Studies in Conservation

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ysic20

Adhesion Systems in New Supports for Mural Paintings: Reversibility Tests

S. Cristina Marín-Marín, Teresa López-Martínez & Victor J. Medina-Flórez

To cite this article: S. Cristina Marín-Marín, Teresa López-Martínez & Victor J. Medina-Flórez (28 May 2024): Adhesion Systems in New Supports for Mural Paintings: Reversibility Tests, Studies in Conservation, DOI: 10.1080/00393630.2024.2356426

To link to this article: https://doi.org/10.1080/00393630.2024.2356426

Published online: 28 May 2024.

STUDIES IN CONSERVATION
https://doi.org/10.1080/00393630.2024.2356426

ORIGINAL RESEARCH OR TREATMENT PAPER

Adhesion Systems in New Supports for Mural Paintings: Reversibility Tests

S. Cristina Marín-Marín[1], Teresa López-Martínez[2] and Victor J. Medina-Flórez[2]

[1]Conservator-Restorer of Cultural Heritage, Granada, Spain; [2]Department of Painting, University of Granada, Granada, Spain

ABSTRACT
This article presents a study that investigates the utilization of diverse adhesives and intervention layers for affixing new supports to archaeological mural paintings that cannot be preserved in their original state. Depending on artwork characteristics (materiality, dimensions, state of conservation, location), various materials can be employed for attaching new supports, encompassing adhesives and intervention layers. Evaluating and assessing these materials is vital to ensure the stability, reversibility, and notably, the retreatability of the artwork. To this end, we have evaluated three commonly used adhesives and three intervention layers applied to new mural painting supports. We prepared test samples of mural paintings affixed to a new support structure, utilizing an aluminum honeycomb core sandwich panel (Aerolam). Through bibliographic analysis, we identified frequently used adhesives and intervention layers, and conducted an initial assessment of their behavior. Subsequently, following an aging process, we conducted color evaluations and reversibility tests to comprehensively study these materials and facilitate an objective comparison of their properties.

ARTICLE HISTORY
Received September 2023
Accepted May 2024

KEYWORDS
Adhesives; intervention layer; aluminum support; accelerated aging; restoration; mural paintings

Introduction

Industrial, economic, and social shifts exert influence on art, prompting the adoption of innovative techniques and materials by artists and those engaged in its conservation and restoration. Throughout history, this scenario has been exemplified, with new materials occasionally resolving issues or deficiencies traditionally faced by practitioners. An illustrative example of this is the replacement, in easel painting, of wooden supports with canvas supports (Rodés Sarrablo 2012), or the integration of acrylic resins as binders in the twentieth century (Chapa Villalba 2014). Similarly, this trend extends to the conservation and restoration of cultural assets, where advancements in materials have led to the discovery of innovative potential solutions for degradation phenomena, durability, transportation, and storage challenges.

Mural paintings are characterized by being integral parts of architectural compositions, so conservation processes mainly aim to avoid separating the artwork from its original support. However, it is not always possible to preserve the paintings in their original location. This may be due to their archaeological origin, where they are often documented as part of collapsed structures, or because they have been subjected to some sort of detachment, a practice commonly conducted in the past (Ferrer Morales 1995; Mora, Mora, and Philippot 1977; Soriano Sancho 2005).

Three methods of detachment for mural paintings exist based on the layers removed (Mora, Mora, and Philippot 1977). Firstly, *stacco a massello* involves removing both the paint layer and its support, including part or the totality of the wall. Although this ancient method is the one that better preserves mural painting characteristics, it is infrequently employed today due to logistical and financial challenges related to wall removal, and its detrimental impact on the architecture (Díaz Gómez 2019). Secondly, *stacco* entails removing the paint layer and plaster without affecting the original wall; this approach necessitates strong cohesion between the paint layer and the layer used for removal. Lastly, *strappo* involves removing only the paint layer, leading to drawbacks such as partial loss of the paint layer and changes in texture.

Whether mural paintings originate from archaeological collapse or have undergone detachment, providing a new support becomes necessary, often posing challenges of reversibility and stressing the artwork, subjecting it to excessively invasive and irreversible materials as well as to extreme vibrations and manipulations (Banyuls Ureña 2012). Such situations, where mural paintings have been replaced onto new supports, reveal the evolution of materials and intervention criteria, transitioning from highly invasive and aggressive treatments to minimal interventions and targeted treatments, emphasizing material compatibility with the artwork, reversibility, and retreatability.

In this context, traditional supports for detached or collapsed mural paintings can be categorized into rigid

CONTACT Teresa López-Martínez tlopez@ugr.es Department of Painting, University of Granada, No. 27 Avenida de Andalucía, 18014 Granada, Spain

and flexible supports. Rigid supports were primarily used for mural paintings detached via *stacco a massello* or *stacco* with relatively thick plaster. One methodology involved reconstructing the back of the artwork, supporting it on a metal mesh attached using a mineral support, usually plaster, and finally fixing it onto a wooden or metal frame (Botticelli 1992). Due to issues like mesh oxidation and degradation of the mineral support, this technique fell out of favor, leading to the adoption of rigid sheet supports. These substitutes for plaster included cement or Eternit, binding the mural painting to a frame made of wood, metal, cement, or slate. These materials had downsides like salt efflorescence, difficulty handling large surfaces, and poor reversibility (Rodríguez Sancho 1995). On the other hand, traditional flexible supports were made from materials such as jute fabric, particle boards, metal and wooden frames, or metal mesh, among others. Many of these materials have been replaced by synthetics due to mechanical movement and biodeterioration issues intolerable for mural paintings (Bosch Roig et al. 2011). The increased production and availability of synthetic resins subsequently led to the development of various new support types, classified as rigid synthetic supports, commonly employed today (Rodríguez Sancho 1995). Within this category, there are rigid foam supports used as single supports, often employed both as an intervention layer and support (Calabria Salvador 2013). Other types are sandwich supports or parallel system supports, typically consisting of two exterior layers adhered with an adhesive and a substance adding body and rigidity, with either honeycomb or rigid foam core structures (Calabria Salvador 2013). Presently, alongside these supports, different materials such as epoxy or polyester resins with fiberglass and cellular polycarbonate are being studied, and materials used as intervention layers or adhesives for joining different elements are also part of this evolution (Botticelli 1992; Parrini and Milano 1981).

The research presented here derived from the necessity to select the most appropriate materials for relocating a mural painting from an archaeological collapse. In 2016, two sections of mural painting measuring 165 × 119 cm and 105 × 75 cm from the late antique period originating from the archaeological site of Cástulo (Linares, Jaén, Spain) were brought to the mural painting restoration laboratories of the University of Granada for restoration (López-Martínez, Medina-Flórez, and García-Bueno 2020). Due to the thickness of the plaster (between 1 and 1.5 cm) and its fragmented condition, it became imperative to apply a leveling plaster after restoration and to adhere the paintings onto a new support structure, a sandwich-type core made of aluminum (Aerolam). To select the most suitable adhesive and intervention layer, a comparative analysis of some of the materials commonly used in these cases was conducted, evaluating them after artificial aging, analyzing their properties and reversibility. The methodology and results obtained from this comparative analysis are presented in this study.

Materials and methods

The main objective of the tests that were conducted was to determine the best intervention layer and adhesive for adhering a mural painting recovered from an archaeological collapse onto a new support. Special attention was paid to the aging process of the materials tested (adhesives and intervention layers) as well as the possible reversibility/retreatability of the adhesion. To achieve this, a distinctive and specialized methodology was employed, which was crucial for attaining clear and reliable conclusions regarding the analyzed materials.

Bibliographic review

A thorough review of relevant literature was undertaken, encompassing classic texts and manuals on mural painting and restoration, such as the work by Mora, Mora, and Philippot (1977), as well as contemporary scientific articles that provide insights into the latest advancements and methodologies currently in use (Banyuls Ureña 2012; Chércoles et al. 2010; Díaz Gómez 2019; Pastor Valls 2015; Regidor Ros et al. 2011). Particular attention was devoted to adhesives and materials commonly employed as intervention layers in these procedures.

Preparation of specimens simulating mural painting plaster

As mentioned in the introduction, this work is linked to the restoration of mural paintings originating from an archaeological collapse, which, after restoration, needed to be placed onto a new support. Due to the irregular thickness of the plaster, a leveling plaster was applied during restoration to facilitate proper adhesion of the paintings to the new support, onto which the intervention layer and the alveolar core support would be adhered.

For the conducted tests, 10 specimens of lime plaster paste and fine silica aggregate (in a ratio of 1:2.5) were prepared to emulate the leveling plaster. The dimensions of the specimens were 5.5 × 11 cm with a thickness of 1 cm. The decision to conduct tests on simulated materials, rather than authentic artworks, offers distinct advantages. It ensures consistent behavior across all specimens, enabling evaluation techniques that might otherwise harm the actual artwork, rendering them unsuitable for real-world application.

A few weeks after the plaster was made, the plaster specimens were adhered to a new support using the chosen adhesives and intervention layers. In all cases, the same support that would be used in the readhesion of the original paintings was used. The support employed was a panel with a 'sandwich' structure. This panel features an external layer coated with fiberglass and epoxy resin, while internally it comprises an aluminum honeycomb core, measuring a total thickness of 12.7 mm. This particular support is sourced from CTS (Aerolam). Recognized for its robust tensile and compressive strength, attributed to the fiberglass and epoxy resin coating, the support also exhibits remarkable resistance against shearing and bending forces. Furthermore, it offers convenient handling, the capacity to achieve a perfectly flat surface, lightweight attributes, stability, and resilience against atmospheric agents (CTS n.d.). Such favorable characteristics have prompted widespread usage of this support material. Notable instances include its application in conserving the polychrome high relief of San Jerónimo Penitente at the Osuna Ducal Pantheon (sixteenth century). Here, an Aerolam f-board was integrated into a steel profile structure, meticulously designed to bear the artwork's vertical load (Baglioni et al. 2011). Similarly, the support played a pivotal role in the exhibition setup for Roman mural paintings at La Quintilla (Lorca) (García Sandoval, Plaza Santiago, and Fernández Díaz 2004), among other notable instances.

Selection of materials for testing

In the process of adhering a mural painting to a new support, it is possible to identify a precise stratigraphy in which one or several intervention layers are interposed between the mural painting and the new support. This intervention layer, which emerged at the *Istituto Centrale per il Restauro* in Rome in 1965 (Urbino, Mora, and Torraca 1965), facilitates the removal of the new support, favoring its reversibility. There are several types of intervention layers. The most common are laminar layers, which require an adhesive to be adhered to the new support and to the mural painting, chemical-adhesive layers formed only by adhesives, and intervention layers formed by lightweight plasters, which have great compatibility with the mural painting but add more weight to the assembly (Díaz Gómez 2019).

In the mural paintings that are linked to this study, it was necessary to apply a leveling plaster prior to the application of the new support. Therefore, it was decided that the most suitable type of intervention layer for this specific case would be a laminar layer, so no additional weight is added to the assembly and a physical barrier is obtained to facilitate reversibility. Thus, three materials widely used as intervention

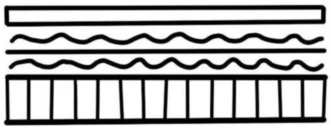

Figure 1. Scheme of the stratigraphy for the nine specimens in which the intervention layer and adhesive are combined.

layers in the adhesion of a mural painting to a new support and referenced in specific literature were selected for testing: gauze (García Sandoval, Plaza Santiago, and Fernández Díaz 2004; Soriano Sancho, Osca Pons, and Roig Picazo 2006), felt (Soriano Sancho 2005), and polyurethane foam (Pasíes Oviedo 2014; Soriano Sancho 2005).

All of them are laminar layers, hence they must be applied using an adhesive that is applied between the mural painting and the intervention layer and between the intervention layer and the new support. Depending on whether total reversibility of the support and intervention layer or partial reversibility (only of the new support while keeping the intervention layer adhered to the mural painting) is desired, a single adhesive or two adhesives of different polarities can be applied to each of these parts. In the case of this study, the intervention layer is adhered on the leveling plaster, so it was not considered necessary to seek partial reversibility, hence the same adhesive was applied between the leveling plaster and the intervention layer and between the intervention layer and the new support (Figure 1). Three adhesives widely used in the adhesion of mural paintings to a new support and referenced in the literature were selected: an acrylic resin in water dispersion mixed with an organic solvent to facilitate its application (Acril 33 + toluene) (Inácio Caetano 2000; Soriano Sancho 2005), an aqueous dispersion of acrylic resin and ethyl vinyl acetate (Beva® O.F. Gel) (Soriano Sancho 2005; Soriano Sancho and Bosch Roig 2008), and an epoxy resin (Epo 150/K15) (García Sandoval, Plaza Santiago, and Fernández Díaz 2004;Soriano Sancho and Bosch Roig 2008).

Each indicated intervention layer was applied with each of the specified adhesives, applying the same adhesive to both the plaster and the new support. The adhesive-intervention layer behavior was analyzed in combination, as it would occur in a real artwork. Only in the case of polyurethane foam, which despite being a laminar layer does not necessarily require an adhesive, was also analyzed individually. In this way, a total of 10 specimens were obtained (Table 1). Their characteristics are detailed below.

Adhesives

Acril 33 mixed with toluene: This adhesive is an acrylic resin in aqueous dispersion, an ethyl acrylate-methyl

Table 1. Summary of materials used in specimen preparation.

Adhesives	Intervention layer
Acril 33 + toluene	Felt (1.5 mm)
	Gauze (4 layers)
	Polyurethane foam (5 mm)
Beva® O.F. Gel	Felt (1.5 mm)
	Gauze (4 layers)
	Polyurethane foam (5 mm)
Epo 150 / K15	Felt (1.5 mm)
	Gauze (4 layers)
	Polyurethane foam (5 mm)
Polyurethane foam	Polyurethane foam

methacrylate copolymer, with commendable properties, including resistance to atmospheric agents, chemical stability both indoors and outdoors, strong adhesive power, pH stability (9.5), and high resistance to yellowing. Moreover, it exhibits notable alkaline resistance, making it suitable for use with hydraulic products (Moreno Cifuentes 1998). It is fully soluble in water and is commonly employed in various restoration processes as a consolidant and adhesive (Banyuls Ureña 2012). Adhesion occurs through solvent evaporation, forming a solidified film that binds the layers (Matteini and Moles 2001).

To facilitate the application of the adhesive and to ensure better adaptation to the irregularities of the substrate, Acril 33 was mixed with toluene. The addition of toluene to acrylic dispersion resins is sometimes employed to increase the thickness of the solution as well as to enhance its adhesion capacity to a lipophilic surface (Borgioli and Cremonesi 2005; Duffy 1989). The preparation proportions were 100 ml of Acril and 60 ml of toluene; both compounds were mixed by stirring for approximately 8 min until a homogeneous and opalescent paste was obtained, which was applied with a spatula.

Beva® O.F. Gel: This is an aqueous dispersion of ethylene vinyl acetate and acrylic resins. It features excellent adhesive dispersion, easy application, and strong adhesion properties on different surfaces (Borgioli and Cremonesi 2005). This adhesive is reversible in toluene, xylene, isopropyl alcohol, or ethanol; these solvents do not cause its dissolution but rather swelling in a gel state. It can be used for various materials, such as paper, textiles, or large-sized paintings where heat treatment is challenging. It also has a low activation temperature, becoming reactivated at 60-65°C.

According to the consulted literature, it exhibits optimal adhesive properties on surfaces of varying materialities, such as felt and fiberglass or paper and plaster, and offers easy reversibility (Soriano Sancho, Osca Pons, and Roig Picazo 2006). It has been used in the restoration of tempera mural paintings on the ceiling of the Palacio de la Duquesa de Almodóvar in Ontinyent. Here, Beva® O.F. Gel was applied to bond the polyurethane intervention layer to an Aerolam support, and to attach the mural painting to a reinforcing linen fabric, then finally bonding the strengthened painting to a new Aerolam support (Soriano Sancho and Bosch Roig 2008).

Like Acril 33 mixed with toluene, Beva® gel was also applied using a spatula at the interface of the plaster-intervention layer and at the interface of the intervention layer-new support.

Epo 150/K15: This is a synthetic adhesive with a chemical reaction mechanism, an epoxy resin that cures through catalysis. The product utilized in this study is marketed by CTS Spain. Transparent and of very low viscosity, it offers excellent strength and stability characteristics, low flammability, and performs well under elevated temperatures (up to 180°C). Some articles dismiss its use due to concerns about imparting excessive rigidity to the intervention layer (Soriano Sancho and Bosch Roig 2008); nevertheless, it has been widely employed for adhering mural paintings to new supports, as seen in the case of the Roman paintings at La Quintilla (Lorca) (García Sandoval, Plaza Santiago, and Fernández Díaz 2004).

This adhesive is commonly used in the construction industry as it offers superior properties among thermosetting resins, since it adheres well to most surfaces and is less flammable (Olivares Santiago, Galán Marín, and Roa Fernández 2003). In the field of mural painting restoration, these properties represent an advantage by providing greater assurance regarding the stability and strength of the adhesion, as well as being less prone to combustion.

For specimen preparation, a mixture of 50 g of epoxy resin and 12 g of reactant K151 was prepared. This blend was stirred for 30 min to achieve the appropriate density and homogeneity. Unlike the other two adhesives, it was applied with a brush due to its more liquid consistency.

Intervention layers

Gauze, felt, and polyurethane foam were chosen. These can act as a sacrificial layer, forming a physical barrier between the work and the new support, without imparting greater rigidity or weight; in addition, they are inexpensive and easy-to-acquire materials.

Gauze: Gauze is a lightweight, loosely woven fabric typically made of cotton (the gauze used in this study has a density of 20 threads per cm^2). It is widely used in restoration, particularly in archaeology for extracting archaeological objects or as reinforcement. In mural painting restoration, it serves as a protective material for the paint layer, often used in conjunction with Japanese paper. Gauze also functions as an intervention layer, reinforcing the reverse of detached or collapsed mural paintings and facilitating the reversibility of the new support (Mora, Mora, and Philippot 1977). Given its thinness and loose weave, four layers of gauze were applied in the preparation of these specimens. Tests with fewer layers did not provide sufficient coverage or a genuine separation between the new support and the plaster.

Felt: Felt is a non-woven fabric created by conglomerating fibers like wool, hair, or fluff. One commonly used type is known as feltrina, with a thickness of 1.5 mm. In tests aimed at selecting a new support for the frescoes of Palomino in the Church of the Saint Johns (Valencia, Spain), felt demonstrated its effectiveness as an intervention layer, facilitating the removal of the new support without harming the artwork (Soriano Sancho 2005).The white felt used in this study is 1.5 mm thick and from the Create Crafts brand. It was cut to the size of the new support, utilizing only one layer due to its considerably greater thickness compared to gauze.

Polyurethane foam: This low-density synthetic resin has significant expansion capacity. Alongside double-sided adhesive tape and adhesive Velcro, it is one of the most commonly used self-adhesive double-sided intervention layers, especially for mural paintings detached through the *strappo* technique (Banyuls Ureña 2012). Its standout characteristics include easy application, low weight, impermeability, chemical inertness, and mechanical reversibility. However, it has certain drawbacks, such as susceptibility to biological attack under unfavorable humidity and temperature conditions, and the potential for dimensional variations in extreme ambient conditions (Pérez Cambres 2016).

In this study, polyurethane foam was applied to a smooth surface, forming a uniform layer 1 cm thick. Once dry, it was cut to the same size as the new support specimens and adhered, along with the other two intervention layers, by adding each of the three adhesives at the interface between the intervention layer and the new support, as well as at the interface between the intervention layer and the plaster. As previously mentioned, since polyurethane foam is the only chosen intervention layer that does not require adhesive for application, another specimen was prepared in which polyurethane foam was directly applied to the new support, followed by positioning the plaster on top, allowing it to dry, and subsequently removing excess polyurethane foam from the edges.

In this way, 9 specimens were obtained in which to analyze the adhesive-intervention layer interaction and one more specimen in which the intervention layer alone was evaluated, obtaining a total of 10 specimens (Figure 2).

Specimen aging

After adhering specimens to the new support, an accelerated aging process was initiated. This approach provides preliminary insights into the behavior of the employed materials without the need to wait for an extended period. While real-world conditions might yield slight variations, these tests offer preliminary information guiding the selection of the most suitable materials.

In order to obtain reliable and efficient results, and considering that this study originated from the restoration of mural paintings recovered from an archaeological collapse, as mentioned in the introduction, efforts have been made to replicate the most extreme climatic conditions that the paintings could encounter if they were to be placed *in situ* at the site to which they belong, the archaeological site of Cástulo (Jaén, Andalusia, Spain). According to the Spanish State Meteorological Agency (AEMet 2024), this location has recorded an average maximum temperature of 37.5° C during the summer months.

Furthermore, various European standards (UNE-EN ISO 9142:2004 Adhesives. *Guide to the selection of standardized laboratory aging conditions for bonded joints testing*; ISO 4892-2:2014 *Plastics. Methods of exposure to laboratory light sources. Part 2: Xenon arc lamps)* and research studies that analyze the aging of adhesives specific to the field of conservation and restoration were taken into consideration (Chércoles et al. 2010; 2016; San Andrés et al. 2013).

Drawing from this collective information, an artificial aging cycle of 144 h was conducted using a Solarbox model 3000e aging chamber equipped with a xenon lamp emitting 550 W/m^2, set at a temperature of 40°C and a relative humidity of 41%. Fluctuations in humidity and temperature have not been considered, following the conditions established in other research studies related to the field of conservation and restoration, as previously cited, as well as the protocol established in the POLYEVART project *Evaluation of Products Used in Conservation and Restoration of Cultural Heritage* (Gómez et al. 2011).

Evaluation methods

For a thorough assessment of the materials used as adhesives and intervention layers, it is essential to determine whether they remain viable for use in heritage conservation as they age or if they undergo significant changes in color, adhesion, and cohesion (Pastor Valls 2015). Additionally, conducting reversibility tests is of great importance to examine the evolution of different materials in this regard after undergoing the aging process.

Evaluation of color changes. Color variations in the adhesives used for adhering a new support can serve as indicators of the loss of some of their fundamental properties, typically resulting from the formation of new functional groups. However, in some cases, color changes may be related to the presence of additives and may not necessarily entail significant changes in the adhesive properties (Borgioli and Cremonesi

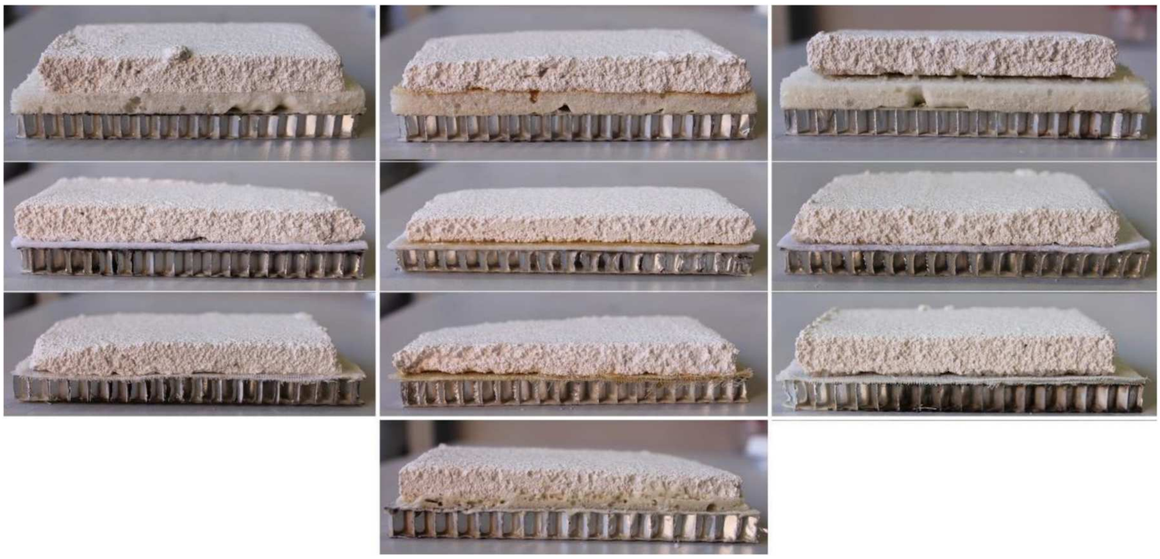

Figure 2. Prepared and documented specimens before aging. Top left: Acril 33 mixed with toluene, intervention layers from top to bottom: polyurethane foam, felt, gauze. Top center: Beva® O.F. Gel, intervention layers from top to bottom: polyurethane foam, felt, gauze. Top right: Epo 150/K15 resin, intervention layers from top to bottom: polyurethane foam, felt, gauze. Bottom: polyurethane foam without adhesive.

2005). Although not the case with this work, in the case of paintings removed using the *strappo* technique, changes in color require particular attention. Given the thinness of the layer removed with this method, significant darkening of the adhesive could lead to a substantial alteration in the perception of the artwork.

For this study, three color measurements were taken from each adhesive-impregnated intervention layer, as well as in the intervention layer that is analysed itself without adhesive (polyurethane foam), at two different time points: before and after aging.

Measurements were conducted using a Konica-Minolta CM-2600d spectrophotometer under the following measurement conditions: diffuse illumination geometry and 8° viewing angle, excluding the specular component (SCE), instrument aperture area of 3 mm, UV illumination set to 0%, standard CIE D65 illumination, and standard CIE 1964 observer. Data management was performed using the SpectramagicTM NX Pro Color Data software provided by Konica Minolta. The instrument was calibrated using the CM-A145 white calibration plate for maximum clarity and the CM-A32 zero calibration box for minimum clarity, both provided by the spectrophotometer manufacturer.

Using the CIELAB color space, as defined by the Commission Internationale de l'Eclairage (CIE) in 1976, the color differences recorded after aging were analyzed using the CIELAB ΔE*ab,10 formula. While the CIEDE2000 color difference formula (ISO/CIE 116-6:2014) is currently recommended by ISO and CIE for specific reference conditions, in this case, due to not meeting all required conditions, it was deemed appropriate to use the CIELAB color difference formula, which is also the most widely used in the field of cultural heritage research (Collado-Montero et al. 2019; Prestileo et al. 2007).

Once calculations were completed and data were managed, the results were presented in graphs to facilitate comparison and discussion.

Reversibility evaluation. When assessing the reversibility of a treatment, it is important to consider that the employed material cannot be completely removed, aiming to minimize the amount of residue that may remain on the artwork.

The chosen processes to verify the reversibility of the intervention layers are based on the characteristics of the selected adhesives and the thickness of the intervention layer. Mechanical, chemical, and thermal reversibility methods were used, evaluating the time taken for the separation of the intervention layers from the artwork, the amount of residue remaining on the back of the plaster, and any notable changes or observations after the process was completed, such as the stiffness that the adhesive may have caused in the intervention layer, the difficulty of solvent application in the case of chemical reversibility, or tool obstruction in the case of mechanical reversibility (Díaz Gómez 2019).

In all cases, the reversibility tests aimed to separate the intervention layer from the new support and the intervention layer from the plaster. Mechanical separation was attempted initially in all cases, using a scalpel to separate the layers or cutting the intervention layer with a 150 × 3.2 mm saw blade.

When mechanical reversibility was not possible, chemical reversibility was tested. For this purpose, the appropriate solvent for each adhesive used was applied: acetone for Acril 33 mixed with toluene and for Epo 150/K15, and ethanol for Beva® O.F. Gel. The solvent was applied in a controlled manner by injection at the plaster-intervention layer and intervention layer-new support interfaces. The syringe was positioned at multiple equidistant points to ensure a uniform distribution of the solvent. This was possible due to the small size of the specimens; in the case of needing to induce reversibility in a larger format, the new support would need to be perforated from the back at various points to inject the solvent. The amount of solvent injected in each case was quantified, and the solvent's action was aided by applying slight mechanical pressure with a scalpel.

In cases such as with epoxy resin specimens, where neither mechanical nor chemical reversibility was possible, experimentation was also conducted with heat application. Dry heat was applied selectively using a hot air gun while applying slight mechanical pressure with a scalpel.

Results

The diverse findings are organized below by the type of adhesive employed.

Acril 33 mixed with toluene

According to the conducted color measurements, the use of Acril initially yielded average values similar to those of epoxy resin (Table 2). After the accelerated aging process, differences emerged depending on the utilized intervention layer. It demonstrated greater chromatic stability than epoxy resin when combined with felt and gauze, and a significant increase in chroma when paired with polyurethane foam (Table 3; Figures 3–5).

Regarding the different intervention layers:

Table 2. Average (AVG) and standard deviation (SD) values of measurements taken from different intervention layers before aging for lightness (L*), red/green (a*), yellow/blue (b*), chroma (C*), and hue angle (h).

Adhesive + intervention layer		L*	a*	b*	C*	h
Acril 33 + polyurethane foam	AVG	77.98	−4.06	8.51	9.44	115.55
	SD	±2.95	±0.44	±0.32	±0.16	±3.15
Acril 33 + felt	AVG	85.56	−4.08	1.24	4.27	163.09
	SD	±1.18	±0.02	±0.38	±0.10	±4.90
Acril 33 + gauze	AVG	85.80	−3.37	9.22	9.82	110.19
	SD	±2.18	±0.14	±0.77	±0.69	±2.25
Beva® O.F. Gel + polyurethane foam	AVG	74.99	0.47	26.02	26.03	89.01
	SD	±0.66	±0.53	±1.43	±1.44	±1.12
Beva® O.F. Gel + felt	AVG	68.37	−0.90	18.82	17.46	95.07
	SD	±0.90	±0.47	±0.54	±1.14	±1.03
Beva® O.F. Gel + gauze	AVG	72.91	0.69	26.29	26.03	89.01
	SD	±0.53	±0.52	±0.89	±0.71	±1.41
Epo150/K15 + polyurethane foam	AVG	70.53	−3.02	6.71	7.36	114.20
	SD	±2.25	±0.33	±0.22	±0.26	±2.31
Epo150/K15 + felt	AVG	81.60	−4.46	0.07	4.46	179.14
	SD	±2.57	±0.17	±0.26	±0.16	±3.41
Epo150/K15 + gauze	AVG	75.54	−3.51	6.79	7.64	117.40
	SD	±2.31	±0.02	±0.30	±0.25	±1.22
Polyurethane foam	AVG	77.86	−3.88	7.09	8.09	118.70
	SD	±0.31	±0.21	±0.10	±0.18	±1.00

Polyurethane foam: Following the aging process, this intervention layer exhibited noticeable degradation in all cases, manifesting yellowing and powdering effects (Figure 6). This yellowing is evident in the increased chroma and decreased hue angle, resulting in a color difference after aging of 36.37 ± 2.97 (Table 3, Figure 4).

Its reversibility was achieved mechanically (Figure 7). This procedure was facilitated by the layer's thickness, which was greater than that of the other evaluated intervention layers, and by the combination with the adhesive. As previously mentioned, this combination prevented excessive rigidity of the layer after aging. Residues left on the plaster were easily eliminated using mechanical methods, such as a scalpel.

Felt: Among the three intervention layers treated with Acril 33, this particular stratum displayed the least color variation following the aging process, with an average value of 3.25 ± 0.75 (Table 3, Figure 3). An alteration in its texture was observed, manifesting increased rigidity in the outer region while retaining flexibility in the inner core.

Mechanical reversibility was not attainable in this case. The adhesive induced stiffness in the outer region of the intervention layer, rendering it too rigid to accommodate the insertion of a scalpel for mechanical action, thus hindering attempts to separate the layer. Likewise, cutting the intervention layer with a saw proved unfeasible due to the accumulation of felt fibers in the tool, impeding the cutting process.

Chemical reversibility was achieved through the injection of a total of 10 ml of solvent. During this application, it was observed that in certain areas, the plaster absorbed a significant amount of acetone, occasionally penetrating the surface of the leveling plaster. Therefore, meticulous attention is required during application. Furthermore, some plaster residues remained attached to the intervention layer (Figure 8).

Gauze: The application of the adhesive in this case proved to be more challenging, given the thin nature of the intervention layer, making it difficult to achieve uniform application without causing wrinkles. However, following the aging process, no significant alterations in its properties were observed, except for a darkening effect ($\Delta L^* = -8.67 \pm 1.21$) (Table 3, Figure 4).

Regarding reversibility, it was achievable through chemical means using 15 ml of solvent. Similar to what occurred with the felt, some plaster residues remained adhered to the intervention layer (Figure 9).

Beva® O.F. Gel

The application of Beva® O.F. Gel as an adhesive did not significantly differ from that of Acril 33. Similar to the acrylic resin, it exhibited good adhesion without

Table 3. Average (AVG) and standard deviation (SD) values of color differences (ΔEa,b,10), lightness (ΔL), chroma (ΔC*), and hue (ΔH*) in CIELAB between intervention layers before and after aging.

Adhesive + intervention layer		$\Delta E^*_{a,b,10}$	ΔL*	Δa*	Δb*	ΔC*	ΔH*
Acril 33 + polyurethane foam	AVG	36.37	−14.44	29.71	15.22	30.38	−13.83
	SD	±2.97	±0.73	±3.10	±1.72	±3.44	±0.97
Acril 33 + felt	AVG	3.25	−1.45	2.90	0.24	1.72	−2.35
	SD	±0.75	±1.77	±0.31	±0.20	±0.37	±0.14
Acril 33 + gauze	AVG	8.73	−8.67	1.05	0.16	0.94	−0.48
	SD	±1.31	±1.21	±0.97	±0.17	±0.91	±0.66
Beva® O.F. Gel + polyurethane foam	AVG	7.83	−5.92	2.58	4.43	2.99	−4.16
	SD	±0.98	±2.21	±1.05	±0.28	±1.07	±0.19
Beva® O.F. Gel + felt	AVG	1.62	1.00	1.27	0.15	−1.26	−0.22
	SD	±2.32	±5.50	±2.45	±0.67	±3.22	±1.55
Beva® O.F. Gel + gauze	AVG	3.09	3.07	0	0.22	−0.27	−0.21
	SD	±0.46	±0.66	±0.85	±0.14	±1.44	±0.51
Epo150/K15 + polyurethane foam	AVG	23.24	4.32	22.83	0.03	22.33	−4.73
	SD	±1.37	±1.15	±1.41	±0.21	±1.37	±0.47
Epo150/K15 + felt	AVG	30.57	−4.07	30.25	1.76	26.49	−14.70
	SD	±0.92	±2.13	±1.06	±0.10	±1.05	±0.29
Epo150/K15 + gauze	AVG	24.72	3.63	24.43	1.00	23.90	−5.16
	SD	±0.10	±0.50	±0.03	±0.09	±0.04	±0.04
Polyurethane foam	AVG	42.11	−19.15	35.91	10.84	35.48	−12.18
	SD	±2.75	±0.62	±2.52	±1.73	±2.77	±0.91

adding excessive rigidity to the intervention layers. However, initial color measurements revealed what was visibly noticeable: the adhesive, once applied prior to aging, displays a more ochre and darker tonality, with higher values of chroma (C*) and a* compared to the other adhesives (Table 2, Figure 10). This darker tonality of Beva® O.F. Gel might pose challenges in cases where it is used on very white and thin plasters, as it could create excessive contrast.

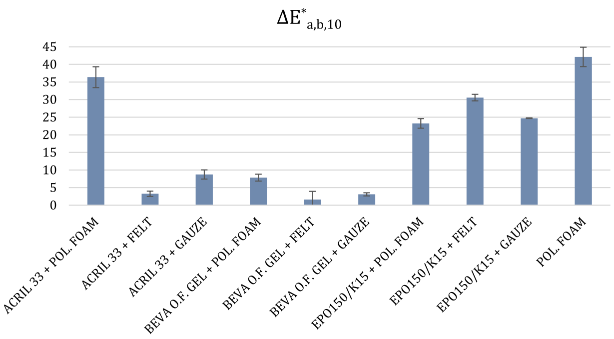

Figure 3. Average values and standard deviation (error bars) of CIELAB color differences (ΔE*a,b,10) between intervention layers before and after aging.

Polyurethane foam: It exhibits minimal deviations in comparison to the adhesion attributes observed with Acril 33 mixed with toluene. Post-aging, a noticeable degradation becomes apparent once again (Figure 11), showing significant powdering. Among the three intervention layers treated with Beva® O.F. Gel, the polyurethane foam layer displays the most pronounced color discrepancy (ΔE*ab = 7.83 ± 0.98). This divergence is attributed to a darkening effect (ΔL* = −5.92 ± 2.21) along with a discernible shift in hue towards a reddish tone (ΔH* = −4.16 ± 0.19) (Figures 3–5, Table 3).

Mechanical reversibility was achieved (Figure 12). The elimination of residues was carried out through mechanical techniques involving the use of a scalpel.

Felt: Following the aging process, this intervention layer exhibited a similar behavior when treated with

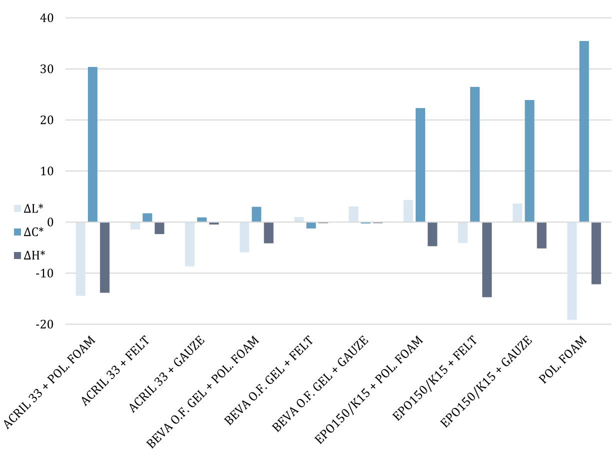

Figure 4. Average values of CIELAB lightness differences (ΔL*), chroma differences (ΔC*), and hue differences (ΔH*) between intervention layers before and after aging.

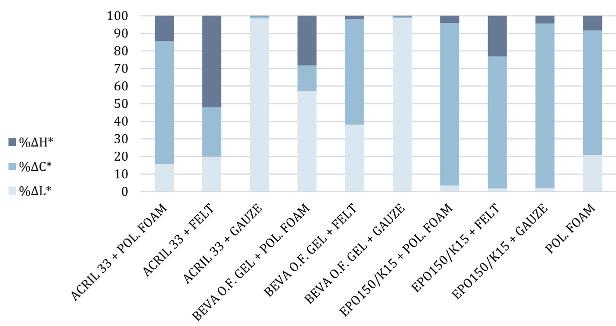

Figure 5. Percent contributions of CIELAB lightness differences (ΔL*), chroma differences (ΔC*), and hue differences (ΔH*) to the total color difference between intervention layers before and after aging.

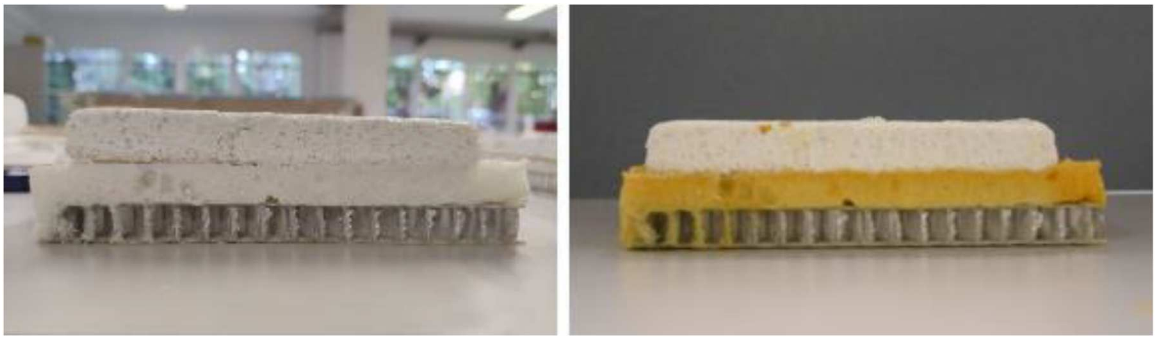

Figure 6. Sample of Acril 33 mixed with toluene + polyurethane foam before (left) and after (right) aging.

Figure 7. Profile after mechanical separation of the Acril 33 mixed with toluene + polyurethane foam sample.

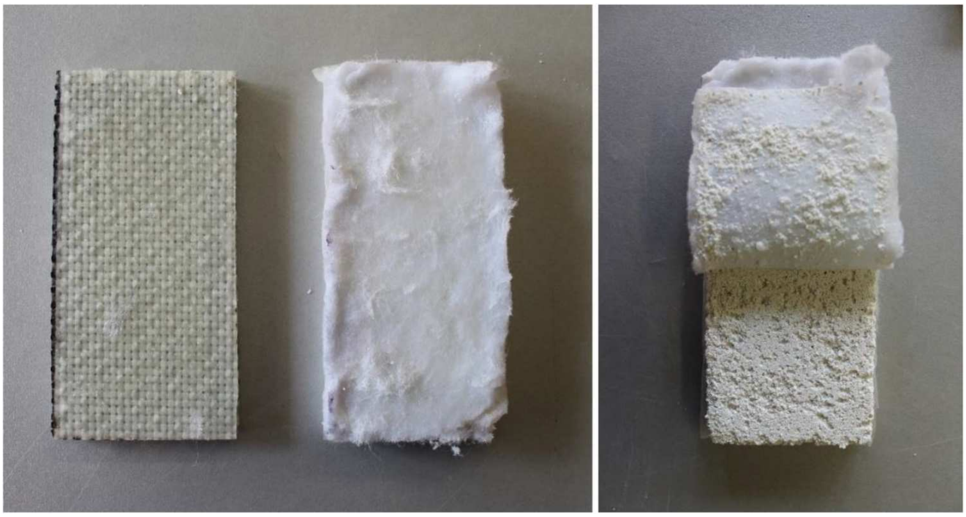

Figure 8. View of the reverse side of the new support and the plaster sample after physical-chemical separation in Acril 33 mixed with toluene + felt sample (left). Reversibility of the intervention layer on the reverse side of the plaster in Acril 33 mixed with toluene + felt sample (right).

Beva® O.F. Gel compared to Acril 33. In both cases, an increase in rigidity was observed in the outer regions. Among the three layers treated with Beva® O.F. Gel, it displayed the least color variation after aging ($\Delta E^*ab = 1.6 \pm 2.32$), primarily attributed to an augmentation in chroma (Figures 4 and 5).

Reversibility was achieved through a chemical process, applying 25 ml of solvent, coupled with the application of mechanical force using a scalpel.

Gauze: Similarly with this adhesive, the application of gauze proved to be more challenging than for the other intervention layers. The color change observed after aging ($\Delta E^*ab = 3.09 \pm 0.46$) is primarily attributed to an increase in lightness ($\Delta L^* = 3.07 \pm 0.66$).

For its reversibility, a total of 20 ml of solvent was injected at different points, with additional mechanical assistance using a scalpel, showing slightly better reversibility compared to felt. Similarly in this case, remnants of plaster adhered to the intervention layer, in addition to adhesive residue remaining on the reverse side of the plaster (Figure 13).

Figure 9. Reverse side of Acril 33 mixed with toluene + gauze test specimen after physical-chemical separation.

Epoxy resin

As previously indicated, significant disparities in behavior between Acril 33 and Beva® O.F. Gel were not observed. However, the epoxy resin, Epo 150/K15, demonstrated a more varied response. On one hand, it demanded an extended adhesive preparation time due to the necessity of achieving a homogeneous mixture between the resin (Epo 150) and the hardener (K15), which took up to 30 min. Conversely, its application was straightforward across all three intervention layers, including the gauze, owing to its more fluid

Figure 12. Beva® O.F. Gel + polyurethane foam sample after mechanical separation.

texture, enabling brush-based application. While no color alteration was noted in the adhesive post-drying, post-accelerated aging revealed a noticeable yellowing effect. This yellowing, alongside the polyurethane foam, constitutes the most prominent chromatic shift (Table 3, Figure 3).

Polyurethane foam: The application of this intervention layer required a larger quantity of adhesive due to its porous nature and lower density, resulting in

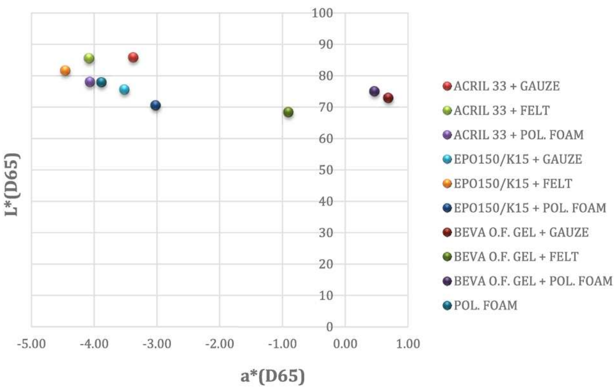

Figure 10. Average lightness (L*) and red/green CIELAB coordinates of the intervention layers before aging.

Figure 11. Beva® O.F. Gel + polyurethane foam samples before (left) and after (right) aging.

Figure 13. View of the layers in the Beva® O.F. Gel + gauze sample before the separation tests (left) and after separation (right).

greater absorption. As a consequence, after accelerated aging the layer hardened significantly, making its mechanical reversibility more challenging; nevertheless, this was achieved using a handsaw. Despite the use of solvent in combination with mechanical action, complete removal of residual materials was not attainable (Figure 14).

Similarly to the pattern observed in other cases involving polyurethane foam, except for its application with Beva® O.F. Gel, the parameter most influencing the recorded color difference was an increase in chroma ($\Delta C^* = 22.33 \pm 1.37$) (Table 2, Figures 3–5).

Felt: Following aging, the entire intervention layer displayed increased stiffness, in contrast to the previous adhesives where the core of the felt remained flexible. With this adhesive, the felt intervention layer exhibited the most significant color difference after aging ($\Delta E^*ab = 30.57 \pm 0.92$), with chroma being the

Figure 14. Epo150/K15 + polyurethane foam test specimen after its separation.

Figure 15. Physical-chemical separation and heat application on epoxy resin and felt sample.

parameter that showed the most notable variation ($\Delta C^* = 26.49 \pm 1.05$) (Table 3, Figure 5).

Regarding reversibility, attempts were made using chemical reversibility through the application of solvent combined with mechanical action; however, this process had no effect on the intervention layer. Therefore, an approach involving the application of heat accompanied by mechanical action was also attempted, but even with this procedure, the separation of the paint from the new support was not achieved (Figure 15).

Gauze: In contrast to the application of other adhesives that caused this layer to wrinkle, hindering its uniform distribution, that was not the case in this instance. The low density of the adhesive allowed for brush application without causing the gauze to wrinkle. Color measurements taken before and after aging revealed an increase in chroma ($\Delta C^* = 23.90 \pm 0.04$) and a decrease in hue angle ($\Delta H^* = -5.16 \pm 0.04$), resulting in a yellowing of the layer (Table 3, Figure 4).

Regarding the reversibility tests, it exhibited a behavior similar to the combination of epoxy resin with felt, with mechanical, chemical, and thermal reversibility all proving to be practically impossible.

Polyurethane foam

As noted, since the polyurethane foam is the only intervention layer that does not require adhesive, a sample was prepared for separate analysis of its behavior (Figure 16).

In alignment with outcomes observed in specimens where the foam exclusively served as an intervention layer, aging manifested similar degradation in the polyurethane foam. This degradation was evidenced by yellowing and a tendency to become powdery. Moreover, the color divergence after aging surpassed that observed when the foam was used in combination with an

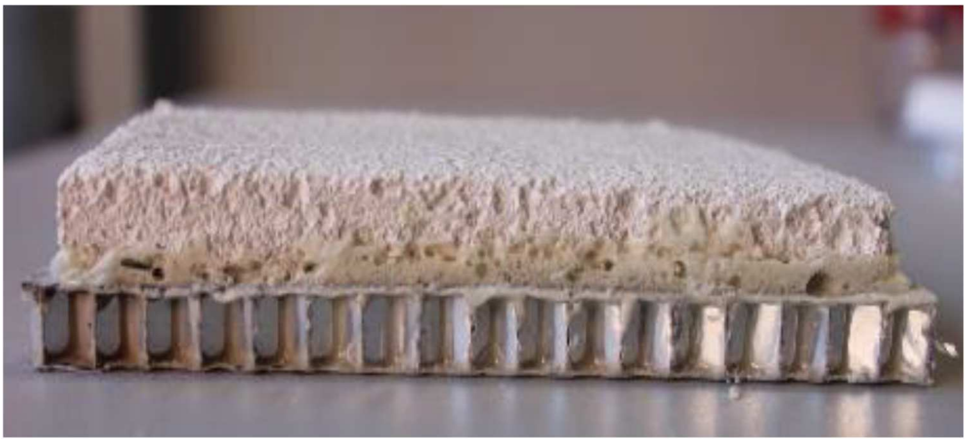

Figure 16. Profile of the polyurethane foam specimen serving as both adhesive and intervention layer.

adhesive ($\Delta E^*ab = 42.11 \pm 2.75$). Among all assessed intervention layers, the foam layer exhibited the most substantial color variance following aging. Furthermore, during application, it proved challenging to exert full control over material distribution, resulting in residues accumulating at the edges of both the plaster and the support. These residues became more conspicuous alongside the yellowing effect.

Regarding reversibility, mechanical reversibility was achievable. Despite the foam layer in this instance being thinner, it still could be cut using a saw to detach the new support from the mural painting's plaster (Figure 17). Residues remaining on the reverse side of the plaster could be readily eliminated through mechanical means employing a scalpel.

Table 4 summarizes all aspects evaluated in each of the samples.

Discussion

During the conducted tests, an analysis was carried out on the preparation of different materials as well as

Figure 17. Polyurethane foam specimen used as adhesive and intervention layer after mechanical separation.

their methods of application, the alterations they undergo upon drying or aging, and their reversibility.

The preparation and application of the three adhesives were generally straightforward, requiring no significant preparation time. In the case of applying Acril 33 and Beva® O.F. Gel with a spatula, the level of difficulty varied based on the rigidity or lightness of the intervention layer employed. However, both adhesives could be spread evenly and effectively fulfilled their adhesive role. Applying epoxy resin with a brush was similarly uncomplicated, although it required more preparation time and a larger quantity of product than the other two adhesives. Its higher fluidity allowed it to penetrate deeper into the intervention layers, particularly affecting the polyurethane foam and resulting in increased stiffness after aging.

For the three types of intervention layers, they exhibited shared characteristics in terms of application based on the adhesive used:

- The gauze used as an intervention layer necessitated the application of several layers, four in this case, to augment the separation between the new support and the mural painting, thus promoting reversibility. Utilizing multiple layers of gauze strengthened the intervention layer's structure and ensured comprehensive coverage of the new support's surface, a result not achieved with fewer layers. The application of Acril 33 and Beva® O.F. Gel proved more challenging with this intervention layer due to their tendency to create wrinkles, attributed to their lightness and thinness. In contrast, the application of epoxy resin yielded more satisfactory results for this intervention layer, as it absorbed less product and enabled a more even distribution.
- The felt employed as an intervention layer stood out for its ease of application. With adequate thickness, only a single layer was necessary for the intervention, and cutting and tailoring it to the desired dimensions

Table 4. Summary of key aspects analyzed for the comparison of adhesives and intervention layers.

Adhesives	Intervention layer	Application	Aging	Reversibility
Acril 33 + toluene	Felt	Spatula	$\Delta E^*_{a,b,10}$= 3.25 ± 0.75 The exterior becomes hardened while the core reamins flexible.	Chemical reversibility, 10 ml of acetone. Extreme care must be taken with the solvent penetration.
	Gauze	Spatula. Wrinkles are created.	$\Delta E^*_{a,b,10}$= 8.73 ± 1.31	Chemical reversibility, 15 ml of acetone.
	Polyurethane foam	Spatula. Requires more adhesive.	$\Delta E^*_{a,b,10}$= 36.37 ± 2.97 Yellowing and powdery texture.	Mechanical reversibility. Removal of residues with a scalpel.
Beva® O.F. Gel	Felt	Spatula	$\Delta E^*_{a,b,10}$= 1.62 ± 2.32 High initial chroma values. The exterior hardens while the core remains flexible.	Chemical reversibility: 25 ml of ethanol and mechanical assistance.
	Gauze	Spatula. Wrinkles are created.	$\Delta E^*_{a,b,10}$= 3.09 ± 0.46 High initial chroma values.	Chemical reversibility: 20 ml of ethanol and mechanical assistance. Fewer residues compared to the felt.
	Polyurethane foam	Spatula. Requires more adhesive.	$\Delta E^*_{a,b,10}$= 7.83 ± 0.98 High initial chroma values. Yellowing and powdery texture.	Mechanical reversibility. Residue removal with a scalpel.
Epo 150 / K15	Felt	Longer preparation time. Brush application. Requires more adhesive.	$\Delta E^*_{a,b,10}$= 30.57 ± 0.92 It yellows with aging. The intervention layer, including the core, has become hardened.	Not reversible
	Gauze	Longer preparation time. Brush application. Does not create wrinkles.	$\Delta E^*_{a,b,10}$= 24.72 ± 0.10 It yellows with aging. The intervention layer, including the core, has become hardened.	Not reversible
	Polyurethane foam	Longer preparation time. Brush application. Requires more adhesive.	$\Delta E^*_{a,b,10}$= 23.24 ± 1.37 It yellows with aging. The intervention layer has become hardened.	Mechanical reversibility. Difficult removal of residues.
Polyurethane foam	Polyurethane foam	By spraying. Generates more residues. Hinders precise mural positioning. Thinner layer compared to when applied with an adhesive.	$\Delta E^*_{a,b,10}$= 42.11 ± 2.75 Degradation. Yellowing and powdery texture.	Mechanical reversibility. Residues easily removed mechanically.

was a straightforward process. Its resistance to wrinkling allowed for smooth application and distribution of all three adhesive types, irrespective of their viscosity. While a greater amount of epoxy resin needed to be applied to felt compared to gauze due to its higher absorbency, all samples utilizing this material displayed robust adhesion between layers.

- Polyurethane foam offered the advantage of achieving the desired intervention layer thickness and facilitating adhesive distribution, whether the adhesive was highly viscous or more fluid. However, this approach had its limitations, including a need for a larger adhesive quantity due to greater absorption, which complicated uniform application. Additionally, cavities could appear in the intervention layer after drying, caused by air bubbles during expansion, potentially accumulating more adhesive. Furthermore, when used alone, without the application of adhesive, it generates more residues when sprayed directly onto the new support instead of being applied with a brush or spatula. Additionally, it hinders the precise positioning of the mural painting on the new support, as the plaster is adhered while the foam is still in the process of expansion and is pliable.

Regarding alterations observed in both adhesives and intervention layers after drying and aging, distinct color changes were noted in all instances, surpassing a threshold of 1.5. These shifts are discernible to individuals with normal color vision and align with color difference values around 1.0 CIELAB units, as described by Huang et al. (2012). Notably, Beva® O.F. Gel exhibited higher chroma values upon drying compared to other layers (which persisted after aging), and a substantial color difference was evident in epoxy resin-applied intervention layers following aging (Figure 3 and Figure 18).

The majority of synthetic resins used in conservation and restoration initially exhibit chromatic transparency, although they may undergo chromatic variations after aging. This alteration can arise from chemical degradation, which in turn can affect the solubility of the resin as well as its initial characteristics of hardness, stability, and variation in mechanical properties (fragmentation, dustiness, etc.) (San Andrés et al. 1995). On the other hand, it is also possible that such chromatic changes result from the presence of additives and may not necessarily entail significant changes in the material's properties (Borgioli and Cremonesi 2005). Sometimes, these color changes lead to obvious modifications visible in the material's properties. However, in other cases, analysis is necessary to determine the exact composition of the materials before and after aging to understand how they have been modified (Pastor Valls 2015; San Andrés et al. 2011).

Figure 18. Gauze samples after aging. Top: Acril 33 mixed with toluene. Bottom: Beva® O.F. Gel. Right: Epo 150/K 15.

In this study, the degradation of polyurethane foam after aging was evident. This polymer is inherently unstable, as are cellulose derivatives such as Beva® O.F. Gel (La Nasa et al. 2018; San Andrés et al. 2011), so it is not surprising that it has exhibited the most degradation among the tested adhesives and intervention layers. Polyurethane foam, in addition to yellowing, tends to depolymerize with aging, undergoing hydrolytic and oxidative degradation. The polymer chains become stiffer over time, eventually breaking into smaller fragments, leading to pulverization (Borgioli and Cremonesi 2005). However, this degradation is somewhat less pronounced when the foam is applied in combination with an adhesive, as observed in other previous studies as well (Díaz Gómez 2019).

Regarding the three adhesives used (Acril 33 + toluene, Beva® O.F. Gel, and Epo 150/K15), changes after aging were not as evident, so it cannot be confirmed without materials analysis whether they underwent internal modifications (San Andrés et al. 2011). Previous literature indicates that acrylic resins such Acril 33, after aging, have exhibited yellowing but no changes in other properties including reversibility, attributing such yellowing to degradation of additives present in the adhesive (Howells et al. 1984), so it could be presumed that the same has occurred in the case presented here.

As for reversibility, polyurethane foam exhibits optimal mechanical reversibility, both when combined with adhesives and when used alone, showing only slightly more resistance when adhered with Epo150/K15. Residue from the intervention layer left on the plaster and the new support can be easily removed with a scalpel.

The other two intervention layers, both gauze and felt, do not allow for mechanical reversibility since all three adhesives they have been adhered with (Acril 33 + toluene, Beva® O.F. Gel, and Epo150/K15) have added stiffness to the layers after aging. This situation has also been documented in other works where the use of adhesives has stiffened the intervention layer employed (Soriano Sancho 2005). Chemical reversibility was possible in the case of Acril 33 and Beva® O.F. Gel, although in both cases plaster residue remained adhered to the intervention layer. This situation does not pose a major inconvenience in this work since it involves a leveling plaster onto which the original plaster would be placed; however, caution would need to be exercised if, instead of a leveling plaster, the intervention layer were directly adhered to the original one.

Regarding adhesives, the epoxy resin Epo 150/K15 is the adhesive that presents the greatest reversibility problems. When used to adhere polyurethane foam, it hinders the removal of residues left on the reverse side of the plaster and the new support. In the case of its use in combination with gauze or felt, mechanical, chemical, or heat-induced reversibility is not possible.

Conclusions

The experiments conducted in this study have enabled an analysis of the behavior of three of the most commonly used adhesives in the application of new supports for mural paintings: Acril 33, Beva® O.F. Gel, and Epo 150/K15, in combination with three different intervention layers (polyurethane foam, felt, and gauze). In all cases it was confirmed that both the adhesives used, and the three types of intervention layers effectively facilitated the adhesion of the mural painting specimens to the new support, without significantly increasing their weight.

The tested intervention layers proved to be easily manageable, allowing for a slight separation between the new support and the mural painting, which facilitates the reversibility process. Both felt and gauze were shown to be quicker, easier, and cleaner to apply than polyurethane foam. However, care must be taken during the application of gauze to avoid the formation of wrinkles, especially when using adhesives with a certain viscosity. On the other hand, polyurethane foam and felt demonstrated higher absorbency, requiring a greater amount of adhesive during application.

After the aging process, the adhesive that exhibited the most noticeable yellowing was the Epo 150/K15 resin, while Beva® O.F. Gel hardly changed its color compared to its initial application, and Acril 33 mixed with toluene showed a slight darkening.

Regarding the intervention layers, polyurethane foam showed a higher level of yellowing and pulverization after aging. While this intervention layer, either in combination with adhesive or when used alone, exhibits the best reversibility, the degradation it undergoes after aging may pose a risk to mural paintings due to the dirt and erosion that the foam residues can cause on the paint layer, as well as the possibility of detachment from the new support.

After conducting reversibility tests, it was observed that, although all the materials used fulfill their adhesive function correctly even over time, not all are reversible; in this regard, epoxy resin showed the worst results, being reversible only in combination with polyurethane foam. On the other hand, both Acril 33 and Beva® O.F. Gel, in combination with the three intervention layers, showed good mechanical reversibility (in combination with polyurethane foam) and good chemical reversibility (in combination with felt and gauze), although after the removal of felt and gauze, plaster residues remained adhered to both intervention layers. Although in this specific case this situation does not pose a major problem as it concerns a leveling plaster and not the original plaster, in other cases where the intervention layer is directly adhered to the original plaster, caution should be exercised.

This work has highlighted the importance of continuing this research by conducting traction tests before and after aging, evaluating other adhesives, and applying the results obtained on decontextualized fragments of real works that do not have aesthetic or documentary value. It also shows the importance of aging studies of adhesives and materials commonly used in the field of conservation and restoration and the need to continue expanding publications and databases related to such data.

Acknowledgment

The authors would like to express their sincere gratitude for the invaluable assistance provided by Dr Mª del Rosario Blanc, Dr Ana García Bueno, and Dr Francisco José Collado Montero.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work received support from the Ministerio de Ciencia e Innovación and Agencia Estatal de Investigación (Government of Spain) under the research project *Estudio de materiales y técnicas de ejecución, ensayos de tratamientos de conservación-restauración y aplicaciones 3D de elementos decorativos del patrimonio* [grant no PID2019-105706GB-100].

References

AEMet Agencia Estatal de Meteorología. 2024. "AEMET OpenData." Accessed from https://www.aemet.es/es/datos_abiertos/AEMET_OpenData.

Baglioni, R., A. Bouzas Abad, J. A. Filter Peinado, and A. Gómez Morón. 2011. "Restauración de San Jerónimo penitente, altorrelieve policromado del siglo XVI. Panteón ducal de la colegiata de Osuna." *Cuadernos de los amigos de los museos de Osuna* 13: 105–108.

Banyuls Ureña, M. 2012. *Estratos de intervención en arranques de pintura mural: estudio de materiales*. Unpublished masters dissertation, Universidad Politécnica de Valencia.

Borgioli, L., and P. Cremonesi. 2005. *Le resine sintetiche usate nel trattamento di opere policrome*. Saonara: Il Prato.

Bosch Roig, P., F. C. Bolívar Galiano, I. Marín Sánchez, and R. M. Montes Estellés. 2011. "Estudio de la susceptibilidad al ataque de microorganismos de los soportes en pintura mural." *XVIII Congreso Internacional Conservación y Restauración de Bienes Culturales, libro de actas Granada* 1: 528–530.

Botticelli, G. 1992. *Metodología di restauro delle pitture murali*. Firenze: Centro Di.

Calabria Salvador, I. M. 2013. *Las pinturas murales de la ciudad Íbero-Romana de Cástulo, Linares (Jaén): Estudio técnico y propuesta de diferentes sistemas de anclaje para su musealización*. Valencia: Universidad Politécnica de Valencia.

Chapa Villalba, J. 2014. *Las resinas acrílicas en dispersión acuosa: alternativas de uso de un material pictórico artístico.* Unpublished doctoral thesis, Universitat Politècnica de València. https://doi.org/10.4995/Thesis/10251/40650.

Chércoles, R., M. San Andrés, J. M. De la Roja, y M. L. Gómez. 2010. "Factores responsables de la degradación química de polímeros. Efectos provocados por la radiación lumínica sobre algunos materiales utilizados en conservación," *Proceedings 11ª Jornadas de Conservación de Arte Contemporáneo*, Madrid (España), 18-19 February 2010, edited by Museo Nacional Centro de Arte Reina Sofía, 2010, 331-358.

Chércoles, R., M. San Andrés, J. M. De la Roja, y M. Gómez. 2016. "Multianalytical aproach for the characterization of polymeric materials applied in cultural heritage," *International Symposium Plastics Heritage*, Berlin (27-29 October 2016), 78-79.

Collado-Montero, F. J., A. I. Calero-Castillo, M. Melgosa, and V. J. Medina Flórez. 2019. "Colorimetric evaluation of pictorial coatings in conservation of plasterworks from the Islamic tradition." *Studies in Conservation* 64 (2): 90–100. https://doi.org/10.1080/00393630.2018.1460924

CTS. "Productos de Conservación y Archivo (s.f.)" https://ctsconservation.com/es/.

Díaz Gómez, T. 2019. "La reversibilidad de los estratos de intervención utilizados en pinturas murales arrancadas." *Arché: Publicaciones del Instituto universitario de restauración del patrimonio de la UPV*, (13, 14 and 15), 57-64.

Duffy, M. C. 1989. "A Study of Acrylic Dispersions Used in the Treatment of Paintings." *Journal of the American Institute for Conservation* 28: 67–77.

Ferrer Morales, A. 1995. *La pintura mural. Su soporte, conservación, restauración y las técnicas modernas*. Sevilla: Universidad de Sevilla.

García Sandoval, J., R. Plaza Santiago, and A. Fernández Díaz. 2004. "La musealización de las pinturas romanas de la Quintilla (Lorca): Restauración y montaje expositivo." *Alberca* 2: 125–138.

Gómez, M., M. San Andrés, R. Chércoles, J. M. de la Roja, S. Santos, P. García, J. Sánchez, et al. 2011. "Revisión crítica de algunos materiales poliméricos utilizados en contacto con los bienes del Patrimonio Culturales." ICOM Committee for Conservation 16th Triennial Meeting Lisbon Portugal 19-23 September 2011, edited by J. Bridgland. paris: ICOM-CC. https://www.icom-cc-publications-online.org/1282/Revision-critica-de-los-materiales-polimericos-en-contacto-con-los-bienes-del-Patrimonio-Cultural

Howells, R., A. Burnstock, G. Hedley, and S. Hackney. 1984. "Polymer dispersions artificially aged." In *Adhesives and Consolidants*, edited by N. S. Brommelle, E. M. Pye,

P. Smith and G. Thomson, 36–43. London: Paris Congress, IIC. https://doi.org/10.1179/sic.1984.29.Supplement-1.36.

Huang, M., H. Liu, G. Cui, M. Luo, and M. Melgosa. 2012. "Evaluation of threshold color differences using printed samples." *Journal of the Optical Society of America A* 29: 883–891.

Inácio Caetano, J. 2000. *Destacamento e montagem em suporte móvel de uma pintura a fresco do Salão Nobre da Câmara Municipal de Vila franca de Xira.* ARTIS – Instituto da História da Arte da FL-UL.

La Nasa, J., G. Biale, B. Ferriani, M. P. Colombini, and F. Modugno. 2018. "A pyrolysis approach for characterizing and assessing degradation of polyurethane foam in cultural heritage objects." *Journal of Analytical and Applied Pyrolysis* 134: 562–572.

López-Martínez, T., V. J. Medina-Flórez, and A. García-Bueno. 2020. Decoración parietal de un edificio paleocristiano en el Conjunto Arqueológico de Cástulo. In *I Simposio anual de Patrimonio Natural y Cultural ICOMOS España*, edited by J. L. Lerma-García, V. M. López-Menchero Bendicho and A. Maldonado Zamora, pp. 139-147. Valencia: Editorial Universitat Politècnica de València.

Matteini, M., and A. Moles. 2001. *La química en la restauración*. San Sebastián: Ed. Nerea.

Mora, P., L. Mora, and P. Philippot. 1977. *La conservazione delle pitture murali*. 2nd ed. Bologna: Editrice Compositori.

Moreno Cifuentes, M. A. 1998. "La consolidación de revestimientos murales en yacimientos arqueológicos," In *Técnicas de consolidación en pintura mural*, edited by J. C. Barbero-Encinas, 55–73. Aguilar de Campoo, Palencia: Fundación Santa María la Real.

Olivares Santiago, M., C. Galán Marín, and J. Roa Fernández. 2003. "Los composites: Características y aplicaciones en la edificación." *Informes de la Construcción* 54 (484): 45–62.

Parrini, P., and M. Milano. 1981. "Carte a frattura predeterminata a base di fibrilla sintetiche poliofeniliche." *Atti del Convegno sul Restauro delle opere d'arte* vol. 1. Florence: Edizioni Polistampa.

Pasíes Oviedo, T. 2014. "La villa de Corneliues (l'Ènova, Valencia): trabajos de conservación y restauración para un proyecto expositivo." *Archivo de Prehistoria Levantina* XXX: 389–400.

Pastor Valls, M. T. 2015. "Estudio del comportamiento frente al envejecimiento acelerado de diversos polímeros." In *Conservación de Arte Contemporáneo, 16ª Jornada*, edited by M. R. Sofía, 117–128. Madrid: Museo Nacional Centro de Arte Reina Sofía.

Pérez Cambres, M. 2016. *La restauración de un soporte expositivo: un ánfora ibérica S. V-IV A.C.* Valencia: Universitat Politècnica de València.

Prestileo, F., G. Bruno, M. F. Alberghina, S. Schiavone, and L. Pellegrino. 2007. "I mosaici della villa romana del Casale di Piazza Armerina: il contributo della indagini colorimetriche per la stesura del protocollo di intervento", *Colore e Colorimetria contributi multidisciplinari. Quaderni di Fotonica e Ottica*, 45-55.

Regidor Ros, J. L., M. P. Soriano Sancho, A. Zalbidea Muñoz, A. Iaccarino Ildeson, and P. Roig Picazo. 2011. "Puesta en práctica de soluciones propuestas para las pinturas arrancadas de Palomino en la Iglesia de los Santos Juanes de Valencia." In *XVIII Congreso Internacional Conservación y Restauración de Bienes Culturales. Libro de actas*, edited by A. M. López-Montes, F. Collado-Montero, V. Medina-Flórez, T. Espejo-Arias and A. García-Bueno 524-529. Granada: Editorial Universidad de Granada

Rodés Sarrablo, T. 2012. "El soporte de tela en la Pintura Europea de los siglos XVI, XVII y XVIII." http://hdl.handle.net/10459.1/46448.

Rodríguez Sancho, I. 1995. "Evolución de los soportes para reforzar y trasladar pinturas. Algunos ejemplos (primera parte)." *Pátina* 7: 84–93.

San Andrés, M., R. Chércoles, S. Santos, J. M. de la Roja, C. Domínguez, y M. Gómez. 2013. "Materials made from Polyolefins used in tasks of Preventive Conservation. A comparative study of their long-term behavior." In *Science and Technology for the Conservation of Cultural Heritage*, edited by M. A. Rogerio, M. Lazzari, and E. Cano, 341–344. London: Taylor & Francis.

San Andrés, M., O. Conejo, A. Sánchez, and J. M. de la Roja. 1995. "Medida del amarilleamiento de algunas resinas sintéticas utilizadas en procesos de conservación-restauración." *Pátina* 7: 102–107.

San Andrés, M., M. Gómez, R. Chércoles, J. M. de la Roja, and M. del Egido. 2011. "Propuesta de evaluación de materiales poliméricos usados en la conservación de objetos patrimoniales." *La Ciencia y el Arte* III: 217–238.

Soriano Sancho, P. 2005. Los frescos de Palomino en la bóveda de la iglesia de los Santos Juanes de Valencia: estudio y aplicación de un nuevo soporte. Unpublished thesis, Universitat Politècnica de València. https://doi.org/10.4995/Thesis/10251/1825.

Soriano Sancho, P., and P. Bosch Roig. 2008. "Análisis mediante abrasímetro lineal de la resistencia de pinturas murales al seco arrancadas y consolidadas por el reverso con resinas epoxi." *Arché: Publicaciones del Instituto universitario de restauración del patrimonio de la UPV* 3: 25–32.

Soriano Sancho, P., J. Osca Pons, and P. Roig Picazo. 2006. "En torno a las pinturas murales arrancadas de la iglesia de los Santos Juanes de Valencia: Estudios para la protección, separación y sustitución de su antiguo soporte." *Arché. Publicación del Instituto universitario de restauración del patrimonio de la UPV* 1: 17–24.

Urbino, G., P. Mora, and G. Torraca. 1965. "Nuovi supporti per affreschi staccati," *Bolletino ICR*, 23-36.