doi.org/10.15392/2319-0612.2025.2653
2024, 12(4A) | 01-11 | e2653
Submitted: 2024-08-28
Accepted: 2024-11-22

Restoration of culturally significant wooden artifacts using gamma radiation curable polyester resins

Pereira, M. A. M. G [a*], Oliveira, M. J. A..; Otubo, L.; Fernandes, V.; Vasquez, P. A. S.

[a] Institute of Energy and Nuclear Research (IPEN / CNEN – SP), Av. Professor Lineu Prestes, 2242, 05508-00, São Pàulo, SP, Brazil.

*Correspondence: mariamoraespereira@usp.br

Abstract: The preservation of cultural artifacts, particularly those made of wood, is a significant concern for conservators due to their susceptibility to damage from xylophagous organisms, fungi, and bacteria. This study investigates the use of gamma radiation to cure polymeric resins for the consolidation of three wood species: cedar (*Cedrela* spp.), canafistula (*Peltophorum dubium*), and ivorywood (*Balfourodendron riedelianum*). Various resins, including polyester LP 8847® combined with styrene, were subjected to gamma radiation to induce cross-linking without the need for catalysts. The results demonstrated that gamma radiation effectively cured the resin, filling wood pores and enhancing structural integrity. The analysis of apparent density showed that cedar, canafistula, and ivorywood exhibit different absorption capacities, with cedar absorbing the most resin and canafistula the least. Optical and Scanning Electron Microscopy confirmed the efficient penetration of resin into the wood samples, indicating that gamma radiation can be a viable technique for wood consolidation and protection against degrading agents

Keywords: gamma radiation 1, polymeric resins 2, wood conservation 3, cultural heritage preservation 4.

doi.org/10.15392/2319-0612.2025.2653
2024, 12(4A) | 01-11 | e2653
Submitted: 2024-08-28
Accepted: 2024-11-22

Restauração de artefatos de madeira de valor cultural, utilizando resinas poliméricas curáveis por radiação gama

Resumo: A preservação de artefatos culturais, particularmente aqueles feitos de madeira, é uma preocupação significativa para os conservadores devido à sua suscetibilidade a danos de organismos xilófagos, fungos e bactérias. Este estudo investiga o uso de radiação gama para curar resinas poliméricas para a consolidação de três espécies de madeira: cedro (Cedrela spp.), canafistula (Peltophorum dubium) e ivorywood (Balfourodendron riedelianum). Várias resinas, incluindo poliéster LP 8847® combinado com estireno, foram submetidas à radiação gama para induzir reticulação sem a necessidade de catalisadores. Os resultados demonstraram que a radiação gama curou efetivamente a resina, preenchendo os poros da madeira e aumentando a integridade estrutural. A análise da densidade aparente mostrou que o cedro, a canafistula e o pau marfim apresentam diferentes capacidades de absorção, com o cedro absorvendo mais resina e a canafistula, menos. A microscopia óptica e eletrônica de varredura confirmou a penetração eficiente da resina nas amostras de madeira, indicando que a radiação gama pode ser uma técnica viável para consolidação da madeira e proteção contra agentes degradantes.

Palavras-chave: radiação gama 1, resina polimérica 2, conservação de madeira 3, preservação do patrimônio cultural, 4.

1. INTRODUCTION

The protection of cultural artifacts, particularly those made of wood that are susceptible to damage by xylophagous organisms, fungi, and bacteria, is a constant concern for conservators and restorers. Generally, various coatings based on resins and adhesives, ranging from natural products to synthetic polymers, have been employed for the preservation of these cultural artifacts. Gamma radiation, specifically derived from Cobalt-60, emerges as an innovative technique, offering advantages over traditional methods, such as instant efficacy, absence of chemical residues, and the ability to penetrate deeply into treated objects, promoting the disinfection of pests and pathogens without damaging the material [1, 2, 3, 4, 5, 6].

This study focused on the investigation of polymeric resins cured by gamma radiation for the consolidation of three wood species: cedar (Cedrela spp. P. Browne), canafistula (Peltophorum dubium), and ivorywood (Balfourodendron riedelianum), with the aim of applying them in the conservation and restoration of cultural heritage artifacts. These wood samples were selected due to their widespread preference among artisans, owing to their popularity, frequency of use, and significance in the crafting of sacred images by master artisans, both in past centuries and in the present day [6].

The studied and characterized resins were as follows: polyester LP 8847®; methyl methacrylate (MMA) monomer; polyester LP 8847® (33%) with styrene monomer (SM) (67%); and polyester LP 8847® (50%) with MMA (50%), all of which were cured through irradiation. The unsaturated polyester resin LP 8847® is an isophthalic resin that exhibits excellent chemical and thermal properties as well as good resistance to hydrolysis [7]. This type of resin is capable of producing high-performance composites when combined with reinforcing materials, which are used in various applications [8].

The research determined the optimal gamma irradiation conditions for curing the resin without compromising the material's structure. The post-irradiation resins were characterized, and the unsaturated polyester resin LP 8847 with styrene was selected for additional testing for impregnation into the wood samples.

2. MATERIALS AND METHODS

The unsaturated isophthalic polyester resin LP 8847® with styrene (SM) was supplied by the Reichhold group and subjected to gamma irradiation to induce cross-linking. Tests were conducted on wood samples of canafistula, cedar, and ivorywood species to evaluate the effectiveness of impregnation and consolidation.

The wood samples (cedar, canafistula, and ivorywood), with dimensions specified in Table 1, were carefully prepared for the impregnation process in the reactor. Initially, the samples were subjected to a vacuum treatment at 20 mmHg in a closed reactor to ensure complete removal of air from the wood pores. The system was then pressurized with nitrogen at 5 atm, creating an inert atmosphere to prevent oxidation of the wood and resin during the process. The resin, contained in an external tank, was transferred into the reactor through a ¼-inch polyethylene hose, driven by positive pressure. This impregnation process ensured complete filling of the wood pores and was maintained for 24 hours to ensure thorough penetration of the resin throughout the samples. After this period, the excess resin was drained, and the samples were carefully removed from the reactor, ready for subsequent stages of analysis. These wood samples were wrapped in cotton fabric and subjected to gamma irradiation in the Cobalt-60 Multipurpose Irradiator, located at the Radiation Technology Center (CETER). The irradiation was conducted for a period of 5 hours, after which the process was interrupted to remove the cotton fabric with excess resin, before returning the samples to the irradiator to complete the necessary curing time.

The characterization of the samples involved analytical techniques such as Scanning Electron Microscopy (SEM), Optical Microscopy (OM), and Apparent Density Analysis. The measurement of the wood samples' density was performed using a precision balance, a container with one liter of water, and a holder to secure the wood sample.

To determine the density of the wood samples, a precision balance, a graduated container with water, and a support were used. Initially, each dry sample was weighed. Next, the initial volume of water in the container was measured. The sample was then fully immersed in the water, and the new volume was recorded (Figure 1). The difference between the final and initial volumes corresponds to the volume of the wood sample. Finally, the density of each sample was calculated by dividing its mass by the determined volume. This simple and effective method allows for the calculation of wood density, a fundamental property for this study. This experiment was conducted at the Laboratory of Wood Anatomy and Properties of the IPA (LAPM/IPA), formerly known as the Forest Institute.

Table 1: Dimensions of samples from three wood species.

Canafístula *Peltophorum Dúbium* Taub.	Pau- marfim *Balfourodendron riedelianum*	Cedro *Cedrela* spp., P. Browne
Length: 7.6 cm	Length: 4.9 cm	Length: 4.9 cm
Width: 1.9 cm	Width: 1.8 cm	Width: 4.9 cm
Thickness: 1.9 cm	Thickness: 1.8 cm	Thickness: 0.8 cm

3. RESULTS AND DISCUSSIONS

The Scanning Electron Microscopy (SEM) analysis (Figure 1) shows the surface morphology of the cut and fracture of the polyester resin sample with 33% styrene and 67% polyester. It can be observed that Figures 1B and 1C exhibit voids and roughness, while Figures 1A and 1D display slight roughness without voids. The presence of styrene directly influences the formation of the polymer network, thereby enhancing the material's stability [9].

In Optical Microscopy (OM) (Figure 2), the samples of wood were examined both before and after the impregnation with resin, consisting of 33% polyester LP 8847® and 67% styrene. Optical microscopy revealed the presence of microfibers and macropores in the canafistula and ivorywood samples prior to impregnation. The impregnation with polyester/styrene resin resulted in the filling of macropores, as evidenced by the color change in the ivorywood. This change indicates a higher concentration of resin in the macropores. The formation of a homogeneous polymer matrix, confirmed by this optical microscopy technique, demonstrates the efficient penetration of the resin into the wood samples (Figure 6). These results, along with the observation that the macropores were filled with resin, suggest that impregnation with radiocurable resins could be a viable technique for the preliminary treatment of sacred imagery pieces, providing protection against insect damage and consolidating areas damaged by such actions.

Apparent Density of Wood Samples: The analysis of the apparent density of the wood samples impregnated with resin showed an increase in density after treatment, indicative of the effectiveness of the impregnation for structural reinforcement of the woods (Tables 2 and 3). The results demonstrate a correlation between the density of the wood and the absorption of the radiocurable resin. This relationship indicates that the ability of each wood species to absorb the resin is influenced by its specific density. This finding is crucial for the application of these resins in the conservation of wooden artifacts, opening new possibilities for the preservation of cultural heritage.

The analysis of the density of cedar (*Cedrela* spp., P. Browne), canafistula (*Peltophorum dubium* (Spreng.) Taub.), and ivorywood (*Balfourodendron riedelianum* (Engl.) Engl.) revealed that cedar falls into the very light category (> 0.40 g/cm³), while canafistula is classified as light (0.40 to 0.55 g/cm³), and ivorywood is categorized as dense (0.80 to 0.90 g/cm³), according to literature data [10, 11, 12]. Additionally, resin absorption tests indicated that cedar had the highest absorption capacity (11.3%), followed by ivorywood (10.8%), while canafistula exhibited the lowest absorption (4.15%). It is important to note that the treatment with resin and radiation did not cause significant changes in the apparent density of the woods.

Figure 2: SEM Images of LP 8847® Polyester: (A) Cross-section; (B) Fracture, 33% LP 8847® polyester with 67% styrene; (C) Cross-section; (D) Fracture, both with 2,500x magnification, cross-linked by gamma radiation

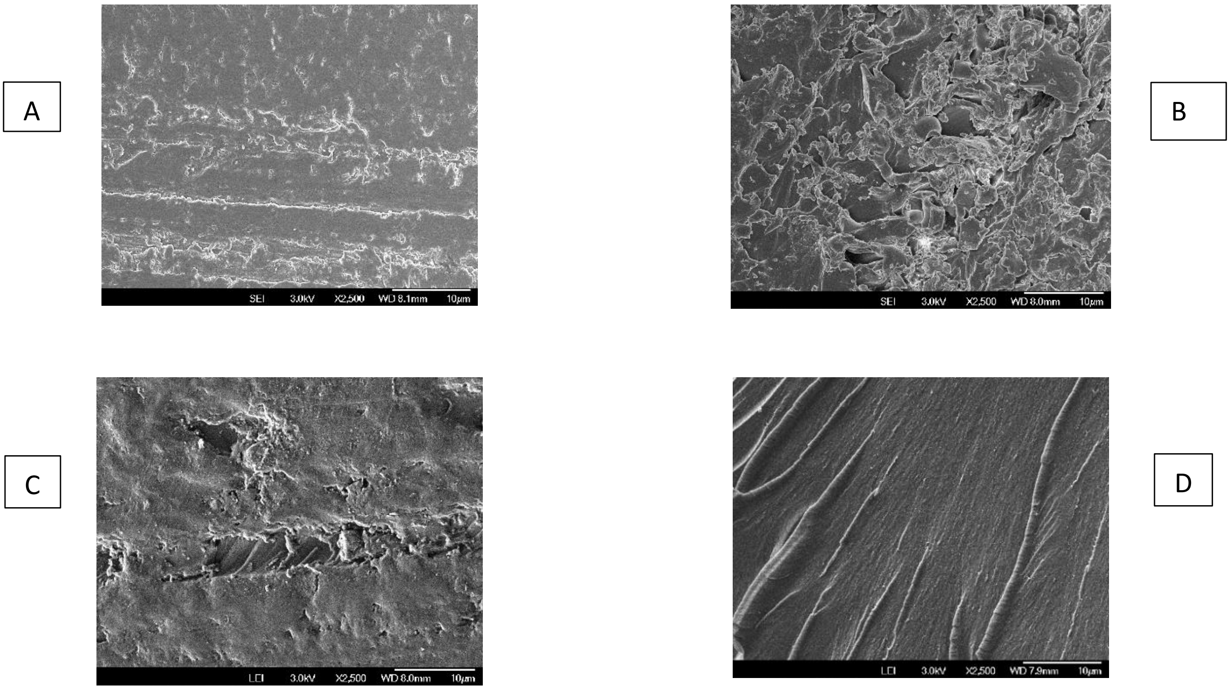

Figure 5: Optical Microscopy of Pau-Marfim Sample – Surface: (a) Before irradiation without resin; (b) With resin and irradiated

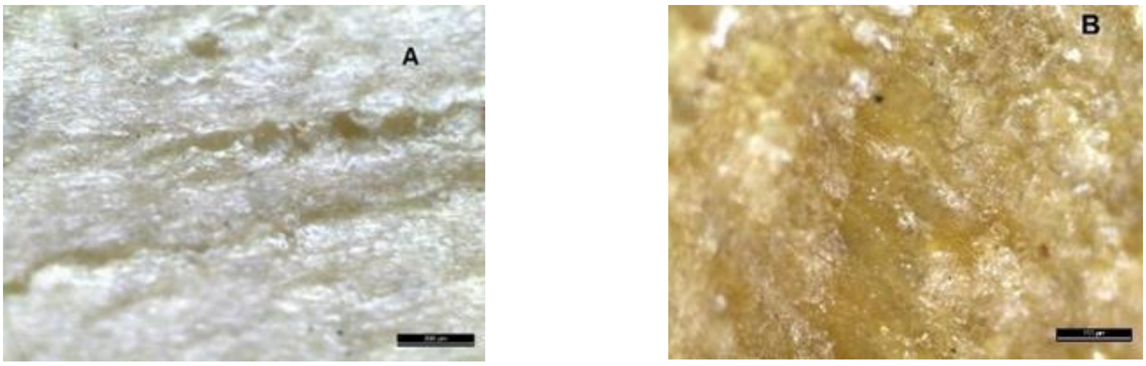

Figure 6: Optical Microscopy of Cedar (*Cedrela* spp., *P. Browne*) Sample – Surface: (A) Before irradiation, without resin; (B) With resin and after irradiation

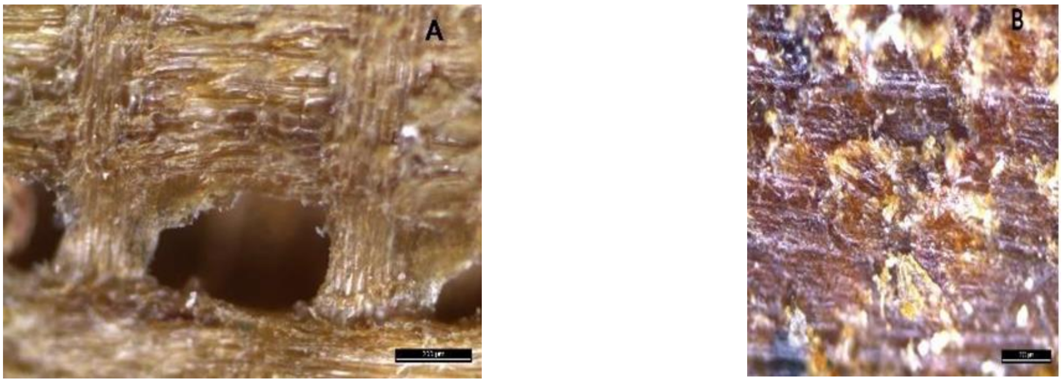

Table 2: Apparent Density of Wood Samples, Non-Irradiated and Without Resin Impregnation

Sample	Species	Dry weight (12%)	Wet weight (12%)	Apparent density (Kg/m³)
1	Ivory wood *Balfourodendronriedelianum* (Eng.) Eng..	21.2	23.81	0.8903
2	Canafistula *Peltophorum dubium* (Spreng.) Taub.	16.64	23.94	0.6950
3	Cedar Cedrela ssp. P. Browne	12.36	24.27	0.5092

Table 3: Apparent Density of Irradiated Wood Samples with Resin Impregnation

Sample	Species	Dry weight (12%)	Wet weight (12%)	Apparent density (Kg/m³)
1	Ivory wood *Balfourodendronriedelianum* (Eng.) Eng..	17.71	19.43	0.9114
2	Canafistula *Peltophorum dubium* (Spreng.) Taub.	21.79	31.31	0.6959
3	Cedar Cedrela ssp. P. Browne	15.02	23.25	0.6460

CONCLUSIONS

Different types of resins were subjected to gamma radiation to achieve cross-linking (curing) without the need for catalysts. Among these resins, LP 8847®, combined with styrene and exposed to gamma radiation, was selected. This combination promoted complete curing of the resin, filling the wood pores and increasing its mass. The results demonstrate the potential of gamma radiation as an effective technique for wood consolidation, offering protection against degrading agents. However, the authors emphasize the need for further research to deepen the understanding of this technique and its applications in cultural heritage conservation. Future research may further explore the optimization of resin formulations and impregnation techniques to enhance the conservation and restoration of wooden sculptures with compromised structural degradation that cannot be restored using conventional methods.

ACKNOWLEDGMENT

The authors acknowledge the financial support from the International Atomic Energy Agency (IAEA), Project 2020.06.IPEN.02.PD, and from REICHHOLD GROUP, represented by Cristian Lorenzetto Campos and Ilson Salvador, Technical Assistance in Brazil, for the sponsorship through the donation of the resin.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

REFERENCES

[1] CANANI, A. S. K. B. Herança, Sacralidade e Poder: sobre as diferentes categorias do patrimônio histórico e cultural do Brasil. **Horizontes Antropológicos**, Porto Alegre, ano 11, n. 23, pp. 163-175, 2005.

[2] FRANCIONI, F. Avaliação do trabalho de definição de padrões do setor cultural da **UNESCO, parte III-1972** Convenção Em relação à Proteção do Mundo Cultural e Herança Natural. 1972.

[3] CRUZ, R. C. A. "Patrimonialização do Patrimônio": Ensaio sobre a relação entre turismo, "Patrimônio Cultural" e produção do espaço. **GEOUSP - Espaço e Tempo**, São Paulo, n. 31, p. 95-104, 2012.

[4] VÁSQUEZ, P. Desinfecção e consolidação de materiais arquivados e artefatos do patrimônio cultural. *In:* Técnicas de Processamento de Radiação. Conferência Internacional sobre Aplicações da Ciência da Radiação e Tecnologia (ICARST 2017) 24 a 28 abr. 2017, Viena. **Livro de Resumos.** 2017.

[5] CHMIELEWSKI , A. G.; HAJI-SAEID, M.; AHMED , S. Progress in radiation processing of polymers. **Nuclear Instruments and Methods in Physics Research**: Section B: Beam Interactions with Materials and Atoms, Amsterdã, v. 236, p. 44-54, 2005.

[6] RIMDUSIT, S.; SOMSAENG, K.; KEWSUWAN, P.; JUBSILP, C.; TIPTIPAKORN, S. Comparison of Gamma Radiation Crosslinking and Chemical Crosslinking on Properties of Methylcellulose Hydrogel. **Engineering Journal**, v. 16, n. 4, p. 1-14, 2012.

[7] NAIKWADI, A. T.; SHARMA, B. K.; BHATT, K. D.; MAHANWAR, P. A. Gamma Radiation Processed Polymeric Materials for High Performance Applications: A Review. **Frontiers in Chemistry**, Lausanne, v. 10, p. 1-15, 2022.

[8] COELHO, B.; QUILTES, M. R. E. **Estudo da escultura devocional em madeira**. Belo Horizonte: Fino Traço, 2014. 188 p. ISBN 978-85+8054-218-9.

[9] REICHHOLD (Mogi das Cruzes). Composites Polylite® LP 8847®. **Boletim Técnico**, Mogi das Cruzes, p. 1-2, 2016.

[10] MELO, A. J. L. **Avaliação da estrutura de tecidos técnicos como elemento reforçante em compósitos poliméricos sistema poliéster isoftálico**. Orientador: Danilo Alves Pinto Nagem. 2013. 89 f. Dissertação (Mestrado em Engenharia

Mecânica) - Universidade Federal do Rio Grande do Norte - Centro de Tecnologia, Natal, 2013. Available at: https://repositorio.ufrn.br/jspui/bitstream/123456789/15705/1/AlanJLM_DISSERT.pdf. Accessed on: 7 apr. 2024.

[11] SPADARO, G.; CALDERARO, E.; RIZZO, G. Ageing due to gamma-radiation of a crosslinked polyethylene. **European Polymer Journal**, Amsterdã, v. 28, p. 257-259, m 1992.

[12] CARVALHO, P. E. R. Pau-Marfim - Balfourodendron riedelianum: Taxonomia e Nomenclatura. **Embrapa Florestas**: Circular Técnica, Brasília, n. 93, ed. 1, p. 1-11, 2004.

[13] FARIAS, D. T.; MELO, R. R. Propriedades físicas da madeira de cinco espécies nativas da Caatinga. **Advances in Forestry Science**, Cuiabá, v. 7, n. 3, p. 1147-1152, 2020.

[14] MELO, A. J. L. **Avaliação da estrutura de tecidos técnicos como elemento reforçante em compósitos poliméricos sistema poliéster isoftálico**. Orientador: Danilo Alves Pinto Nagem. 2013. 89 f. Dissertação (Mestrado em Engenharia Mecânica) - Universidade Federal do Rio Grande do Norte - Centro de Tecnologia, Natal, 2013. Available at: https://repositorio.ufrn.br/jspui/bitstream/123456789/15705/1/AlanJLM_DISSERT.pdf. Accessed on: 7 apr. 2024.

[15] NAIKWADI, A. T.; SHARMA, B. K.; BHATT, K. D.; MAHANWAR, P. A. Gamma Radiation Processed Polymeric Materials for High Performance Applications: A Review. **Frontiers in Chemistry**, Lausanne, v. 10, p. 1-15, 2022.
