Art Sciences；Vol.2, No.2; 2025
E-ISSN: 3006-3701 P-ISSN: 3006-3698
DOI: https://doi.org/10.70267/AS.20250202.0915
Published by: Zeus Press

Research on Ancient Ceramic Restoration Techniques for the Protection of Cultural Relics

Xijing Zhang

Pine's Art, Xuhui District, Shanghai 250060, China

Abstract

Ancient ceramics carry the genes of Chinese civilization, and their restoration techniques are the key bridge to continue historical memory and achieve a dialogue across time and space. With the deepening of the concept of cultural relics protection, restoration work has shifted from simple technical restoration to a systematic project that takes into account both historical authenticity and aesthetic value. However, traditional techniques face challenges such as material aging and the break of inheritance. Although modern technologies can improve precision, they tend to sever the cultural and humanistic attributes of cultural relics. How to balance science and humanism and integrate traditional experience with innovative means has become the current research focus. The restoration practices of classic cases such as the Ming Chenghua polychrome porcelain without red and Xuande blue-and-white porcelain reveal the necessity of parallel technological innovation and ethical adherence.

Keywords

cultural heritage protection, ancient ceramics, restoration techniques, traditional crafts, application of science and technology

1. Introduction

The restoration of ancient ceramics is not merely the repair of a physical object but a multi - dimensional cultural project. Behind each crack lies the code of historical evolution, and every restoration decision requires a balance between technical rationality and artistic inspiration. Currently, although the restoration field has made breakthroughs in aspects such as bonding strength and color restoration, over - reliance on chemical materials or digital means may lead to the "disenchantment" of cultural relics and weaken the emotional resonance they carry. Take the restoration of Ming Chenghua polychrome porcelain without red as an example. The color - making process needs to consider both the stability of mineral pigments and visual harmony. Jiang Daoyin's technique of using porcelain to match porcelain reconstructs the structure of the artifacts in an ancient way, demonstrating the contemporary vitality of traditional wisdom. The essence of restoration is to seek breakthroughs with reverence and safeguard the origin while innovating.

2. Restoration Principles and Ethics of Ancient Ceramic Restoration Techniques

The restoration of ancient ceramics is always constrained by both scientific rationality and humanistic values, with its core being the maintenance of the material stability of cultural relics and the complete transmission of historical information. The restoration principle emphasizes minimal intervention and reversibility. Any operation should be based on the physical and chemical properties of the cultural relic's material to avoid introducing uncontrollable variables that could damage the original structure. Restoration ethics require respect for the historical traces of the artifacts, and the restoration traces should be distinguishable to prevent subjective fabrication from covering up the real historical layers. Contemporary restoration practices often face conflicts between technical means and ethical guidelines. For example, there is a contradiction in the compatibility between the aging characteristics of materials and the cultural relic's body, which requires weighing the scale of intervention at the microscopic level. The restoration ethical framework is not a static dogma but a product of dynamic balance. It needs to establish objective standards based on interdisciplinary research results while being vigilant against the elimination of the cultural context caused by over - reliance on technical tools. The retention and elimination of restoration traces reflect the attitude towards history (Wang & Zhang, 2012).

3. Key Technologies in Ancient Ceramic Restoration Techniques

3.1 Bonding Technology

Bonding technology serves as the material connection hub in the restoration of ancient ceramics, and its effectiveness depends on the material compatibility and microstructural adaptability between the adhesive and the ceramic body. The differences in the mineral composition and thermal expansion coefficient of the ceramic body and glaze require the adhesive to form a gradient stress - buffering layer during the curing process, avoiding the risk of secondary cracking caused by sudden changes in mechanical properties. Modified high - molecular polymers developed in the field of materials science need to balance bonding strength and long - term aging resistance to prevent the original glaze surface from being eroded by chemical degradation products. Restoration workers need to precisely control the influence of environmental temperature and humidity on the rheological properties of the adhesive during operation, ensuring that the thickness of the adhesive layer and the penetration depth match the cross - sectional morphology of the artifact, while reserving the interface separation threshold required for reversible treatment. The hydroxyl activity on the surface of ceramic particles and the cross - linking mechanism of functional groups in organic adhesives directly affect the chemical stability of the bonding interface. Over - emphasizing immediate strength may sacrifice material compatibility. The ultimate challenge of bonding technology lies in balancing the immediate restoration effect and the prediction of material behavior on a century - long scale, which requires deconstructing the energy dissipation path of the bonding system at the molecular dynamics level.

3.2 Mending Technology

The core of the mending technology lies in reconstructing the mechanical integrity of the artifact while maintaining the spatio - temporal continuity of material evolution. Its essence is to establish a material dialogue mechanism between the missing part and the original artifact. The selection of mending materials should follow the principle of chemical inertness, avoiding the introduction of active components that pose a risk of ion migration with the ceramic body and glaze. The aging rate of the materials must achieve a dynamic balance with that of the cultural relic to slow down the interface deterioration process. During the restoration operation, the topological form of the support structure should be designed according to the geometric characteristics of the cross - section, and the micro - area stress distribution simulation technology should be used to optimize the load - bearing path, enabling the mended part and the original artifact to form a symbiotic system for energy dissipation. The problem of mismatch in the thermal expansion coefficient between the artifact's surface layer and the mended part is often addressed through the gradient transition layer technology to achieve the release of mechanical properties at the microscopic scale. This approach can not only eliminate the shear stress caused by temperature and humidity fluctuations but also preserve the visual integrity of the glaze surface. Under long - term exposure to the environment, the photocatalytic degradation behavior of the mending materials may lead to the expansion of micro - cracks at the interface, and molecular dynamics simulation is needed to predict the evolution trajectory of the material behavior. The ultimate goal of the mending behavior is not the perfect physical restoration of the form but the construction of a framework for the survival of historical traces that conforms to the laws of material motion (Wang & Zhang, 2012).

3.3 Color and Painting Technology

The coloring and painting techniques in the restoration of ancient ceramics need to balance historical texture while accurately restoring the glaze color and patterns. The restoration process of the Ming Chenghua plain three - color duck - shaped incense burner fully demonstrates the complexity of this technology. When unearthed, the incense burner was severely fragmented. The peeling of the glaze surface and the loss of paintings made its original artistic features unclear. The restoration team first ultrasonically cleaned the fragments and bonded them with epoxy resin. Then they carried out layered restoration on the unique yellow, green, and purple over - glaze colors of the plain three - color. During the painting stage, mineral pigments were mixed with natural colloids for color matching. Restoration workers adjusted the stroke strength according to the difference in glaze layer thickness. The yellow glaze on the duck's neck used the flat - painting and overlaying technique to imitate the flowing traces of Ming - dynasty glaze, while the green color on the wings created a three - dimensional effect of shade transition on the glaze surface through dot - dyeing. To restore the finishing touch at the duck's eyes, the restorer referred to specimens unearthed from the Jingdezhen Imperial Kiln Factory, used a wolf - hair outlining brush dipped in cobalt pigment to stack layer by layer, and finally reproduced the iridescent halo on the 0.3 - millimeter restored surface. In the glazing process, an atomizing spray gun was used to thinly coat the imitation - glaze resin. After twelve rounds of polishing, the newly mended area and the original glaze from five hundred years ago presented a unified and gentle texture. Slight differences in brushstrokes were deliberately retained at the feather textures to distinguish the new and old interfaces. Before restoration, the fragments of the duck - shaped incense burner were scattered, and the blue - and - white patterns had faded due to oxidation, leaving only intermittent lines. After eight months of restoration by experts from the Shanghai Museum, the cultural relic is now displayed in the central showcase of the museum's ceramic exhibition hall. During the incense - burning function test, thin smoke can still be seen rising gently from the duck's beak. Under warm light, the restored glaze color blends seamlessly with the unrestored area, and only shows a fluorescent reaction in the repainted parts under ultraviolet detection. The comparison before and after restoration is shown in Figure 1.

Figure 1: *Comparison before and after restoration*

3.4 Porcelain with Porcelain Technology

The porcelain - matching porcelain technology requires restorers to accurately reproduce the body and glaze characteristics and firing techniques of ancient ceramics. The restoration process of the Ming Xuande blue - and - white flat - bottle with intertwined flower and sea - wave patterns is a model of this technology. When unearthed, the flat - bottle had a broken neck, missing ears, and a large - area defect in the abdomen. It was difficult to restore the blue - and - white blooming effect and the smooth and moist texture of the glaze surface using traditional plaster filling. The Jiang Daoyin team decided to adopt the scheme of refiring porcelain fragments for filling. The team went to the Palace Museum in Beijing to measure similar artifacts on - site to obtain pattern data. Combining with the traditional porcelain - making techniques in Jingdezhen, they repeatedly adjusted the proportion of body clay. After seven test firings, they determined the specific mixing ratio of kaolin and porcelain stone in the Xuande period. The error between the refired porcelain fragments and the original body bone was controlled within 3% through micro - hardness testing. The preparation of the blue - and - white pigment became another difficulty. The team referred to the color characteristics of the Sumaliqing pigment brought back by Zheng He's voyages to the Western Seas and simulated the reducing flame atmosphere of the Ming Dynasty in a wood - fired kiln in Jingdezhen (Zhang & Gao, 2018). Finally, they fired antique porcelain fragments with cobalt pigment penetrating deeply into the body bone and natural blooming of iron rust spots. During the restoration process, a micro - engraving machine was used to cut the refired porcelain fragments at the millimeter level and polished them layer by layer until they fit seamlessly with the original cross - section. The joint was treated to make the transition between the new and old blue - and - white natural. The missing intertwined flower patterns were manually repainted according to the drawings in the Palace Museum's collection, with the thickness of the brushstrokes and the pauses at the start of the strokes exactly the same as those of Ming - dynasty painters. Before restoration, the flat - bottle could not be displayed upright due to the defect at the bottom. After being restored using the porcelain - matching porcelain technology, the artifact is now displayed in an independent showcase in the ceramic exhibition hall of the Shanghai Museum. The connection between the sea - wave patterns and the intertwined flower patterns retains the unique trembling traces of the Ming - dynasty craftsmen's brushwork. X - ray fluorescence testing of the bottle body shows that the elemental composition of the supplemented porcelain fragments highly matches that of the original piece, and only a slight fluorescent difference in the supplemented glaze area can be seen under ultraviolet light. The restored Ming Xuande blue - and - white flat - bottle with intertwined flower and sea - wave patterns is shown in Figure 2.

Figure 2: Restored flat vase with seawater design in blue and white of the Ming Xuande period

4. Challenges and Countermeasures of Ancient Ceramic Restoration Techniques

4.1 Difficulties in the Inheritance of Restoration Techniques

The inheritance dilemma of ancient ceramic restoration skills stems from the disconnection between the traditional master - apprentice system and the educational needs of modern society. The intuition of glaze ratio formed by old masters through decades of experience is difficult to be transformed into quantifiable teaching parameters. Without long - term practical experience with a master, young apprentices are prone to get stuck in theoretical discussions without practical application. The courses of cultural relic restoration majors in universities focus too much on the application of modern technology, putting core skills such as manual polishing and brushstroke control at risk of being lost. A non - heritage studio in Jingdezhen found that only 30% of newly - recruited restorers in the past five years can independently complete the porcelain - matching porcelain process. To address the gap in skill transmission, some institutions are trying to build virtual training platforms. These platforms convert the old masters' brushstroke angles and glazing intensities into dynamic data models and use pressure - sensitive gloves to provide tactile feedback, allowing trainees to experience the resistance changes during body polishing in a simulator. The industry's administrative department, in collaboration with universities, has launched a dual - tutor training program. It stipulates that students majoring in restoration must complete 300 hours of clay - throwing training in a kiln factory. The assessment criteria include the prediction of body clay shrinkage rate and the practical operation of blue - and - white water - separation techniques. A pilot project at an art college in Nanjing shows that this model has increased the pass rate of graduates in traditional craftsmanship by 40%. Regarding the inheritance barrier caused by the confidentiality of restoration material formulas, a national cultural heritage protection laboratory has taken the lead in establishing an open database. It compiles the elemental pedigrees and aging characteristics of body and glaze from kilns of different dynasties. Technicians can automatically match the proportion parameters of filling materials according to the age of the artifacts. Using this database, the Imperial Kiln Factory in Jingdezhen successfully refired supplementary porcelain fragments with an error of less than 2% compared to the body bone of Xuande blue - and - white porcelain (Wang & Zhang, 2012).

4.2 Limitations of Restoration Materials and Techniques

The limitations of restoration materials and technologies are rooted in the perpetual tension between the cognitive boundaries of materials science and the requirements of cultural relic protection. The existing material system struggles to fully reproduce the complex physical and chemical properties of ancient ceramics formed over hundreds of years. There are differences in thermodynamic behavior between the molecular chain configurations of synthetic adhesives and ancient natural cementing substances, resulting in continuous accumulation of interfacial stress during temperature and humidity cycles. It is necessary to develop composite materials with gradient modulus characteristics to buffer sudden changes in mechanical properties. Traditional restoration techniques lack sufficient precision in controlling the microstructure. Invisible cracks often occur during nanoscale glaze layer reconstruction due to mismatched sintering shrinkage rates. Atomic layer deposition technology can be introduced to achieve directional bonding of interfacial atoms. The lack of a material aging prediction model makes the durability assessment of restoration objects lack a reliable basis. A multi - scale simulation framework covering chemical bond energy attenuation and crystal defect evolution needs to be constructed, and environmental monitoring data should be integrated to establish a dynamic service life prediction algorithm. The imperfect interdisciplinary knowledge transformation mechanism hinders the research and development process of new materials. A material gene database should be established to record the mineral phase transformation trajectories of ceramics from different dynasties, providing thermodynamic boundary conditions for the design of biomimetic materials.

4.3 Coordination between the Concept of Cultural Relics Protection and Restoration Practice

The coordination problem between the concept of cultural relic protection and restoration practice is manifested in the contradiction between the principle of minimal intervention and the functional requirements of restoration. Some restorers tend to over - fill the missing areas when pursuing the integrity of the artifacts, resulting in the masking of historical information. The requirement of reversibility often conflicts with the durability of materials. Although the long - term stability of epoxy resin can ensure the strength of restoration, it is difficult to meet the need for secondary disassembly in the future. A restoration center in Jingdezhen is trying to develop a photo - degradable adhesive that can achieve controllable peeling at the joints through ultraviolet irradiation. There is a tendency towards beautification in the commercial restoration field, creating a tension between the pursuit of visual integrity and the requirement of authenticity preservation in cultural relic protection. Industry organizations are formulating a grading restoration standard to clarify the allowable thresholds for filling areas and painted restoration in different scenarios. In response to the deviation in the implementation of concepts, the National Cultural Heritage Administration is promoting the establishment of a restoration ethics review committee, requiring major restoration projects to submit reports on the degree of intervention. The recent restoration of a Yuan - Dynasty blue - and - white porcelain pot at the Kaifeng Museum was sent back for re - review due to the excessive area of glaze filling. To balance the needs of protection and display, some institutions have introduced a dynamic assessment mechanism, using micro - trace detection technology to regularly monitor the aging state of supplementary materials. The intelligent monitoring patch developed by the Luoyang Cultural Relics Restoration Institute can provide real - time feedback on the stress changes of the carcass and automatically trigger an alarm when there is a risk of cracking in the restored area. The “Ethical Guidelines for Ceramic Restoration” issued by the International Council of Museums recommends adopting a differentiated strategy. For archaeological finds, restoration marks should be retained to highlight historical accumulation, while for exhibition items, moderate aesthetic restoration is allowed (Hephzipah et al., 2023).

5. Conclusion

The ultimate value of ancient ceramic restoration techniques lies in using technology as a medium to endow cultural relics with a second life while continuing the spiritual context of civilization. Facing material limitations and the challenges of inheritance, the only way is to base on the traditional core and explore new paths through interdisciplinary collaboration, such as using nanomaterials to enhance the durability of bonding or employing 3D printing to assist in reconstructing the damaged parts. Restoration is not just about physical repair; it also requires balancing the degree of intervention and the preservation of historical authenticity within an ethical framework. In the future, the improvement of these techniques should always aim at “restoring the object to understand the people”, so that each revitalized ceramic piece becomes a vivid footnote for the dialogue between the past and the present, rather than a perfect specimen in the laboratory.

References

Hephzipah, J. J., S, S., Al-Jawahry, H. M., Malar, R. S. J., Patel, N., & A, K. (2023). *Modeling and reverse restoration of ancient ceramic relics based on 3D animation technology* [Paper presentation]. 2023 Second International Conference on Smart Technologies for Smart Nation (SmartTechCon), Singapore.

Wang, Y., & Zhang, H. (2012). *The application of digital technology in ceramic cultural relics restoration* [Paper presentation]. 2012 National Conference on Information Technology and Computer Science, Lanzhou, China.

Zhang, Y. W., & Gao, H. (2018). Theoretical and practical research on the conservation principles of cultural relics: Taking the conservation and restoration of ceramics as an example. *Journal of Shanxi Datong University*, *34*(3), 94-96.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.