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Replacement of CaO by Recycled Bone Ash in Whitewares

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Abstract

Usually, CaO is a main ingredient used in about 15 to 20% of whitewares. The uniqueness of this study is calcium oxide that is replaced by calcite bone ash and it has prominent mechanical and chemical properties of whiteware products which are more suitable in naturally occurred recycled bone ash than calcium oxide (CaO), for containing pure calcium hydroxyapatite and partially K-Feldspar under the calcination around 1000°C for 24 hours. Chemical and mechanical characterization (density, percentage firing shrinkage, percentage water absorption, MOR, and impact strength) of both sintered bodies containing CaO and bone ash are evaluated. Additionally chemical composition, thermal properties, XRD, and EDX images are also tested. However, it is observed that properties of whitewares are enhanced by the addition of bone ash which accelerates the formation of anorthite phase as well as leads to more intensity on β-tricalcium phosphate (β-TCP) and hinders the creation of mullite.

Keywords: Bone ash, calcium hydroxyapatite, β- tricalcium phosphate (β-TCP), anorthite, mullite.

1. Introduction

Calcium hydroxyapatite (HAp) is an achievable component present in teeth and bones, and research on biomimetic and environment-friendly materials has gained significance in the industry and biomedical sectors[1]. It can substitute cations and anions and can bond with organic molecules which can be of different sizes [2]. The world and industries are on energy conservation, achieving this, industries are continually exploring the use of alternative fuels and raw materials. Using this bio-waste for combustion in cement industries can help reduce the emission and spread of greenhouse gases and contagious diseases [1]. 0, 1, 2, and 5 weight percent CBB were used to make hard porcelain, which was then sintered at temperatures between 1100 and 1400 degrees Celsius. The sample with 2% CBB had the maximum tensile strength of all the samples, although its sintering temperature was 50 °C lower than that of the sample with 0% CBB. Depending on the amount of CBB used, two mechanisms were seen during porcelain sintering: for 1 and 2% of CBB, the mullite production dictated the ultimate shrinkage without affecting the initial sintering temperature, while for 5%, liquid formation lowered the initial sintering temperature [3]. Bones are used in agricultural purposes, cement, and ceramic factories [4]. Hydroxyapatite (HAp) may be extracted from bone or teeth using a variety of techniques, such as thermal breakdown, alkali hydrolysis, co-precipitate, sol-gel, hydrothermal extraction, and microwave heating [5] [6]. Synthetic HAp's smaller crystal sizes enhance surface and porosity, promoting bone growth, but can cause structural deterioration and low mechanical strength, necessitating a limit on scaffold porosity [7], [8], but the high cost of ultra-high purity chemicals needed for production, unwanted by-product chemical compounds, and the absence of additional elements like sodium (Na), silicon (Si), iron (Fe), or minerals such as carbonate. Hayek et al. successfully precipitated high-quality HAp by carefully controlling pH and temperature using the method of alkaline hydrolysis [9]. Furthermore, both Lehr et al. and Seuter et al. have reported successful synthesis of HAp via the solid-state route [10]. The hydrothermal technique has also proven to be an effective method for single-crystal HAp synthesis, as demonstrated by Mosebach et al. [11].

Bones have mechanical characteristics and are stiff because of their inorganic components. Nonstoichiometric hydroxyapatite (HAp), whose molar ratio of calcium to phosphorus deviates from the usual ratio of 1.67, is a model compound that mimics the mineral phase of bones [2]. It has previously been stated that bone ash makes up around 50% of the items made from bone in China [12]. Excellent mechanical qualities, such as increased strength and hardness, are imparted to bone china by bone ash. Bone ash is also responsible for the white look of bone china, which makes it a good substitute for porcelain [13]. By using bone ash, environmental pollution both from landfills and carbon dioxide will be reduced, contributing to the mitigation of climate change and providing affordable materials for construction with high compressive load [14].

In this study, research has been carried out to synthesize hydroxyapatite (HAp) by using the thermal decomposition method to enhance the physical and mechanical properties of whitewares and the effects of HAp addition with the replacement of CaO by bone ash in whitewares is compared. Valuable insights were provided by extensive research to enhance whiteware properties.

2. Materials and Methods

Here, two different batch compositions were prepared, one for CaO and another for Bone Ash. Working elements were collected from the Nano-synthesis lab, Dept. of GCE, RUET. Potash feldspar, included atoms are potassium (K), aluminum (Al), silicon (Si), oxygen (O), and so on, Kaolinite was the source of aluminum silicate minerals, quartz provides Silica, after calcining collected bone from different hotels and restaurants, they were ground with ball mill for 5 hours. For initial binding Carboxymethyl Cellulose (CMC) was used. To ensure the excellent mechanical, physical, and chemical properties of adding bone ash in whiteware samples were examined, materials characterization XRD and EDX were also done.



Figure 1. Experimental Procedures (a to d, Bone calcination and 1 to 8 sample preparation).

The following characterizations were carried out to justify the properties of synthesized products:

Impact Strength

In the laboratory, Impact strength was measured by using 'Izod Impact Tester,' the standard Impact strength result was measured by the following equation: specimen for ASTM is 64 x 12.7 x 3.2 mm.

$$S = \text{—} \tag{1}$$

Bending Strength (MOR)

In the laboratory, MOR test was done by using a 'Three Point Bending Tester', following the ASTM D-790M standard test method.The following equation measured the bending strength result:

$$\text{——} \tag{2}$$

Density Measurement

The following equation did density measurement:

$$\text{———} \tag{3}$$

Porosity Measurement

Excessive porosity is harmful to whitewares, at high-temperature HAp changes its phase to liquid and fills the internal gap of the whiteware body.

The following equation did porosity measurement:

$$\frac{ht \qquad ht}{ht \qquad ht} \tag{4}$$

Percentage Firing Shrinkage

Percent firing shrinkage was measured by the following equation:

$$\frac{\qquad\qquad\qquad\qquad\qquad\qquad}{\qquad\qquad\qquad\qquad\qquad\qquad} \tag{5}$$

Corrosion Test

In the laboratory, a corrosion test was performed by using HCl, NaOH, and Distilled Water for samples.

3. Results and discussion

3.1. Mechanical, physical, and chemical data analysis.

Tests		CaO	Bone ash
Impact Strength		1.28 J/cm2	1.91 J/cm2
Bending Strength (MOR)		50 MPa	73 MPa
Percent Water Absorption		0.12 %	0.05 %
Porosity		5 %	2 %
Density		0.75 g/m³	1.55 g/m³
Percent Firing Shrinkage		0.48 %	0.26 %
Corrosion Test	HCl	0.11 %	-0.08 %
	NaOH	0.07 %	-0.05 %
	Distilled H_2O	0.02 %	-0.01 %

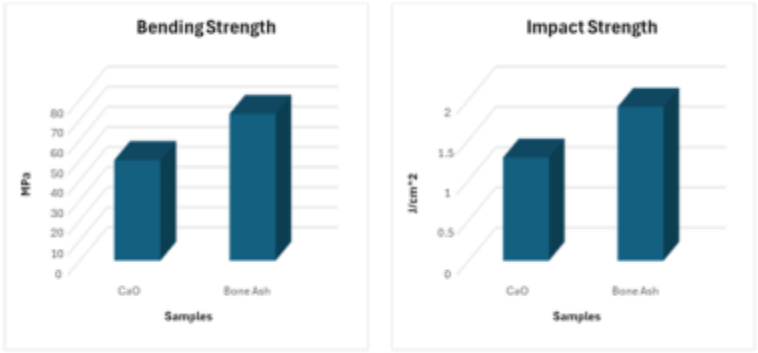


Figure 2. Mechanical Properties of Both whiteware Samples, Containing CaO and HAp .

Above this table, HAp of bone ash enhanced materials' strength and workability significantly comparing that of the CaO, In comparison to bricks made using clay as a reference (strength of 20 MPa), bricks made with bone ash at concentrations of 5%, 10%, and 15% exhibited strengths of about 41.6, ~49.3, and 46.1 MPa, in that order. Specimen 10 BAC (Bone Ash Content) and 15 BAC had the highest compressive strengths, although they also had larger bulk densities than sample 5BAC [14]. For natural k-feldspar, hydroxyapatite was added to the ceramic manufacturing in increments of 5, 10, and 15%. When ceramic was heat-treated at a lower temperature, the hydroxyapatite breaks down and produces calcium oxide and phosphate bonds that facilitate the rapid liquid phase development. The densification was enhanced by the rapid liquid phase creation, as demonstrated by the examination of water absorption, bulk density, linear shrinkage, and apparent porosity. Following the heat treatment, the ceramic samples' mechanical qualities were improved by the addition of hydroxyapatite [15].

3.2. XRD Characterization

Table 1 highlights the high intensity concerning the 2 theta angle of both the sample containing CaO and Bone ash. The XRD data assured the presence of Hap of bone ash in the prepared sample. All three species of animal bones cow, galline, and caprine showed peaks that primarily corresponded to the HA phase in the sintered samples. With higher sintering temperatures, all samples' HA phases also displayed increased crystallinity [16]. It reveals the presence of crystalline HAp phase having a hexagonal structure along with additional second phases and the crystallinity of CaO having a cubic structure. The presence of HAp gives high crystallinity on whitewares. The ternary phases diagram of a conventional ceramic sample (0 wt% hydroxyapatite) comprises silica, alumina, and potassium feldspar, with a liquid phase temperature of approximately 1000°C [17]. When hydroxyapatite is added to a ceramic sample, it decomposes and forms a phase of tricalcium phosphate and lime. Thus,

lime, phosphate, and alumina made up the system's ternary phase diagram. It might melt at a lower temperature of around 900°C into a liquid phase that can increase the ceramic samples to heat up [11]. The rapid liquid phase aided by the HAp caused the crystalline quartz in the ceramic sample to dissolve more quickly at a lower maturation temperature. Melting some of the raw materials causes the surface morphology to change at 1000°C, increasing density and decreasing roughness. The partly liquid phase flow and water released during the breakdown of kaolin are what cause the tiny pores on the surface to open. Furthermore, it has been claimed that HAp found in calcined bones may change into beta-tricalcium phosphate, which catalyses the transesterification process [18].

$Al_2O_3{\cdot}2SiO_2$ Metakaolin + CaO Lime → $CaAl_2Si_2O_8$ Anorthite, Phase changes of materials [14].

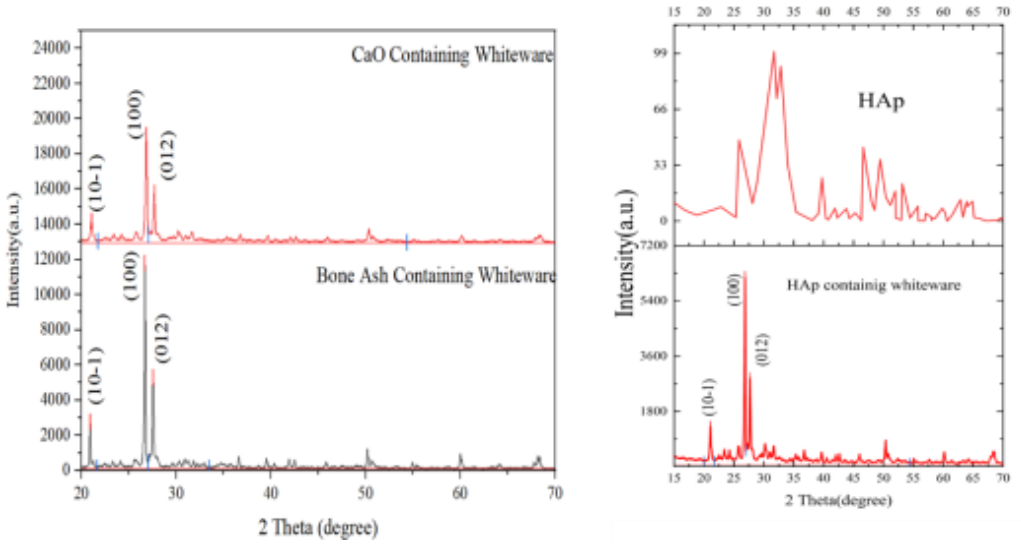


Figure 3. XRD of Both whiteware Samples Containing CaO and Bone ash.

Table 1. XRD of Both Whiteware samples containing CaO and HAp.

Samples	Elements	References	2Theta[deg]	Crystallographic Planes (hkl)
CaO	Quartz	JCPDS	26.65	(1 0 0)
		96-500-0036	20.87	(1 0 -1)
	Lime	JCPDS	35.83	(0 2 0)
		96-900-6745	30.89	(1 1 1)
Bone Ash	Quartz	JCPDS	26.75	(1 0 0)
		96-153-2513	20.95	(1 0 -1)
	Lime	JCPDS	35.83	(0 2 0)
		96-900-6745	30.89	(1 1 1)
	Pure HAp	JCPDS	31.72	(2 1 1)
		96-900-2215	32.84	(0 3 0)
			32.12	(1 1 2)

3.3. EDX Characterization

EDX conforms and shows the percentage of elements and colour-mapping highlights the location. The primary components of bone ash, according to the EDX analysis, are calcium and phosphorus, with small amounts of silicon found in bone ash and laterite soil. These elements enhance the cementitious quality and compressible strength of the sample body. According to our findings, hydroxyapatite aided enhance the cementitious ability of the Bone ash and produced greater compressive strengths. This was demonstrated by X-ray and EDX using Ca and Si.

Densification begins at the same temperature, but only the ultimate shrinkage increases proportionately to the Calcined Bovine Bone (CBB) at 0, 1, and 2% CBB. The specific gravity of the mullite phase is approximately 3.26 g/cm3, which is noticeably greater than the density of glass. Since the amount of quartz is almost the same, there is more shrinkage because of the higher final density produced by the addition of mullite and the corresponding decrease in glass contents. Nonetheless, the densification temperature for porcelain with 5% CBB is noticeably lower, most likely because of the lower temperature and increased glass content. In the latter instance, shrinkage is mostly attributable to liquid phase sintering [19]. It is well known that a Ca/P ratio of 1.67 is the typical stoichiometric comparison for Bone-Derived Hydroxyapatite (BHA) between calcium and phosphate. In this work the ratio of Ca and P was too high for sintering at elevated temperatures for introducing β-tricalcium phosphate (β-TCP), the current study's findings demonstrated that the extracted BHA's Ca/P ratio burned at 800°C, 900°C, and 1,000°C, respectively, with values of 1.849, 1.718, and 1.810 [20].

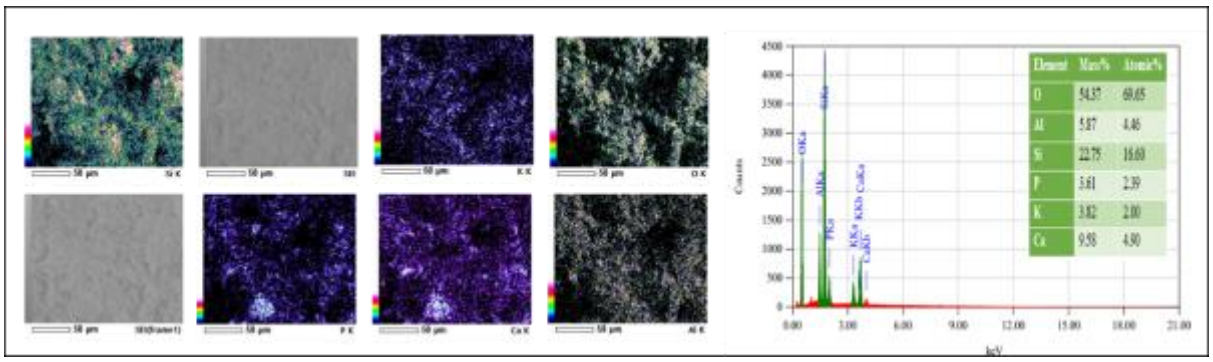


Figure 4. EDX of the sample containing Bone Ash.

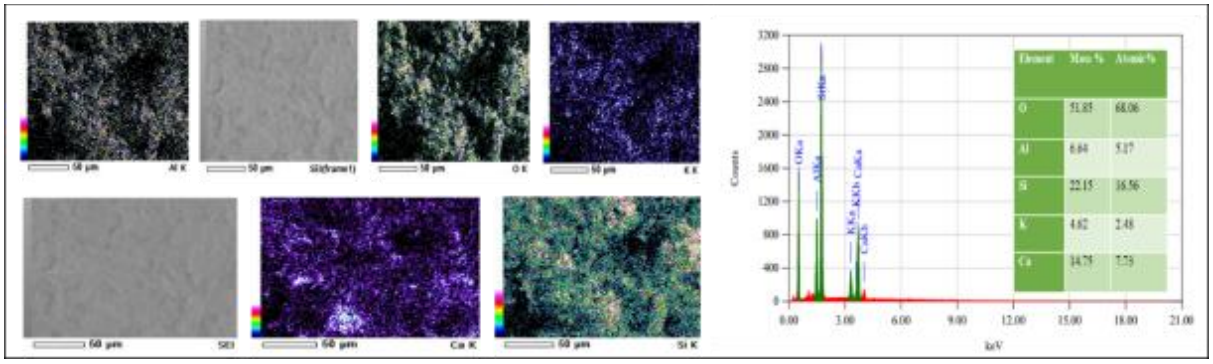


Figure 5. EDX of the sample containing CaO.

To confirm the element of CaO and HAp EDX analysis was performed. Phosphorous an element of HAp was found in the sample containing bone ash. The EDX patter shows that the main crystalline phases present in the sample were anorthite and quartz embedded in a glassy phase. The Figure reveals that sub-angular quartz grains are surrounded by a glassy rim of fine crystalline anorthite grains. EDX patterns confirm the presence of residual quartz and the formation of anorthite phase. This result is also demonstrated by the XRD findings.

4. Conclusions

The purpose of using calcined bone ash has outstanding mechanical and chemical properties. 15 gram for both CaO and HAp containing samples have 1.28 J/ cm^2 and 1.91 J/ cm^2 impact strengths respectively. CaO and HAp samples have 50 MPa and 73 MPa bending strengths. CaO and HAp samples have 5% and 2% porosity. Others features shrinkage, density, corrosion test's have significant value. The results had come due to reacting as a fluxing agent, and it had melted before other materials of high melting temperature, enhanced in the melting properties for liquid phase formation and made the samples more densed that were observed in this work, EDX and XRD had confirmed

the presence of HAp element. Utilizing the bone ash is a good waste management and important source of pure HAp.

5. Acknowledgement

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6. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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