

UV Ageing of Epoxy Resins for Surface Protection of Masonry Bridges:

ATR-FTIR and GC-MS Analysis

UV stárnutí epoxidových pryskyřic pro povrchovou ochranu zděných mostů: analýza metodami ATR-FTIR a GC-MS

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Summary

Epoxy resins are increasingly applied in conservation and strengthening works of masonry bridges, where they serve as binders, coatings, or adhesives. Their durability under outdoor exposure is critical, since ultraviolet (UV) radiation can initiate photochemical degradation. This study investigates the UV ageing of two epoxy resin systems, designated HEX and CH, in the context of their potential use for protective coatings in bridge rehabilitation. ATR-FTIR spectroscopy combined with GC-MS analysis was used to evaluate chemical changes after 1584 h of UV-A exposure. The HEX resin showed pronounced photooxidation, evidenced by strong carbonyl and hydroxyl bands and reduction of epoxy ring signals, whereas CH exhibited significantly lower degradation. GC-MS confirmed higher residual benzyl alcohol and lower antioxidant (BHT) content in HEX, correlating with inferior UV stability. The findings indicate that resin CH offers more reliable long-term performance for surface protection of masonry bridges exposed to natural weathering.

Key words

Epoxy resins, masonry bridges, UV ageing, ATR-FTIR, GC-MS, protective coatings.

1. Introduction

Historic masonry structures represent a significant part of cultural heritage. Their long-term preservation requires protection against moisture ingress, atmospheric pollution, and weathering, while ensuring that original materials remain visible and structurally sound. Coating systems are one of the key protective strategies, providing a barrier against environmental agents and extending service life. However, the design and selection of coatings for heritage applications must take into account not only performance, but also compatibility with historic substrates and reversibility of interventions.

1.1. Requirements for Coatings in Heritage Conservation

Protective coatings for historic masonry differ from modern industrial applications in several aspects:

- **Water repellence and breathability** – The coating must prevent liquid water penetration but allow vapor diffusion, avoiding damage from trapped moisture.
- **UV and weather resistance** – Exposure to solar radiation and fluctuating climatic conditions requires high stability of the coating material.

- **Chemical compatibility** – Coatings should not react negatively with masonry minerals, lime, or existing conservation materials.
- **Reversibility** – Interventions in heritage structures should be removable or retreatable without irreversible effects.
- **Aesthetic neutrality** – Coatings should maintain the authentic appearance of masonry surfaces and avoid undesirable gloss or color change.

1.2. Types of Coating Systems

Several types of coatings are applied to historic masonry:

1. **Silane- and siloxane-based hydrophobic coatings [1]** – Widely used for water repellence due to their good penetration, vapor permeability, and long-term durability.
2. **Mineral coatings (limewash, silicate paints) [2]** – Provide traditional appearance and compatibility with lime-based substrates, offering limited protection but excellent reversibility.
3. **Polymeric coatings (acrylic, epoxy, polyurethane) [2]** – Ensure strong protective films and chemical resistance. Their use must be carefully evaluated because of limited breathability and potential incompatibility with historic materials.
4. **Nanocomposite and hybrid systems [3, 4]** – Recent research explores coatings with nanoparticles (e.g., TiO₂, ZnO, SiO₂) to improve photocatalytic self-cleaning, UV resistance, or antibacterial properties while maintaining permeability.

2. Experimental Methods

2.1. Materials and Sample Preparation

Two commercial epoxy resins, designated CH and HEX, were prepared as thin films on cardboard substrates and cured according to manufacturer's recommendations. These formulations were selected as representative systems potentially applicable in protective coatings for bridge masonry.

2.2. UV Exposure

Samples were exposed in a MYTRON climate chamber equipped with UV-A (340 nm) lamps at 45 ± 2 °C, 45% RH, for 1584 h, simulating long-term outdoor ageing conditions relevant for bridge surfaces.

2.3. ATR-FTIR Analysis

Spectra were recorded using a Nicolet iN10 spectrometer with a diamond ATR crystal, covering 4000–500 cm⁻¹ at 1 cm⁻¹ resolution. Ten random spots per sample were averaged to obtain representative spectra.

2.4. Complementary GC-MS Analysis

Residual components were analyzed to quantify benzyl alcohol and antioxidant BHT, since both significantly influence the stability of epoxy coatings in long-term structural applications.

3. Results and discussion

3.1. FTIR Results

- **HEX resin** (Figure 1): strong carbonyl band increase ($\sim 1730\text{ cm}^{-1}$), broadened hydroxyl band ($3200\text{--}3500\text{ cm}^{-1}$), reduction of epoxy absorption ($\sim 910\text{ cm}^{-1}$), and emergence of aromatic degradation products ($\sim 1600\text{ cm}^{-1}$).
- **CH resin** (Figure 2): moderate increases in C=O and OH bands, minimal decrease of epoxy signal, weaker aromatic bands.

The HEX formulation suffered advanced photooxidation, while CH retained higher structural integrity, indicating better suitability for protective coatings.

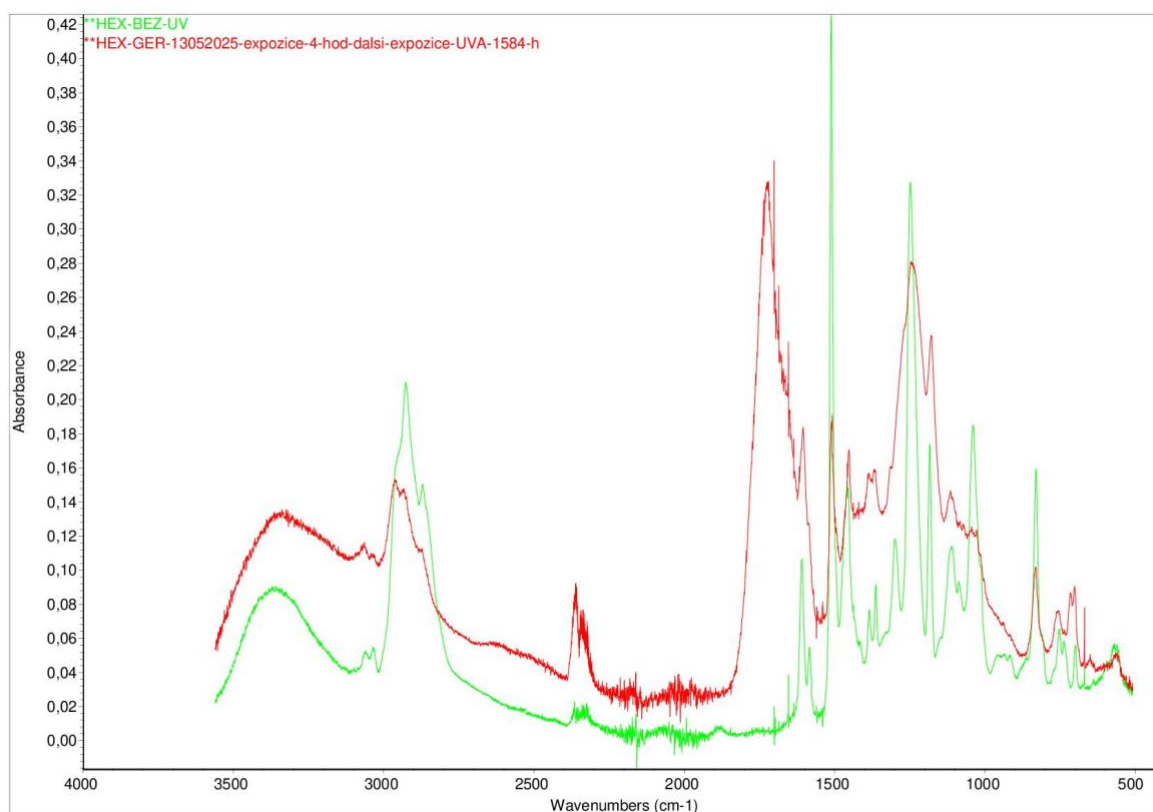


Figure 1. Results of ATR-FTIR analysis of the HEX sample. **Green spectrum** – sample without exposure, **red spectrum** – sample after exposure to UV-A.

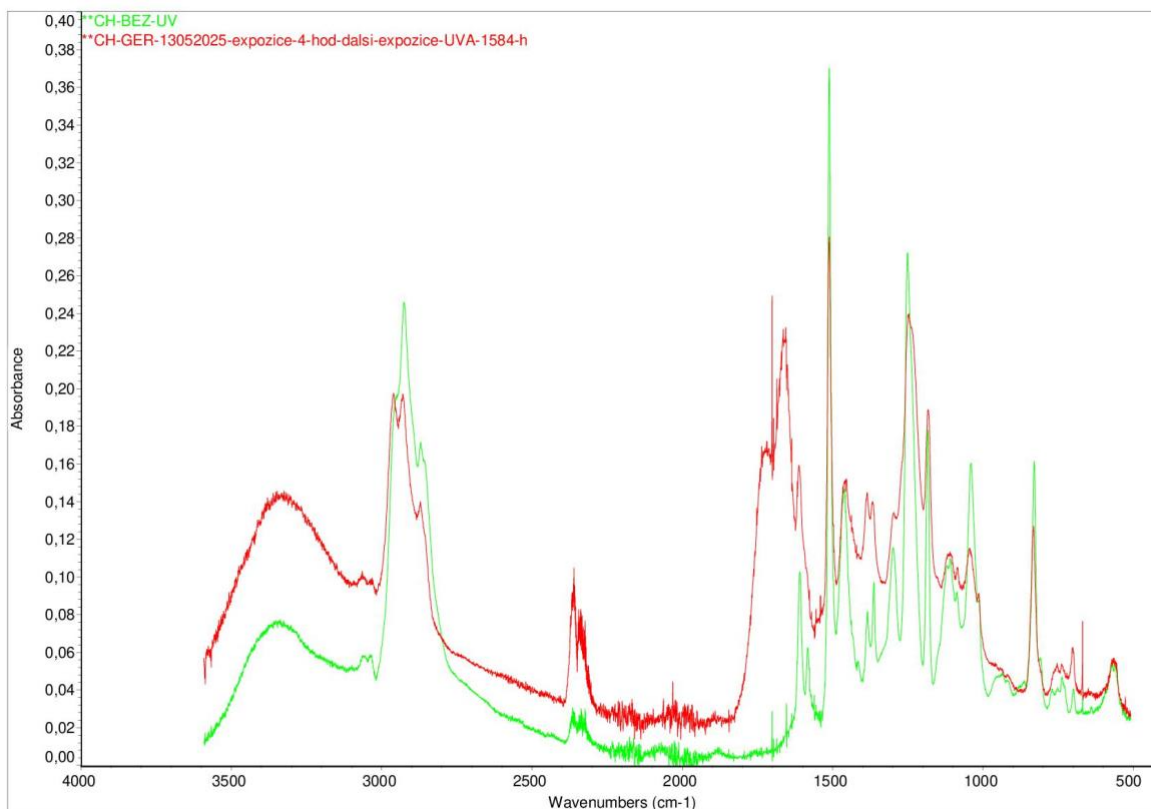


Figure 2. Results of ATR-FTIR analysis of the HEX sample. **Green spectrum** – sample without exposure, **red spectrum** – sample after exposure to UV-A.

3.2. Correlation with GC-MS (Table 1.)

- HEX contained $\sim 1.6\times$ more residual benzyl alcohol, reducing curing efficiency and accelerating degradation.
- CH contained $\sim 1.3\times$ more BHT antioxidant, improving stabilization against UV-driven oxidation.
- Thermal analysis confirmed higher volatile content in HEX, pointing to reduced stability.

Table 1. Correlation of GC-MS and FTIR findings with interpretation of degradation mechanisms.

Findings	GC-MS	FTIR	Interpretation
Higher benzyl alcohol content	✓	Increase in –OH bands	Enhances hydrolysis, polarity, and degradation
Lower BHT content	✓	Increased formation of C=O, –OH	Lower UV stability, less effective protection
Aromatic backbone (bisphenol A)	✓	Bands at $\sim 1600\text{ cm}^{-1}$	Susceptibility to UV radiation, “yellowing”
Mechanical damage / disintegration	✓ (observed in HEX)	Strong FTIR band changes	Correlates with chemical degradation of the polymer

3.3. Implications for Masonry Bridge Rehabilitation

For coatings and adhesives in bridge rehabilitation, these results suggest that HEX formulations may undergo rapid loss of protective properties under UV exposure, leading to surface embrittlement and yellowing. In contrast, CH formulations provide higher UV resistance and thus greater reliability in preserving structural and aesthetic functions of masonry bridges.

4. Conclusion

Epoxy resin formulations differ significantly in their resistance to UV-induced degradation. Resin HEX exhibited advanced ageing with substantial chemical changes, linked to higher benzyl alcohol content and lower antioxidant levels. Resin CH showed markedly improved stability, making it a more suitable candidate for protective applications in the rehabilitation of masonry bridges.

Selecting UV-stable epoxy systems is essential to ensure long-term durability of coatings and adhesives used in structural conservation. ATR-FTIR combined with GC-MS offers a powerful diagnostic approach to guide material selection in bridge engineering practice.

5. Acknowledgments

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References

- [1] LISCI, Carla; SITZIA, Fabio; PIRES, Vera; and MIRÃO, José. *Aging of Limestones and Silane–Siloxane-Based Protective Hydrophobics: The Impact of Heating–Cooling and Freeze–Thaw Cycles*. Heritage, 2024, 7(12), pp. 6657–6682. ISSN 2571-9408. Available at: <https://doi.org/10.3390/heritage7120308>. [Accessed 2025-09-01].
- [2] SADAT-SHOJAI, Mehdi and ERSHAD-LANGROUDI, Amir. *Polymeric coatings for protection of historic monuments: Opportunities and challenges*. Journal of Applied Polymer Science, 2009, 112(4), pp. 2535–2551. ISSN 0021-8995. Available at: <https://doi.org/10.1002/app.29801>. [Accessed 2025-09-01].
- [3] ALDOSARI, Mohammad Ateeq; DARWISH, Sawsan S.; ADAM, Mahmoud A.; ELMARZUGI, Nagib A.; and AHMED, Sayed M. *Using ZnO nanoparticles in fungal inhibition and self-protection of exposed marble columns in historic sites*. Archaeological and Anthropological Sciences, 2019, 11(7), pp. 3407–3422. ISSN 1866-9557. Available at: <https://doi.org/10.1007/s12520-018-0762-z>. [Accessed 2025-09-01].
- [4] CİNTEZĂ, Ludmila Otilia and TĂNASE, Maria Antonia. *Multifunctional ZnO Nanoparticle-Based Coatings for Cultural Heritage Preventive Conservation*. In: *Thin Films*. IntechOpen, 2021. ISBN 9781838819866. Available at: <https://doi.org/10.5772/intechopen.94070>. [Accessed 2025-09-01].