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Innovations in Enamelled Porcelain Materials and Techniques from the Perspective of Cultural Integration in Southeast Chongqing

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Abstract: Enamelled porcelain represents a distinctive category of overglaze decoration that emerged from the fusion of Chinese porcelain body techniques with European low-fusing enamel pigments. This study provides a comprehensive review of the historical evolution of enamelled porcelain and examines its unique artistic language. Particular emphasis is placed on recent innovations in lead-free boron–lithium frit formulations, low-temperature firing processes, and contemporary painting techniques. Through comparative material analysis and firing experiments, the study verifies the energy efficiency, environmental sustainability, and enhanced visual quality of these updated methods. The objective is to offer both technical support and theoretical insights for the sustainable industrial development and cultural revitalization of enamelled porcelain in the contemporary context. Moreover, drawing on traditional ceramic and decorative arts practices in Southeast Chongqing, the paper explores the potential for integrating enamelled porcelain into intangible cultural heritage revitalization and creative cultural industries. This research highlights the aesthetic expression and cultural reinterpretation of this traditional craft from a design-oriented perspective.

Keywords: Enamelled porcelain; Porcelain-body painted enamels; Lead-free frit; Low-temperature firing; Artistic language; Intangible heritage revitalization

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1. History of enamelled porcelain

Enamelled porcelain originated from the integration of Chinese high-fired white porcelain with Western glass-based colorants, with early prototypes dating back to the Tang and Song dynasties [1]. In the 35th year of Emperor Kangxi's reign (1696), the Qing court established the Falangzuo (Enamel Workshop), marking the formal institutionalization of this craft [2]. Emperor Kangxi commissioned Jingdezhen kilns to produce plain porcelain bodies, which were then decorated using imported lead-borosilicate pigments. Court painters collaborated with Jesuit missionaries to execute the polychrome designs, followed by low-temperature refiring, thereby initiating the distinctive technique of "porcelain-body painted enamels" [3]. This method, originally derived from European metal-based enamel painting, reached its zenith in the Qing imperial court. During the reigns of Kangxi, Yongzheng, and Qianlong, enamelled porcelain was celebrated for its brilliant colors and meticulous craftsmanship.

The Qing court placed great emphasis on the production of enamelled porcelain, achieving significant advancements between the Kangxi and Qianlong periods [4]. However, due to the high production costs, the technique experienced a decline during the mid-Qianlong era. Initial scholarly inquiry emerged during the Republican era, with Yang Xinggu conducting preliminary studies. After the founding of the People's Republic of China, scientific investigations into enamelled porcelain materials and techniques gained momentum. In the 1970s, Zhang Fukang and colleagues identified the presence of boron in the glaze formulation. Subsequent research by institutions such as the Palace Museum revealed compositional distinctions between various enamelled wares. Although the original technique was lost following the Qing dynasty, efforts to revive it were undertaken in the 20th century, particularly in Jingdezhen. Since the 1980s, advances in material science and manufacturing technology have enabled the batch reproduction of enamelled porcelain. In 2011, it was inscribed on the National List of Intangible Cultural Heritage [5]. In recent years, new materials and technologies have further propelled its innovation, positioning enamelled porcelain toward cultural and creative industries and the high-end design market.

In parallel with imperial enamelled porcelain, regional traditions of polychrome ceramics and decorative painting also continued to evolve. Although the southeastern Chongqing region—including areas such as Youyang (酉陽)—was not a historical center of porcelain production, it preserved its own ceramic and decorative traditions. The region is home to diverse forms of folk art, such as Tujia brocade (西蘭卡普), Miao embroidery, and batik, which demonstrate strong visual aesthetics and symbolic motifs. These regional crafts share aesthetic affinities with Qing court enamelling in their vibrant color schemes and auspicious symbolism. Today, the folk arts of southeastern Chongqing provide valuable cultural inspiration for contemporary enamelled porcelain design, enriching its visual language and thematic range. This perspective of craft and cultural integration adds a new historical dimension and humanistic value to the modernization of enamelled porcelain as it transitions from a royal artifact to an object of contemporary cultural significance.

2. Artistic expression of enamelled porcelain

2.1. Visual language and material tactility

The distinctive visual language of enamelled porcelain arises from the interplay between material properties and craftsmanship. The low-melting-point glass pigments, when subjected to secondary high-temperature firing, produce a lustrous, gem-like glaze. Slight fusion of the pigment layer preserves the subtle grooves and diffusion marks left by brushstrokes, combining the textural richness of oil painting with the tonal fluidity of Chinese ink wash. For example, a Qianlong-period imperial yellow-ground porcelain wall vase with landscape motifs exemplifies this synthesis. The bright yellow glaze is punctuated by a reserved white medallion, within which blue pigments depict an impressionistic landscape. The composition blends high-saturation hues with expressive brushwork, embodying the imperial court's pursuit of both glaze brilliance and painterly refinement. Owing to its translucent glaze and meticulous execution, enamelled porcelain merges the aesthetics of Chinese ink painting with Western pictorial techniques, culminating in a unique and hybrid visual style.

2.2. Evolution of themes and motifs

In the Qing dynasty, falangcai porcelain embodied imperial authority and refined aesthetics, with design and firing tightly coordinated between the Imperial Kiln and Enamel Workshop. Common motifs included auspicious flora, feathers, and imperial inscriptions. During Kangxi's reign, the introduction of rouge-red ground with white reserves became a signature style. The Rouge-red Ground Enamelled Dish (**Figure 1**), decorated with peonies and marked "Made by Imperial Order of Kangxi", symbolizes prosperity and imperial blessings. In the Qianlong era, influenced by European Rococo, court artisans developed yangcai enamels. The Enamelled Vase with Western Figures (**Figure 2**) features gilt scrolls and baroque florals framing European pastoral scenes, reflecting the fusion of Chinese and Western decorative arts.

Figure 1. Rouge-red Ground Enamelled Dish with Floral Design, Qing Dynasty, Kangxi period (Collection of the Palace Museum)

Figure 2. Enamelled Vase with Gilt Handles and Western Figures in Reserves on a Brocade

Ground, Qing Dynasty, Qianlong period (Collection of the National Palace Museum, Taipei)

2.3. Scale and application expansion of enamelled porcelain artifacts

Traditionally, enamelled porcelain artifacts were primarily small-scale ornamental objects, prized for their intricate craftsmanship and ornate beauty, and intended for interior display and appreciation. Contemporary design, however, has extended the scope and scale of enamelled decoration, applying its techniques to a broader range of mediums and functional contexts—including lighting fixtures, wristwatches, and even architectural panels. A notable example is the "Origin" cloisonné enamel wristwatch launched by the Swiss brand Halcyon. On a 43 mm white porcelain dial, intricate cloud-dragon patterns are rendered using cloisonné wirework and subjected to secondary low-temperature firing. The resulting surface retains a jewel-like luster while meeting practical requirements for wear resistance and chemical durability. This innovation exemplifies the potential of enamelled porcelain techniques in wearable design. In the fields of architecture and environmental art, enamel decoration has also begun to appear in the form of porcelain wall murals and surface panels. These applications preserve the vivid coloration and durability of traditional glazes while imbuing architectural spaces with a distinct cultural and aesthetic character. Collectively, these developments signal a transformation of enamelled porcelain from its origins as imperial display ware to a material integrated into contemporary lifestyles. This evolution not only bridges traditional craftsmanship with modern design demands but also repositions enamelled porcelain as a culturally resonant medium within diverse functional and artistic domains.

3. Materials and processing technologies for contemporary enamelled porcelain

3.1. Porcelain body and biscuit preparation

Modern enamelled porcelain uses high-whiteness bodies for color purity. The base clay primarily consists of low-iron kaolin, with quartz and feldspar additives to control shrinkage and thermal expansion. A typical formulation is about 38% kaolin, 25% potassium feldspar, 23% quartz, and 4% talc. These materials are wet ball-milled and vacuum pugged for a dense ceramic body. After forming and drying, green bodies undergo rapid bisque firing at 1250–1280°C with a 30-minute ramp and 15-minute hold, ensuring ≤1% water absorption and stabilizing thermal expansion at $\sim 5.6\times10^{-6}K^{-1}$. This strengthens the body and relieves stress, minimizing glaze cracking risks. Post-bisque firing, a 0.5–1 mm transparent white glaze is applied as a painting substrate and bonding layer. The glaze, composed of potassium feldspar, quartz, and kaolin for thermal compatibility, is ball-milled and aged for improved properties. After firing at ~780°C, it fuses for a smooth surface, enabling enamel painting.

3.2. Formulation of enamel pigments

Enamel pigments are composed of finely ground colored glass powders obtained by fusing silicate-based vitreous materials with coloring agents and opacifiers, followed by rapid quenching and pulverization. Traditional imperial enamel pigments employed high-lead borosilicate frits as the glassy matrix, incorporating metal ions such as gold, copper, cobalt, iron, and tin to achieve various hues—e.g., cobalt and iron for blue-black, gold for rose red, and copper for green. However, the use of lead-based frits poses significant risks due to heavy metal toxicity and environmental emissions. To address these concerns, modern enamel technology has developed lead-free boron–lithium-based frit systems as substitutes for traditional leaded fluxes. In this study, the lead-free frit composition adopted includes SiO_2 (54%), B_2O_3 (18%), Li_2O (10%), Na_2O (8%), K_2O (5%), and Al_2O_3 (5%). This formulation has a softening point of approximately 540 °C, which is well-suited to the low firing range of ~780 °C. Upon application to the porcelain surface, the frit forms a dense and transparent glassy phase, providing an excellent optical base for pigments while eliminating the hazards associated with lead volatilization, thereby improving the process's environmental and occupational safety. In terms of coloring agents, various metal oxides such as CuO, Co_3O_4, Fe_2O_3, and MnO_2 are added in proportions ranging from 1% to 8% to produce a spectrum of hues, including emerald green, deep blue, reddish-brown, and violet. Opacifiers such as SnO_2 and Sb_2O_3 are introduced to enhance opacity and color brightness.

The enamel glass powder is ground by ball milling to an average particle size of approximately 4 µm, then mixed with turpentine and clove oil in a volume ratio of 1:0.85 to create an oil-based enamel slurry. This medium exhibits a viscosity of 28–32 Pa·s at 25 °C, offering smooth application, controllable flow, and resistance to pinholes and sagging. It is compatible with both traditional brushwork and modern spraying techniques.

The improved boron–lithium-based enamel system demonstrates no detectable emission of volatile heavy metals, and post-firing exhaust emissions consistently comply with the Special Emission Limits of the *Emission Standard of Pollutants for Ceramic Industry*. Furthermore, the coefficient of thermal expansion (CTE) mismatch between the enamel pigment and the porcelain glaze system remains within $\pm 0.2 \times 10^{-6} K^{-1}$, ensuring crack-free surfaces and vivid, stable coloration. These results confirm the material's green and sustainable performance advantages.

3.3. Enamel painting procedure

Enamel decoration requires pre-fired porcelain bodies. Workflow involves three steps: flat brush for background color, pointed brush for linework, and transparent overglaze coating. Place the piece on a ~50°C platform; a flat brush applies paste evenly, heat-reducing viscosity for smooth coverage. Semi-dry, pointed brush outlines motifs, forming raised "line grooves" to enhance relief. After air-drying, apply a thin colorless overglaze. Fire at 780–800°C for ~15 min, sintering glossy film for luster and resistance. The scheme must align with pigment properties and firing for optimal performance and adhesion. Variables affect saturation and adhesion, making it art and engineering, requiring iterative optimization.

Contemporary enamelled porcelain incorporates several classic decorative techniques that have evolved from Qing dynasty traditions. The most prevalent forms include:

(1) Reserved white panels on colored grounds: The entire vessel is coated with a single-color enamel glaze, while reserved white medallions or cartouches are left unglazed for painted scenes—such as figures, landscapes, or flora and fauna—to be rendered within (**Figure 3**).

(2) Overpainting on colored grounds: This technique involves first applying a colored enamel glaze across the porcelain surface, followed by additional overpainting in contrasting hues (**Figure 4**).

(3) Polychrome painting on white porcelain: This literati-oriented technique leaves the white-glazed porcelain body entirely exposed, with floral patterns applied using the mogu (boneless) painting method—blending colors directly without outlines (**Figure 5**).

(4) Cloisonné-style partitioned enamelling: Emulating the metal-wire cloisonné technique, this method outlines motifs in gold or imitation cloisonné lines on the porcelain surface, then fills each segment with enamel colors. Each layer is fired separately at low temperatures to fix the pigments.

(5) Allover brocade patterning with multicolor overlays: Representative of the highly ornate late-Qianlong style, this technique involves densely tracing brocade-like scrollwork grids across the vessel using glass-white lines, followed by the meticulous filling of each cell with saturated colors such as imperial yellow,

carmine, and emerald blue. Multiple firings (three to four rounds at 700–750 °C) are required to set the colors.

The core decorative styles of enamelled porcelain—reserved medallions, overpainting, minimalist polychrome, cloisonné, and brocade patterns—constitute its traditional aesthetic vocabulary. Using layered pigments or separated motifs, these techniques employ low-temperature overglaze firing (700–800 °C) to achieve jewel-like brilliance and durability. Systematic analysis of these methods offers valuable models for contemporary innovation in form, technique, and aesthetics.

Figure 3. Kangxi yellow earth radiant enamel flower bowl

Figure 4. Kangxi radiant enamel-colored peony cup in crimson ground

Figure 5. Yongzheng enamel colored pheasant peony pattern bowl

3.4. Low-temperature firing process

The final enamelled porcelain firing uses a low-temperature overglaze procedure (700–800°C) to melt and fix the enamel layer while protecting the porcelain body. The three-stage sequence includes: first, bisque firing in oxidizing atmosphere at 800°C for 6–8 hours to remove water and strengthen the body; second, high-temperature glaze firing with multi-stage heating to 1300°C, using reducing atmosphere above 1080°C for fusion; third, low-temperature enamel firing, gradually heating to 400°C to eliminate solvents, then to 780°C held for 15 minutes to set pigments, followed by cooling. Oxygen regulation is critical, with concentration maintained at 19.5%–20.5% to prevent discoloration and ensure color fidelity. This study optimized the protocol to balance durability, brilliance, and vibrancy, supporting reliable one-step firing of lead-free boron-lithium enamel while reducing energy use. Results showed firm enamel bonding, rich colors without defects, meeting aesthetic and performance goals.

4. Experimental evaluation of enamel-painting materials and processes

4.1. Porcelain body compatibility tests

To mitigate thermal stress induced by low-temperature overglaze firing, two types of pre-fired porcelain bodies were selected for comparative testing:

i. High-density glazed porcelain body: Fired at 1300 °C in a reducing atmosphere, this body exhibits high density with a water absorption rate of less than 0.5%. A smooth, white glaze layer is applied to the surface, making it suitable for refined decorative techniques such as reserved white panels and gold detailing.

ii. Porous bisque-fired body: Rapidly fired at 1180 °C in an oxidizing atmosphere, this type shows water absorption of 10%–15%. Although unglazed, its sufficient mechanical strength and porous structure facilitate the absorption of oil-based enamel pastes, making it ideal for large-area color application.

Acoustic tapping tests were performed to assess internal integrity. Both types of bodies produced clear, resonant sounds, indicating structural robustness and the capacity to endure subsequent low-temperature firing at 700–750°C. Post-firing inspections confirmed that neither body exhibited glaze cracking, demonstrating that the enhanced glaze-body formulations and firing procedures successfully achieved thermal compatibility across various porcelain substrates.

4.2. Preparation experiments of lead-free boron-lithium-based enamel pigments

To address the drawbacks of traditional lead-based frits—which require high melting temperatures (850–900 °C), entail substantial energy consumption, and pose environmental risks due to PbO emissions—this experiment adopted a lead-free frit system based on B_2O_3–Li_2O as a substitute. The enamel formulation consisted of 90%–95% frit and 5%–10% colorants. The selected pigments included copper oxide (CuO), cobalt oxide (Co_3O_4), iron(III) oxide (Fe_2O_3), manganese dioxide (MnO_2), and several zirconium-based composite stains, ensuring stable chromatic performance. The pigments were subjected to wet ball milling for 48–60 hours using a material-to-ball-to-water ratio of 1:2:0.6. The resulting slurry was refined to a fineness where residue on a 10,000-mesh sieve was limited to 0.01%–0.02%, and the specific gravity of the paste was controlled at 1.50–1.65 g/cm³. After milling, the pigment slurry was screened through a 120-mesh sieve to remove ferrous impurities, then naturally dried and low-temperature baked to achieve a moisture content of 5%–8%. The final enamel pigment retained excellent rheological properties even after six months of ambient storage. When applied to ceramic test pieces and fired once at low temperature, the pigment layers exhibited uniform coloration, good adhesion, and no signs of bubbling or sagging. These results verify that the boron-lithium-based lead-free frit system is technically feasible for multi-pigment compatibility and stable low-temperature chromogenic performance.

4.3. Performance testing of painting and firing

Using the aforementioned improved process, eight representative enamel color systems were trial-produced on a series of test cups. The testing procedure involved adjusting the specific gravity of the enamel slurry to approximately 1.55 g/cm³. A broad base layer was applied using a flat brush, followed by the use of a fine brush loaded with white enamel to outline raised contour lines. Different colors were then filled into designated zones. After air-drying at room temperature, the test pieces were fired once in an electric kiln at 700–750 °C under an oxidizing atmosphere, with a holding time of 15 minutes to ensure complete fusion and solidification. Post-firing results revealed that the enamel layers fused seamlessly with the underlying glaze and exhibited a slightly raised, three-dimensional surface texture. The hues appeared vivid and pure, confirming the reliability of the boron-lithium lead-free pigment system under single low-temperature firing. Further environmental durability testing included thermal cycling between −20 °C and 80 °C, as well as 24-hour immersion in 5% hydrochloric acid. The enamel surfaces showed no signs of blistering, cracking, or noticeable discoloration, indicating excellent weather resistance and chemical stability. These results demonstrate that the newly developed enamel system possesses strong environmental robustness, making it suitable for long-term service applications.

4.4. Validation results

Based on the experimental studies, key findings include: using both high-density white-glazed and porous bisque bodies meets differing artistic needs—fine gold detailing and large-area coloring. The B_2O_3—Li_2O lead-free frit combined with 700–750 °C firing reduces energy use by ~20% versus traditional methods, while improving color saturation, adhesion, and environmental safety. As shown in **Figure 6**, single-fired samples across eight color families achieved the desired gloss and color purity, with firmly bonded layers. These innovations enhance enamelled porcelain's sustainability and artistry, supporting future large-scale applications.

5. Contemporary transmission of craftsmanship and cultural-creative practice

In the 21st century, the revival of enamelled porcelain is marked not only by technological innovation but also by the integration of cultural inheritance and creative transformation. The revitalization and industrialization of intangible cultural heritage (ICH) in the Wuling Mountains region of southeastern Chongqing offer valuable inspiration for contemporary enamelled porcelain design. In 2014, the region was officially designated as a National Cultural and Ecological Protection Zone. Under this framework, local governments have adopted a "ICH+" development model to promote the integration of traditional craftsmanship into modern life, such as "ICH + tourism", "ICH + poverty alleviation", and "ICH + industry."

For instance, the Taohuayuan Scenic Area in Youyang County has introduced heritage crafts like Miao embroidery, creating both cultural enrichment and employment opportunities. Similar initiatives have emerged in Shizhu and Pengshui, where heritage workshops (非遗工坊) have become catalysts for local employment. By 2023, Chongqing had established 85 such workshops, with Miao embroidery practices from Youyang and Pengshui selected as national exemplary cases. The revitalization of intangible heritage has reinvigorated traditional crafts and opened new directions for the design and cultural significance of enamelled porcelain.

Contemporary designers can draw on innovations in ethnic minority craftsmanship, integrating them into enamelled porcelain production to foster a dialogue between tradition and modernity. For example, the high-saturation color palettes and diamond motifs found in Tujia brocade can be translated into geometric or border decorations on enamelled porcelain. Similarly, auspicious floral and animal patterns in Miao embroidery can enrich the iconographic repertoire of enamelled designs. Some ceramic artists have already experimented with incorporating Xilan Kapu brocade patterns through overglaze enameling on ceramic panels and vessels, achieving striking visual effects. This form of cross-disciplinary fusion demonstrates that enamelled porcelain can successfully integrate ethnic artistic elements to develop culturally rooted creative products.

Furthermore, the "design intervention" model observed in the industrialization of ICH in southeastern Chongqing merits attention. By involving professional designers to extract and reinterpret traditional motifs and techniques, these crafts can be better adapted to contemporary market demands. In the field of enamelled porcelain, design-driven innovation could take the form of culturally themed products inspired by Tujia and Miao traditions, or the use of digital tools to parameterize traditional patterns that are then hand-painted onto porcelain surfaces—balancing mass production with bespoke customization. Such exploratory practices are already emerging within the cultural and creative industries of Chongqing and its neighboring regions, suggesting promising future developments.

The successful integration of intangible heritage and creative industry practices in southeastern Chongqing provides a meaningful reference for the revitalization of enamelled porcelain. On one hand, the protection and innovation of regional craftsmanship revitalize traditional Chinese aesthetics in contemporary contexts. On the other hand, the incorporation of local cultural elements into the historically imperial medium of enamelled porcelain expands its design vocabulary and enriches its cultural depth. This model of "dual empowerment" demonstrates that traditional craftsmanship must be embedded within contemporary discourses—balancing cultural and practical values—to achieve sustainable development. For enamelled porcelain in particular, embracing regional culture, diverse aesthetics, and emerging technologies will be essential to shaping its future trajectory.

6. Conclusions

Falangcai porcelain emerged in the late 17th century from Chinese-European fusion, peaking in the Qing Dynasty. Despite its brilliance, it faces bottlenecks like health risks and high energy consumption.

PbO-based fluxes pose health and environmental hazards.

High firing temperatures (850–900°C) cause elevated energy use, conflicting with conservation goals.

This study, reviewing history and characteristics, innovated with lead-free boron-lithium frits and lower temperatures (700–750°C), validating key conclusions.

(1) Enhanced safety: Boron-lithium lead-free frit eliminates lead toxicity, with low-temperature firing emissions meeting national standards, improving workplace safety and artisan health.

(2) Energy efficiency: Low-temperature firing at 700–750°C reduces energy by 18–22% vs. conventional methods, lowering carbon footprint.

(3) Decorative quality: Boron-lithium frit with controlled firing curve yields saturated colors, smooth finishes, and acid resistance. Falangcai surfaces show vivid colors and strong adhesion; raised lines enhance depth and expression.

(4) Cultural innovation: Regional ethnic crafts revitalize falangcai, incorporating Tujia and Miao patterns to enrich its scope. Fusion with imperial traditions makes it a culturally resonant medium in contemporary art.

Lead-free frit formulation and precise temperature control are key technologies for the green development of enamelled porcelain. These innovations reduce energy consumption, eliminate pollution, and ensure product quality, laying a solid foundation for its revitalization. In the future, advanced technologies like digital glaze spraying may further decrease energy use, enhance pattern rendering, and broaden application domains. Continued research into long-term weather resistance and refinement of standards remains essential. By preserving traditional craftsmanship while meeting modern demands, enamelled porcelain is poised for high-quality, sustainable development.

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Disclosure statement

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