Material characterisation of laminated artworks in the czech republic: Influence of abrasive blasting and organic solvents on the restored surface

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This study presents the material composition of laminated artworks created on the territory of today's Czech Republic between 1950 and 1990. During a field survey, more than 60 objects were evaluated, and for 48 of them, the chemical composition of the resin matrix was determined using analytical methods. Approximately one third of the artworks were made of epoxy resins, despite the fact that their use was considered less suitable at that time compared to unsaturated polyester resins. For laboratory testing, model samples were prepared from selected unsaturated polyester (UP) and epoxy (EP) resins. The influence of abrasive blasting with different media and the application of selected organic solvents on the surface properties of the resins was studied. Laser confocal microscopy revealed that resin hardness affects the surface topography after blasting, with the lowest roughness observed after blasting with limestone. Among the solvents tested, acetone was found to be the most aggressive toward the polymer matrix. The findings contribute to the optimisation of conservation strategies for laminated artworks exposed in outdoor environments.

INTRODUCTION

Glass-fibre-reinforced laminates represent an important class of industrial composite materials that have also become widely used in artistic practice during the second half of the twentieth century [1]. The early use of these materials in art production in Czechoslovakia was primarily driven by their ability to substitute traditional, expensive sculptural materials. By the late 1960s, glass laminates had become equivalent to conventional sculptural media and in many respects even surpassed them. Laminates allowed sculptors and architects to design large-scale, lightweight, and dynamically shaped works, often intended for installation in public spaces.

From a material standpoint, glass laminates consist of glass fibres that serve as reinforcement and a polymer matrix acting as a binder. The contemporary literature on materials [2, 3] most frequently refers to unsaturated polyester resins (UP) used for glass laminates due to their easy processability and low cost. Epoxy resins (EP) were generally not recommended for lamination due to their less favourable mechanical characteristics and significantly higher price. Although EP resins are still more expensive than UP resins even today, they are superior in terms of mechanical and chemical resistance [4].

In artistic practice, laminates are typically produced by hand-laying, applying layers of reinforcement impregnated with resin into a mould where the material cures. The first applied layer – known as the gelcoat – does not contain reinforcement and serves both protective and aesthetic functions. The gelcoat layer is crucial for the long-term stability of the composite, and special attention must be paid to the correct curing agent ratio and the recommended thickness [5, 6]. The maximum strength and durability of both the UP and EP systems is usually achieved after post-curing at elevated temperatures, as specified in technical data sheets. However, such post-curing is practically unfeasible for large-scale outdoor sculptures, and it can be assumed that most artworks were never post-cured. Consequently, their resistance is lower than expected for fully cured materials [7]. For this reason, additional protective surface coatings (ideally reversible) are recommended.

When the gelcoat layer becomes damaged, its repair is necessary to prevent water from entering the underlying laminate structure. In cases of severe damage, larger surface areas must often be reconstructed or supplemented. When filling losses or retouching, newly applied resins often exhibit a higher gloss than the original aged surface. To achieve an authentic appearance, the surface gloss can be reduced using suitable abrasive blasting. This method allows for fine micromechanical adjustment of the surface topography, in which light reflection differences are reflected. In addition, abrasive blasting can serve as a gentle cleaning technique, particularly to remove oxidised layers, dirt, or old coatings before applying new protective layers. Such coatings, if designed to be reversible, often contain organic solvents that may affect the polymer matrix.

The objective of this work is to survey existing historical laminated artworks in the Czech Republic in terms of resin composition and surface condition and to evaluate the behaviour of selected epoxy and polyester resins when subjected to abrasive blasting with different media and when exposed to commonly used organic solvents found in conservation coatings.

EXPERIMENTAL

Field survey

A survey of laminated artworks located in public spaces was conducted in the Czech Republic. Each accessible object was photographically documented and visually evaluated, with special attention paid to the condition of the surface layer. Based on the observed condition, the artworks were classified into four categories:

Category C1 – Compact surface without signs of damage or water penetration through the gelcoat layer

Category C2 – Occurrence of fine hairline cracks to a limited extent.

Category C3 – Presence of more extensive cracking and loss of cohesion, but without delamination of the substrate.

Category C4 – Severe cracking, missing parts of the surface layer, and exposed glass-fibre reinforcement.

The elemental composition of the laminates was determined using a portable X-ray fluorescence spectrometer (Olympus Delta 50 Professional), which allowed estimation of fillers and pigments. Based on the elemental profiles, the type of resin could often be inferred. Since the investigated artworks were assumed to have been produced by hand lay-up at ambient temperature, curing of the unsaturated polyester resin would have required the addition of a cobalt-containing accelerator. Thus, the detection of cobalt in the XRF spectrum was considered indicative of a polyester-based laminate.

For objects exhibiting severe surface degradation, small samples (~2–3 mm²) were taken and analysed by ATR-FTIR spectroscopy (Nicolet iZ10, diamond crystal, 4 cm^{-1} resolution, nitrogen-cooled MCT detector) to confirm the type of resin.

Preparation of model samples

The unsaturated polyester (UP) and epoxy (EP) resins used for laboratory tests are listed in Table 1. All samples were prepared according to the manufacturers' technical data sheets. Some systems allowed for optional post-curing at elevated temperature; however, post-curing was deliberately omitted, as it is technically impractical for large-scale sculptures.

The resins were cast into cylindrical silicone moulds with a diameter of 50 mm and a height of approximately 10 mm. After curing, Shore D hardness (PCE-DD A/D durometer) was measured at ten points on each sample and the mean values and standard deviations were calculated.

Surface treatment by abrasive blasting

The abrasives tested and their specifications are summarised in Table 2. Abrasive blasting was carried out using a portable COBRA M sandblaster equipped with a 1 mm nozzle. The air pressure was maintained at 3 bar. Each sample was blasted on one half of its surface, while the other half was masked with durable tape to serve as a control. Blasting was carried out uniformly for 30 seconds at a fixed distance of 10 cm at an incidence angle of 30°.

The surface roughness was subsequently evaluated using a laser scanning confocal microscope (Olympus OLS5000 LEXT) and expressed as the areal roughness parameter S_a.

Tab. 1 Tested UP and EP resins

Resin type	Designation	Hardener	Supplier
UP – ortho, standard	Havelpol 2 (H2)	Butanox M50 2%	Havel Composites, s.r.o.
UP – ortho + MMA, UV	Havelpol 4 (H4)	Butanox M50 2% + Co accel. 0.5%	Havel Composites, s.r.o.
UP – ortho, high strength	Havelpol 5 (H5)	Butanox M50 2% + Co accel. 0.5%	Havel Composites, s.r.o.
EP – transparent	LH 210	H 10, UV stable	Havel Composites, s.r.o.
EP – universal	LH 289	H 289	Havel Composites, s.r.o.
EP – medium speed curing, laminating	Veropal LAM 200	Veropal LAM 200 – component B	Synpo, a.s.
EP – casting	Veropal UV Plus 100	Veropal UV Plus 100 – comp. B	Synpo, a.s.
EP – fast curing, laminating	Veropal LAM AERO 45	Veropal LAM AERO 45 – comp. B	Synpo, a.s.

Tab. 2 Specification of abrasives used for blasting

Abrasive	Designation	Grain size [mm]	Hardness [Mohs]	Supplier
Synthetic brown corundum	F180	0.075-0.090	9	Abranova, s.r.o.
Limestone – marble grit	Carolith VA	0.200-0.500	3	KRUSTAshop, s.r.o.
Quartz sand	ST 56	0.063-0.100	7	Sklopísek Střeleč, a.s.
Natural garnet	Mesh #80 RA	0.180-0.425	7-8	Abranova, s.r.o.
Crushed plastic	Type II	0.18-0.25	3.5	Abranova, s.r.o.

Application of organic solvents

Selected organic solvents were applied to the surfaces of the cured model samples using three strokes of a cotton swab. The following solvents were tested: acetone, propan-2-ol, toluene, White Spirit (Severochema; boiling point 155-194 °C; flash point 39 °C; content of aromatics 2-25 wt. %), xylene (isomeric mixture), hexane, and Shellsol® T (a mixture of aliphatic and cyclic hydrocarbons without aromatics). Solvents were chosen because of their common occurrence in conservation coatings. Except for the mixtures (white spirit, Shellsol® T), all were used with analytical grade purity (p.a.).

After solvent evaporation, the surface of each sample was inspected under a stereomicroscope (Olympus SZX9) to detect visible changes in colour or surface texture.

RESULTS AND DISCUSSION

Field survey of laminated artworks

More than 60 laminated artworks created between 1950 and 1990 were examined during the field campaign. These artworks typically included freestanding sculptures, reliefs, and architectural panels integrated into monuments. For forty-eight objects, the chemical composition of the resin matrix was determined using XRF and, in selected cases, confirmed by ATR-FTIR spectroscopy.

Among the analysed objects, thirty were made of unsaturated polyester resins (UP) and 18 were epoxy resins (EP). The discovery that nearly a third of the surveyed works were fabricated using epoxy resins was rather unexpected. According to the technical literature for artists, epoxy systems were considered expensive and unsuitable for lamination [1], with their use mainly recommended for adhesives and solvent-free coatings. In contrast, the vast majority of glass-fibre-reinforced artworks worldwide were produced using UP resins. A rare international example of an epoxy-based outdoor sculpture is Jardin d'émail (1974) by Jean Dubuffet, located at the Kröller-Müller Museum in the Netherlands.

However, in Czechoslovakia, artists often faced material shortages and had to rely on whatever resins were locally available. Domestic production of synthetic resins was limited and largely dependent on national sources, as imports from Western countries were strongly restricted [8].

The sculptures examined were divided into four categories according to the degree of surface deterioration, reflecting the presence of cracks and the exposure to glass reinforcement (see section "Field survey"). The results are shown in Figure 1 as a stacked-bar graph. Only about 15 % of objects, regardless of resin type, were classified as Category C1 with an intact surface. The most damaged categories (C3 and C4) represented approximately 55 % of UP resin objects and nearly 70 % of EP resin objects.

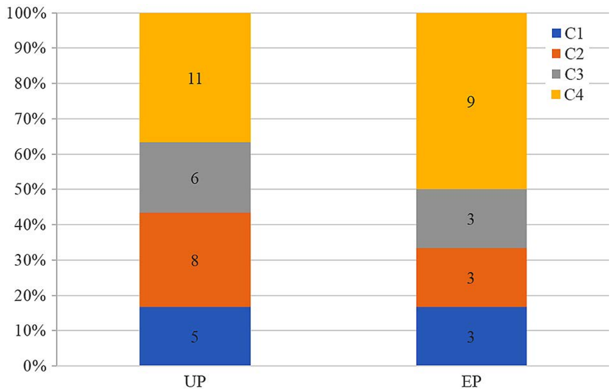

Fig. 1. Percentage distribution of deterioration categories for laminated artworks made of UP and EP resins. Numbers in blocks indicate the number of objects in each category

Although degradation depends on numerous factors (i.e. environmental exposure, maintenance, and manufacturing quality), the data suggest that historical EP laminates tend to deteriorate more rapidly and exhibit a higher propensity to crack. Among the common types of damage identified in outdoor laminated artworks [9], crack formation and penetration of water into the fibre reinforcement are among the most critical, as they compromise both mechanical integrity and long-term preservation of the object. Consequently, epoxy-based artworks may present a greater risk of irreversible loss than those made from polyester systems.

Hardness of tested resin samples

The mechanical response of the resins during abrasive blasting is strongly influenced by their hardness and toughness. The Shore D hardness measurements for all tested samples are summarized in Figure 2. The results indicate that the (UP) resins exhibit a higher hardness compared to that of the (EP) resins. All UP resins reached similar hardness values around 85 Shore D, while the EP resins LH 210, LH 289, and AERO 45 showed comparable values near 80 Shore D. The LAM 200 epoxy resin was slightly softer and the UV 100 casting resin showed the lowest hardness among all tested systems.

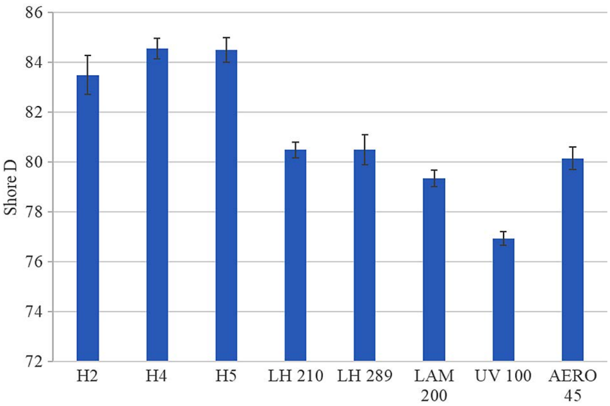

Fig. 2. Shore D hardness of tested UP and EP resin samples

Surface topography after blasting

The surface reliefs of the UP resins obtained by laser confocal microscopy are presented in Figure 3, where colour maps represent topographic variations. All UP resins showed similar surface morphologies for each abrasive medium. The smallest surface height variations (i.e., the lowest roughness) were observed after blasting with corundum, limestone, or sand, whereas blasting with garnet and plastic abrasives resulted in more pronounced topographic extremes (blue = depressions, red = peaks).

This trend correlates primarily with particle size: garnet and plastic abrasives possess larger grains than corundum and sand, producing coarser surface features. Interestingly, despite its relatively large grain size (0.2-0.5 mm), limestone yielded one of the smoothest surfaces. This effect is attributed to its low hardness and brittleness – limestone particles fragment upon impact, resulting in a predominantly polishing rather than cutting mechanism. In contrast, corundum, although composed of fine particles, has very high hardness and angular geometry, causing intensive micro-fracturing of the polymer matrix and roughly doubling the peak-to-valley height differences compared to limestone.

The surface topography of EP resin samples is shown in Figure 4. Unlike UP systems, EP resins exhibited more pronounced differences between individual formulations and abrasives.

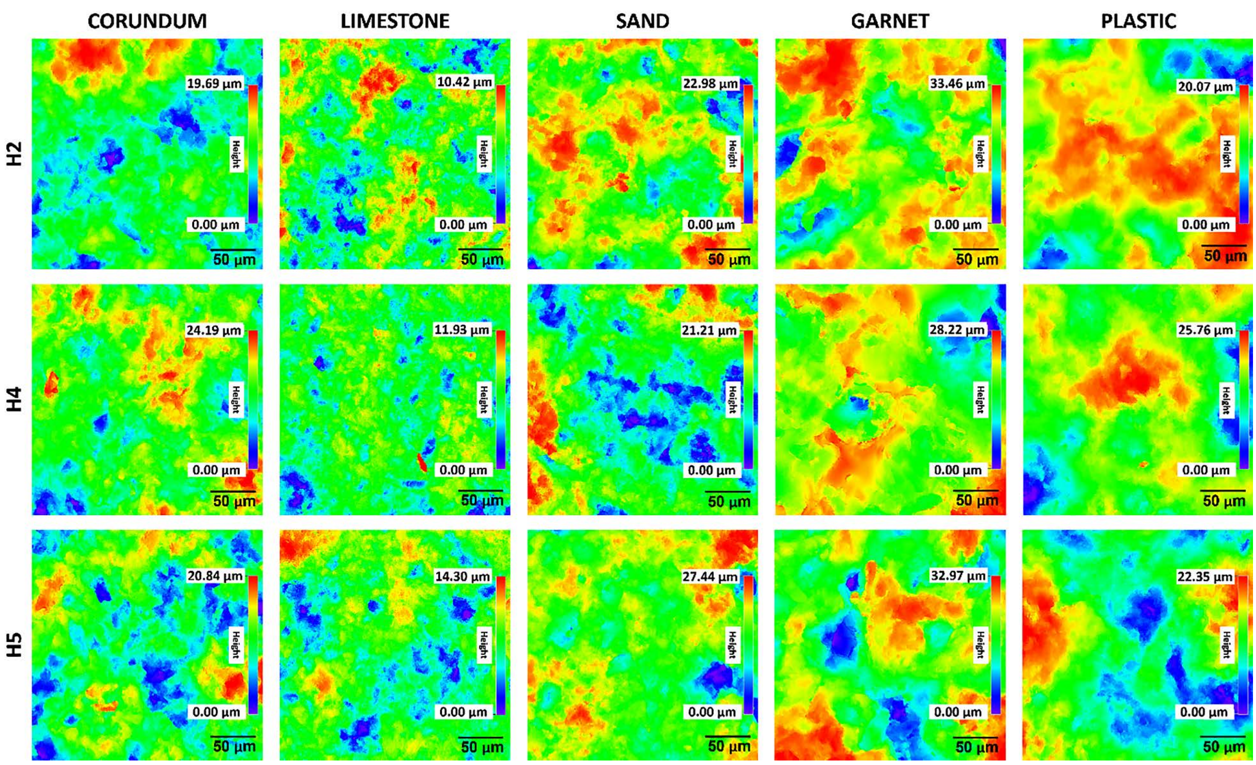

Fig. 3. Topography of blasted UP resin surfaces (colour-coded height mapping)

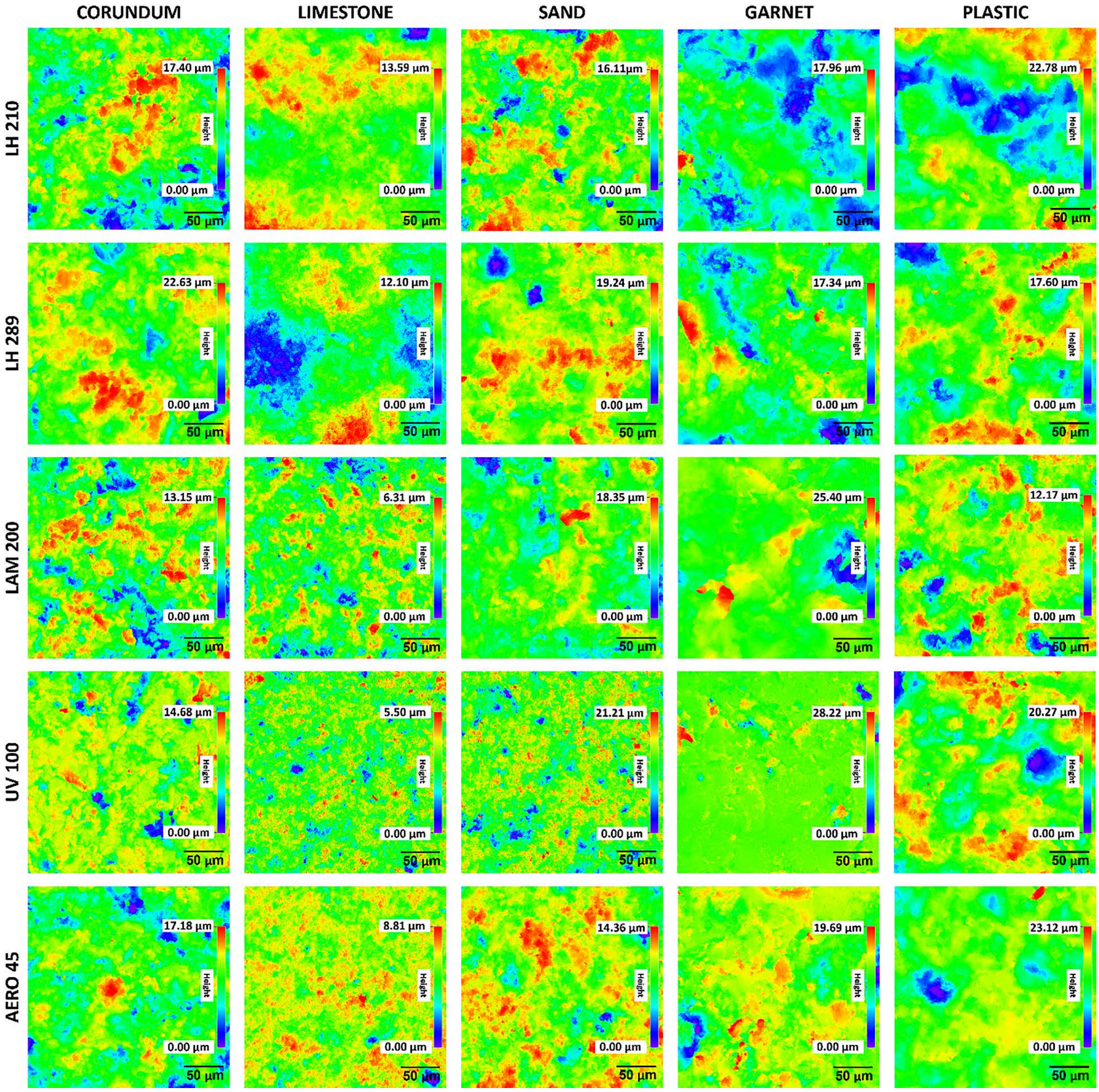

Fig. 4. Topography of blasted EP resin surfaces (colour-coded height mapping)

For LH 210 and LH 289, the surface patterns were relatively similar regardless of the abrasive used. In both cases, the surfaces displayed large regions of positive and negative height extremes, suggesting a localised brittle fracture during blasting. The LAM 200 resin, which is slightly softer, exhibited a visibly finer microstructure for all abrasives, especially corundum, limestone and sand. An even finer topography was observed for the softest resin, UV 100, particularly after blasting with corundum and limestone. The AERO 45 system showed surface morphology comparable to LH 210 and LH 289.

Overall, surface topography correlated well with resin hardness: softer EP systems developed smoother, less pronounced textures, while harder ones exhibited greater relief contrast. The only exception was observed for the plastic abrasive, which did not show a consistent dependence on resin hardness.

Quantitative roughness evaluation

The areal surface roughness parameter (S_a) was used to quantify the surface changes after blasting. The results for UP resins are presented in Figure 5, and for EP resins in Figure 6.

All UP systems exhibited comparable S_a values for the same abrasive, though the largest variability occurred for garnet, likely because of its larger particle size and thus stronger abrasive effect. The highest roughness values were obtained for garnet, while the lowest ($S_a \approx 1.5$ µm) were measured after limestone blasting.

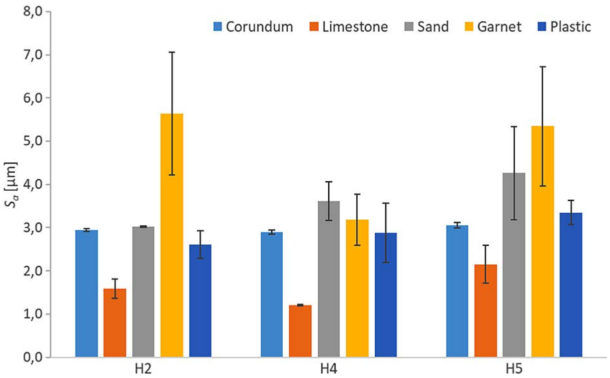

Fig. 5. S_a parameter after blasting for UP resins

For EP resins with similar hardness (LH 210, LH 289, AERO 45), S_a values were also very close for the same abrasive. In particular, AERO 45 showed slightly lower roughness than LH 210 and LH 289 after blasting with limestone. The softest resin, UV 100, consistently exhibited the lowest S_a values among all resins, regardless of the abrasive type. This suggests that soft epoxies can achieve very smooth surfaces even after exposure to harder or sharper abrasive particles.

Blasting with plastic abrasive did not show a predictable relationship between surface roughness and resin hardness, generally producing intermediate S_a values comparable to those of corundum. In general, plastic abrasives had inconsistent and difficult-to-predict effects on the surfaces of EP resin.

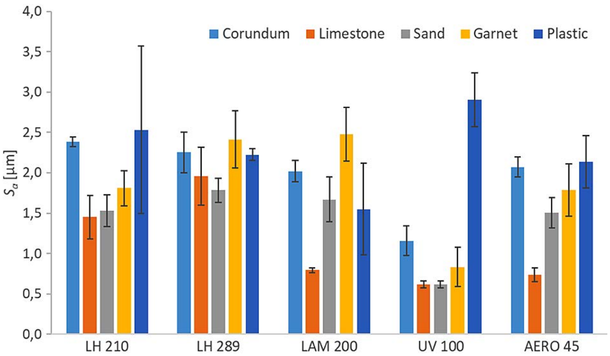

Fig. 6. S_a parameter after blasting for EP resins

Interaction with organic solvents

Surface alterations caused by contact with organic solvents were visually evaluated using optical microscopy. Figure 7 shows the typical surface damage of the polyester resin H2 after the application of acetone. The regular linear pattern observed on the surface originated from the silicone mould texture; however, after solvent exposure, this pattern was disrupted due to partial dissolution and softening of the surface layer.

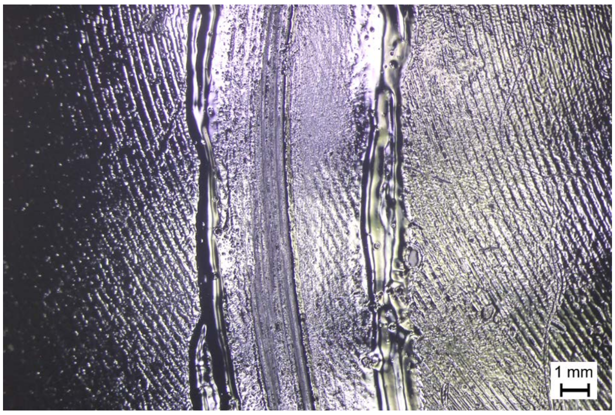

Fig. 7. Damage to the surface of the polyester resin H2 after acetone application

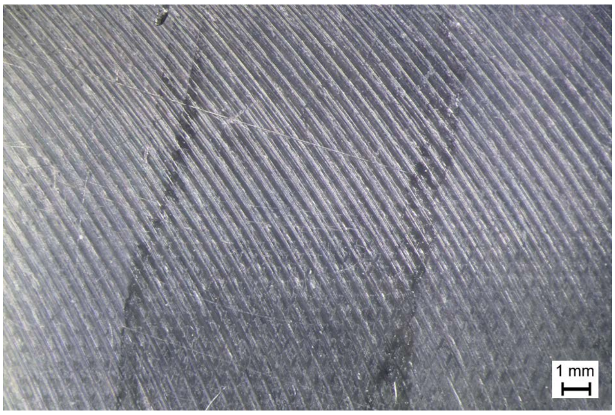

Fig. 8. Darkening of the epoxy resin LH 210 after acetone application

In contrast, Figure 8 illustrates a different type of damage, concretely visible darkening and boundary formation in the treated area of the epoxy resin LH 210. When either of these two effects (surface disruption or discolouration) occurred, the solvent was classified as damaging to the respective resin.

Table 3 summarises the occurrence of damage for all resins and solvents tested. The notation "YES" indicates that one of the two types of damage described above was observed.

The data clearly show that acetone was the most aggressive solvent for both resin systems. Only the UV 100 and AERO 45 epoxy resins withstanded acetone exposure without visible alteration. Historically, acetone has even been used to polish polyester laminates, as it effectively dissolves and smooths the surface layer [1].

Among the UP resins, H2 and H5 were more sensitive to polar solvents than H4. Nonpolar solvents, such as white spirit, hexane, or Shellsol® T, did not cause any detectable damage. The increased resistance of H4 may be related to its formulation containing methyl methacrylate (MMA), which reduces the surface inhibition of polymerisation caused by atmospheric

Tab. 3 Occurrence of surface damage after solvent application

	H2	H4	H5	LH 210	LH 289	LAM 200	UV 100	AERO 45
Acetone	YES	YES	YES	YES	YES	YES	NO	NO
Propan-2-ol	YES	NO	YES	NO	YES	YES	NO	NO
Toluene	YES	NO	YES	NO	NO	NO	NO	NO
White Spirit	NO	NO	NO	NO	NO	NO	NO	NO
Xylene	YES	NO	YES	NO	NO	NO	NO	NO
Hexane	NO	NO	NO	NO	NO	NO	NO	NO
Shellsol® T	NO	NO	NO	NO	NO	NO	NO	NO

oxygen. Typically, thin surface layers of UP resins can remain under-cured and therefore more susceptible to solvent attack; the specific composition of H4 likely mitigates this issue.

Epoxy resins generally exhibited higher chemical resistance. For LH 210, LH 289, and LAM 200, exposure to acetone caused only a colour change without structural damage. The UV 100 and AERO 45 systems showed no alteration under any of the tested solvents, confirming their superior resistance and suitability for use in restoration environments where solvent-based coatings can be applied.

CONCLUSIONS

From the combined field survey and laboratory experiments on abrasive blasting and solvent application, the following main conclusions can be drawn:

Among the laminated artworks examined in the Czech Republic, the majority were made of unsaturated polyester (UP) resins; however, epoxy (EP) systems represented an unexpectedly high proportion – approximately 30%.

Statistical evaluation indicates that historical EP laminates tend to deteriorate faster than UP laminates, with a higher proportion of epoxy-based objects falling into critical condition categories.

Both the abrasive type and the hardness of the resin significantly influence the surface morphology. Softer EP resins exhibit lower roughness even after exposure to hard abrasives, while harder UP resins achieved minimal roughness after blasting with soft limestone particles.

Acetone proved to be the most aggressive solvent for both resin systems, while nonpolar aliphatic solvents (hexane, Shellsol® T) did not cause detectable surface damage. Protective coatings formulated with nonpolar solvents therefore appear to be suitable for use on laminated artworks.

Further research will focus on the long-term monitoring of surface changes after various conservation treatments and on assessing environmental ageing effects on the polymer matrix.

Acknowledgement

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