Filling materials for easel paintings: when the ground reintegration becomes a structural concern

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ABSTRACT Paint losses are a common problem in easel paintings, and their treatment demands both aesthetic and structural consideration. Several filling formulations used throughout history for the completion of missing areas of the ground and paint layers in easel paintings are discussed. Since literature on fillers normally refers to their handling properties, this research is focused on the study of their mechanical and dimensional behaviour. This paper also shows how environmental fluctuations affect the properties of traditional fillers (made of skin glues), synthetic formulations and those manufactured commercially, discusses the strength of these materials and determination of the allowable relative humidity range for their proper structural stability.

KEYWORDS easel paintings, losses, filling materials, mechanical properties, dimensional response

Introduction

Theoretical studies on the structure of paintings and the distribution of forces within the painting structure have been carried out since the early 1980s (Mecklenburg 1982). Nevertheless they are rarely considered when planning the reintegration of the missing areas of the pictorial layer. Matching colour and texture seems to be the conservator's primary consideration in guaranteeing the integrity of the work. As a consequence, filling losses become a routine treatment with scant attention paid to structural suitability and the stability of the materials used.

This research demonstrates that apart from aesthetic issues, the physico-mechanical analysis of filling materials is recommended in order to determine the stability of the materials in use and, ultimately, the stability of the work of art (Fuster 2006). Different approaches are required by different types of paintings depending on their support and, according to current investigations, canvases are the most challenging case due to their complex behaviour.

Filling materials and the structure of paintings

Previous research has shown how forces are distributed within canvas paintings, and this is directly determined by the stretching of the painting, the levels of relative humidity (RH) and by the underlying support (Hedley 1988; Mecklenburg and Tumosa 1991; Mecklenburg 2005). There are no 'pre-tension' forces in panel and copper paintings. Copper does not have any dimensional response to RH and for this reason fillers for paintings on copper do not need to be as strong and flexible as those used for canvas paintings. Furthermore the wood or copper in these types of paintings actually constitutes the support in structural terms but this is not true for canvas paintings, where there are different forces acting on each of the layers. This arises both from stretching and as a consequence of environmental fluctuations. In general, for most values of RH, glue size is the actual support of traditional canvas paintings in structural terms. Canvases mounted onto rigid auxiliary supports behave in much the same way as do paintings on wood or copper.

In the case of canvas paintings the 'primary force' is in the size layer. The concentration of forces usually takes place in the lower layers and is separated from the paint layer. This is mainly due to the high stiffness and strong dimensional response to RH fluctuations, of skin glues. Under restraint, the dramatic shrinkage of the size layer results in very high stresses when the canvas is desiccated (Mecklenburg 1988; Roche 2003, 2005). This means that one should look for a flexible and strong filler, but not as stiff as the fillers required for panels, so that it has good cohesion and adhesion. On the other hand, a stable filling material, one not responsive to environmental fluctuations, is also needed. Finally, the mechanical properties of the filler should be similar to those of old paints (in terms of modulus or stiffness, strength etc.). The reason for this is that by matching the dimensional response and the mechanical properties of an old paint it is possible to have fillers that will behave in a similar way. This means that both fillers and paints will be able to withstand similar environmental oscillations thereby guaranteeing the stability and durability of the filler. In other words, there is structural compatibility.

To summarise, fillers for canvas paintings must fulfil several structural conditions (Fuster *et al.* 2006).

- They must be able to withstand the stresses generated within the painting. This means that they must maintain a proper distribution of forces (Fig. 1). The presence of filling materials in the painting structure alters the normal distribution of forces, since the filler force (F_2) is usually greater than the support force (F_3) (Fig. 2). For that reason, if tensile forces are acting within a painting, both filler and canvas will behave in a different way, and the filler will contract. A very weak or excessively flexible filler can also cause out-of-plane deformation. Therefore the filling material must be as stiff as old paint, to maintain proper in-plane continuity.
- A strong and resistant filler is required, to provide good cohesion and adhesion. Good cohesion means good internal strength, otherwise it will crack and fail. Proper adherence to the textile support and other materials in the painting is also needed.
- It must be as dimensionally stable as possible, since old paints generally do not react strongly to oscillations of temperature or RH.
- It must be easily removable without damaging the paint film.
- Other properties such as absorbency and hardness should also be considered since they could influence later treatments such as texturing, retouching and varnishing.
- Obviously, it is essential that the material does not crack (it must have sufficient cohesion) during the drying process. It is of equal importance that the mixture does not develop lumps or air bubbles that would create protuberances or small orifices in the surface of the filler. Those defects could be the origin of fissures and later cracking.

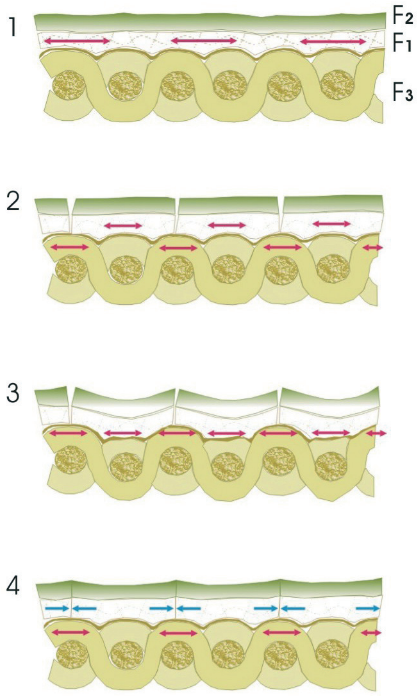

Figure 1 Location of the geometric centre of forces in a painting: (1) prior to cracking of ground and paint film; (2) force relocation immediately after cracking of ground and paint film (3) force realignment displacing all layers out of picture plane, causing 'cupping'; (4) forces in unrestrained painting in low RH: the glue is in tension whereas ground and paint layers are in compression (Mecklenburg 1982).

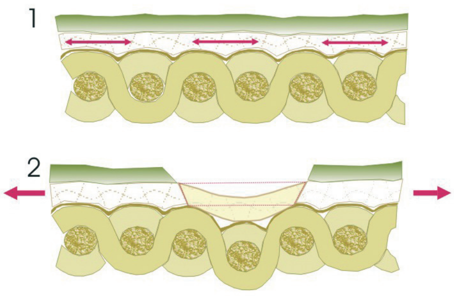

Figure 2 Location of fillers in the structure of a canvas painting: (1) geometric centre of forces in a painting; (2) different behaviour of filler and paint under tension.

Materials and methodology

Previous studies have shown the influence of environmental fluctuations in both the mechanical properties and the dimensional response of artists' materials, as well as the role played by grounds within the structure of a painting, laying the foundations of this study. This research focuses on the characterisation of several filling materials by:

- Quantifying strength and stress development, mechanical properties, chalk-to-glue ratio and pigment volume concentration (PVC) of fillers, depending on the type of binder they contain and their adhesive concentration.
- Analysing the dimensional response of several formulations to RH fluctuations at constant temperature.
- Studying the effects of RH fluctuations on the mechanical properties of both adhesives and fillers.

This study of the mechanical properties and dimensional response of cultural materials has shown that the selection of a suitable filler for the treatment of losses in canvas paintings is possible by correlating changes induced in both the behaviour of painting materials and fillers.

Sample preparation

Since many different formulations have been widely used throughout history (Green and Seddon 1981; Schneider 1981), the selection of those most representative focused on the initial issues that needed to be resolved. As a consequence, variations on the standard formulations selected were also made according to changes in the adhesive concentration and the chalk-to-glue ratio and/or the PVC.

Fillers tested were obtained from different types of adhesive (natural and synthetic). Calcium carbonate ($CaCO_3$) was used in all the specimens. Traditional fillers (skin glue plus an inert material), synthetic formulations and ready-mixed commercial ones (Loew and Solz 1988) were cast. In the case of skin glue fillers, each mixture was prepared with and without the addition of molasses (17%). The objective was to determine if this material really acts as a plasticiser to provide extra flexibility to the filler, as related in old treatises.

Samples were prepared and applied on a polyester sheet over a flat surface. Any sample that cracked during drying was not selected. This preparation procedure also provided valuable information about the physical properties of the different formulations (colour, density, ductility etc.), as well as information related to the drying time and their handling properties.

The day following their preparation, 0.75 cm wide samples were cut with a scalpel. Those with little fissures or cracks were rejected. The edges of the samples were sanded to avoid premature failure due to pre-existing cracks. Typically 13 × 0.76 × 0.035 cm (length × width × thickness) filler samples were obtained whereas adhesive samples were about 18 × 0.76 × 0.013 cm. Table 1 shows those samples which had suitable properties for further investigation.

Table 1 Materials suitable for tensile testing.

Group	Adhesive/binder	Inert
Traditional fillers	*Colletta*	Calcium carbonate
	Björn skin glue	
	Williams & Higgins skin glue	
	Flake skin glue	
Synthetic fillers	Mowiol 04-M1	Calcium carbonate
	Plextol B500	
	Acryl 33	
	Mowilith DMC2	
Commercial fillers	BEVA gesso	
	BEVA vermiculita	
	Stucco Zecchi	
	Masilla Caremi	
	Modostuc	
	Blumestukko	
	Polyfix	
	'Do it best' lightweight spackling	
	DAP vinyl spackling	
	'One Time' spackling	

Experimental

Experiments focused on tensile testing and swelling isotherm measurements. More than 150 gesso filler samples were cast and tensile tests were run to determine both their mechanical properties and dimensional response to RH fluctuations. In addition, the combined data were extremely helpful for determining the allowable RH range within which each filler could undergo moderate dimensional changes without apparent damage.

Results and discussion

Mechanical behaviour

The mechanical properties of fillers are determined by the chalk-to-glue ratio and PVC as well as the characteristics and concentration of the adhesive used to make them (Fig. 3). Adhesive strength influences the cohesive strength of fillers as well as their adhesion to the substrate.

In normal environmental conditions (23 °C, 50% RH) the addition of any inert material considerably reduces the ultimate tensile strength (UTS) of the adhesive in both traditional and synthetic formulations. UTS, the stress a material can withstand before it fails, is inversely proportional to the chalk-to-glue ratio. An excessive amount of inert (PVC around 80%) results in a weak, extremely flexible and absorbent filler. Fillers with high PVC easily crack when exposed to extreme RH fluctuations. A higher proportion of adhesive (low PVC) causes the filler to have a high UTS and high stiffness.

The modulus of elasticity of all samples dramatically increase in desiccated conditions, leading to very stiff and brittle fillers. However with high RH values, the samples become very flexible and develop an increase in their ability to elongate without breaking (this is the strain to failure value, expressed as a percentage of elongation before failure occurs). In such conditions both the UTS and the stiffness decrease dramatically.

Traditional fillers

With the addition of molasses very interesting observations can be made. Molasses cause traditional fillers to exhibit a greater change in dimension in response to RH fluctuations. In normal environmental conditions (23 °C, 48% RH), the samples had a strain to failure about 0.0075, that is, an elongation of about 0.75% in comparison to an elongation of only about 0.4% for those fillers with a similar PVC but without molasses. Molasses provide some extra flexibility (about 15% more than the same formulation without them) and the strain to failure slightly increases too.

In desiccated conditions, fillers without molasses do not appear to experience significant variations in the strain to failure values whereas the strength increases considerably. Nevertheless, in the case of fillers containing molasses, the maximum elongation before breaking dramatically decreases about 15–50% in comparison to the value observed in normal environmental conditions. It has also been observed that these formulations become 20–50% stiffer. This means that fillers containing molasses become very brittle at low RH.

At high RH (about 80%), formulations both with and without molasses become extremely plastic, mainly due to the hygroscopic behaviour of skin glues, resulting in very flexible and weak fillers. Again, this behaviour is even more dramatic in the case of fillers containing molasses (± 4.5% elongation, see Fig. 4).

Synthetic fillers

In the case of synthetic fillers, only Mowiol-04M1 was tested due to its easy removability with water (Falvey 1981; Hebrard and Small 1991), but it was also soon rejected as it proved to be an extremely responsive material to RH oscillations. In the tests at 10 °C and 50% RH, Mowiol no. 9 behaved as a weak and very brittle material with a high UTS (±12MPa) and a limited strain to failure (±0.35%). The addition of chalk also changes the mechanical properties of Mowiol no. 9: its UTS decreases (±4MPa) whereas the maximum elongation before breaking slightly increases.

In normal environmental conditions (23 °C, 55% RH) Mowiol no. 9 has an appropriate breaking strength (±2.5 MPa) while the strain to failure is about 1.5%: this is a material that experiences significant dimensional variations with RH oscillations. In desiccation conditions, Mowiol no. 9 filler turns into a stiff and strong filler (6.2 MPa). With such a UTS and since it deforms only about 0.4% (75% less than in normal environmental conditions), it can be considered as a brittle filler. In 80% RH, Mowiol no. 9 behaves plastically (with a UTS around 0.5 MPa) and can experience a dimensional elongation higher than 2% without breaking (Fig. 5).

Ready-mixed commercial fillers

Only three of these could be tested due to deficiencies in their handling properties, nevertheless, none of these fulfilled the mechanical properties required. 'Do it best', even in normal environmental conditions, is a very weak filler (±0.4MPa) while its strain to failure is over 0.015, i.e. 1.5% elongation. Thus, it can be considered an extremely flexible filler, with a low breaking strength and a dramatic dimensional response to RH fluctuations. Modostuc is the filler with the lowest UTS (0.05 MPa) as well as a reduced ability to deform before breaking. It is also a very hygroscopic material that reacts dramatically even to moderate RH changes. BEVA gesso shows extremely plastic behaviour too. The elongation experienced in normal environmental conditions is higher than 2%, while the UTS is only about 1.8 MPa. This filler is also very soft.

Dimensional response

The addition of any inert makes the adhesive and binder mixture become less responsive to RH fluctuations. As a consequence, the higher the PVC, the lower the dimensional response. Also, skin glues' ability to change dimensionally in response to RH oscillations decreases as they are subjected to several consecutive cycles of extreme RH oscillations (Fig. 6).

These tests revealed that molasses make the fillers more reactive to RH. The dimensional strains generated by RH changes are greater than they can withstand. By comparing the mechanical properties of each formulation with the results from swelling tests it can be concluded that, in spite of the extra flexibility molasses provides to traditional fillers, it also limits the RH fluctuations which the filler can withstand before failure. In practice, this means confining the filled painting to a moderately stable environment with very small RH oscillations. This is the only way to guarantee the structural stability of the filler and to avoid failure due to environmentally induced stresses.

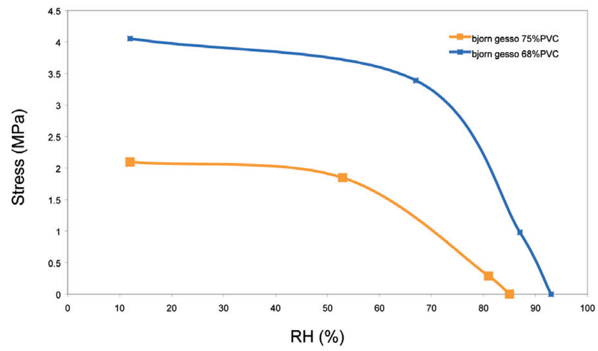

Figure 3 Stress-strain curves of several Björn fillers with different PVC.

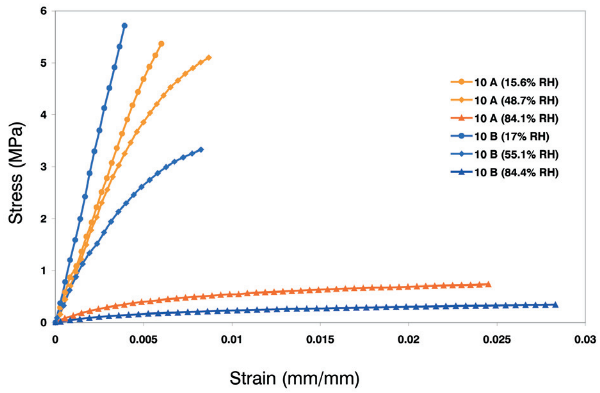

Figure 4 Stress-strain curves of Björn skin glue and Björn fillers with (10B) and without (10A) molasses. The addition of any inert makes the adhesive become less responsive to RH fluctuations.

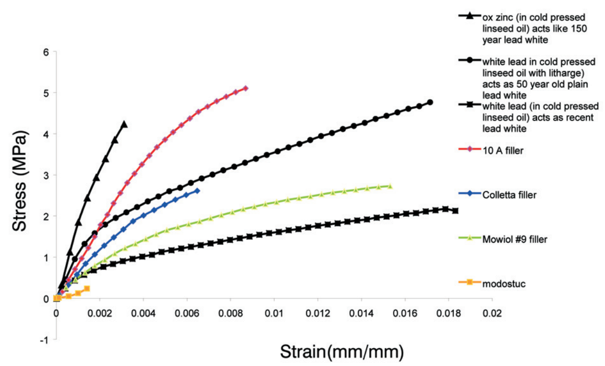

Figure 5 Stress-strain curves for six different gesso samples at 48% RH and 22 °C, compared to the mechanical properties of several oil paints.

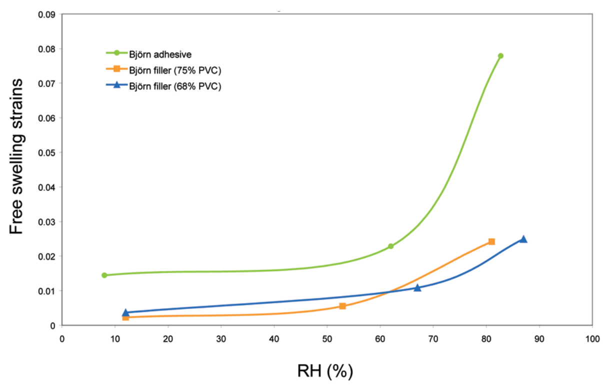

Figure 6 Swelling isotherm curves for Bjorn fillers, showing the influence of PVC.

In general, the maximum elongation before breaking observed in the samples is about 0.2–0.6%. This means that these fillers originally have a very limited strain to failure. This is the consequence of a specific adhesive concentration and the chalk-to glue ratio. The point here is that their maximum strain to failure and their dimensional response to RH ranges governs what the fillers can endure without breaking.

Fillers without molasses can withstand RH fluctuations of about 30–50% or more, whereas the presence of molasses reduces the range to lower than 20%. A good example to illustrate this is Björn gesso: without molasses it withstands 25–75% RH as opposed to 38–62% RH with molasses added. Accordingly, the addition of molasses does provide extra flexibility in normal environmental conditions. But the disadvantages of such an additive are more important: both the strain to failure and the UTS of fillers containing molasses dramatically decrease. This results in a lower ability to withstand moderate dimensional variations.

There is one exception to the above rule: *colletta* filler (a recipe based on rabbit skin glue). Even containing molasses, it can withstand the highest swelling deformation (0.52%) as well as a wide RH range (20–80%). As a consequence, it can be considered a more durable material, since it can withstand RH fluctuations as well as significant dimensional changes without apparent damage (Fig. 7).

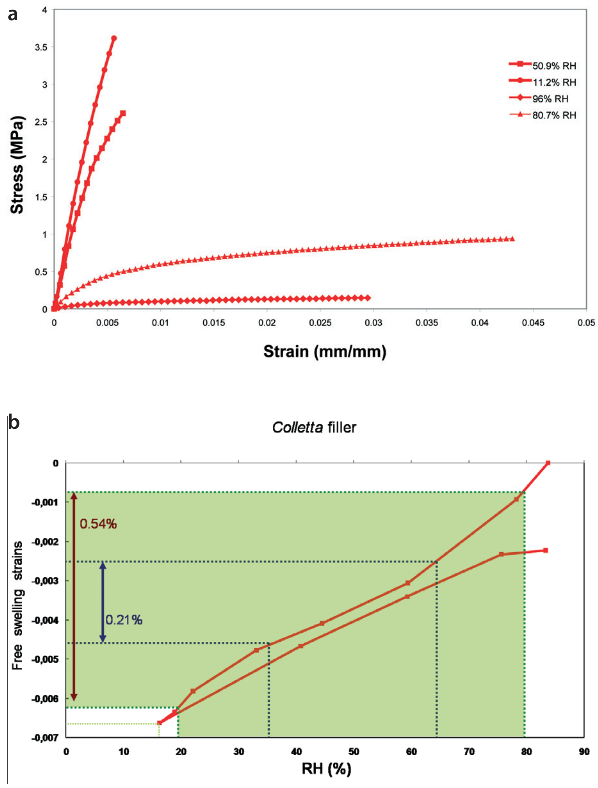

Figure 7 (a) Mechanical properties of *colletta* filler and (b) allowable RH fluctuations for *colletta* filler ranking between 20% and 80%.

For synthetic formulations, Mowiol no. 9 is extremely reactive to RH oscillations and behaves in a plastic way, as is shown in the swelling isotherm measurement. Its UTS and stiffness are also very limited, and this means a high probability of failure if extreme RH changes take place. A more detailed observation reveals that this filler behaves in the opposite way to traditional fillers. Consecutive cycles of extreme RH values make the strain to failure values increase progressively: whereas it is about 5.5% in the first cycle, it increases up to 6% in the second. Skin glue fillers' ability to deform with RH oscillations progressively decreases as they are subjected to consecutive cycles.

Mowiol no. 9 was finally rejected too as its RH range is ±47–53%. This means that a suitable environment for it must be around 50% with only ±3%RH oscillations. Therefore, Mowiol no. 9 cannot be recommended since a stable, constant and 'safe' environment will be very difficult to achieve for such RH-sensitive material (Fig. 8).

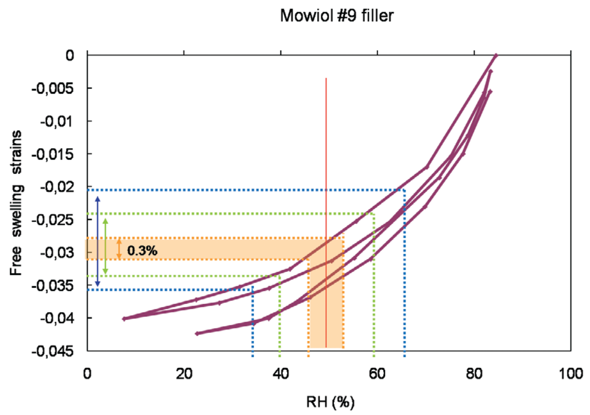

Figure 8 Acceptable RH fluctuations for Mowiol no. 9 filler.

Reversibility

Another criterion used to select fillers to test was their ease of removal. Water was preferred in order to avoid the use of organic solvents that could damage the original paint. Cleaning tests revealed that all traditional fillers (with and without molasses) are easily removable with water. Synthetic fillers were not found to be soluble in water except for the one formulated with Mowiol 04-M1. Commercial ready-mixed fillers can be removed with water, except for BEVA gesso and BEVA vermiculita (Fuster *et al*. 2004).

Conclusion

This research has answered most of the questions posed in the introduction, and has also indicated the structural requirements that fillers for canvas paintings should meet. Early tests reveal that in spite of similarities in appearances and chemical composition, skin glues can present different mechanical properties depending on their origin, purity and concentration. In the case of fillers formulated with skin glues, despite their structural suitability, significant changes induced in the behaviour and dimensional response of traditional formulations by recommended substances such as molasses were demonstrated.

For synthetic formulations, problems were related to their composition as well as differences depending on grades and manufacturers. Mowiol 04-M1 was the only one of the synthetic fillers worth testing because of its solubility in water as well as its apparent compatibility with original materials. Nevertheless tests revealed limitations due mainly to its significant dimensional response to RH oscillations.

For commercial ready-mixed fillers, only Modostuc, BEVA gesso and 'Do it best' were worth testing. However, their lack of strength makes them unsuitable for use as fillers in canvas paintings.

To summarise, traditional fillers can be considered a good option for the completion of the missing areas of the ground and paint in canvas paintings. Changes induced in the behaviour of fillers as a function of the properties of the skin glue used in their formulation become extremely helpful from a mechanical point of view, since fillers with specific stiffness, flexibility or strength can be formulated depending on the properties of the original paint. There are some other important but secondary issues such as compatibility with the original materials, as well as their easy use and removal, that make these formulations a good option. Most of these features are difficult to achieve with the synthetic formulations tested.

The important point here is that the selection of skin glues that present good mechanical properties, an appropriate dimensional response and consequently a suitable RH range for stable behaviour should make the addition of other types of substances such as molasses unnecessary. Such substances have been traditionally recommended by recipe books and old legends based on empirical knowledge. In most cases, however, in spite of an apparent improvement in specific handling properties, these additives have been shown not only to weaken and diminish the structural suitability of these formulations, but also to limit the allowable environmental conditions for works treated with them to 'narrow' ranges where only very limited RH oscillations are allowed.

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Suppliers

- Acryl-33, Plextol B-500: Röhm and Haas GmbH, Germany (www.roehm.com/).
- BEVA gesso: Conservator's Products Company, USA (www.talas-nyc.com/).
- BEVA vermiculita: Casa do restaurador, Brazil (www.casadorestaurador.com.br/).
- Björn hide glue no. 251 grade: Björn Industries. Inc., USA (www.bjorn.net/).
- Blumestukko: Laboratorios Rayt, Spain (www.rayt.com/).
- Caremi: Caremi Pigmentos – Productos de Conservación y Restauración Artística, Spain (www.caremi-pigmentos.com).
- DAP vinyl spackling: DAP Inc., USA (www.dap.com/).
- 'Do it best' lightweight spackling: Do it best Corp., USA (www.doitbestcorp.com/).
- Modostuc: Plasveroi International, Via Camussone 38 – Loc. Giovenzano, 27010 Vellezzo Bellini (PV), Italy.
- Mowilith DMC2: Celanese Chemicals, USA (www.celanese.com/).
- Mowiol 04-M1: Hoechst, Germany (www.hoechst.com/).
- 'One time ' lightweight spackling: Red Devil Inc., USA (www.reddevil.com/).
- Polyfix: Lepage, USA (www.talas-nyc.com/).
- Stucco per restauro: Zecchi colore – belle arti, Italy (www.zecchi.it/).

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