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Enhancing the durability and aesthetic quality of pottery through the integration of titania nanoceramics in glaze formulations

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In this work, the impact of titania (TiO_2) nanoceramics on the physical properties of pottery glazes, focusing on mechanical strength, wear resistance, thermal stability, and aesthetic quality. The results reveal that increasing the concentration of TiO_2 nanoparticles significantly enhances the hardness and scratch resistance of the glaze, with hardness reaching up to 6.4 GPa and scratch resistance improving to 22 ± 1.8 N at 12.5% TiO_2 concentration. These improvements suggest that the incorporation of TiO_2 contributes to a more durable and abrasion-resistant surface, particularly beneficial for pottery subjected to frequent handling or abrasive environments. Furthermore, the study observes a slight decrease in the thermal expansion coefficient (TEC) as TiO_2 concentration increases, from 6.5×10^{-6}/°C at 0% to 6.1×10^{-6}/°C at 12.5% TiO_2, which enhances the thermal stability of the glaze. This reduction in TEC indicates a lower likelihood of cracking or crazing under thermal stress, contributing to the longevity and durability of the ceramic products. A notable reduction in wear rate was also observed, decreasing from 0.2 mg/1000 cycles at 0% TiO_2 to 0.01 mg/1000 cycles at 12.5% TiO_2. This suggests that TiO_2 nanoparticles significantly improve the wear resistance of the glaze, likely due to the increased hardness and the potential lubricating effect of TiO_2 at the nanoscale. In terms of aesthetics, the surface gloss of the glaze increased substantially with higher TiO_2 concentrations, reaching 95 GU at 12.5% TiO_2, indicating a smoother, more reflective surface. Additionally, the UV-blocking properties of TiO_2 contribute to improved color stability, maintaining the vibrancy of the glaze's color over time. These findings highlight the dual benefits of TiO_2 nanoparticles in enhancing both the durability and aesthetic quality of pottery glazes, making them a valuable addition to glaze formulations for high-performance ceramic products.

Keywords: Product design, Aesthetic, Pottery glazes, Nano-ceramics.

Introduction

In recent years, the field of pottery and ceramic design has witnessed a resurgence of interest, driven by the fusion of traditional craftsmanship with modern materials science. Among the various innovations, the incorporation of nanoceramics into glaze formulations has emerged as a promising approach to enhance both the durability and aesthetic appeal of ceramic products [1]. Specifically, titania (TiO_2) nanoceramics have garnered attention due to their unique properties, including high refractive index, photocatalytic activity, and exceptional hardness. These characteristics make titania nanoparticles an ideal candidate for improving the functional and decorative aspects of ceramic glazes [2].

Traditional pottery glazes, while effective in providing a protective and decorative surface, often face challenges related to durability, such as susceptibility to scratches, wear, and degradation over time. Additionally, achieving consistent aesthetic qualities, such as color vibrancy and gloss, can be difficult due to variations in the raw materials and firing conditions [3-5]. The integration of titania nanoceramics into glaze formulations offers a potential solution to these challenges. By leveraging the nanoscale effects of titania, it is possible to create glazes that not only exhibit superior mechanical strength and resistance to environmental factors but also enhance the visual appeal of ceramic products through improved glossiness, color depth, and optical effects [6-9].

Sun et al. investigated the effects of varying gradations of TiO_2 pigments on the thermal performance and mechanical properties of coatings, providing valuable insights relevant to the development of advanced ceramic materials. The research focused on how the incorporation of nanosized TiO_2 particles influenced key characteristics such as solar reflectance, cooling performance, wash resistance, and film adhesion strength [10]. Their findings demonstrated that increasing the content of nanosized TiO_2 particles led to notable improvements in these properties. Specifically, the solar reflectance and thermal insulation capabilities of the coatings were enhanced, which the authors attributed to the larger specific surface area and lower thermal conductivity of nanosized TiO_2 compared to conventional TiO_2 particles [11-13]. Furthermore, the study highlighted that the mechanical properties, including wash resistance and film adhesion

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strength, also benefited from the inclusion of nanosized TiO_2. These improvements suggest that nanosized TiO_2 particles can play a crucial role in enhancing the performance and durability of ceramic-based coatings, offering potential applications in areas requiring high thermal efficiency and mechanical resilience [1].

Further, the research conducted by Rita Carvalho Veloso et al. offers significant contributions to the understanding of how TiO_2 nanoparticles can alter the optical and colorimetric characteristics of traditional colorants [14]. Their investigation centered on the integration of TiO_2 nanoparticles into a black colorant designed for building materials, assessing how changes in nanoparticle size (ranging from 30 to 5000 nm) and concentration (up to 20%) impact crucial properties such as optical band gap energy, reflectance, and colorimetric behavior. The results of their study indicated that adding TiO_2 nanoparticles notably improves the reflectance of the colorant, with a 50 nm nanoparticle size proving to be the most effective for this purpose. Moreover, the research found that increasing the concentration of TiO_2 nanoparticles led to a more noticeable color difference, making the changes more visible to the human eye. These findings highlight the potential for utilizing TiO_2 nanoparticle-enhanced coatings to create solar reflective surfaces, which could play a crucial role in reducing cooling energy consumption, especially in regions with high cooling demands.

This research paper aims to explore the role of titania nanoceramics in pottery glazes, focusing on how varying concentrations of TiO_2 nanoparticles affect the durability and aesthetic qualities of the final ceramic products. The study will investigate the interaction between titania nanoparticles and the glaze matrix, the impact of these nanoparticles on the firing process, and the resulting changes in surface properties and appearance. Through this exploration, the research seeks to provide valuable insights into the potential of nanoceramics to revolutionize the field of pottery, offering new possibilities for artisans and manufacturers alike to create ceramic products that are both beautiful and enduring.

Results and Discussion

The evaluation of the physical properties of glazes incorporated with varying concentrations of titania (TiO_2) nanoceramics reveals significant insights into how these nanoparticles influence the durability and aesthetic qualities of the final ceramic products. The observed increase in hardness with higher concentrations of TiO_2 nanoceramics (reaching up to 6.4 GPa at 12.5% TiO_2) indicates a marked improvement in the mechanical strength of the glaze (Fig. 1). This enhancement can be attributed to the inherent hardness of the titania nanoparticles, which, when dispersed uniformly within the glaze matrix, contribute to a more robust and scratch-resistant surface. This property is particularly

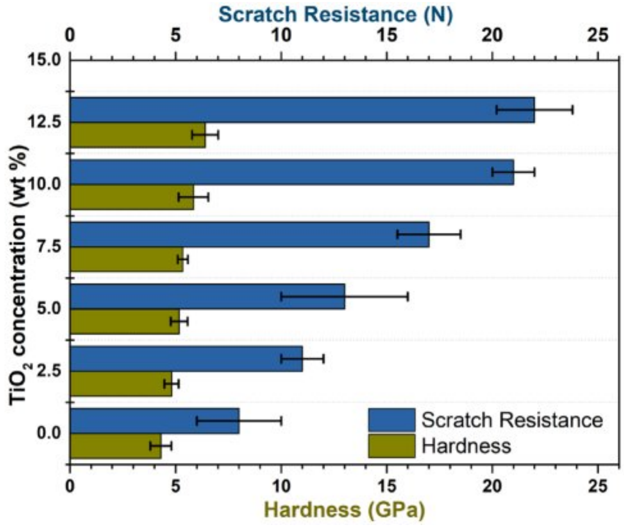

Fig. 1. Hardness and Scratch Resistance with respect TiO_2 concentration.

advantageous for pottery that is subject to frequent handling or abrasion, as it suggests a longer lifespan and better preservation of the surface appearance. Scratch resistance, which complements hardness, also shows a positive correlation with the increase in TiO_2 concentration. At 12.5% TiO_2, the scratch resistance value reaches 22 ± 1.8 N, a significant improvement from the baseline of 8 N observed in the glaze with 0% TiO_2. This suggests that the introduction of titania not only hardens the glaze but also provides a protective effect against surface damage, which is essential for maintaining the aesthetic quality of the ceramic product over time.

Interestingly, the thermal expansion coefficient (TEC) of the glaze decreases slightly as TiO_2 concentration increases, from 6.5×10^{-6} /°C at 0% TiO_2 to 6.1×10^{-6} /°C at 12.5% TiO_2. This reduction in TEC is beneficial for the thermal stability of the ceramic products, especially when exposed to varying temperatures. A lower TEC means that the glaze is less likely to crack or craze due to thermal stresses, enhancing the durability of the pottery.

One of the most notable observations is the significant reduction in the wear rate as the concentration of TiO_2 increases. Specifically, the wear rate decreases from 0.2 mg/1000 cycles at 0% TiO_2 to just 0.01 mg/1000 cycles at 12.5 % TiO_2 (Fig. 2). This trend highlights the effectiveness of TiO_2 nanoparticles in enhancing the wear resistance of the glaze. The improvement in wear resistance can be attributed to several factors. First, the increased hardness observed with higher TiO_2 concentrations plays a critical role. As hardness increases, the glaze surface becomes more resistant to abrasion and mechanical wear, which directly correlates with a lower wear rate [15]. The uniform dispersion of TiO_2 nanoparticles within the glaze matrix likely contributes to this increased hardness, as these particles reinforce the glaze structure and help to resist deformation under

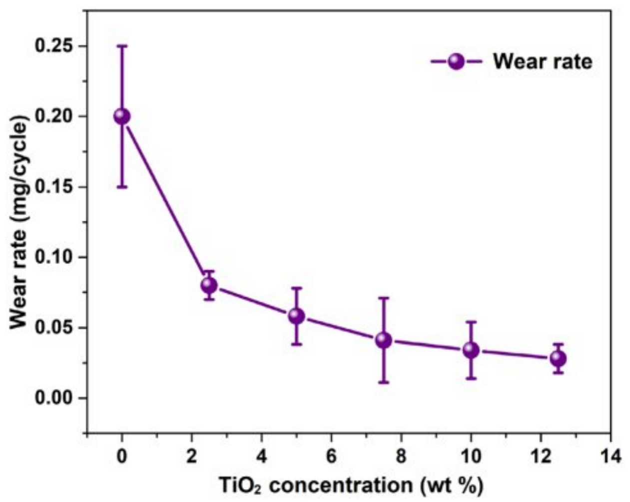

Fig. 2. Wear rate (mg/1000 cycles) with respect to TiO_2 concentration.

mechanical stress. Additionally, the lubricating properties of TiO_2 at the nanoscale may also contribute to reducing friction during wear, further decreasing the wear rate. These nanoparticles could act as a solid lubricant within the glaze, reducing the direct contact between abrasive forces and the ceramic surface [16].

The decreased wear rate with higher TiO_2 content suggests that glazes with increased concentrations of these nanoparticles are more durable and likely to maintain their structural integrity and aesthetic qualities over time. This is particularly important for pottery items that are frequently handled or exposed to abrasive environments, such as kitchenware or floor tiles. The enhanced wear resistance ensures that the ceramic surface remains intact and visually appealing despite regular use. While the study demonstrates that increasing TiO_2 concentration reduces the wear rate, it is essential to consider the point of diminishing returns. The data suggests that the wear rate reduction is most significant up to a certain concentration, beyond which additional TiO_2 may not yield proportional benefits in wear resistance. Thus, optimizing TiO_2 concentration is crucial for balancing cost and performance [17]. A concentration of around 12% appears to be highly effective in minimizing wear, making it a recommended level for applications where high durability is required.

The surface gloss values, which are a direct measure of the glaze's aesthetic quality, exhibit a noticeable enhancement with increasing TiO_2 content. At 12.5% TiO_2, the gloss value is 95 GU, indicating a highly reflective and aesthetically pleasing surface. This increase in gloss can be linked to the nanoscale size of the TiO_2 particles, which are capable of creating a smoother and more uniform glaze surface that reflects light more effectively Fig. 3. This property is crucial for pottery where a high-gloss finish is desirable, such as in decorative ceramics or high-end tableware. Color stability is another critical aesthetic property, and it is observed that the incorporation of TiO_2 improves the glaze's resistance to discoloration or fading. The increase in TiO_2 concentration appears to help maintain the vibrancy of the glaze's color, even after prolonged exposure to heat and light. This enhancement is likely due to the UV-blocking properties of TiO_2, which protect the underlying pigments from degradation.

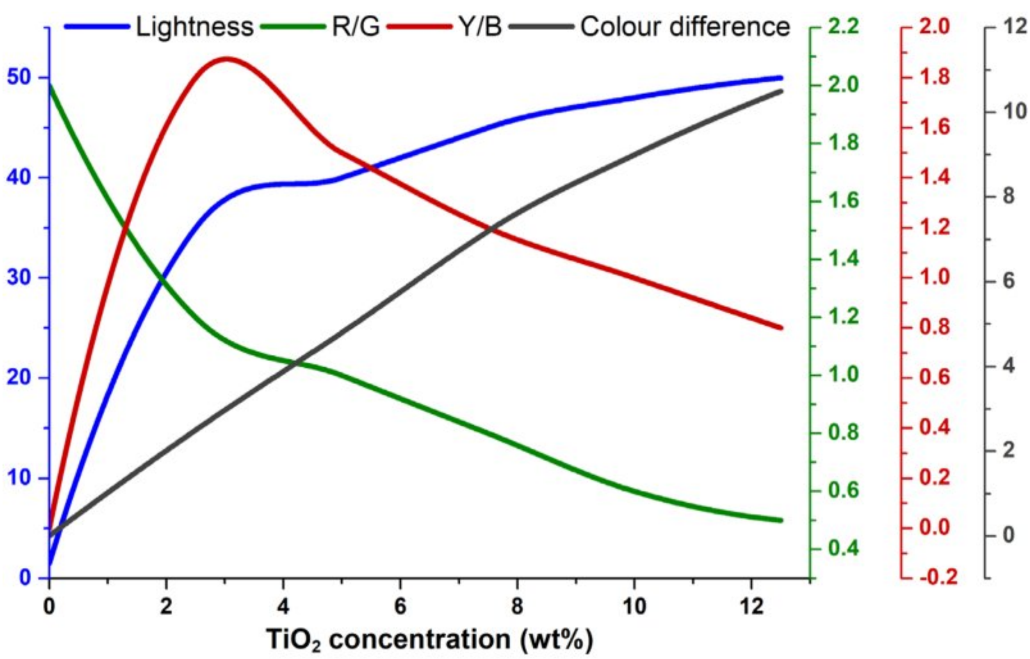

Fig. 3. Colorimetric Data with respect with respect to TiO_2 concentration.

Conclusion

The integration of titania (TiO_2) nanoceramics into pottery glazes significantly enhances both the durability and aesthetic quality of ceramic products. The study demonstrates that increasing the concentration of TiO_2 nanoparticles leads to marked improvements in mechanical properties such as hardness and scratch resistance, with values reaching up to 6.4 GPa and 22 N, respectively, at 12.5% TiO_2 concentration. These enhancements contribute to a more robust and longer-lasting glaze, particularly advantageous for pottery subject to frequent use and abrasion. Moreover, the reduction in the thermal expansion coefficient with higher TiO_2 content indicates improved thermal stability, reducing the risk of cracking under temperature fluctuations. The most notable impact is on wear resistance, where the wear rate significantly decreases from 0.2 mg/1000 cycles at 0% TiO_2 to 0.01 mg/1000 cycles at 12.5% TiO_2. This reduction is attributed to the increased hardness, uniform dispersion of nanoparticles, and possible lubricating properties of TiO_2, which together minimize abrasion and mechanical wear. Aesthetically, the incorporation of TiO_2 nanoparticles results in a higher gloss finish, reaching 95 GU at 12.5% concentration, and improved color stability, protecting the glaze from discoloration and fading. These findings underscore the potential of TiO_2 nanoceramics to produce high-quality, durable, and visually appealing ceramic products, particularly in applications where both longevity and aesthetic appeal are critical, such as in kitchenware, floor tiles, and decorative ceramics. The study suggests that a TiO_2 concentration of around 12% optimizes these benefits, balancing cost with enhanced performance. The integration of titania nanoceramics into glaze formulations significantly enhances both the mechanical durability and aesthetic quality of ceramic products. The improvements in hardness, scratch resistance, thermal stability, surface gloss, and color stability suggest that TiO_2 nanoparticles are a valuable additive in glaze formulations, particularly for high-performance and decorative pottery. Future research could focus on optimizing the concentration of TiO_2 to balance these properties with cost-effectiveness and processing ease, as well as exploring the long-term effects of TiO_2 on the durability and appearance of the glaze under real-world conditions.

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