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Preserving cultural heritage through radiation-curing resin consolidation: a case study of an indigenous ceramic vessel

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Abstract: This article presents a case study on a ceramic vessel belonging to the Amazonian indigenous people, Asurini do Xingu, to investigate the use of gamma radiation for consolidating cultural heritage. Traditionally, gamma radiation is used to impregnate cultural artifacts with a radiocurable resin. In this study, the consolidating resin was applied only to the external surface of the vessel by brushing. The object was weighed before and after consolidation, and a colorimeter was used to evaluate possible color changes. The results indicated that the method was effective, with no negative effects on the appearance of the cultural item.

Keywords: Gamma radiation, cobalt-60, radiation polymerization, consolidation, ceramic.

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Preservando o patrimônio cultural por meio da consolidação com resina de cura por radiação: um estudo de caso de um vaso cerâmico indígena

Resumo: Este artigo apresenta uma investigação sobre a aplicação da radiação gama como método de consolidação de bens culturais, tendo como estudo de caso um vaso cerâmico pertencente ao povo indígena amazônico Asurini do Xingu. Os métodos tradicionais de consolidação de bens culturais com uso da radiação gama envolvem a impregnação do objeto por uma resina radiocurável. Este estudo fez uso de uma resina consolidante aplicada por meio de pincelamento, apenas na parte externa do vaso. A pesquisa incluiu pesagens do objeto antes e depois do processo de consolidação, além da avaliação de possíveis alterações de cor utilizando um colorímetro. Os resultados indicaram a eficácia do método, sem evidências de mudanças negativas no aspecto do bem cultural.

Palavras-chave: radiação gama, cobalto-60, polimerização por radiação, consolidação, cerâmica.

1. INTRODUCTION

Indigenous artifacts have been collected by anthropological museums worldwide. These artifacts often comprise both organic and inorganic materials, posing specific conservation challenges due to their diverse compositions. Such objects are rich in meaning, conveying the cosmological and ontological precepts of their respective cultures. From the perspective of Western science, some of these objects may possess intrinsic imperfections from their creation, making them more vulnerable over time. Adverse environmental conditions can further accelerate their deterioration.

Ceramic vessels produced by the Asurini people of the Xingu, who call themselves *Awaete* and live in the state of Pará, Brazil, exemplify the fragility of these material records. Women craft these vessels for cooking, storing, and serving food. Additionally, pottery holds symbolic significance for the Asurini, as it is found throughout their village [1], reflecting the social, economic, and ritual dynamics of their community.

The vessels are decorated with paintings made from iron oxide (goethite and hematite) and manganese, giving them yellow, red, and black colors. Feathers and plant fiber stems are used as fine brushes to create geometric patterns [2] such as zigzags, diamonds, straight lines, crossed lines, and curves (Fig. 1).

Figure 1: Decoration of Asurini pottery.

Source : Silva, F.A. [2].

After the painting has dried, the ceramist applies a thin layer of Jatobá (*jutaika*) resin to the exterior of the vessel (Fig. 2). The resin melts when the vessel is heated and is then applied using a stick once it touches the hot surface. This process gives the ceramic a varnished finish. Ceramists believe that the thinner the resin layer, the better the finish, especially when applied by more experienced hands. During the resin application, women are advised to refrain from eating, drinking, urinating, and defecating, as these activities can cause the resin to harden prematurely, compromising the quality of the varnish coverage [2].

Figure 2: Resin application to ceramics.

Source : Vidal, J.-J. A. [3].

Resin finishes pose the greatest conservation challenge for Asurini ceramics. A conservation survey conducted by the Museum of Archeology and Ethnology of USP (MAE-USP) on ceramic objects from the Regina Müller Collection found that 61.7% of the items had lost Jatobá resin due to cracking. This fragility may be inherent to the ceramic itself or may result from handling, storage issues, or environmental fluctuations.

When the resin is lost, the varnished surface detaches from the decorated area, taking the previously applied decoration with it (Fig. 3).

Figure 3: Loss of Jatobá resin and paint layer in ceramics.

Source : Ana Carolina Delgado Vieira, 2023.

Asurini ceramics feature graphics that reflect aspects of the indigenous worldview, serving as important teaching tools for younger generations. Therefore, preventing deterioration processes such as these is vital to the preservation of this material culture.

To maintain the integrity of historical artifacts, consolidation is an essential practice in conservation treatments. When a consolidant penetrates a porous material, it solidifies and enhances the artifact's resistance. Consolidation in remedial conservation treatments can be achieved partially through brushing or injections, or completely by impregnating the objects with the consolidating agent. The selection of consolidants is based on criteria such as mechanical compatibility with the material, viscosity, volatility, molecular weight, and contraction properties [4]. When choosing a consolidant, conservators must consider the aging properties, undesirable aesthetic changes, dimensional incompatibilities, reversibility, and toxicity of the material.

The use of Paraloid B-72 and Primal AC-33 thermoplastic acrylic resins on Asurini ceramic vessels at MAE/USP yielded unsatisfactory results. Due to the fragility of the Jatobá varnish, injecting consolidant into its fractures caused the displacement of the acrylic resins and detachment of other areas. Brushing the consolidant on the surface was also ineffective, as it did not penetrate the ceramic substrate to fix the varnish but merely deposited on the top surface.

The failure of traditional conservation methods has led us to adopt a new strategy. Using ionizing radiation to consolidate monomers appears promising, as it allows polymerization without chemical changes or temperature increases [4]. For the disinfestation of museum objects, gamma radiation has proven to be a great alternative to using persistent and toxic pesticides [5, 6, 7, 8]. Since the 1960s, radiation has been used to consolidate wood and stone [4]. For decades, ARC-Nucléart and other research studies have published and applied successful methods for treating fragile materials using less toxic and more reversible solvents [9, 10, 11].

Radiation-based consolidation offers several advantages over traditional methods, such as controlling the reaction rate, minimizing temperature increase, and preventing undesirable changes to the object [10]. Radiation curing allows consolidating resins to form three-dimensional structures, which enhance the mechanical properties of weakened objects. Additionally, gamma rays, with their high penetration power, provide uniform polymerization and more homogeneous results [4]. However, this method is irreversible and should be considered only if all other conservative treatment options have failed.

This study aims to investigate the effectiveness of a resin based on unsaturated polyester and styrene for consolidating an Asurini vessel. It seeks to compare the vessel's physical properties before and after treatment and to examine any potential changes in the object's colors.

2. MATERIALS AND METHODS

2.1. Object selection

The Regina Müller collection at MAE/USP comprises 128 Asurini vases. As previously mentioned, most of these objects show loss of the decorative layer due to resin detachment. For this experiment, we selected a vase that is not part of the museum's collection, despite having many potential candidates.

This particular vase was chosen from the Laboratory for Interdisciplinary Studies on Technology and Territory (LINTT - MAE/USP). It was made by a young Asurini ceramicist in 2017. In ritual performances called the *turé cycle*, this type of vessel (*já'eniwa*) is used for serving porridge [1]. However, this specific vase was never used and was instead kept as a didactic object. A large crack runs along the wall of the vessel, exposing the internal ceramic paste as a result of the loss of parts of its upper edge and wall (Fig. 4).

Figure 4: Vessel selected for the experiment.

Source : Ana Carolina Delgado Vieira, 2023.

Due to the similar conservation problems between this object and the vases in the MAE/USP collection, we chose to conduct this experiment on a non-accessioned object. This approach allows us to evaluate and discuss the results, aiming to inform future treatments for acessioned items into the museum's collections.

2.2. Sample characterization

To document the intervention process and evaluate any aesthetic changes to the vase post-procedure, photographs were taken before and after the experiment. A digital bench scale was used to measure the vessel's weight increase after consolidation and the rate of resin impregnation before and after intervention.

Colorimetric assessments were conducted using a PCE-CSM 8 device equipped with the CIEDE2000 color coordinate system and SQC8 Color Management Control System

(0°/45° geometry; 58 mm diameter aperture) connected to a computer. Each measurement positioned the analyzed point at the center of a white tile for reference, with spectra of white and black recorded using calibrated standards before each measurement session. Six measurement points were strategically chosen to represent the various colors on the vase (Table 1), accounting for its geometric aspects. Measurement locations were carefully selected to ensure proper positioning of the colorimeter.

As part of evaluating potential changes in resin performance and color stability over time, measurements were taken before, 96 hours after, and 8 months after the radiation consolidation procedure. Throughout the post-irradiation period, the vessel was stored in a sealed box at room temperature, shielded from light.

Table 1 : Ceramic vase colorimetric samples description.

SAMPLE	IMAGE	SAMPLING POINTS AND PREDOMINANT COLORS
01 03		Yellow (black stains) Red
02		Black
04		Loss area (clay without resin and pigments)

SAMPLE	IMAGE	SAMPLING POINTS AND PREDOMINANT COLORS
05		Internal section undecorated
06		Yellow (bottom)

2.3. Resin

The resin used was Resapol® LP 8847 from Reichhold Technology do Brasil, applied as received from the supplier. According to the manufacturer, this isophthalic unsaturated polyester resin offers high resistance to hydrolysis, climatic conditions, and thermal distortion. Composed of 50% polyester resin and 45% styrene, it exhibits a slight yellowish color and has a specified Brookfield viscosity at 25°C.

Before applying the resin, the ceramic surface was gently cleaned with soft brushes. Gamma radiation consolidation typically involves impregnating objects with unsaturated polyester resin [6]. In this experiment, the resin was applied by brushing, only on the external surface of the object, which was necessary to fix the Jatobá resin layer and decoration (Fig. 5). Due to the resin's toxicity, application was conducted in a ventilated environment with Personal Protective Equipment (PPE) in use. Since the internal part of the object did not exhibit conservation issues, it was left uncoated with consolidating resin.

Figure 5: Application of the resin on the external surface of the vessel.

Source : Ana Carolina Delgado Vieira, 2023.

To identify whether the natural pigments had been dissolved by the resin, we initially applied it to a small section of the vase. However, the Jatobá resin serves multiple functions including waterproofing, varnishing, and isolating the pictorial layer. No pigments were solubilized during the conservation process, thereby eliminating the necessity for any preparatory conservation actions before coating the piece with resin.

2.4. Consolidation using gamma irradiation curing

The polymerization process of the resin using gamma radiation was conducted at the Multipurpose Gamma Irradiation Facility of the Nuclear and Energy Research Institute, IPEN–CNEN/SP (Fig. 6). This facility is classified as a panoramic wet storage source compact irradiator (IAEA - Category IV and Group 1, according to CNEN), meaning that a panoramic wet source storage irradiator is a controlled human access irradiator in which the radioactive source is stored and fully shielded in a pool of 7m depth of deionized water [12].

The facility utilizes cobalt-60 source pencils where the radioactive material is encapsulated in corrosion-resistant stainless steel. These source pencils were loaded into specified positions within source modules, which in turn are distributed across the source racks. These racks serve as structures housing all the source pencils, facilitating the movement of the source system from the pool bottom to the irradiation level. As of 2015, the installed activity of the facility was approximately 11.1 PBq (300 kCi) [13]. Currently, the Multipurpose Gamma Facility operates with around 140 kCi.

Figure 6: Multipurpose Gamma Irradiation Facility – IPEN-CNEN/SP.

Source : Ana Carolina Delgado Vieira, 2019.

The absorbed dose, D, represents the energy absorbed per unit mass of irradiated matter at a specific point within the region of interest. It is defined as the mean energy, d_ε imparted by ionizing radiation to the matter in a volume element, divided by the mass, dm, of that volume element:

$$D = \frac{d\varepsilon}{dm} \tag{1}$$

The SI derived unit of absorbed dose is the gray (Gy), which replaced the earlier unit of absorbed dose, the rad, 1 Gy = 1 J/kg = 100 rad. The PMMA-Harwell dosimetry system was employed to calculate the absorbed dose in the irradiated samples [14].

During this investigation, polymerization of the unsaturated polyester resin was conducted under gamma rays at absorbed doses of 48 kGy, with a dose rate of 1 kGy.h-1. To ensure uniformity in absorbed dose, a brief pause was incorporated into the irradiation procedure after 24 hours to manually rotate the object.

3. RESULTS AND DISCUSSIONS

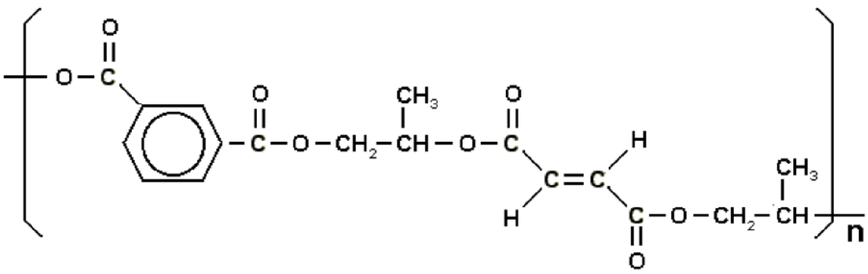
3.1. Consolidation through resin impregnation and curing with gamma radiation.

The consolidation process involves applying ionizing radiation after brushing the resin onto the object's surface. During this process, gamma rays are absorbed by matter, generating reactive ionic species, free radicals, and solvated electrons [4, 15]. These reactive species initiate cross-linking through chemical mechanisms during polymerization. Studies have shown that the dose rate significantly affects the efficiency of polymerization processes involving ionizing radiation [15].

Radiation polymerization progresses through three distinct stages. Initially, free radicals are formed to initiate the process. The second phase involves the propagation of these free radicals along the polymer chain, leading to the formation of active oligomers. At this stage, the resin begins to crosslink and gel, typically accompanied by a mild exothermic reaction [15]. Finally, the termination stage results in a three-dimensional network of polymer chains, establishing a crosslinked structure generated by radiation curing [4].

Molecular chains of isophthalic unsaturated polyester resins (Fig. 7) contain unsaturated bonds. During polymer radiation curing, these bonds react with each other and with reactive species generated in the process, forming an infusible and irreversible three-dimensional polymer [15, 16].

Figure 7: Isophthalic polyester chain.



Source : Melo, A. J. L. de [16].

During radiation polymerization processes, the carbon-carbon double bond molecules of the polymer react with styrene through a free radical mechanism [15, 16]. Solvents can influence the speed and yield of polymerization by absorbing radiation energy and contributing to the formation of additional free radicals crucial to polymerization [17]. The inclusion of isophthalic acid in the resin promotes the formation of longer polymer chains, thereby enhancing the mechanical, chemical, and thermal properties of the polymer [16].

The gamma rays utilized in the curing process generate stable materials, and the parameters employed in the radiation treatment ensure process safety. This process does not involve significant thermal activation or chemical additives. The high intensity of gamma radiation applied during this process facilitates bulk polymerization, resulting in a highly uniform final product within a short timeframe [4, 15].

In the case of the resin applied to the exterior of the vessel, polymerization yielded a uniform coating. Studies have noted that artifacts consolidated using gamma radiation [17] exhibit resistance to moisture absorption. This characteristic is particularly crucial for Asurini ceramics, where fluctuations in environmental conditions can lead to the separation of the Jatobá resin layer from the ceramic substrate.

According to Table 2, the vessel's weight increased post-consolidation, indicating a 0.68% resin impregnation without a significant increase in the artifact's original mass.

Table 2 : Mass before and after treatment consolidation with resin.

MASS BEFORE (MB) THE TREATMENT (G)	MASS AFTER (MA) THE TREATMENT (G)	IMPREGNATION RATE RETAINED IN THE VASE (%) = 100·(MA - MB)/MA
1450	1460	0.68

3.2. Colorimetry

Color differences can be quantified as the relative distance between two reference points within a color space. This difference is typically expressed as delta E (ΔE) and is calculated by comparing the L*a*b* values, a three-dimensional representation where L* ranges from black to white. The a* axis indicates redness (positive values) and greenness (negative values), while the b* axis represents yellowness (positive values) and blueness (negative values). ΔE calculations measure the magnitude but do not necessarily indicate the direction of the difference [18, 19].

Several systems to measure the color already exist. The CIELAB system, published in 1976 by the Commission Internationale d'Eclairage (CIE), has become the universally accepted colorimetric reference system for quantifying and communicating color [20]. The CIEDE2000 color-difference formula, derived from CIELAB, represents a more sophisticated and computationally complex method compared to earlier color-difference equations [21]. Examining color parameters individually is crucial for gaining deeper insights into the color changes induced by irradiation.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L s_L}\right)^2 + \left(\frac{\Delta C'}{k_c s_c}\right)^2 + \left(\frac{\Delta H'}{k_H s_H}\right)^2 + R_T \frac{\Delta C'}{k_c s_c}\frac{\Delta H'}{k_H s_H}} \qquad (2)$$

In this study, color changes were evaluated using the criterion proposed by Hardeberg [18] regarding the relationship between ΔE and the perception of color change (Table 3). The author suggests a range of values to determine the acceptability of color differences. This criterion has been found suitable for materials with heterogeneous surfaces [22] and is applicable to monitoring cultural heritage.

Table 3 : Hardeberg's criteria about the perception of color change.

ΔE	Effect
< 3	Hardly perceptible
$3 < 6$	Perceptible, but acceptable
> 6	Not acceptable

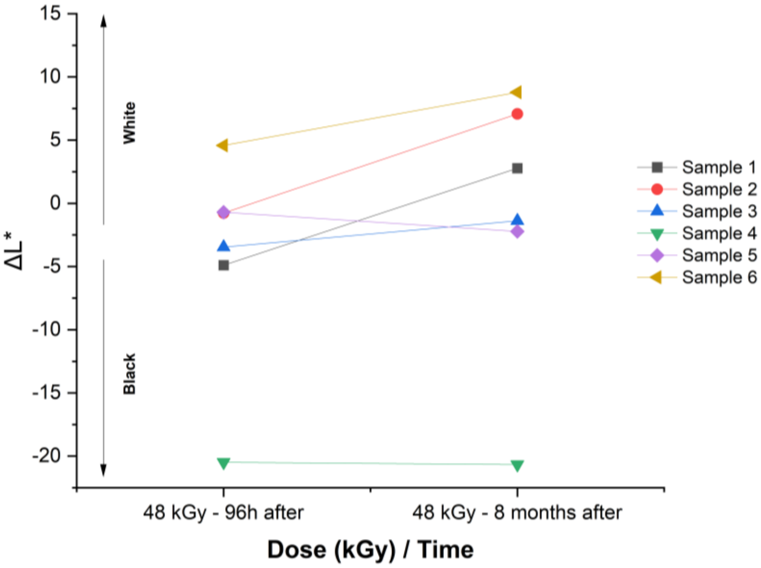
A colorimetric analysis of the monitored points on the object is presented in Table 4.

Table 4 : Perception of color change measured before and after irradiation on the object. Dose treatment 48 kGy (dose rate 1 kGy.h-1).

MEASURED POINTS	ΔL* VALUE - LIGHTNESS DIMENSION (BLACK TO WHITE)		ΔA* VALUE - REDNESS / GREENESS		ΔB* VALUE - YELOWNESS / BLUENESS		ΔE_{00} - PERCEPTION OF TOTAL COLOR DIFFERENCE	
	96 h after irradiation	8 months later	96 h after irradiation	8 months later	96 h after irradiation	8 months later	96 h after irradiation	8 months later
Sample 1	-4.89	2.77	0.39	0.25	4.42	3.38	4.46	2.81
Sample 2	-0.76	7.07	12.44	2.82	-7.78	5.93	13.31	6.50
Sample 3	-3.46	-1.38	-0.95	0.79	2.61	0.27	3.29	1.13
Sample 4	-20.48	-20.65	3.50	3.64	2.08	2.54	19.84	20.00
Sample 5	-0.70	-2.22	0.52	0.92	0.12	-0.42	0.77	2.12
Sample 6	4.57	8.77	0.95	1.17	6.97	2.81	4.89	8.14

The L* values at the analyzed points (Fig. 8) indicated negative values 96 hours after irradiation, suggesting darkened areas, except for point 6, which showed positive values indicating lightening. Over the course of eight months post-irradiation, a general lightening of the sample points was observed, with the exception of point 5, which tended to darken. Point 4 exhibited a notable change in L* value, particularly significant in an area where polychromy had been lost. The application of resin resulted in a more saturated appearance, resembling the finish of the decorated areas. This result was very encouraging from a conservation standpoint because the area of loss that had previously stood out was now mimicked after the resin treatment. This area remained stable for 8 months following irradiation.

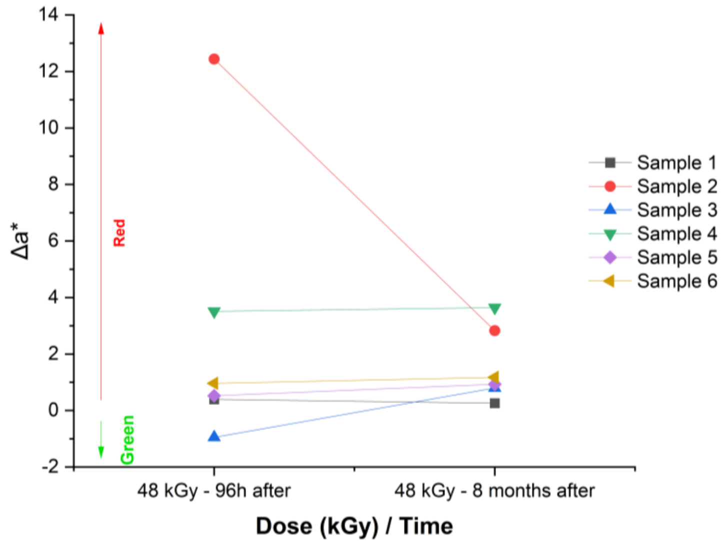
Figure 8: Color parameters ΔL*, 96 hours after and 8 months later.



Source : the authors.

The a* values remained stable across most points, except for points 2 and 3, following irradiation (Fig. 9). Point 2 initially showed the highest a* value 96 hours post-irradiation, which subsequently decreased significantly after 8 months. This area uses black pigment as a decorative element. Point 3 initially exhibited a greenish tendency in the red pigment 96 hours after irradiation. However, after 8 months, there was an increase in a* values, indicating a return to reddish coloration.

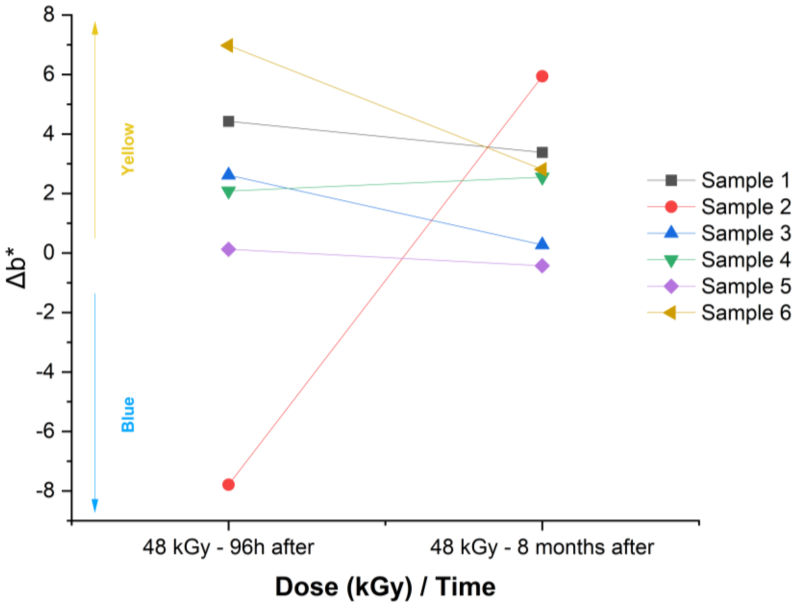
Figure 9: Color parameters Δa*, 96 hours after and 8 months later.



Source : the authors.

The b* values (Fig. 10) showed a slight increase after irradiation, suggesting a tendency for the object to yellow, except at point 2 where the concentration of black pigment in the vessel affects the readings. Over the initial 8 months following treatment, the values at sampled points tended to decrease, indicating a shift in color towards blue. Point 2, however, exhibited a significant increase in b* value, reinforcing its tendency towards yellowing.

Figure 10: Color parameters Δb*, 96 hours after and 8 months later.



Source : the authors.

In Figure 11, the comparative values of color change perception based on ΔE00 are presented. 96 hours after irradiation, points 1, 3, and 6 (located at the lower part of the vessel) exhibited values that met the criteria for noticeable but acceptable changes (ΔE 3 < 6). Point 5, inside the vessel and not covered by resin, did not show noticeable changes due to the radiation dose applied. Conversely, points 2 and 4 would be considered unacceptable if Hardeberg's criterion were applied.

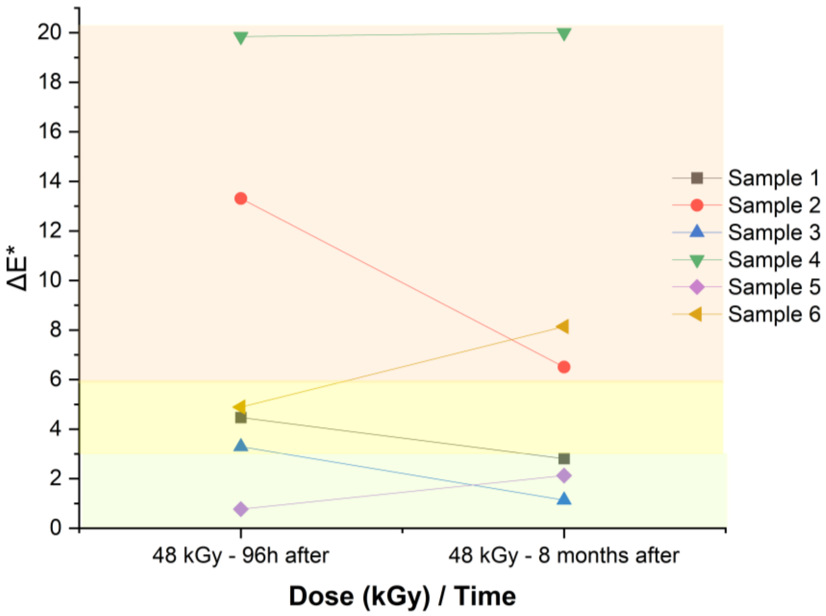
After 8 months of radiation processing, there was a trend of reduction in ΔE values at sampled points 1, 2, and 3. Points 1 and 3 were classified as changes hardly perceptible. Point 5 showed an increase in ΔE value but still remained within an acceptable category.

A notable reduction was observed at Point 2, according to Hardeberg's criterion for noticeable but acceptable changes. It is noteworthy that Point 2, where black pigment is concentrated, showed increased a* values and decreased b* values, without noticeable aesthetic changes visible to the naked eye.

After 8 months, measurements at point 4 showed no change. This point represents the clay area without decoration. The increase in L* and a* values at this point resulted in satisfactory color saturation for the final treatment outcome, even though, theoretically, according to the Hardeberg criterion, the values fall within the range of unacceptable changes.

In contrast, point 6 showed higher ΔE values, now categorized as unacceptable changes. Upon measuring this point after 8 months, it was observed that the base of the vessel exhibited roughness. This roughness may have been caused by contact with the vessel's storage box before the resin had fully cured within the initial 96-hour period of irradiation. This surface alteration likely contributed to the higher ΔE values and other observed parameters.

Figure 11: The perception of total color difference (ΔE), 96 hours after and 8 months later.



Source: the authors.

After treatment, the vase now exhibits a final appearance reminiscent of the characteristic shine seen on Asurini vases. Compared to the original Jatobá resin, the polymerized resin has imparted a smooth, shiny, and uniform film to the vase. Particularly in areas where the original polychromy was lost, the final appearance is highly satisfactory, as the resin has saturated the clay color, replicating the overall look of the object (Fig. 12).

Figure 12: Before and after treatment details of the areas of loss.

Source: Ader Gotardo, 2023.

3.3. Actions taken post-consolidation treatment

The application of resin to the vessel effectively resolved the issue of Jatobá varnish cracking. The homogeneous, continuous film successfully reinforced the weak areas, providing a positive outcome for previously damaged sections. This uniform result contrasts with challenges typically encountered in conventional consolidation methods using thermoplastic resins. However, certain aspects of this method require improvement.

Following the treatment, new conservation issues arose. Resin accumulation was observed at certain points along the vessel's edge, forming hardened droplets (Fig. 13).

Figure 13: A detail of the vessel's rim from the inside.

Source: Ana Carolina Delgado Vieira, 2023.

The vase was placed on a paper plate with the front facing down when the resin was applied. Due to the vessel's irregular geometry, resin drops formed on areas that did not touch the plate. Conversely, regions in contact with the plate adhered to it (Fig. 14).

Figure 14: A detail of the edge with adhered material.

Source: Ana Carolina Delgado Vieira, 2023.

Removing resin droplets and material adhered to the vessel can only be achieved through mechanical means, as the resin cannot be dissolved chemically. To address this, a scalpel and a micro grinder with a rubber tip were employed to remove resin droplets and adhered material from the vessel's edge. However, this intervention led to the detachment of a small portion of the polymerized resin film in the highlighted region shown in Figure 15.

Figure 15: Mechanically removing droplets results in the polymerized resin detaching from the vessel edge.

Source: Ana Carolina Delgado Vieira, 2023.

The area was consolidated by injecting Paraloid B-72 dissolved in xylene at a 20% concentration. After application, the adhesive was left to dry for 24 hours at room temperature. Following gamma radiation treatment, this constituted the sole remedial intervention performed on the object.

3.4. Future treatment protocol suggestion

To prevent issues like previously reported resin deposits and foreign material adhesion during future treatments, we recommend the following protocol:

a) Use an internal support made from a rigid material, such as expanded polyethylene, to support the vessel's inner portion throughout the process.

b) Apply the resin to the vessel only after it has been securely placed on the support, ensuring no unintended contact with the resin or external materials.

c) Clean the vessel's edge thoroughly before resin impregnation to eliminate any unwanted resin deposits.

d) Pause radiation processing after 5 hours of polymerization to prevent new resin deposits from forming on the vessel's edge.

4. CONCLUSIONS

The consolidation treatment conducted at IPEN was highly successful, effectively consolidation the resin to the vessel and preventing decoration loss. According to the weight measurements, the resin impregnation was sufficiently compatible with brush application.

Using radiocurable resin for consolidation has proven viable through brush application, adapting conventional methods like those developed by ARC-Nucléart, which involve complete resin impregnation. The treatment preserved the original glossy finish of the Jatobá resin, characteristic of these indigenous vessels.

Colorimetry analysis revealed no adverse changes in the visual appearance of this cultural artifact. Given the nuanced areas of loss and the absence of detrimental alterations, this method presents a promising alternative for preserving Asurini ceramic vessels facing similar conservation challenges.

Asurini vessels are culturally significant, valued by potters who are often proud of their craft, often collecting these pots as expressions of their identity [1]. Beyond serving as teaching tools, these vessels play a crucial role in transmitting traditional knowledge, reflecting the worldview and cultural identity construction of the Asurini people of Xingu [23].

In Brazil, indigenous communities seek to strengthen their identities by reconnecting with anthropological museum cultural items. Interacting with these artifacts helps enhance memory and learn production techniques, fostering self-esteem and cultural identity. Collaboration with the Asurini do Xingu aligns with MAE/USP's ongoing initiatives with indigenous communities, with future collaborations aiming to involve Asurini potters directly in the conservation of ceramic vessels. Such efforts underscore the need for dialogue with stakeholders regarding the benefits and drawbacks of treatments like these in indigenous cultural heritage conservation.

Future studies could incorporate additional analytical techniques to characterize resins, exploring aging properties to monitor potential changes in polymer chemical structures due to light exposure or environmental fluctuations. Research may also contribute to developing radiocurable, reversible consolidants, exploring less toxic options and resins with varying gloss levels to broaden consolidant choices suitable for different finishes of Asurini vessels.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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