



# Revolutionizing Ceramic Artistry: Harnessing the Potential of Cow Bone Ash as a Sustainable Opacifier in Enamel Production

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

The demand for opacifiers in ceramic industries necessitates exploration into sustainable alternatives due to the expense and scarcity of traditional materials. Opacifiers are crucial in ceramic production, imparting opacity to glazes, and are often imported, increasing production costs. As a result of these limitations, this study explored the feasibility of utilizing cow bone ash as a cost-effective and sustainable alternative opacifier to tin and zirconium oxides in enamel production for ceramic applications. Through a process of recycling cow bone, bone ash was synthesized and subjected to chemical analysis. Enamel formulations were prepared using bone ash and compared with those containing tin oxide. The physical and chemical properties of the enamels were evaluated, including opacity, durability, and resistance to chemical attack. Results

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indicate that cow bone ash exhibited comparable properties to traditional opacifiers, offering clarity, stability, and resistance to chemical deterioration. Moreover, cow bone ash presented a sustainable solution, utilizing waste material and reducing reliance on costly imports. This research signifies a substantial advancement in ceramic enamel production, promoting sustainability and innovation within the industry. By harnessing cow bone ash as an opacifier, ceramists and chemists can achieve cost efficiency while mitigating environmental impact, paving the way for a more eco-friendly future in ceramics.

*Keywords: Opacifiers; glazes; cow bone ash; ceramic enamel; sustainable materials.*

## 1. INTRODUCTION

Ceramic industries use opacifiers as enamel for ceramic production and most small-scale ceramic industries depend on imported raw materials including opacifiers which are expensive. Opacifiers are finely ground materials or substances added to another material to make the ensuing system opaque. In ceramic production, opacifiers are mixed with transparent glaze using a line blend. They do not enter the glaze melt but remain as small white particles suspended throughout the glaze [1]. They reflect light and make the glaze opaque, hence forming enamel [2].

Enamel is an opaque, glassy, and decorative substance that can be applied to metallic or other hard surfaces for ornament or as a protective coating [3]. The process of enameling includes applying a thin coat to metal and other hard surfaces at high temperatures, when the enamel melts, it fuses to the object. Enamel is useful in the production and decoration of many laboratory equipment and household goods and appliances such as cooking vessels, cooktops, sinks toilet bathtubs, wall tiles, dishwashers, and laundry machines. Enamel is also used architecturally as a coating for wall panels and can be used externally to provide weather resistance and desirable appearance, or internally to provide wear resistance [3–5].

Bone ash is the white powdered material (ash) left from the burning (calcination) of bones. Typical bone ash consists of about 55.82% calcium oxide, 42.39% phosphorus pentoxide, and 1.79 % water [6,7]. The exact composition of these compounds varies depending upon the type of bones being used, but bone ash is primarily composed of calcium phosphate with formula  $(Ca_3(PO_4)_2)$ . It usually has a density of around 3.10 g/ml and melts at temperatures above 1670 °C [8]. Bone ash has been found useful as a raw material for ceramic applications and other allied industries. In ceramic, calcium acts as a stiff glass-former. The calcium oxide

present in the bone ash gives strength and stability to ceramic wares and also serves as a fluxing agent in high-temperature glaze [6,9].

This study was designed to develop an opacifier from bone ash that can be used as alternative enamel to tin and zirconium oxides which are expensive to procure, scarce, and sometimes unavailable. The major impact of this study is to aid the artistic technique in painting with different identified oxides of colour stains which had been difficult to achieve on celadon glazes with dark colour characteristics. The use of bone as an opacifier for this study will also serve as a means of converting waste to wealth, enhance solid waste management, and encourage innovative practice, especially for the development of cottage-level ceramic production and institutional practice.

## 2. EXPERIMENTAL

**Sample Collection and Preparation:** Cow bones were collected from abattoirs in Afikpo, Nigeria. They were immersed in water for 48 hr., washed thoroughly, rinsed, and sun-dried. They were boiled in water with the addition of potash, washed, rinsed, and dried again. The bones were calcined at 1100 °C in an electric kiln (Type-P5900, England) until chemically combined water and organic matters were all removed. The calcined bone was milled to a finer particle size of 5 µm with an Egde milling machine (Pascal Engineering, England) with a porcelain jar.

**Chemical Analyses:** Chemical analysis of enamel produced from bone ash was done to determine elements such as silicon, aluminium, iron, calcium, magnesium, potassium, zirconium, sodium, and barium. The enamel was digested with HCl/HNO<sub>3</sub> mixture using the US EPA 3050B method [10]. Before analyzing the enamel with atomic absorption spectrophotometer (Bulk Scientific, 210 VGP), the instrument was calibrated using standard solutions of known concentrations for the above elements. Calibration curves are constructed by measuring

the absorbance of standard solutions at various concentrations. Then, the digested enamel samples were introduced into the instrument. Since the instrument measures the absorbance of light at specific wavelengths corresponding to the characteristic absorption lines of the elements present in the sample, then the concentration of each element in the enamel was determined by comparing the absorbance of the sample to the calibration curve. The concentrations of the respective elements were later converted into their respective oxides [11,12].

**Enamel Formulation:** The enamel was formulated following the method of Gestrelus et al. [13] with slight modifications. Approximately 100 g of the pulverized sample was weighed with an electric weighing balance (Mettler PN163) and thoroughly mixed with 40 cm<sup>3</sup> of water so that it could stick to the body of the ware. The slurry product formed was smeared on ceramic wear. The smeared items were subjected to firing under full oxidation and atmospheric conditions at 1100 °C. For comparison, tin oxide (reference) was prepared and applied in the same manner.

**Durability Test:** The test ceramic cups imprinted with enamels from bone ash and tin oxide were immersed in 1.0 moldm<sup>-3</sup> solutions of hydrochloric acid and sodium hydroxide separately overnight. Their resistance to chemical attack was observed after 24 hrs.

### 3. RESULTS AND DISCUSSION

The cow bone after calcination is presented in Figs. 1 and 2, respectively are the cow bone ash after crushing and the control sample (tin oxide), which was used for comparison.

Fig. 3 presents the chemical analysis of bone ash. From the result obtained, the calcium oxide content of the bone ash was 78.079 %. This high value of calcium oxide would give more strength and stability as ascertained by Ayilaran [8] to

ceramic wares when compared to those produced with tin oxide. The percentage content of phosphorus pentoxide (P<sub>2</sub>O<sub>5</sub>) was 0.087 %; this showed that the enamel produced from cow bone had the characteristics of low thermal expansion coefficient, high resistance to thermal shock and durability; high chemical resistance, rapid setting, and good glossy surface [1,14]. Aluminium oxide also increases the viscosity, chemical, and thermal resistance. It helps in reducing the expansion coefficient and favours an opaque finish [6].

Zirconium oxide content represents the property of bone ash as an opacifier. The zirconium oxide content as obtained in this research was 0.041 %. This oxide also improves resistance to acid [15]. The % silica component was very low. This is expected since low silica content helps to harden the vitreous system and increases the mix viscosity [14,16,17]. Both magnesium and barium oxide performed the same functions of integrating anti-acid enamels, increasing enamel resistance and viscosity. Zinc oxide is an excellent flux that lowers the expansion coefficient and improves brilliance and surface quality [9,16]. Potassium and sodium oxides lower the elasticity and increase enamel brilliance. Phosphorus oxide alters the opacity of the finish (shining), improves colour stability, and reduces chemical resistance. Calcium oxide is a very good adherent agent [6,16].

Physical examination of enamel produced from bone ash had a low bloating when compared with that of tin oxide. Also, the samples decorated with bone ash enamel had a low tendency of crawling [18]. In terms of opacity, the ceramic cups decorated with bone ash and zinc oxide enamels came out brilliantly (Fig. 4). This indicated that cow bone ash is a good enamel opacifier as tin oxide. The durability test of the opacifier produced and that from tin oxide was excellent as the ceramic cups were resistant to acidic and basic attack [15].



**Fig. 1. Cow bone after calcination**



Fig. 2. Bone ash (left) after crushing and commercial tin oxide (right)

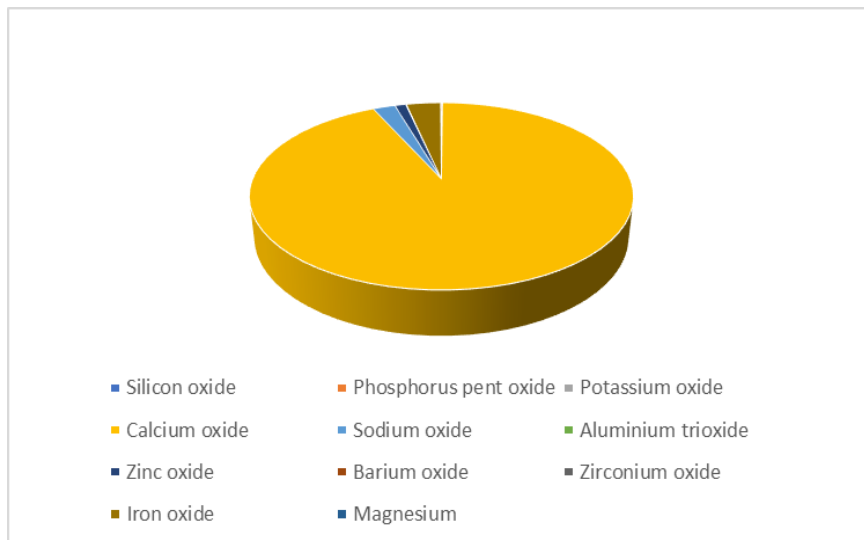


Fig. 3. The chemical analysis (oxides) of bone ash



Fig. 4. Enamels from bone ash (left) and tin oxide (right) print on ceramic cups

#### 4. CONCLUSION

This research highlighted the promising potential of cow bone ash as a sustainable opacifier in ceramic enamel production. Through rigorous

comparative analysis, it was established that the enamel formulated from cow bone ash exhibits commendable clarity and resistance to chemical deterioration, akin to the industry-standard tin oxide. The successful application of this

alternative not only provides a cost-effective solution but also addresses concerns related to the scarcity of tin oxide. By embracing cow bone ash as a viable substitute, ceramists and chemists gain access to a resourceful platform that not only contributes to cost efficiency but also mitigates environmental impact. This research thus marks a significant stride towards promoting sustainable practices within the ceramics industry. The utilization of cow bone, once regarded as waste, not only enhances the industry's economic viability but also underscores the importance of innovative, environmentally conscious approaches in material sourcing. This study has opened avenues for further exploration and implementation of alternative materials in ceramics, fostering a sustainable and eco-friendly future for the industry. The successful integration of cow bone ash as an opacifier heralds a shift towards responsible and innovative practices in ceramic enamel production and provides a platform for artistic painting on ceramic wares.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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