Research on the Influence of Herbal Materials on the Color-Generation Mechanism of Kiln-Transformed Glazes in Jizhou Ceramics

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Keywords: Jizhou Kiln Ceramics; Yaobian Coloration; Herbal Materials; Chemical Composition; Firing Regime; Microstructure

Abstract: As an important kiln site of the Song Dynasty in China, the kiln transformation process of Jizhou ware holds a significant position in the history of Chinese ceramics due to its unique artistic style and technological innovation. The phenomenon of kiln transformation arises from the interaction between glazes and the kiln atmosphere, forming unpredictable colors and textures through redox reactions of metal elements such as iron and manganese. Traditional kiln transformation techniques relied on mineral materials and chemical pigments, whereas herbal materials, with their rich chemical components and unique physical properties, have gradually become an important direction for exploring new color-rendering mechanisms. The research conclusions reveal that Chinese herbal materials achieve precise regulation of kiln-transformation color through the synergistic effects of chemical composition and physical properties, providing a scientific basis for the modern innovation of traditional techniques. Future research can further expand the range of Chinese herbal materials selection, optimize the precision of process parameter control, and combine machine learning with first-principles calculations to construct quantitative models linking material composition, firing regimes, and color characteristics. Meanwhile, interdisciplinary collaboration should be strengthened to explore the innovative application of Chinese herbal composite additives in ceramic art and functional material fabrication, promoting the deep integration of traditional craftsmanship with modern technology and injecting new momentum into the sustainable development of the ceramics industry.

1. The History and Kiln-Transformation Characteristics of Jizhou Kiln Ceramics

As an important kiln site of the Song Dynasty in China, the Jizhou Kiln holds a crucial position in the history of Chinese ceramic art. The kiln site is located in what is now Yonghe Town, Ji'an City, Jiangxi Province, and its development can be traced back to the late Tang and Five Dynasties periods, reaching its peak during the Northern and Southern Song Dynasties. During this period, the Jizhou Kiln not only achieved a fusion and innovation of northern and southern ceramic techniques but also pioneered a new realm in ceramic decorative art through its unique kiln-varnish black glaze technique. The phenomenon of kiln variation, as a natural result of the interaction between glazes and kiln atmosphere during firing, mainly involves the oxidation-reduction reactions of metals such as iron and manganese at high temperatures, producing unpredictable textures and colors on the glaze surface. Jizhou kilns skillfully utilized this characteristic, combining techniques such as paper-cut paste decoration and leaf imprinting, successfully creating visually striking pieces such as paper-cut paste bowls and leaf-patterned Jian bowls. Among them, the firing technique of the leaf-patterned Jian bowls is particularly exquisite. By placing mulberry leaves and other plants on the surface of the ceramic body, the leaf patterns and glaze colors merge after high-temperature firing to produce an artistic effect characterized by "clear leaf veins and rich glaze color." This creative method, combining natural motifs with kiln-varnish techniques, fully reflects the ancient craftsmen's deep understanding of material properties and firing principles.

The social and cultural environment of the two Song dynasties provided an important driving force for the prosperity of the Jizhou kilns. The elite scholar-official class of the Song dynasty highly admired tea culture, giving rise to tea-drinking practices such as tea preparation competitions and tea-tasting contests. This social trend directly boosted the market demand for black-glazed tea

  DOI: 10.25236/icetmr.2025.020

bowls. Due to their thick bodies and smooth, warm glazes, black-glazed tea bowls clearly showcased the 'bite of the tea' effect during tea competitions, making them highly sought after by everyone from royal nobility to common people. Jizhou kiln artisans, responding to market demand, combined kiln transformation techniques with the functional requirements of tea utensils. While meeting practical needs, they also gave the tea bowls unique artistic value through variations in glaze depth and naturally diffused patterns. This positive interaction between market demand and artistic innovation led Jizhou kilns to develop a distinctive system of kiln transformation techniques with unique regional characteristics.[1]

The formation of the kiln transformation technique not only relies on the accumulated experience of craftsmen but is also closely related to the proportion of raw materials, the structure of the kiln, and the firing schedule. Research shows that the color expression of Jizhou kiln's black glaze is closely associated with the content of metal oxides such as iron and titanium in the glaze, while the control of the kiln atmosphere (such as alternating oxidation and reduction processes) directly affects the crystallization pattern and color layers of the glaze surface. It is noteworthy that some kiln transformation techniques may incorporate the direct participation of plant materials. For example, the firing of woodland leaf Jian bowls requires placing fresh mulberry leaves inside the bowl, and as the leaves carbonize at high temperatures, the organic substances released may catalyze chemical reactions on the glaze surface. This practice of introducing natural plant materials into the firing process not only enriches the color effects of kiln transformation glazes but also reflects the ancient philosophy of craftsmanship exemplified by "Nature's creation and human ingenuity."

The unique value of the kiln transformation art of the Jizhou Kiln in the history of ceramics lies in its perfect integration of natural creativity and human craftsmanship. Artisans, by controlling glaze formulas, temperature gradients within the kiln, and atmospheric changes, ensure that the glaze patterns on each piece become irreplicable works of natural art. This creative philosophy of "intentionally seeking change, unintentionally seeking technique" breaks the formulaic constraints of traditional ceramic decoration, providing important inspiration for the development of ceramic art in later generations. Modern scientific methods applied to the archaeological excavation and craft restoration of the Jizhou Kiln site have further revealed that the use of herbal materials (such as plant leaves and natural mineral pigments) may play a key role in the mechanism of kiln transformation coloration, opening new avenues for exploring the scientific essence of traditional craftsmanship. The kiln transformation technique of the Jizhou Kiln is not only an outstanding representation of ancient Chinese ceramic technology but also serves as a bridge connecting natural laws and human aesthetics. The underlying materials science and artistic philosophy continue to hold significant research value and practical reference today.[2]

2. Background and Significance of Incorporating Herbal Materials

Against the backdrop of continuous exploration and innovation in the field of ceramic art, the technical boundaries and aesthetic expression of traditional kiln transformation techniques have gradually reached a bottleneck. Kiln transformation phenomena, which involve unpredictable color changes in glazes under high-temperature firing, have always been studied in terms of the chemical element composition and firing methods. How to inject new cultural connotations and scientific value while maintaining the authenticity of the craft has become an important topic in contemporary ceramic research. In this context, introducing Chinese herbal materials into the study of kiln color transformations not only reflects a creative reinterpretation of traditional cultural resources but also opens up an innovative interdisciplinary path for ceramic art.

As an important carrier of traditional Chinese medicine, Chinese herbal medicine offers a rich array of research subjects for materials science due to the diversity and functionality of its chemical components. Studies have shown that components found in Chinese herbal medicine, such as alkaloids, flavonoids, and volatile aromatic substances, can undergo redox reactions with metal oxides in ceramic glazes under certain conditions, thereby altering the microstructure of crystal growth on the glaze surface.

From a cultural perspective, the introduction of herbal materials into ceramic art creates a profound connection with traditional Chinese medicine culture. During the kiln firing process, the decomposition and recombination of herbal components not only reflect the scientific principles of material transformation but also subtly embody the philosophical concept of 'harmony between heaven and humanity.' This integration endows ceramic works with dual cultural attributes: they retain the uncontrollable aesthetic characteristics of traditional kiln transformations while also imbuing the pieces with health-preserving functions through the pharmacological properties of the herbal materials.[3]

At the level of technological innovation, the application of Chinese herbal materials has expanded the controllable boundaries of kiln transformation coloring. Traditional kiln transformation processes rely on precise control of glaze formulas and subtle differences in firing temperatures, whereas the introduction of Chinese herbal materials, through the thermal decomposition products of organic components, provides new variables for the generation of glaze colors. This innovative approach aligns with the current materials science concept of "bio-inspired material design," which aims to optimize material performance by mimicking the characteristics of natural substances. For example, the carbonization process of polyphenols in Chinese herbs at high temperatures may form nanoscale particles that embed into the glaze layer, thereby affecting light refraction and color presentation.

Research on the application of Chinese herbal materials in ceramic kiln color development not only establishes an innovative interdisciplinary experimental platform but also reshapes the expressive boundaries of ceramic art through both material and cultural dimensions. The exploration of its mechanisms will deepen the understanding of the reaction patterns of natural materials in high-temperature environments and provide theoretical support and practical paradigms for the contemporary transformation of traditional craftsmanship. The development of this research direction signifies a shift in ceramic art from purely aesthetic pursuits to a paradigm that values scientific, cultural, and practical significance equally, carrying important academic value and practical implications.

3. The Influence of Chinese Herbal Materials on Jingdezhen Kiln Porcelain: Taking Mulberries as an Example

Experimental studies have shown that different types of Chinese herbal materials exhibit significant differences during the ceramic firing process. This phenomenon is mainly closely related to the chemical properties of the organic substances, metallic elements, and mineral components in the Chinese herbs. Taking mulberries as an example, representative samples of Jizhou Kiln black-glazed cups (mulberry) were selected as the research subjects for migration testing, phase analysis, microstructure and element distribution analysis, as well as chemical composition analysis.

3.1 Displacement Detection

The system evaluated the chemical safety of the Jizhou kiln black-glazed cup (Mulberry) under extreme usage conditions. According to the GB31604.34-2016 and GB31604.24-2016 standards, a special test on lead and cadmium migration was conducted. The experiment involved placing pre-treated samples in a 4% acetic acid solution and soaking them for 24 hours under a constant temperature of 22°C to accurately simulate the environment of acidic food contact. The test results (Table 1) show that the migration levels of lead and cadmium were both below the detection limits of the instruments, significantly better than the limits specified in GB4806.4-2016 "National Food Safety Standard for Ceramic Products," fully confirming the safety and compliance of the sample in scenarios involving contact with acidic food.[4]

3.2 Phase Analysis

Using X-ray diffraction (XRD) technology, the phase composition of a Jizhou kiln black-glazed cup (Mulberry) was accurately identified. Representative sample fragments were selected for the experiment, finely ground, and evenly spread on a glass slide, then subjected to high-resolution scanning in an X-ray diffractometer. Through software, the XRD patterns were deeply analyzed, revealing that the main phases of the sample are mullite and quartz. Among them, mullite, as the primary crystalline phase, exhibits high refractive index characteristics that create significant contrast with the glassy phase [Bin Yan, Li Yingxiang, Qian Ruifen. Studies on the sintering process of kaolin–quartz–feldspar porcelain bodies]. This effectively enhances the diffuse reflection of the glaze, giving the black glaze a rich sense of depth; while quartz particles, through scattering, suppress the formation of metallic luster. The combined action of these two components collectively shapes the unique visual effect of the mulberry black glaze.

3.3 Microstructure and Element Distribution Analysis

Investigating the black color formation mechanism of the black-glazed cup (Mulberry) from the Jizhou kiln, a comprehensive analysis of the sample's microstructure and elemental distribution was conducted using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) techniques. Small pieces of the sample were selected, finely polished, and observed under SEM, revealing a smooth surface with multi-scale particle structures. EDS elemental analysis showed that the surface was mainly rich in O, Si, Ca, Al, K, and Fe, with the surface content of Fe reaching as high as 4.69%, significantly enriched by 24.7 times compared to the bulk phase, forming Fe_3O_4 nanocrystallite clusters of 10–50 nm. These nanocrystallite clusters achieve efficient absorption of the entire visible light spectrum through surface plasmon resonance (SPR) effects, presenting a deep black color. Meanwhile, K and Zn elements also show surface enrichment, reaching 4.40% and 0.64%, respectively, which are higher than the bulk values. The enrichment of K effectively lowers the melting temperature range, promoting the migration and enrichment of Fe2; whereas the enrichment of Zn, by substituting Fe2 in the Fe_3O_4 lattice, significantly enhances the thermal stability of the iron crystal structure.

3.4 Chemical Composition Analysis

In order to further quantitatively analyze the chemical composition of the black-glazed cup (Mulberry) from the Jizhou kiln, X-ray fluorescence spectroscopy (XRF) was used for comprehensive testing of the samples. The experiment selected sample fragments, which were ground and pressed into pellets before being analyzed with the XRF instrument. To address the matrix effects and spectral interference present during analysis, this study employed the standard sample calibration method, effectively improving the accuracy of the results. The data show that the sample contains 71.98% SiO_2, 24.10% Al_2O_3, 2.37% K_2O, 0.19% total Fe_2O_3, and 0.10% Zn. The excellent translucency of the high-silicon glass matrix further highlights the color-rendering role of iron. The addition of K_2O helps lower the melting temperature, effectively promoting the migration and enrichment of Fe^{2+}, providing a solid chemical basis for the black coloration.

4. Conclusion

This study reveals the multidimensional mechanisms through which herbal materials influence the color development in Jingdezhen kiln ceramics, highlighting that the type of herbs, their proportion, and processing parameters are the core influencing factors. Through organic–inorganic reactions, special color schemes and textures are generated, exhibiting performance superior to traditional methods while maintaining biological safety. Future research should focus on the controllable impact of herbal materials on the kiln transformation process, such as precisely regulating the morphology, color purity, and spatial distribution of glaze patterns by adjusting material ratios, pre-treatment methods, or firing regimes. Additionally, it is necessary to explore the synergistic effects among different herbs, for example, the combined influence of herbal formulas on the melting characteristics of metal oxides and surface tension, in order to elucidate the synergistic coloring mechanisms in multi-component systems. These research directions can not only deepen the understanding of the scientific principles behind traditional Jingdezhen kiln techniques but also provide new ideas for developing ceramic coloring technologies with natural and environmentally friendly features, promoting the collaborative development of traditional craftsmanship and modern materials science.

Acknowledgements

2021 National Social Science Foundation Cold-Discipline Research Project: Collation, Restoration, and Reproduction of Excavated Jizhou Kiln Shards (21VJXT020)]

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