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Cover photograph: Stowe House, Buckinghamshire, wrought iron lantern over central Marble Saloon. Courtesy of Ed Morton, the Morton Partnership Ltd. Background image was commissioned by Selby Abbey for repair work undertaken by Purcell Miller Triton.

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Editorial

In attempting to interpret and understand a building fully it is necessary to consider not only the aesthetic, but also the functional factors that have influenced its creation. While much has been written about architectural style (and there is a growing body of work considering the development of various building types) some types have been largely overlooked. Two such neglected building types are the subject of papers in this issue of the Journal.

Nick Cox draws our attention to the boathouse, a building type now sadly dwindling in number due to neglect. After briefly charting the place of the boathouse in the designed landscape of the country house, he chronicles the rescue of a seriously dilapidated example of historic importance in the park at Belton House, Lincolnshire. In relating how this delightful Swiss/neo-Tudor, Salvin-designed building was saved he focuses on the importance of the historic research, archaeological evidence and technical understanding that guided the complex process of its conservation.

Emily Gee's paper invites us to consider the purpose-built lodging houses or hostels that were erected to cater for the influx of single women attracted to new job opportunities in cities, particularly London, towards the end of the nineteenth century. Many of these jobs arose in the wake of inventions such as the typewriter and telephone, and providing suitable accommodation for the single women who operated them became a pressing social issue. By looking at the building type in its historical context, the paper provides a basis upon which to make informed decisions for the future of such buildings. Those buildings that survive in anything like their original internal form provide an important record in the social history of the working woman, and as such deserve some measure of protection, or should at least be recorded before they are lost to adaptation or redevelopment.

The remaining papers are of a more technical nature and deal with the impact of fire on stone, the repair of marble, and cantilever stone staircases respectively.

Effective fire risk management is essential for the safe occupation of any type of building irrespective of its age or cultural importance. While safety will always be the paramount concern, in the case of a historic building there will be an equally strong desire to protect, as far as possible, the building fabric from the harmful effects of fire and the necessary actions of firefighters to bring fire under control. In the aftermath of a fire a thorough examination of a building's fabric will be necessary to establish the extent of the damage and to formulate a repair strategy. A succinct summary of our current understanding of what happens to the surface of stones subjected to the damaging effects of fire is provided by Miguel Gomez-Heras and his colleagues. Their paper also supports the installation of water misting or fogging fire suppression systems, which minimize the damage to the surface of stones, so commonly encountered when more traditional water-based firefighting methods are employed.

Jonathan Kemp's paper offers an interesting insight into the current practices and materials adopted by specialist conservators for filling voids in marble surfaces. It is the accepted view that because the quality and condition of individual pieces of marble, and the environment in which they are located, can be quite variable there can be no universal 'one size fits all' approach to repair. The views of conservators collected by the author highlight their differences in approach and materials used, indicating that contemporary practice is still evolving and no consensus view yet prevails. Hopefully this paper will stimulate further discussion and debate amongst practitioners and promote the dissemination of knowledge and the establishment of best practice.

Our final paper looks at the elegant cantilever stone stairs that were made popular in the Georgian period by fashionable architects, including William Chambers and Robert Adam, and that have long been a source of interest. Their graceful flights seem to float in the air, defying gravity, causing the observer to ponder on how they work without collapsing. Ian Hume provides a clear non-mathematical explanation to readers unfamiliar with the structural principles involved and, in addition, offers pithy advice about common faults and what to look out for during inspections. For those with doubts about the structural adequacy of these stairs the reported results of load testing will provide comfort and reassurance.

Professor Peter Swallow

Fills for the Repair of Marble

A Brief Survey

Jonathan Kemp

Abstract

This paper is concerned with the approaches, materials and techniques used by conservators in the filling of voids in damaged marble surfaces. It will focus on methods for making small-scale surface patches and fills to cracks and fissures rather than covering descriptions of fills that increase the structural integrity of an object.

Comments will be made throughout on the environmental, economic, ethical and aesthetic demands that inform the various approaches. For example, the requirements for a fill viewed at eye level will be different from those for one made on a more remote aspect; equally one made in an exposed harsh aspect may have different requirements from one made in a controlled environment.

Introduction

The paper has been stimulated by recent discussions among conservators, including specific enquiries about which materials to use in making fills to an external marble monument sited in an area of heavy traffic in a cold climate, and fill materials appropriate for two marble sculptures within the orangery of an English country house.

However, this article is not so much about 'how to', but is rather an attempt to represent the ways people are currently tackling the filling of voids in marble. There have been a number of conservation studies that have focused on particular fill materials for translucent substrates, including marble, but there is an absence of recent qualitative surveys to indicate what conservators are actually using.

A questionnaire was compiled and distributed within the conservation profession[1] during autumn 2008, and although the response was statistically insignificant, a range of approaches was identified. The questionnaire was framed to elicit the preferred techniques and materials when approaching fills to white and/or coloured marbles, both internally and externally. The questionnaires asked for the reasoning behind any preferences, which also gave scope for stating if a non-interventionist approach was preferred. This paper will describe some technical/material details, and indicate some of the demographic differences in approach gleaned from the survey.

Before reporting on the results of the survey, it is relevant to consider three questions:

What is a fill for?

Fills are designed to repair voids in any substrate, whether decorative, sculptural or architectural. Thus fills might be executed either for aesthetic reasons or in the name of preventive conservation where, for example, a crack in a stone is filled to deter the accumulation of airborne particulates or the ingress of water. The same materials might also be used for the restoration of any detail losses to the object, but it is worth noting that the decision on which fills should be used and at what level is often taken at the planning stage of any programme of works. In the UK, conservation policies favour the retention of losses of detail to sculpture or elements of architectural ornament as part of the history of that object. While any putative modelling of lost detail is seen by some as conjectural, other architectural conservators present the case that where there is an obvious form, as with repetitive mouldings or ornament, fills can be justified to reinstate damaged profiles.

Impact of the condition of the substrate?

Whatever the reason for their execution, fills invariably vary in size and scale. Some respondents indicated that the size of a void can determine the decision whether to insert a carefully selected and worked replacement marble piece into the void rather than using a fill. Although this method often requires the rationalization of existing material by carving or planing broken surfaces, it has commonly been preferred over executing ‘plastic repairs’ to damaged architectural or monumental surfaces. However, even the most carefully made indent (the English term for this type of replacement) will still require a bonding and filling agent to be applied.

Figure 1 Trajan Column, Rome, Italy. Image showing a patchwork of repairs including grey cement-based fills to cracks and fissures on the uncarved area of the column base.

The tooling with a chisel of the exposed surface of the fill area to provide a key, and the dovetailing or perpendicular cutting of its edges to avoid a feathered edge to the fill are common to the filling of architectural surfaces. These are not considered as appropriate techniques for sculpture (nor, arguably, for architectural surfaces), and consequently, fill materials are often required to be adhesive to avoid any removal of the substrate.

Whatever the area that is to be filled, whether on sculpture or architectural detail, the substrate should be made stable, and any friable material either consolidated or removed as appropriate. All interfaces should also be cleaned, and any previous fill materials should be removed as far as possible to help mitigate any potential instability between it and the new fill.

Figure 2 Santa Anastasia Church, Verona, Italy. Part of the façade made from Verona 'marble' (a polishable limestone) and two unidentified black and white stones, also described as marble. The image shows multiple surface fractures and evidence of previous repairs including signs of previous indentation (cut surface to lowest moulding of pilaster) and cement repairs (middle moulding to pilaster).

What are the ideal fill characteristics?

Following on from the work of Griswold and Uricheck[2] fills should be chosen so that:

- they are reversible, i.e., can be removed without adding to or removing from the substrate;
- they adhere or bond to the substrate, yet remain weaker, and are sacrificial;
- they are inert or compatible with the substrate, so that, for example, they do not introduce soluble salts, highly alkaline or acidic materials, or impart mechanical stresses;
- they are capable of being colourfast and rendered to mimic the optical properties of marble;

Figure 3 Marble Arch, London. Image shows marble indents embedded in both cementitious fill material (middle indent) and lime mortar (lower indent). Cracks to the marble are also very apparent, with failing cementitious fills marring the surface.

- they are not harmful to the environment and can be applied safely;
- they are cost-effective to execute.

Those fills made to objects that are outdoors should especially be:

- stable in ultraviolet (UV) light;
- durable, that is, able to resist persistent weathering patterns including freeze–thaw cycling and temperature fluctuations (both daily and annually);
- similar in their physical behaviour to the substrate, so that properties such as thermal expansion coefficients, hygric swelling/contraction rates, water vapour permeability, water absorption/porosity, modus of elasticity, etc. fall within, or close to, the same physical parameters of the substrate.

Figure 4 Tombstone Panel, Whitechapel, London. Disaggregating 'sugary' marble exhibiting a consequential loss.

Approaches to fills to external marble

As with ancient marble, unsheltered external marble presents a higher opacity than unweathered internal marble. This is principally due to the chemical reaction of rain, a natural weak carbonic acid, with the calcium carbonate of the marble to form water-soluble calcium bicarbonate that is subsequently washed away causing the erosion of the surface. Thus translucency, a particular property of indoor marble, is less of a requirement for outdoor fills, though it is often obtainable through the use of synthetic resins. Furthermore, synthetic resins (particularly polyester and epoxy resins) are generally viewed as being unsuitable because they are materially incompatible with marble and appear to deteriorate more rapidly when exposed to outdoor conditions, even with the addition of UV filters. As responses to the questionnaire illustrate, there seems to be a fairly strong preference for using inorganic materials for outdoor fills.

Lime-based fills

Calcium hydroxide ($Ca(OH)_2$) in the form of lime putty is prepared by mixing quicklime (calcium oxide), obtained by burning limestone, with water. A lime mortar suitable for use as a fill is produced by adding profiled aggregate, either stone, sand and/or marble powders, typically in the ratio 3:1 (aggregate: lime putty).

Pozzolans, including trass (a volcanic ash), brick dust and metakaolin, might be added in 5–10% amounts to accelerate the curing, and earth pigments can be added to the mix for colour matching. As the mortar cures, carbon dioxide is absorbed from the atmosphere and the lime slowly reverts to calcium carbonate. These softer sacrificial lime mortars are central to the filling of voids to external marble, especially for older, weathered and more opaque marbles, because of the compatibility of their chemical and physical properties with the substrate.

Hydraulic limes are more durable and so might be useful in exposed environments. They are less workable than lime-putty mortars and also reduce water permeability – NHL 2, or, as appropriate, the more hydraulic NHL 3.5 grades are suitable for historic works. However, the practice of hydraulic lime gauging to impart increased strength to non-hydraulic lime putty is generally problematic over the long term and should be avoided in good practice.

Thus lime-based mortars fulfil many of the prerequisites for a good fill, by remaining weaker than any marble substrate, being easily removable,

Figure 5 Coloured fill made to corner of a marble element of fountain using hydraulic lime (NHL 3.5) and silver sand (1:3) colour-matched with earth pigments.

non-toxic, and cost-effective. An exact aesthetic rendering is more difficult to achieve but this might sit well with ethical guidelines regarding the visibility of alterations made to original material.[3]

With regard to this latter point one respondent details a recipe of lime putty, silver sand and marble dust in equal measures (1:1:1), with the addition of a small (<2.5%) amount of casein to aid in the 'burnishing' of the fill to an approximation of the surface finish. A note of caution is also added as sometimes the casein can cause fills to slump during drying.

Another conservator writes elsewhere[4] that the incorporation of a low percentage of UV 'colour-stable acrylic' resin, which 'does not act substantially as a binder', followed by fine sanding will produce a gloss finish to the fill. Noting that over time the gloss levels to the fill and the substrate will change differentially, he adds that the fills can be reworked in future years to rematch the gloss of the substrate. Furthermore, where the addition of the acrylic might induce some shrinkage cracks, these may be refilled over time 'with contrasting colours to produce very convincing veining'.

He also states that although he has used epoxy resins extensively for outdoor 'repairs' to stone, he now never recommends them as 'an exposed patching material'. He advocates lime-based materials, even when making fills to black marble. In the case of variegated and multicoloured marbles, he recommends using lime-based fills 'in the tradition of the scagliola technique, where the various colours are blended and pigmented throughout the entire depth of the fill'.

Finally he makes the point that fills he made ten years ago on a complexly coloured marble piece showed only a 'margin of discolouration at the join' on recent inspection. He also notes that a white lime-mortar fill to an adjoining piece of cornice made of Carrara marble had unfortunately discoloured as a result of being 'in a high moisture zone' and had attracted biological infestation.

Colouring lime mortars with earth pigments is both a widespread and longstanding practice. One conservator suggests a ratio of 1 ml of pigment to 30 ml of mortar as a rough and ready rule of thumb, although another conservator in the US commented that, in her experience, dry pigments can wash out over time. She did not indicate the manner in which they had been applied, but states that after a year her uncoloured lime-mortar fills darken with biological growth and 'pretty much match' the weathered marble of the gravestones she is responsible for. Her final comment emphasizes the point that different practitioners have variable expectations for fills, and that while her fills are by no means invisible 'they look pretty good'.

Inorganic proprietary fill mixes

For larger scale voids, 'patching' seems to be a widespread phenomenon in architectural conservation, particularly in the US, Italy and Germany. In the US this might in part be due to liability laws (where the supplier not the operative can be made liable for any post-contract defects) but might be, and more importantly, because of the dearth of skilled masons in the US who could otherwise carry out the technique of stone indentation.

Griswold and Uricheck[5] report that commercial restoration patching mixes have a lower alkalinity, soluble salt content and are empirically weaker than cement-based building products. They are often a mix of silicates and carbonates, sometimes with added pozzolanas, but their exact recipes remain undisclosed because of protection under proprietary copyright laws. One conservation firm, working mainly in cemeteries in the US, uses a commercial preparation, M120, a completely inorganic product designed by the Dutch company Jahn, as a 'single component, cementitious, minerally-based mortar ... for the repair of marble'. The firm report that they are not 'a big fan of field mixes', finding the commercial products more convenient and consistent. They have used Jahn M120 for ten years and also a newer mix, US Heritage's MT15 (a whiter and finer preparation based on a mix of 'silicates, carbonates, ferric oxides') for four years, although express concern that the latter has an exothermic reaction when mixed. Both products, because they are free of synthetic resins, do require a minimum depth, dovetailing and keying to the substrate surface before application.

Synthetic resin fills

An important property for any fill used externally is its ability to withstand degradation from water ingress. All resins will absorb some moisture but polyesters, unlike acrylics and epoxies, will gradually lose mechanical strength through water absorption because of the presence of hydrolysable ester groups in their molecular structures (also see Nagy).[6] Water absorption will increase hygric swelling and contraction rates and increase fill weight, further increased if, for example, a hydrophilic filler such as fumed silica is used as a bulking agent. Absorption can thus potentially lead to the physical breakdown of the fill through an increased exposure to environmental decay mechanisms.

Other contraindications to their use in conservation, are both their resistance to organic solvents – which reduces the success of any attempt to reverse any aged adhesion bonds – and their tendency to discolour/breakdown under the effects of UV light. Furthermore, although both polyesters and epoxies can be softened and removed with dichloromethane (i.e. the main agent active in the commercial paint stripper 'Nitromors'), at the time of writing, the conservation profession is actively trying to get an exemption for their use of this chemical from the proposed European Commission restrictions on its use.[7]

With all synthetic resins there is also the issue of 'creep'. This should not be confused with resin migration, where the resin or hardener bleeds into an unsealed substrate during curing and creates dark lines around the edges. 'Creep' is the term used to describe the permanent deformation of a polymer that can occur slowly either under long-term stress or where temperatures rise to above the Tg (glass transition phase) of a resin (known as 'cold flow' when this happens at room temperature).

Various respondents have indicated that when they do use polyester or epoxy resin fills they first seal the interfaces of the damaged marble with an acrylic resin, Paraloid B72 (an ethyl methacrylate copolymer, known as Acryloid B72 in the US). This is used in a 10% solution in acetone, or possibly in the less volatile 50:50 mix of acetone and industrial methylated spirits (IMS). Part of a study (Podany et. al)[8] on B72 focused on this use as a barrier both to aid in the reversibility of polyesters and epoxies, and to limit their migration into the substrate. It reported that, if allowed to dry thoroughly before the application of the second resin, B72 was a suitably strong barrier to work with structural joints made in those other resins and increased the 'reversibility of bonds where polyester or epoxy is used as the adhesive'. This is because it seems to block the migration of those resins or their amine- or amide-based hardeners into the substrate.

With reference to creep, it is also worth noting here that B72 has a Tg of around 40°C and three commonly cited resins used for fills, the polyester Akemi Marmokitt 1000 and the epoxies Hxtal NYL-1 and Araldite 2020, have Tgs of around 70°C, 42°C and 43°C respectively. One question that the above-mentioned study did not tackle was whether the exotherms of such polyester and epoxy resins, reaching temperatures that exceed that the Tg of B72, in some way compromise its barrier effect. Jerry Podany reported that he had not observed any disruption when using the two in combination for structural joints, stating that he would 'assume that this is because the epoxy layer is so thick and also because the stone is such an effective heat sink', but also adding the caveat that, as polyester resin 'carries more heat in curing', he could not say that there was actually no effect.[9] B72, with its lower Tg and higher modulus of elasticity, would also do nothing to mitigate resin creep under adverse conditions.

Bulking agents

Synthetic resins achieve a good visual match to original material in terms of translucency, colour and texture. However, it is the choice of bulking agent that will ultimately define the final characteristics of the fill. The refractive index of the chosen material will either be isotropic (uniform in all dimensions), as is the case with glass microballoons, or more commonly anisotropic, as with, for example, marble dust and fumed colloidal silica. A material that is isotropic with a refractive index that matches that of the substrate will be transparent, whereas anisotropic materials are always birefringent, i.e., they have more than one refractive index (Nagy),[10] and so are more difficult to match with the refractive index of the substrate. In practice, popular white fill materials include fumed colloidal silica, a lightweight filler of 99.9% silicon dioxide 'practically free of contaminating metallic salts' (Nagy);[11] marble dust, which is also anisotropic and has a large diverse particle distribution; and glass microballoons, which are hollow sodium borosilicate spheres filled with air. With regard to the latter, although in principle isotropic, this air within the microballoons can cause birefringence (Nagy).[12] Other anisotropic fillers cited by respondents include aluminium oxide (also known as synthetic onyx or shoa alumina), alabaster powder (both boiled and unboiled), talc (hydrated magnesium silicate), and washed and dried silver sand.

Acrylic resins

Paraloid B72 has been used for the filling of small fissures externally where, due to the insufficient size and depth of the void, an inorganic mortar might fail. An initial application of 10–15% B72 in acetone to the void will aid adhesion of the later fill. The fill itself usually consists of around 25% B72 in acetone or a 50:50 mix of acetone and IMS mixed with glass microballoons/aluminium hydroxide/marble dust and earth/dry pigments to match. B72 is arguably unsuitable for larger fills because of its relative softness and low durability, plus it has a tendency to snag or attract grit particles when finished with grit papers or Micromesh™ cloths. However, it has been used, in the same way as lime mortar, to cap larger voids filled with a more structural polyester or epoxy resin to mitigate the effects of, for example, UV light.

Epoxy resins

Thermosetting epoxies, unlike polyesters (see below) cure with little molecular rearrangement and so have a typical shrinkage rate of between 2 and 5%. Furthermore, no volatile by-products are expelled. These qualities, along with their known strength, hardness and optical qualities, make them attractive as fill materials for some exterior uses, especially on newer marble works where translucency and/or a polished finish is demanded.

In answers to the questionnaire, two optically-low viscosity, water-clear epoxy resins, developed specifically for glass and ceramic conservation, were expressly recommended by some conservators: Hxtal NYL-1 and Ciba-Geigy Araldite 2020.

Hxtal NYL-1 (Hxtal) is well documented as remaining clear and transparent over time when exposed to direct light or artificially aged under UV,[13] and, accordingly, was used to conserve the Portland Vase at the British Museum. It comes in two parts, (A and B), both of low viscosity, and used in a 3:1 w/w (weight to weight mix, rather than volume/volume) mix ratio. Two drawbacks are that small air bubbles will nearly always be apparent (degassing in a small vacuum chamber helps), and when freshly mixed, it is very liquid. If left to stand for several hours it will thicken, but it cures slowly (at around 25°C) and can take over a week for a final set (Shashoua et al).[14] Hxtal can be tinted with dry pigments and made more opaque, with fumed silica as the usually preferred filler. When bulked and tinted, it is a near invisible filling material which can be filed and scalpelled. To achieve a polished surface, it can then be rubbed with grit paper (e.g. grades 0 and 00) and Micromesh™ cloths (grades 3600 (coarse), 6000 (medium) and 12000 (fine)), before being finished with micro-crystalline wax.

Hxtal might be useful for making *in-situ* smaller surface fills where translucency or gloss is required, but, because of its slow setting, it is difficult to work into larger and thicker fills.[15] Davison[16] describes a casting technique for the gap filling of glass that could be adopted for the filling of larger voids in marble; and Griswold and Uricheck[17] also mention a similar casting technique as applied to marble, that uses polythene film to cast into and incorporates microcrystalline wax with fumed silica as a filler to emulate 'large-crystal translucent marbles'.

Another conservator has written[18] of using fumed silica in Hxtal NYL-1 to match translucent white marble in an outdoor setting. The addition of small amounts of white vitreous enamel powder helped give the fill both a white and translucent quality, and simulate a saccharoidal surface. Mix ratios are up to 10:1 (fumed silica: Hxtal) which makes a non-slumping paste; these higher mix ratios provide a weaker final fill which can be removed more easily should that be necessary.

Where a more robust and more economic fill is required, and it is possible to use an epoxy in a viscous form, then some respondents recommend Araldite 2020, bulked out in combination with either marble dust, marble powder, glass microballoons or aluminium hydroxide together with dry pigments. One conservator points out that this might only be an option where reversibility was not a dominant factor.

Araldite 2020 is a low viscosity, water-clear, two-part resin that cures over 24–72 hours and which has a refractive index similar to that of glass. Surfaces to be filled should be degreased with, for example, either acetone or isopropanol which should be allowed to completely evaporate before applying the resin mix (parts A and B mixed, as with Hxtal, in a ratio of 3:1 w/w). In the study by Shashoua et al.[19] it was recorded as having a very low shrinkage rate of 0.68% at full cure. Hxtal also had a similarly low shrinkage rate of 1.72% when measured against a typical 5% rate from most commercial epoxies. However, the study also reported that under light and heat aging tests Araldite 2020 discoloured.

A combination of synthetic resins and white cement can also be used. A German respondent suggests a mix of white cement and an acrylic dispersion (either Primal AC 35, Plextol K360 or Plextol K540 in 5–10% concentrations) with crushed marble for large fills. This is followed by a final retouching of the surface with acrylic or silicon emulsion paints. Alternatively, the white cement can be mixed with an epoxy emulsion (Remmers EP 2 K (Funcosil Epoxy Repair Mortar LW)) and crushed marble with retouching again being optional.

This respondent also uses an epoxy resin (Remmers Epox ST 100 (Viscacid Epoxy Construction Resin 50)), with crushed marble for large fills, whereas for finer cracks and fissures he suggests two other epoxy resins in combination with marble dust: Araldite Epotek 301-2 and Remmers Injection Resin 100 (Viscacid Epoxy Injection Resin 100).

One note of caution should be mentioned here – all epoxies should be mixed in a well-ventilated area or in a fume cabinet with all appropriate personal protective equipment worn. Bisphenol A (diphenylpropane) constitutes the major part of all epoxies and is potentially carcinogenic, furthermore amine-based hardeners are classified as irritants.

Polyester resins

Thermosetting polyester resins also have good optical and physical properties that can make them appealing to use in some circumstances. They can, however, shrink by up to 8% due to molecular rearrangement as they cure, and such shrinkage can be associated with internal stresses that can ultimately weaken the fill material. They are also toxic to the user and expel styrene for some time. They therefore require equal health and safety measures to those used for epoxy resins.

One respondent often uses a two-part, water-clear polyester resin paste, Akemi Marmorkitt 1000. This is combined with either marble dust, marble powder, glass microballoons or aluminium hydroxide together, as appropriate, with dry pigments (e.g. ivory, black, yellow ochre, raw umber, cobalt blue or cadmium red) and/or slate dust. For larger gap fills she incorporates sections of marble or limestone in the resin as ballast. She prefers to use aluminium hydroxide as a bulking agent, stating that it forms a good dense workable paste which also has less colour change than glass microballoons or marble dust. Fills can be worked to a final finish with solvents, and take

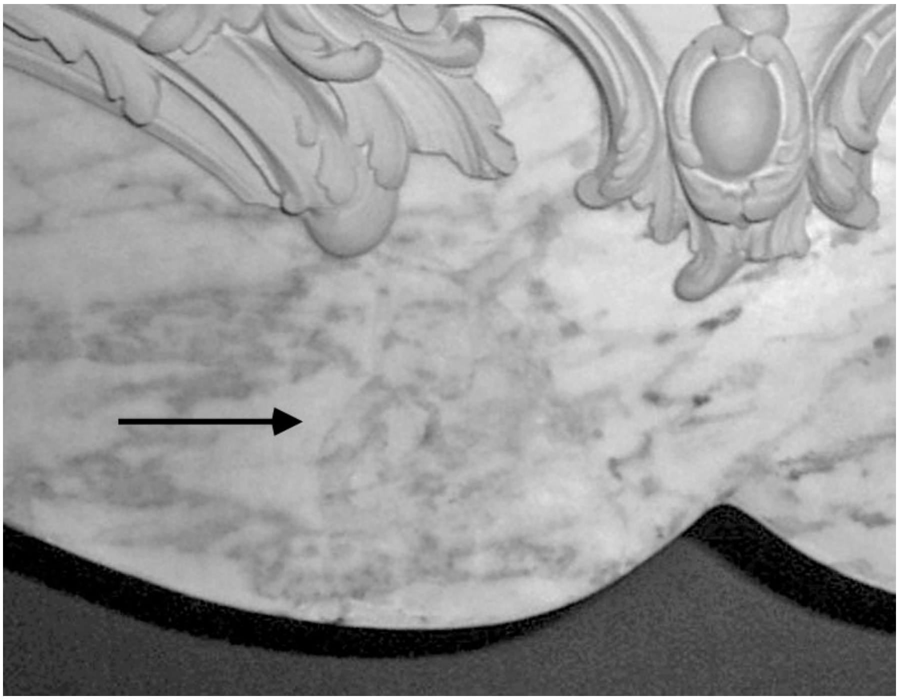

Figure 6 Polyester resin fill (clear embedding resin) mixed with earth pigments to variegated marble fire surround (area above left curve).

a polish if required. On curing they are durable and should remain weaker than the substrate, and are more readily reversible if a barrier solution of Paraloid B72 has been applied.

The recommended resin/hardener mix ratio ranges from 100:1 to 100:4. This will give pot life varying from 3–10 minutes (at 20°C), with a full cure in 48 hours. Using the lower ratio can give a longer time in which to use the resin but increases the risk of surface tackiness after curing. Surface tackiness can also occur due to the presence of atmospheric moisture, the use of a higher amount of hardener (>4%), using an aged hardener or because the resin has been stored in a refrigerator and used before it has reached room temperature. It is also available in two other grades, specified by the manufacturer as 'flowing', for small fills, and 'extra-flowing' for fissures.

The Akemi Marmorkitt is often described as having light stabilizers added to help mitigate the usual symptoms associated with polyesters exposed to an external environment: yellowing, brittleness, crazing and adhesive failure. However, a search through the company's technical data sheets could find no information confirming this. In fact, under its advisory notes, the company says that the 'hardened filler has a slight tendency to yellowing'. Furthermore, they state that there is a 'limited durability of bondings which are frequently exposed to humidity and frost' which might, in part, be because the thermal expansion coefficients between the hardened resin and stone are significantly different.

Fills for internal marble

All fills, whether for internal or external marble, are made from mixtures of organic or inorganic binding or adhesive agents bulked out with a variety of fill materials. Because the optical properties of any binder–aggregate combination are always inherently different to marble, there is a tendency to favour the use of synthetic resins for fills to indoor marble, with epoxy, polyester and acrylic resins all commonly used. One of the biggest challenges lies in replicating the translucency of an indoor marble, because all resin/fill combinations are different in their isotropism/anisotropism compared to marble. These differences significantly affect the scattering, refraction and reflection of light. This is crucial for fills to indoor marble as they are often visible at eye level.

Small fills elicit variations on a theme, with B72 being favoured. Documentation on the use in conservation of this acrylic copolymer resin is quite comprehensive and it is especially preferred as a fill medium because of the ease of reversibility.

A 15% Paraloid B72 solution in acetone:IMS (50:50) mixed with combinations of marble dust, marble powder, glass microballoons or aluminium hydroxide and dry pigments or slate dust as appropriate, is preferred for small fills by one conservator. However, another reports that although the mix of B72 in acetone, glass microballoons (to aid translucency), whiting (a powdered and washed white chalk used here to reduce shrinkage) and fumed silica (to help mitigate the presence of air bubbles) provided good colour and translucency, it also produced too many air bubbles and was very difficult to model because of a natural propensity for gravitational slumping.

The use of B72 with particular fill aggregates has been recently researched by Julie Wolfe, Associate Conservator at the J. Paul Getty Museum, Los Angeles. She has, at the time of writing, made a study of the relationships between B72 and various fill materials[20] and has observed that some combinations seem to make the resultant fills very difficult to redissolve. She also notes that the most translucent fill material appeared to be fumed silica (Aerosil R7200). However, generally speaking, the more translucent the fill, the greyer its cast, and that opacity also increases with a decrease in particle size. Her conclusions, in comparing the properties of 25 fill formulations in combination with B72, include the suggestion that an ideal resin concentration of 60% w/v in acetone is the threshold level for loading, with no problems with shrinkage, except in the case of fumed silica, but that some bubble formation is to be expected in all combinations. She also reports that their working properties are very variable.

Bulked Paraloid B72 fills can be made for larger voids to indoor marble, and one conservator describes making a fill material of approximately 2:1 of glass microballoons and Paraloid B72, 40% in acetone (1 part paraloid [40% paraloid/60% acetone w/w,] mixed with 2 parts glass microballoons). She describes the fill as being lightweight and fairly easy to shape and sand, after being given four days to harden, before finally being touched-in with dry pigments dispersed in acetone.

Other conservators prefer to use the Hxtal or Akemi Marmorkitt 1000, as detailed for external fills above, especially as these resins are generally more protected from environmental degradation by being indoors. Detachable cast epoxy fills have also been used, fixed *in situ* with concentrations of B72 applied as a bonding and jointing medium.

In contrast, in another response, animal glue and gypsum plaster mixes are preferred both for large and small fills. Mixes of gypsum and animal glue (bone, rabbit or beef skin glue), with crushed marble, and dry pigments as appropriate, are recommended, followed by retouching when necessary with acrylic paint. As an alternative the respondent also uses encaustic waxes (beeswax with resin additives) with the addition of dry pigments and polishing as appropriate. For small fills he also uses acrylic dispersions with marble powder (Primal AC 35, dissolved 5–10 % in water or Plextol K 360 + K 540 in the same concentration), with added dry pigments for coloured marbles.

Gypsum plaster[21] has, along with lime mortar, been used over several centuries for the bedding of indoor, mainly church, monuments made from marble. As a fill material it is commonly used as a cheap and relatively quick measure to disguise any surface voids, with the only proviso being that care must be taken that the surrounding edges of the substrate are stable before gypsum is used as it expands when set.

One UK-based respondent reports that a commercial modified gypsum plaster product, Polyfilla (in the US 'Permafill'), has been preferred by some institutions, including the British Museum. The plaster is modified with cellulose-based additives which strengthen the mix and whiting which acts as a retardant and makes it easier to model. Its material compatibility is cited along with light fastness (it can be coloured in mixing or painted after application) and its non-hazardous classification. As it does not darken over time any treated crack will not discolour around its edges and can be easily removed. Modelling time is 30 minutes and it can be easily cut back and refined with varying finishing techniques. Larger fills can be built up gradually, with low or negligible shrinkage, and without being too hard. Texture can be altered with the addition of various aggregates as appropriate. It can be made to match ancient marble and even alabaster where translucency is not an issue. One proviso is that the paste should be mixed with the minimum of water so that smearing is avoided as the material can enter the surrounding pore structure. Furthermore, when left to dry excess material should be removed with a white rubber. The correspondent also suggests that Polyfilla, as with gypsum plaster, also has an added function as a 'live' indicator during the transportation of any object with a suspected structural weakness.

Conclusion

Every piece of marble is different and therefore there can be no universal approach or recipe that will fit all contexts. While in one sense this is a trivial conclusion, in another, as this brief survey article describes, there is a very real difference in the level of conservators' expectations about how fills should look. Expectations slide along an axis running from fills that are harmonious but visible, to those that are invisible. Generally, it is from

Figure 7 Unfilled crack to black marble jamb to a church monument.

where on this axis that the conservator makes their intervention that will determine materials they will use for any particular fill. This determination is offset by codes of ethics, such as the Venice Charter[22] and the International Council of Museums' Code of Ethics for Museums[23] which both require that a visual distinction is manifest in any alterations, including fills, made to an original material.

It is apparent from the survey that there is a lesser requirement placed on external fills to be invisible. This view seems to be generated almost solely by the limitations in the physical and chemical properties of the various fill materials suitable for external use. In other words, the strictures of the cited codes of ethics are affected almost by default, rather than by any strong ethical determination.

If this weaker expectation is accepted for external fills because of material limitations, then the same cannot be said of fills made internally. Here the aesthetic is strongly determined by the choice the conservator makes with regard to the visibility of their interventions, as the material processes described by some respondents allow for an almost perfect invisibility, especially over the short term.

Finally, and in stark contrast, the survey elicited only one explicit approach to the question of what ultimately determines any aesthetic expectations to fills. In conversation, some colleagues working on outdoor marble for a national institution in Germany simply expressed their preference for leaving all voids and cracks just as they are, as part of the history of that object. By applying such rigorous ethical absolutism they write themselves out of discussions about what fills are for, or how any prevalent ethical strictures should be interpreted.

Biography

Jonathan Kemp
Jonathan Kemp has over fifteen years' experience as a senior sculpture conservator and consultant working on a range of movable and immovable artefacts dating from between 2000 BC to the twentieth century.
He has worked extensively in stone, plaster, fresco, ceramic and artificial stone in both public and private UK holdings and on international projects in Spain, the Ukraine, and, most recently, Iran. Currently he is a senior sculpture conservator at the Victoria and Albert Museum, London.

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Notes

1 Various members of the profession have been contacted either directly, or indirectly with the questionnaire, and it has been posted to various organizations, including conference delegates to Stone 2008, various ICOMOS country secretariats, as well as the internationally distributed Conservation DistList.

1. Please describe the materials and techniques you most commonly use when making large and small fills to:
    a. outdoor marble [white]
    b. outdoor marble [grey/coloured/black]
    c. indoor marble [white]
    d. indoor marble [grey/coloured/black]
2. Please describe briefly the reasons for your preferences.
3. Please describe briefly any vernacular/localized approaches to fills you have knowledge of.

2 Griswold, J. and Uricheck, S., 'Loss compensation methods for stone', *Journal of the American Institute for Conservation*, Vol. 37, No. 1, Article 7, 1998, pp. 89–110.
3 International Council on Monuments and Sites, *International Charter for the Conservation and Restoration of Monuments and Sites* (The Venice Charter 1964), ICOMOS, Paris (1964), cf. Article 12. 'Replacements of missing parts must integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence'.
4 Andrew Thorn, 'Infilling outdoor marble sculpture' Conservation DistList, 17 May 2008; http://cool-palimpsest.stanford.edu/byform/mailing-lists/cdl/2008/0540.html, accessed 6 February 2009.
5 Griswold, J. and Uricheck, S., *op. cit*.
6 Nagy, E., 'Fills for white marble: Properties of seven fillers and two thermosetting resins', *Journal of the American Institute for Conservation*, Vol. 37, No. 1, 1998, pp. 69–87.
7 See http://ec.europa.eu/enterprise/chemicals/legislation/markrestr/preparation_en.htm, accessed 6 February 2009.
8 Podany, J., Garland, K. M., Freeman, W. R. and Rogers, J., 'Paraloid B-72 as a structural adhesive and as a barrier within structural adhesive bonds: Evaluations of strength and reversibility', *Journal of the American Institute for Conservation*, Vol. 40, No. 1, 2001, pp. 15–33.
9 Personal communication 2008.
10 Nagy, E., *op. cit.*
11 Nagy, E., *ibid.*
12 Nagy, E., *ibid*.
13 'Research on Tinted Epoxy Fillers (Epoxy Putties) Used as Fillers on Porcelain Artefacts', *Newsletter of the ICOM Committee for Conservation Working Group* – 'Glass, Ceramics and Related Materials', Issue 4, Spring 1998, pp. 5–7.
14 Shashoua, Y. and Ling, D., 'A Comparison of Fynebond, Hxtal NYL-1 and Araldite 2020 Epoxy Adhesives for Use in the Conservation of Glass', *Conservation News*, No. 66, July 1998, pp. 33–6.
15 It is also very expensive with, at the time of writing (January 2009) a cost of over £58/$75 for 133/150g (UK/US prices and weights respectively).
16 Davison, S., 'Reversible fills for transparent and translucent materials', *Journal*

of the American Institute for Conservation, Vol. 37, No. 1, Article 4, 1998, pp. 35–47.

17 Griswold, J. and Uricheck, S., *op. cit.*

18 See *Western Association for Art Conservation News*, Vol. 12, No. 2, May 1990, pp. 9–15. http://cool-palimpsest.stanford.edu/waac/wn/wn12/wn12-2/wn12-207.html accessed 22 January 2009.

19 Shashoua, Y. and Ling, D., *op. cit.*

20 Wolfe, J., 'Affects of bulking Acryloid B-72 for marble fills', *Journal of the American Institute for Conservation*, forthcoming.

21 Gypsum plaster is made by heating calcium sulphate (CaSO4 – 2H2O to remove part of the water to create a hemi-hydrate (CaSO4 – 1/2H2O) that reconverts to a hydrated calcium sulphate upon setting.

22 International Council on Monuments and Sites, *op. cit.*

23 International Council of Museums, *ICOM Code of Ethics for Museums*, ICOM, Paris, 2006 states: '2.24 Collection Conservation and Restoration: The museum should carefully monitor the condition of collections to determine when an object or specimen may require conservation–restoration work and the services of a qualified conservator–restorer. The principal goal should be the stabilization of the object or specimen. All conservation procedures should be documented and as reversible as possible, and all *alterations should be clearly distinguishable from the original object or specimen*.' (Author's italics).