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ARCHAEOLOGICAL GLASS CONSERVATION: COMPARATIVE APPROACHES AND PRACTICALITIES OF USING ACRYLIC RESIN FILMS AS GAP FILLS

HANA BRISTOW AND JAN DARIUSZ CUTAJAR

The conservation of archaeological vessel glass is notable for the challenges inherent in loss compensation and has seen conservators creatively manipulating many materials with varying degrees of success. Conventional gap-filling techniques using epoxy resins are now widely regarded as inappropriate. One of the latest emerging techniques is the use of customizable Paraloid B-72 films, established by Stephen Koob and his colleagues at the Corning Museum of Glass. This article presents two alternative approaches to loss compensation in archaeological glass using acrylic resin gap fills. The authors reflect on their independent experiences in adapting this technique and consider each against the backdrop of Koob's own recommendations. The approaches described here illustrate the practicalities, challenges, and conclusions drawn from the application—through trial and error—of this technique. It also highlights the similarities and differences in decision making by the conservators working separately at the University College London and the Royal Albert Memorial Museum while replicating a given treatment methodology. Additionally, it advocates the use of collaboration and knowledge sharing in tackling a conservation issue. Ultimately, through sharing these experiences, both case studies serve as a guide for conservators wishing to implement similar treatments in the future. It is hoped that in doing so, the professional conservator's repertoire for the treatment of archaeological glass will be expanded on, allowing for the significance of fragmentary archaeological glass to be better preserved.

KEYWORDS: Glass, Archaeological conservation, Gap fills, Acrylic resins, Paraloid B-72

1. INTRODUCTION

Archaeological glass conservation presents numerous challenges to conservators faced with the task of loss compensation, whether to impart structural reinforcement or visual continuity. The inherent fragility of archaeological glass objects is typified by their degraded condition and weakened internal structure resulting from burial and subsequent excavation, and is further exacerbated by considerable fragmentation and material loss (Davison 1978; Newton and Davison 1989; Cronyn 1990; Oakley 1992; Weijand 1999; Davison 2003; Koob 2006). Where a significant portion of a glass object has survived, the desire to view and study it as a single object, rather than as a collection of fragments, has driven conservators to explore a range of materials and methods for creating gap fills.

For many years, epoxy and polyester resins have been the choice materials for glass gap fills owing to their transparency, close refractive index to glass, high glass transition temperature (T_g), and application in a variety of reconstruction techniques (Fisher 1988; Cronyn 1990; Hogan 1993; Fontaine 1999; Oakley 1999; Tennent 1999; Weijand 1999; Henderson 2000; Ling 2000, 2002; Davison 2003; Koob 2006; Piloni 2007; Davison 2009; Roemich 2010; Barton, Meek, and Roberts 2013; Roemich and van Lookeren 2013). However, their long-term chemical instability and concomitant yellowing, together with an increased risk of damage to surrounding glass from physical stress as they degrade over time, mean that these materials are in no way ideal when applied to extremely fragile archaeological glass. Furthermore, casting techniques for these resins normally demand a high level of object handling either for direct casting or through creating a mold for indirect casting.

It is also worth mentioning the use of Japanese tissue paper (made from the Asian mulberry tree), either impregnated with acrylic resin or otherwise, as another class of commonly used fill material for archaeological glass (e.g., Barton, Meek, and Roberts 2013; Williams 2015). Tissue paper fills have often intended to address the aforementioned failings of epoxy and polyester fills but have limitations of their

own. Notwithstanding that these paper fills impinge less on the glass, are much more chemically stable, and are easily reversed, they remain minimally structurally supportive, they do not take compound curves well despite their versatility, and they are usually successful only in either transmitted or reflected light viewing conditions, but not both.

In light of this, in 2011, Koob and his colleagues at the Corning Museum of Glass advocated a new technique for making custom acrylic films or sheets from Paraloid B-72 (polyethyl methacrylate/polymethyl acrylate copolymer) suitable for gap-filling archaeological glass (Koob et al. 2011). Most notably, when compared to thermosetting resin and paper fills, key advantages of this technique include the ability to prepare casts away from the object, their long-term chemical stability, the versatile working properties of a thermoplastic acrylic resin, and the possibility for easy future removal. The success of this technique and further developments shared by Koob and his team offer an exciting opportunity for conservators elsewhere to adopt the same approach for reconstructing and reinforcing archaeological glass objects (Koob, van Giffen, and Hanna 2013).

This article describes the implementation of two such treatments conducted independently by the authors during their graduate training as objects conservators in the UK. By reflecting on our independent experiences in following and adapting this technique, our evaluations offer an interesting comparison of methods based on Koob's methodology while providing useful examples of the practicalities and challenges of this technique.

2. CASE STUDIES

The two case studies presented here relate to two different glass vessels, hailing from contrasting historical periods, geographical regions, and cultural contexts. Unsurprisingly, then, their respective chemical and physical makeups are also different. Their conservation treatments were likewise carried out in two different contexts, one being the University College London (UCL) Institute of Archaeology (IoA) MSc laboratories in London and the other being the conservation facilities at the Royal Albert Memorial Museum, Exeter. Despite these differences (also reflected in the availability of resources, institutional deadlines, etc.), both vessels exhibited similar states of condition, having been fractured into a large number of fragments, most of which were inherently fragile due to their weakened structure and pronounced thinness.

The first glass vessel (fig. 1) is an example of medieval Sassanid glassware, markedly characterized by its greenish-yellow coloration and stylistic features (Goldstein 2005; Gyselen 2007). The vessel has a wide, teardrop-shaped rim with a thick rounded lip that stems into a long, narrow neck ending in a wide, inverted, pyriform-shaped, thin body with a thick, concave base. A handle with a thick flared tongue at the rim thins and curves its way to the surface of the body, where it thickens once again. Concentric striations around the rim suggest that the glass was blown, which is consistent with its context (*Encyclopaedia Iranica* 2015a, 2015b). The handle was then most likely added after blowing. Portable x-ray fluorescence (pXRF) spectrographic analysis was inconclusive in determining its specific provenance but revealed a content of approximately 0.5% to 1% K₂O, 5% CaO, 1% Mn, 0.6% Cl, 0.2% S, and 0.2% Fe, which might suggest a natron glass with trace minerals from raw materials or added colorants.¹

The vessel formed part of a private Iranian collection; it was then donated to the UCL IoA in the early 1990s. The vessel had been conserved twice before, with one documented treatment taking place at the



Fig. 1. Left: Sassanid vessel before conservation and in fragments. Right: The vessel after conservation in 2015. Artist/title unknown, possibly 3rd to 7th century AD, glass, 99 × 91 × 67 mm (at rim), University College London Institute of Archaeology Conservation Teaching Collection, 6303.

UCL IoA in 1997 and physical evidence on the piece pointing to a prior undocumented intervention. The more recent treatment involved deconstructing and gap filling the object due to failing cellulose nitrate joins, which resulted in its fragmentation into more than 53 pieces (fig. 1). This compromised its continued survival and interpretation as a complete artifact and, thus, its sensory and evidentiary significance. The situation was all the more exacerbated by the very fragile and thin nature of the glass body.

The conservation treatment described in this article hence targeted enhancement of the vessel's sensory and evidentiary layers of significance to allow its appreciation as a whole vessel and, therefore, also permit its study for research purposes. As such, the treatment ideally aimed to join and support all major fragments.

The second case study concerns a 17th century glass beaker (fig. 2) excavated in the city of Exeter, UK, in the 1970s and since stored at the Royal Albert Memorial Museum in Exeter (Allen, Archibald, and Brown 1984). The vessel is an example of *façon de Venise*, a style rooted in the 15th century when Venetian glasshouses perfected the formula for *cristallo* (or crystal glass) to produce extremely thin-walled and colorless glass objects (Willmott 2004; Weller 2008).

Just over half of the beaker survives in 34 fragments—enough material to appreciate its original complete form, with its intact circular concave base and straight tapering body with widely spaced vertical ribs and subtly curved rim. In 1997, the beaker underwent conservation work during which it was reconstructed with cellulose nitrate adhesive and loosely mounted upside-down over a modern glass former. The glass mount was evidently intended to assist in supporting the reconstructed vessel by allowing joined fragments to hang from the vessel's base. By 2015, however, the state of this treatment had significantly deteriorated: failing joins left fragments dangling precariously and made the object extremely vulnerable to structural breakdown and further damage. Furthermore, the mount offered no real support and hindered aesthetic appreciation of the object.

The main objective of the 2015 conservation treatment was to stabilize the object by making it structurally sound and to increase its potential as a research object within the museum's archaeology



Fig. 2. Beaker after 1997 conservation treatment, photographed in 2015. Royal Albert Memorial Museum, 300/1988/G155.

collection. As such, it was desirable to view the object in an upright position to allow viewing of the interior as well as the exterior, without the need for an obtrusive mounting system.

Both case studies clearly demonstrate the shared conservation aims to impart structural stability to the vessels in order to preserve them in a reconstructed state, which intended to enhance their aesthetic and informative value.

Considered together, the two glass conservation treatments highlight how archaeological glass—vessel glass in particular—presents numerous challenges to its conservation in which reconstruction is the primary objective. More specifically, archaeological vessel glass presents an inherent fragility arising from the degraded and structurally weakened constituent glass, which can also be very thin. In our examples, the glass ranged from 0.2 to 0.35 mm at their thinnest points. Furthermore, vessel glass usually suffers from considerable material loss. A substantial proportion of the glass object will often not have survived burial, meaning that large areas of loss require an adequately strong and durable fill material. Our vessels presented at least a 35% loss of original material. Consequently, reconstructed archaeological glass vessels will normally require additional structural support to ensure their preservation. This is all the more so due to their three-dimensional forms, which instills a desire to view them as freestanding objects, without the need for a mounting system. Above all, archaeological glass cannot be re-fused as a means of reconstruction, thus necessitating some form of fill material to provide stabilization.

Clearly, then, each of these requirements will determine the choice of materials used in a gap-filling treatment. Since each archaeological glass object will constitute different compositions, thicknesses, states of condition, and forms of construction, the selection of an adequate fill material and method to manipulate it to the conservator's task at hand necessitates a targeted approach. Furthermore, it must be kept in mind that, as well as the aforementioned highlighted factors and the desired treatment outcome, the choice of fill is sometimes influenced by external factors, such as the availability of time and resources or the skill and confidence of the conservator. The following sections illustrate these points through our direct experiences in replicating Koob's methodology for using acrylic resin films.

3. ALTERNATIVE APPROACHES TO GAP FILLING WITH ACRYLIC RESINS

The long-term success of any reconstructive treatment heavily depends on the materials and methods selected for gap fills intended for structural reinforcement together with their respective compatibility with the material under reconstruction. In contrast to loss compensation for aesthetic purposes, our gap fills were to act as bridges between critically weak areas requiring stability and reinforcement and would simultaneously aid the practical assembly of the vessel. From an aesthetic and ethical standpoint, the addition of modern gap-fill material to the objects was kept to a minimum to avoid detracting from the surviving original glass.

Acrylic gap fills offer key advantages over those made with epoxy or polyester resins for use with archaeological glass (Koob, van Giffen, and Hanna 2013; Down 2015). The latter two material classes have been the most popular to date (cf. Koob 2006, for example) but are often inappropriate for archaeological glass. This is principally due to the long-term chemical instability of epoxies and polyesters, which induces discoloration (usually observed as yellowing) as a result of chemical breakdown (Down 2000, 2001, 2009, 2013, 2015). This, in turn, necessitates retreatment and concomitant excessive handling of the fragile glass together with an associated risk of further damage. Another inherent chemical property that renders the resins of the epoxy/polyester group unfit for this purpose is their high-strength adhesive bond, which inevitably exerts unwarranted physical stresses onto the archaeological glass as they degrade over time.

Associated casting techniques for epoxy and polyester fills present further problems in comparison to the options offered by acrylic resins. Often, the former are cast directly onto the glass object. Epoxy and polyester resins are thermosetting plastics; the related exothermic release of heat may cause damage to adjacent glass fragments. Although indirect casting methods are also possible in a similar manner to direct casting, they involve increased handling and manipulation of the original glass material, which also pose risks to the artifact.

Japanese tissue paper impregnated with resin has also proved to be a popular choice as a cast material for archaeological glass owing to its long-term chemical stability and the fact that it does not exert undue pressure on surrounding glass (Barton, Meek, and Roberts 2013; Williams 2015). However, their lack of physical strength means that they are inappropriate except for use as minimally supportive fills, and they do not take compound curves well.

In light of this discussion, acrylic resins offer a suitable alternative to epoxy and polyester resins when applied to archaeological glass. For these reasons, acrylic resin films were judged by both authors to fulfill the criteria demanded of gap fills with respect to the treatments of the beaker and Sassanid vessel.

Both of us delineated similar criteria for our gap fills. Importantly, fills would need to be lightweight yet strong, with some flexibility for manipulation, as well as being simple to produce and insert with a minimal number of manipulations of the glass to reduce the risk of further damage and disruption of joins through handling. They also had to match the thinness of the glass as closely as possible while offering the possibility of easy removal without needing to dismantle the entire object should retreatment of localized areas in the future be necessary. Finally, both conservators desired the possibility to manipulate the appearance of fills in terms of color (or tint) and opacity to achieve a harmonious and unobtrusive aesthetic. Koob's methodology for producing acrylic films, summarized in the next section, offers the flexibility to fulfill the majority of these criteria.

3.1 Koob's Methodology

As of 2011, Koob and his team at the Corning Museum of Glass have advocated a new technique for making acrylic resin films for gap fills (Koob et al. 2011; Koob, van Giffen, and Hanna 2013). In essence, this methodology entails the following steps:

- First, a 30% w/v solution of Paraloid B-72 in acetone is made up.
- Separately, a small amount of ethanol is poured in a 1:5 ratio (Koob et al. 2013) with respect to the volume of acetone used to prepare the Paraloid B-72 solution. The addition of ethanol slows down the solvent evaporation rate, thus minimizing the formation of bubbles.
- If tinted fills are required, a small amount of dry ground artists' pigment may be added to the ethanol; this is then stirred and the particulate material allowed to settle. The mixture can then be decanted into the Paraloid B-72 solution.
- The final mixture is stirred once more and allowed to homogenize. The resultant solution is then carefully poured into a preprepared, solvent-resistant tray lined with silicone-release paper.
- The tray is inserted into a partially sealed solvent atmosphere and allowed to cure over a period of a minimum of 4 to 5 days.

The following sections deal specifically with our experiences in preparing the acrylic resin mixtures, casting the resin films, and subsequently manipulating them, before finally incorporating them with the glass object in alternative ways to those described by Koob et al. (2011, 2013).

3.2 Experiences of Working With Paraloid B-72 Gap Fills

3.2.1 Resin Mixtures

Despite Koob's insistence on the exclusive use of Paraloid B-72 for making the resin sheets, the resultant cast prepared for the beaker was too flexible to be used as an effective structural fill. In hindsight, this could have been due to the warm temperature conditions inside the laboratory in which the cast was left to set; however, this remains inconclusive. It also appeared that several other variables provided a good opportunity to experiment with materials to establish the best combination for a cast of the correct strength, color, opacity, and thickness.

Consequently, a series of casts were produced to test the range of properties afforded by different additions to the resin mixture. To modify the strength of casts, varying proportions of Paraloids B-72, B-48N (polymethyl methacrylate/polybutyl acrylate) and B-44 (polymethyl methacrylate/polyethyl acrylate) were used to make up resin mixtures, either used neat or in a 2:1 ratio. Several materials were also tested for their effectiveness as opacifiers, including fumed silica, marble dust, whiting, and titanium dioxide. To alter the color (or tint) of fills, three hues of dry ground artists' pigments were added, again either neat or combined, depending on the success of the color match with the beaker. These included Cornelissen pearl lustre Pearl Copper, Cornelissen pearl lustre Gold Pearl, and Cornelissen pearl lustre Platinum Gold.

Parameters that were kept constant throughout the experiment included a 30-mL volume of resin per test batch, a 30% w/v concentration of resin in solvent, the surface area of open box molds (65×100 -mm base surface area) and the number of molds placed together in a polypropylene box left to cure (fig. 3). The addition of 4 mL ethanol (that amount used in accordance with the methodology set out in Koob et al. 2011) was also kept constant.

After the resin sheets had cured over a period of 4 to 5 days, they were assessed by simple qualitative methods. To test their hardness, each sheet was cut with a pair of scissors, which gave a good sense of their flexibility or brittleness. Simply touching and manipulating the sheets were also effective indicators; all of the sheets were retained in order to make further comparisons as experimentation progressed. Another key quality assessed was the sheet's ability to deform when gently heated and then retain this new form—in other words, its potential for manipulation. If the sheet had a tendency to revert back to its original form, its use as a gap fill would exert undue pressure on the glass and was therefore deemed unsuitable. Assessing appearance was done by comparing the resin sheet side by side with the original glass in good light.

As was to be expected, the addition of Paraloids B-48N or B-44 created less flexible and progressively harder casts. After assessing 16 casts of different resin mixtures, the preferred resin mixture consisted of a 2:1 mixture of Paraloids B-72 to B-48N, respectively, as it gave the cast strength without brittleness. With regard to opacifiers, fumed silica was found to be effective for providing translucency, while marble dust was good for creating an opaque glass effect. Both whiting and titanium dioxide gave a conspicuous speckled effect due to the difficulty in fully homogenizing these materials within the resin mixture. Dry ground artists' pigments were very effective for tinting the casts; however, they should not be depended on for achieving opaqueness as well as color since it is easy to oversaturate the mixture (fig. 4). To avoid this, it is advisable to limit the amount of dry pigment added to a maximum of 1.5 micro spatulas per 30 mL resin mixture batch (1 micro spatula equaling approximately half the size of a pea).

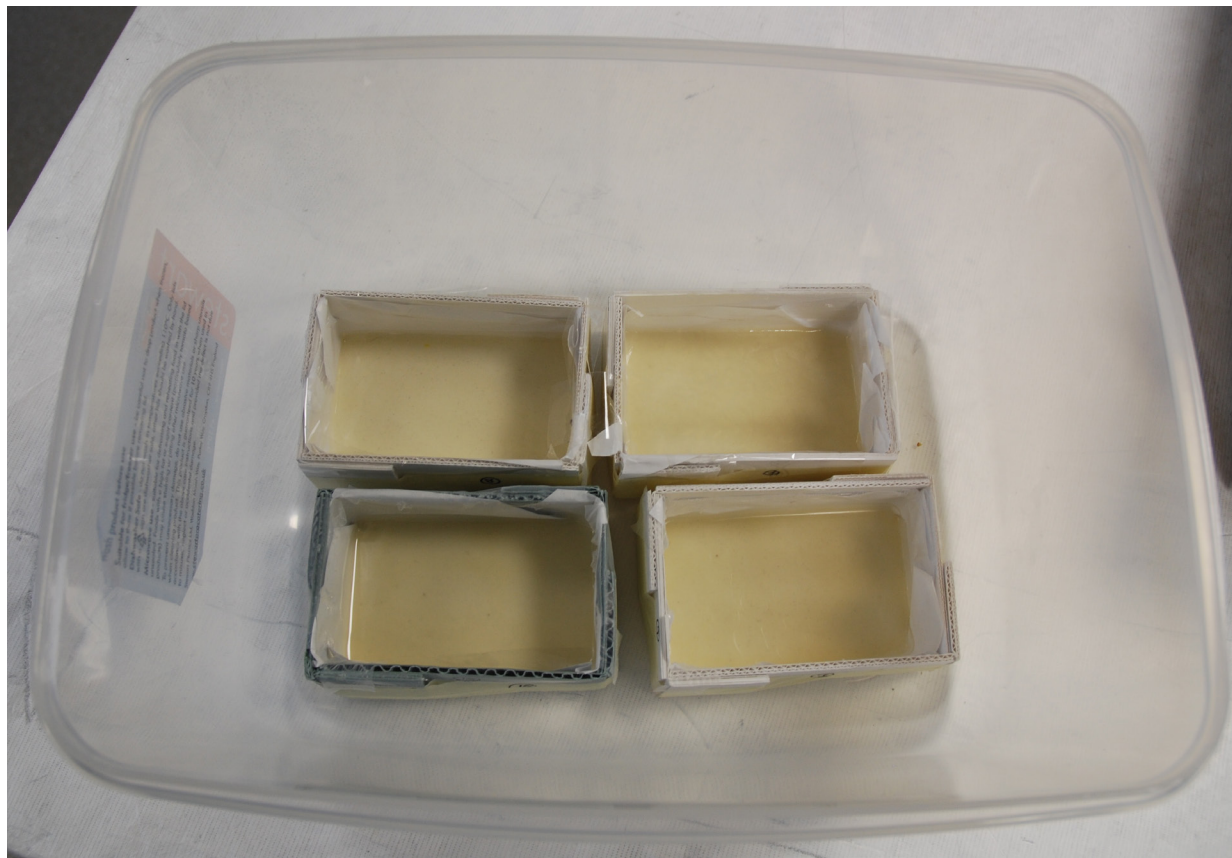


Fig. 3. Acrylic resin test batches placed together in a polypropylene box before the lid is secured by all but one corner to create a vapor chamber with a slow evaporation rate

3.2.2 Casting Procedure

Having determined the appropriate composition of the resin film, the next task is to successfully cast the Paraloid film. We have already highlighted the variables inherent in the constituent materials of the resin mixture. Another characteristic over which we have control is the thickness of the film, which requires some trial and error to cast as required. This is especially difficult since the film's volume decreases upon drying as the solvent evaporates. Indeed, our experiences align with Koob and others, who record a shrinkage in volume of approximately 70% for concentrations of 30% w/v in acetone (Koob, van Giffen, and Hanna 2013; Loeschberger 2014).

The possibilities for casting are limited by one's own sense of creativity and available resources. From our experience, some methods are easier, faster and more cost-effective to implement than others. One possibility is to fashion trays out of cardboard cutouts or solvent-resistant polyethylene trays, and line these with silicone-release paper to facilitate removal of the film once cured. This method was adopted by the authors as a readily available and rapid solution to creating molds for immediate use. A slightly more time-consuming method, which nevertheless allows for customization and texturization of the casting area, involves preparing trays out of silicone rubber, using the base of a tile, for example, to form the casting area. Surface textures on the mold may also be introduced at this stage.



Fig. 4. Cracking caused by the addition of too much dry pigment, resulting in oversaturation and loss of cohesive strength

Once the resin is poured into the tray, it is important to place the trays into an acetone atmosphere by partially enclosing them in either a plastic (e.g., polypropylene) box with the lid on but not fully closed or a Ziploc (polyethylene) bag or polyethylene sheeting. This step is specifically designed to slow down the rate of solvent evaporation, which helps prevent bubble formation in the film. Placing 5- or 10-mL beakers containing acetone and cotton wool as a wick inside the enclosure was found to be a practical way of achieving this.

It is essential to emphasize at this point that films normally require at least 4 to 5 days to cure sufficiently, since any less than this will result in too flimsy a film due to the high concentration of residual solvent. Both for Paraloid B-72—only fills and the 2:1 Paraloid B-72/B-48N fills, it was found that 4 to 5 days of curing provided the best results. Subsequently, the films may be pulled off the tray using tweezers (fig. 5). When the films are still fresh from the solvent atmosphere, they can be textured if necessary. One way of achieving this is by using Plastazote (Ethafoam, expanded polyethylene foam) cutouts to leave a mottled surface impression to imitate weathered glass. Nitrile gloves with added grip marks on the fingertips are also effective for texturing. After further drying, the film is ready for manipulation in preparation for its final incorporation with the vessel.

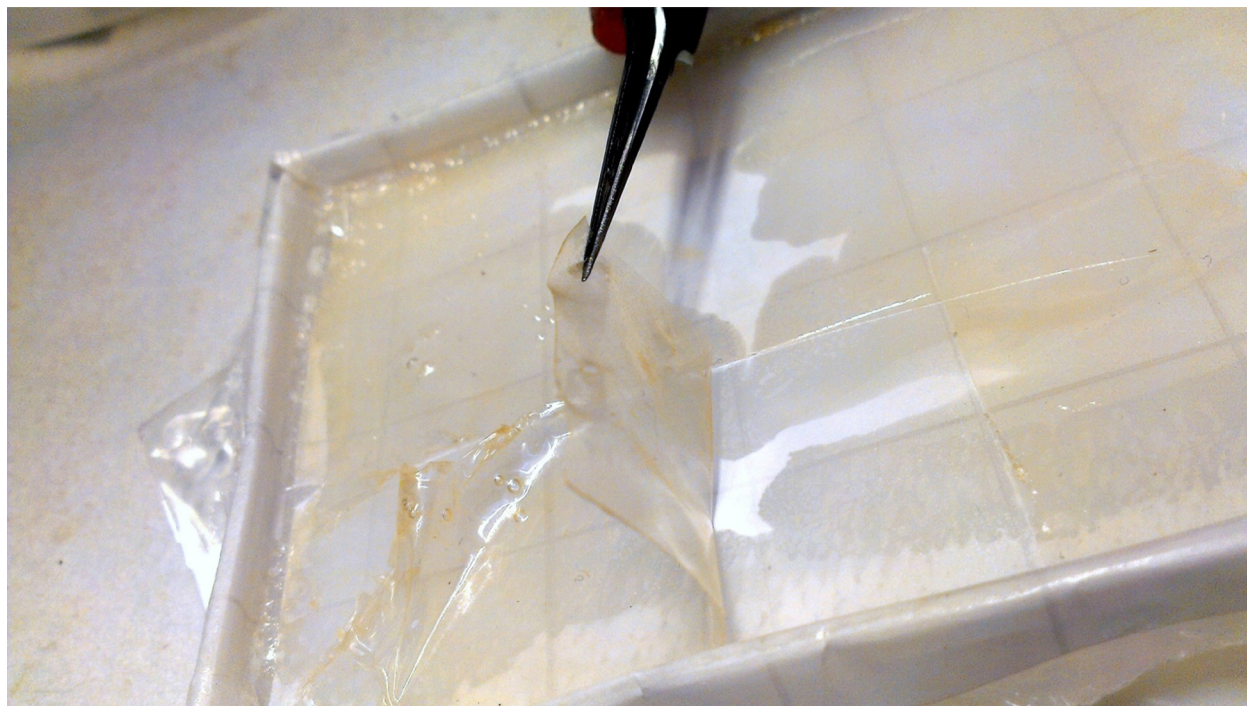


Fig. 5. An example of how the films can be removed from the trays with ease using tweezers

3.2.3 Manipulation

The many ways available to manipulate the acrylic films is a major advantage of this technique—this is what makes it so versatile and essentially less stressful for the conservator than many other casting techniques currently practiced. Through our own experiences, it is possible to share some practical tips and reflections regarding the practicalities of gap filling using acrylic resin casts. The next sections offer guidance for mastering steps following the initial preparation of the cast resin sheets, as explored during the reconstructive treatment of the beaker.

3.2.3.1 Defining the Area of Loss Compensation

A simple but effective method for defining the area of loss compensation on the glass object involves very gently tracing the outline of the loss using either pencil on tracing paper or marker pen on a piece of Melinex (Mylar, polyester film; fig. 6). It is helpful to backlight the object to clearly highlight the area of loss. It is important to factor in any curvature at this stage, which provides another reason for using a rigid yet flexible material such as tracing paper. Extreme care should be exercised throughout this stage so as not to exert pressure on any part of the glass object.

3.2.3.2 Cutting the Fill from the Resin Sheet

Once an approximate tracing for the gap fill is obtained, it can be placed behind the resin sheet, ensuring that the matte side is face up if you want this side to appear on the exterior face of the glass object (fig. 7). It is important to use a very sharp scalpel for cutting to ensure maximum accuracy and reduce the risk of slippage from a blunt blade. The scalpel blade is a versatile cutting tool from this point, due to the variously shaped blades that are commonly available (e.g., #10A and #15). Small sharp scissors may also be used for this task. Another tip is to position the cast resin sheet in such a way that the gap-fill area is positioned left of the cutting line (for right-handed individuals) so that any accidental slips will affect



Fig. 6. Defining the area of loss compensation by carefully taking a tracing using a pencil and tracing paper against the backlit object

only the area outside of the fill. If the resin sheet is too hard to cut easily, it can be softened by heating it with a hairdryer for a few seconds. It is worth remembering at this stage that detailed refinements to the fill edges should only take place once it is manipulated to the correct curvature, discussed in the next section. It is therefore recommended to leave a small margin around the edges for later refinement.

3.2.3.3 Heating to Create Curvature

Once the fill is cut to roughly the right shape, it is time to adjust its curvature. The application of heat takes advantage of the resin's thermoplasticity, making it flexible enough to bend into the correct form, which then hardens again as it cools. This stage involves holding the fill between your fingers under a hairdryer for approximately 20 seconds and letting it cool down. Another advantage is that the resin can be repeatedly heated and cooled, allowing for multiple attempts at finding precisely the right curvature.

3.2.3.4 Inserting the Gap Fill

Before adhering the gap fill to the glass object, it is important to carefully insert it into the area of loss to check for a tight fit. Normally, refinements to the edges of the fill will have to be made at this point. For example, the undulating walls of the beaker meant that each edge of the fill had to take on slightly different angles to align correctly with the surrounding break edges. This stage required patience as edges were carefully trimmed with a scalpel away from the object and repeatedly checked against the area of



Fig. 7. Cutting the gap fill to size

loss. Tips for this stage include having the object well lit so that you can clearly see the quality of edge alignment and handling the fill with tweezers for optimal care (fig. 8).

3.2.3.5 Creating Lipped Fills for Use With Very Thin Break Edges

In cases in which the surrounding glass is much too thin to accommodate the thicker edges of the fill, the fill edges may be manipulated to create a slightly overhanging lip that will bolster support in these particularly vulnerable areas. This was done for the beaker by carefully applying a heated spatula (set to low heat) over silicone-release paper onto the edges of the fill so that it softened and molded around the thin glass break edge (fig. 9).

3.2.4 Alternative Structural Support

The final step in the treatment is to adhere the resin fill into place. Adhesion into the area of loss can take place by activating the edges with solvent (Koob et al. 2011; Koob, van Giffen, and Hanna 2013). This, however, can slightly alter the join edges. Therefore, it is often preferable to introduce additional Paraloid B-72 as an adhesive. This is especially important if the cast constitutes a mixture of resins—for example, Paraloids B-72 and B-48N—since B-72 has optimal properties as a strong but flexible adhesive for archaeological glass, while its marginal difference in chemical composition will assist in the neat removal of the fill in the event of future retreatment. The Paraloid films can also be used to perform other structural roles; these were trialed on the Sassanid jug as described in the next section.

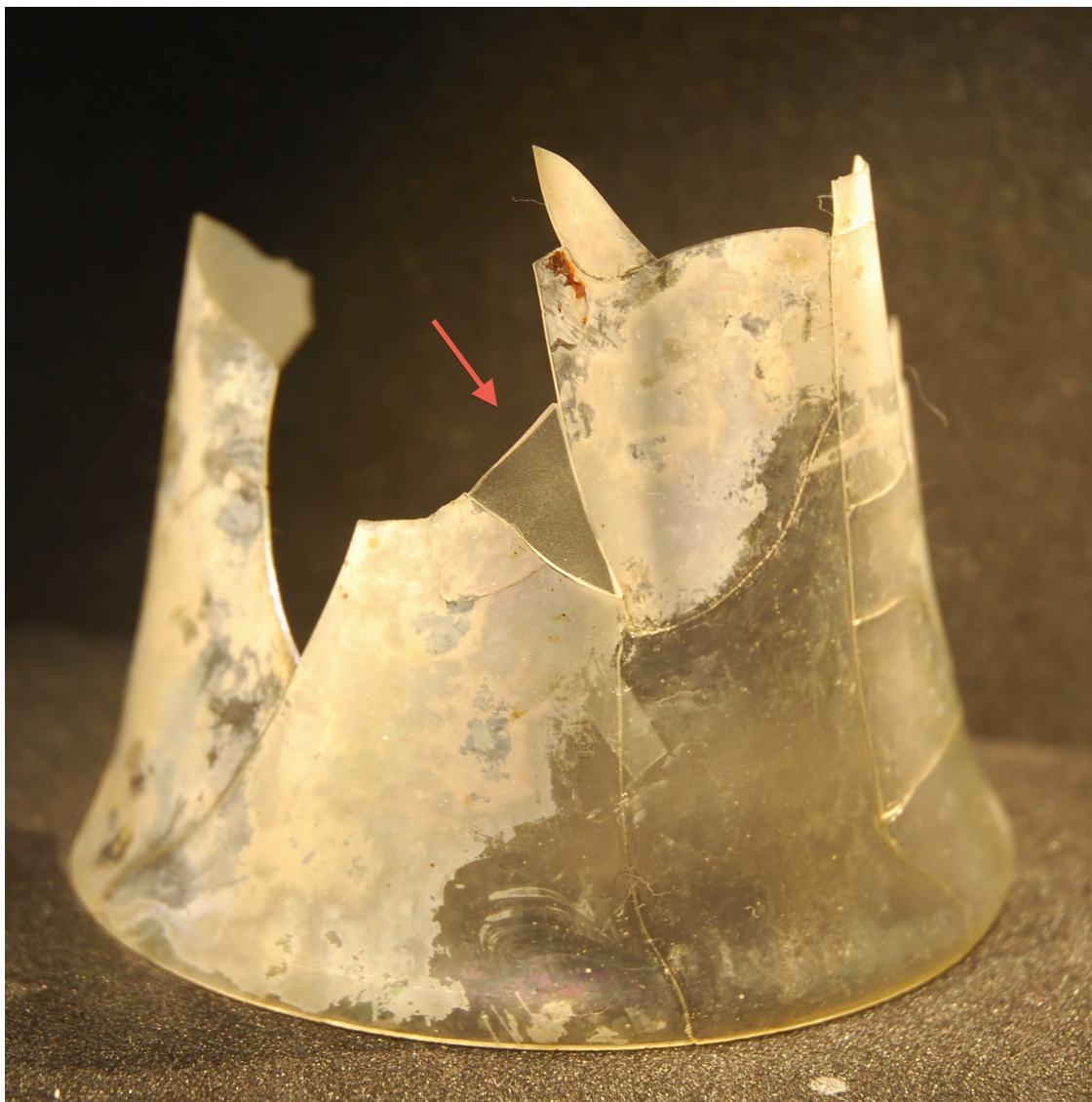


Fig. 8. A prepared gap fill ready to be adhered to the surrounding glass, indicated by the red arrow

3.2.4.1 Tabs

Looking at the Sassanid jug's construction, the handle and rim at the top are the heaviest components on the vessel. This exerted a lot of tension on the rest of the glass body, which caused reconstructed joints to buckle even though the adhesive had set. As a result of experimentation with casting the resin films, a very thin sheet of 30% w/v Paraloid resin (of only a few millimeters' thickness) had been cast. This was too thin to provide any structural role in its own right. However, it was found to be highly effective when cut into small supporting tabs placed across breakage joins. Performing the same function that tape strips would during a dry reconstruction, these permanent Paraloid tabs, applied perpendicular to the direction of the stress, permitted the stabilization of the thin, curved surface of the vessel. Their thin nature and customizable tinting also means that they are virtually invisible to the naked eye (fig. 10) but remain visible under UV radiation and via their documentation. The method of application of the tabs is quite straightforward. Tabs may be cut with a fresh scalpel blade (ideally to the length of a few millimeters long and wide), laid across a join using tweezers, and then very gently solvent activated using the tip of a fine-pointed brush.



Fig. 9. Heated spatula applied to the edges of a gap fill to create a lip

3.2.4.2 Adhesion via Backing on the Vessel Interior

The resin films can also be applied as recessed, supporting fills rather than directly in plane within an area of loss. This form of adhesion is particularly suited to the backing of very thin glass. This is because very thin films, such as the ones used as tabs described earlier, can become brittle upon drying if used as in plane fills and therefore do not provide enough physical strength to fulfill their role as a structural gap fill.

To create a recessed fill, the film is tailor cut, as described in section 3.2.3.2, to fit the area presenting losses in such a fashion so as to structurally stabilize the local area (fig. 11). Given that the area is accessible, the fill is then attached to the interior edges around gaps in the vessel. Recessed fills proved extremely useful for curved surfaces, where the vessel glass thinned significantly and could not bear its own weight without additional support (fig. 12). Recessed fills were found to be much more easily applied when fresh from the solvent atmosphere, as they were still slightly tacky, providing a satisfying adhesion to the glass surface without the need for solvent activation, which can cause bubbling. Plastazote can also be used to delicately press the film into the correct angle of curvature against a



Fig. 10. Left: The tabs highlighted to indicate their placement on the vessel. Right: The tabs as they look to the naked eye.

Melinex sheet covering the vessel. The film can then be cut to follow join lines and weathering patterns, which allow facile blending with the glass material. Admittedly, from an aesthetic viewpoint, this technique is suitable only where weathering affects the archaeological glass. Fills were never applied over iridescence so as not to interfere with this form of glass deterioration.



Fig. 11. Left: Recessed fill (A) indicated by the blue arrow is stabilizing the fragments in the area where it was locally applied. Right: The same fill seen from the reverse side.

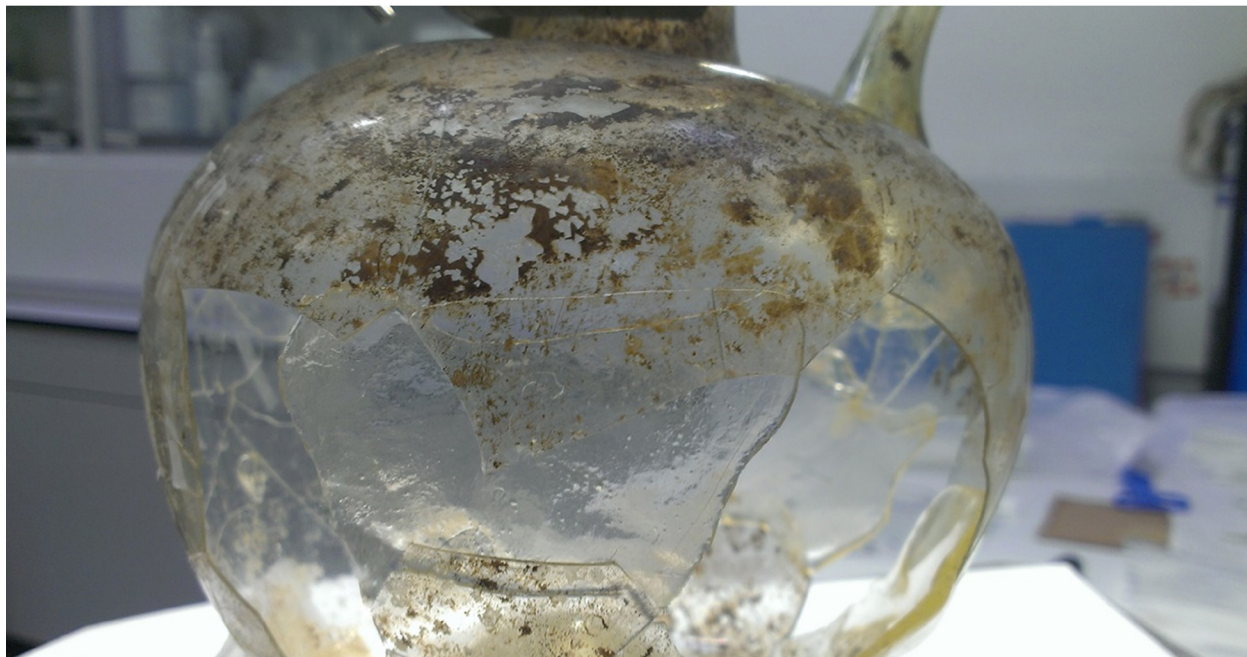


Fig. 12. An example of using a recessed fill to stabilize the curved surface on the Sassanid vessel, where the glass was too thin to attach any in-plane fills

In this manner, the recessed fill spans the area of loss, stabilizing overhanging edges while helping to distribute the weight of the body more evenly. Interestingly, this technique can also be used to support nonadjacent joins in sprung glass, where a conventional resin fill would not fit well.

4. CONCLUSION: REFLECTIONS AND CRITIQUE

Acrylic resin gap fills hold much promise for delivering safer, more versatile conservation treatments on archaeological glass objects than is possible with epoxy or polyester resins. The approach is also much less time-consuming and stressful than many other casting techniques. Once the preferred resin composition is established and the casting and manipulation stages are mastered, the possibilities for application are numerous.

In this article, we have drawn attention to the many advantages of this technique. Most of the preparation is done without direct contact with the glass and there are no complex molding operations involved. Casts can withstand multiple reworkings at the manipulation stage; thus, making adjustments is straightforward and there is no need to be worried about having to get the exact curvature perfect the first time round. In this way, it is a more forgiving method. The fills are easily removable should future retreatment be necessary, particularly if adhered with a resin of a slightly different chemical composition to that of the fills (e.g., using Paraloid B-72 to adhere a B-72/B-48N cast). Multiple casts can be cut from a single resin sheet or sheets can be stored for future use, which ultimately enhances the efficiency of this technique. Further investigation into the optimal storage recommendations for the preprepared resin casts would be welcome. Of particular note from the case studies presented here is the use of lipped fills, tabs, and recessed fills to overcome potential difficulties.

Some important considerations should nevertheless be borne in mind when implementing this technique. Depending on the size and thickness of the cast resin mixture upon curing, adequate time is

needed for a sufficient amount of solvent to evaporate before the cast is ready to be extracted from its mold. If this stage is rushed, the resultant fills will be too flexible and could end up slumping over a short period of time following the treatment. The rate of solvent evaporation is affected by the material and thickness of the container used as a vapor chamber as well as the number of casts left to cure inside. For example, multiple casts placed inside a thick polypropylene box will take longer to cure than one cast placed inside a thin polyethylene bag.

Through sharing these experiences, it is hoped that both case studies presented here offer a complementary guide for conservators wishing to implement similar treatments, thus expanding the professional conservator's repertoire of gap-filling techniques and allowing for the significance of fragmentary archaeological glass to be better preserved.

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NOTE

1. The glass was analyzed directly on the surface using an Innov-X Systems/Olympus Delta Premium DP-4000 handheld *p*XRF, using the built-in "Soils" mode with 20 seconds per setting for a total time of 60 seconds per analysis. Beam 1 operates at 40 kV and 89 μ A with a copper filter, Beam 2 operates at 40 kV and 52 μ A with a 2.0-mm aluminum filter, and Beam 3 operates at 15 kV and 68 μ A with a 0.1-mm aluminum filter.

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