-like appearance as a result of multi-layered gluing.

An example of transparency achieved can be seen in the nave window of the village church in Gültz near Schwerin/ Mecklenburg-Western Pomerania built in 1880. The window consists of square-shaped colourless glasses with a uniform muslin coat on which a floral grisaille painting has been applied. Muslin glass is a colourless glass discoloured by sand blowing or etching, on which the grisaille painting is applied in various shades of grey. The glass exhibited a spider's web-like fissure pattern. Flakes and defects were visible in the central fissure area. Colourless or white dyed "adhesive-glass-powder mixture" was used to perform the repair (see Figure 9).



Figure 9: Detail of one grisaille fissure area before (left) and after restoration (right).

Viscosity

Viscosity can be adjusted to the work conditions. Despite adding glass powder, the adhesive mixture has a low viscosity, therefore, a time-delayed application to allow the adhesive to start curing and thickening is advantageous particularly for wider fissure patterns. However, the addition of colourless glass powder can be used to increase viscosity if needed to bridge wider gaps.



Figure 10: Detail of the chapel of Klein Glienicke in Potsdam from 1877 during restoration with bars to position the fragments (left), the pane after restoration (right).

In the chapel of Klein Glienicke in Potsdam-Babelsberg/ Brandenburg built in 1877, a window with figured glass paintings had large cracks and defects. A cracked section of a multicoloured architectural drawing had been repaired using multiple lead comes, spoiling the impression of the picture as a whole (compare Figure 1 and Figure 10). Their removal left gaps of 2 to 4 mm width. Gluing and filling the gaps was carried out by a combination of techniques. First, the “adhesive-glass-powder mixture” was applied at high viscosity to form bars between the fragments which enabled individual fragments to be positioned (see Figure 10 left). The resulting joints were filled with the “adhesive-glass-powder mixture” either in one work step or layer by layer depending upon the required colour intensity. The final result (see Figure 10 right), without the disfiguring comes, greatly improves the aesthetic appreciation of the glass window.

Combinations

Gaps may exhibit various crack patterns. Therefore combinations of various joining techniques are necessary for optimum gluing. Thus very narrow cracks can be joined with clear Araldite 2020, while wider cracks or defects as well as superficial flaking can be filled with an “adhesive-glass-powder mixture”. This method was used for gluing a round window of the Bethmann Hollweg grave chapel in Hohen Finow/Brandenburg built in 1893 (see Figure 11). The blue glass in a crescent-shaped pane had small geometrical shapes with multiple fissures

and larger shell-shaped chips in some places. Narrow cracks were glued with clear Araldite, while the chips were filled with the “adhesive-glass-powder mixture”.



Figure 11: Round window from the Bethmann Hollweg grave chapel in Hohen Finow/ Brandenburg from 1893, before (left) and after restoration (right), cracks were filled with clear Araldite while the parts flaked off were filled with the “adhesive-glass-powder mixture”.

Conclusions

The objective of the research project was to investigate new ways of filling gaps for the restoration of stained glass windows. The methods should meet conservation standards for historic buildings and offer applications in line with standard practice in restoration. The change in properties of modified “adhesive-glass-powder mixtures” was investigated on model samples using fissure and gap gluing techniques. The new mixture was characterized by comparing it with a clear and a pigmented adhesive.

The samples with added glass powder provided the best results in each case, independent of the gluing medium selected. Adding glass powder reduced yellowing, particularly in epoxy resins. On the one hand the less adhesive in the mixture reduced the yellowing potential; while on the other hand the glass powder in the mixture provided protection against yellowing, since a glass as a whole provides protection against UV-radiation. Weathering tests using a climate chamber with UV irradiation proved the UV-protection of glass: samples with pure epoxy resin behind a protective cover glass did not exhibit any yellowing phenomena. The precise effect of glass powder providing protection against UV-induced degradation of the polymer network should come under scrutiny and should be clarified by further tests.

Four-point bending and tensile tests on the samples with glass powder indicated an increased strength compared to samples without added glass powder. Moreover, hardness, glue adhesion and viscosity can be modified and thus adapted to the restoration requirements. Variable application enables high colour brilliance and a glass-like appearance.

The findings were applied to four selected restoration objects of the 19th Century and the epoxy Araldite 2020 was selected due to its good long term experience in stained glass conservation in Germany and its comfortable mixing and application. Exemplary repairs were performed on several glass segments using the method developed. A detailed record keeping of the restoration work will enable the long-term behaviour of the modified “adhesive-glass-powder mixture” to be checked.

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Materials and Suppliers

CAF 3:

Bluestar Silicones Germany GmbH, Headquarter for Germany-Austria-Switzerland:
Hans-Sachs-Strasse. 4, D-23566 Lübeck Tel.: +49 451 60981 23 Fax: +49 451 60981 11
webmaster.silicones@bluestarsilicones.com

Conloc UV-684:

EGO GmbH & Co. KG, Lilienthalstraße 7, 82205 Gilching, Germany
Tel: +49 (0) 81 05/217-0, Fax +49 (0) 81 05/217-33, www.ego.de

Araldite 2020:

Bodo Möller Chemie GmbH, Senefelderstraße 176, D-63069 Offenbach/Main
Tel.: +49 (0)69 838326-0, Fax: +49 (0)69 838326-199, <http://www.bm-chemie.de/content/de/>

Glass powder in different grain sizes (56µm-200µm) and colours:

Kremer Pigmente GmbH & Co. KG, Hauptstr. 41 – 47, DE 88317 Aichstetten
Tel. 0049 75 65 911 20, Fax 0049 75 65 16 06, <http://kremer-pigmente.de>
SCHOTT AG, Hattenbergstrasse 10, 55122 Mainz, Germany,
Tel. +49 (0)6131/66-0, Fax +49 (0)6131/66-2000, www.schott.com

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- la simulation des dommages environnementaux infligés aux matériaux dans des caissons climatiques.

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