# The Effect of Cow Bone Particulate on the Mechanical Properties and the Microstructure of Aluminium Brass

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## ABSTRACT

This study investigates the mechanical properties and microstructural characteristics of aluminium brass composites reinforced with varying percentages of cow bone particulate (CBP). The analysis includes stress, strain, elongation at yield, Brinell hardness, and impact resistance measurements, complemented by microstructural examination. The results show that increasing CBP content enhances the stress capacity and hardness of the composites, with stress values rising from 2.2123 N/mm² at 0% CBP to 3.9951 N/mm² at 3% CBP, and Brinell hardness increasing from 52.98 BHN to 103.63 BHN. Conversely, strain values decrease from 16.8% to 13.26%, indicating a reduction in ductility. Impact resistance also diminishes with higher CBP content, from 43.52 joules at 0% CBP to 32 joules at 3% CBP. Microstructural analysis reveals that CBP particles are distributed both as clusters and fine isolated particles within the brass matrix, influencing grain size and boundary strength. These findings suggest that while CBP reinforcement enhances the hardness and stress resistance of aluminium brass, it also introduces brittleness, affecting the material's overall ductility and impact resistance. The study provides valuable insights into the potential applications and limitations of CBP-reinforced aluminium brass composites.

**Keywords**: Aluminium brass; Cow bone particulate; Reinforcement materials; Composite materials; Metal matrix composites; Hydroxyapatite

## INTRODUCTION

Aluminium is the most abundant metal in the Earth's crust [1]. Due to its advantageous technical properties—such as lightness, high reflectivity, thermal conductivity, electrical conductivity, non-toxicity, ductility, and hardness—aluminium, along with brass, is increasingly employed in engineering applications [2], [3]. Brass, an alloy of copper and zinc, can be further enhanced by adding aluminium, resulting in aluminium brass. This material, typically composed of 88% copper, 2% zinc, and 10% aluminium, exhibits remarkable resistance to various forms of corrosion, making it ideal for use in heat exchangers and condensers [4], [5]. Recent research in material engineering has focused on reinforcing aluminium brass with agro-wastes to develop new materials with improved mechanical properties, such as hardness, impact strength, microstructure, and tensile strength [6], [7], [8]. Numerous studies have explored the use of various agro-wastes to reinforce aluminium brass and improve its properties. For instance, Prasad and Mustafa et. al., conducted a study on the synthesis and wear behaviour analysis of SiC- and rise hush ash (RHA)-based aluminium metal matrix composites [9]. Similarly, Saravanan and Kumar demonstrated that reinforcing AlSi10Mg with RHA increased its tensile and compressive strength while reducing ductility [10]. Further research by Subrahmanyam et al. focuses on combination of RHA and fly ash (FA) to enhance the mechanical properties of aluminium brass, showing a linear increase in hardness with higher RHA content [11]. Researchers have been progressively enhancing the mechanical properties of brass and aluminium composites by incorporating various bio-wastes. Cow bone particulates and horn [12], snail shell particles [13], carbonized eggshells [14], and rice husk ash have all been studied for their potential to improve aspects like sliding resistance, tensile strength, and hardness.

Some researchers have investigated the microstructure and mechanical properties of different aluminium alloys reinforced using different materials. Oluwadare et al. [15] investigated the effect of tin addition on the mechanical properties and microstructure of aluminium bronze with 4% Nickel. It was discovered that the tensile strength of the composite was increasing and later decreased as the quantity of tin increase. The hardness increases as the tin increases while the impact resistance decreases. Hacka and Musa investigated the effect of adding boron on the microstructure, thermal and mechanical properties of Al-5% Mg 2% Ti alloy [16] The Vickers micro-hardness value and tensile strength of the aluminium composite was increased when boron was added. Gubicza et al. [17] studied the effect of adding magnesium on the mechanical properties and microstructure of a highly pure aluminium. The results show that stable microstructure was developed at higher strains due to addition of magnesium. Addition of magnesium also increases the dislocation density leading to an increase in proof stress over a wide range of strain.

One innovative approach involves using cow bone particulate as a reinforcement material. Cow bone, primarily composed of hydroxyapatite and collagen, offers potential enhancements in wear resistance, hardness, and tensile strength when integrated into aluminium brass [18]. The mechanical properties of cow bone particulate can positively impact the properties of aluminium brass, enhancing its hardness, wear resistance, and tensile strength [19]. However, the optimal amount of cow bone particulate must be determined to avoid undesirable effects such as reduced ductility and toughness [3]. While significant research has been conducted on reinforcing aluminium brass with various agro-wastes, the use of cow bone particulate remains relatively unexplored. This study aims to fill this gap by investigating the impact of cow bone particulate on the mechanical properties and microstructure of aluminium brass. By optimizing the cow bone particulate content, the study seeks to enhance key properties such as hardness, tensile strength, and wear resistance, all while maintaining acceptable levels of ductility and toughness.

## MATERIALS AND METHOD

### Materials

Materials used in this work include cow bone, Aluminium brass (Aluminium, Zinc and Copper), foundry equipment including the furnace, crucible furnace, electric arc and furnace for sand casting. The tests and equipment needed to investigate the effect of cow bone particulate addition on the microstructure and mechanical properties of aluminium brass. Include the Universal Tensile Testing Machine and Brinell Harness Testing Machine, Tensometer Machine and Rockwell Hardness Testing Machine.

The copper was obtained from copper windings and purchased from the market and cow bone was obtained from Leyson Integrated Services Ltd, while aluminium and zinc were sourced from A-Net Products Concept. 43 Old Otta Road Orile Agege, Lagos, Ikeja, Lagos.

### Method

### Sample Preparation

Sand-casting method was employed to prepare the specimens. A wooden pattern was created to form the mould cavity within a drag and cope assembly using an incorporated gating system. The dry sand mould, made from green sand, was dried in an oven or naturally before the molten metal was poured. The aluminium brass, consisting of 88% copper, 10% aluminium, and 2% zinc, with cow bone particulate added in varying amounts (1-3 %) as shown in Table 1, was melted in the furnace and cast into the mould cavity. After preparing and selecting specimens with different composition ratios, the crucible furnace was fired up and ready for charging materials for melting.

### Casting and Melting Process

To investigate the feasibility of producing aluminium brass and manipulating its mechanical properties using local techniques, sand casting was selected for its low cost, ease of use, and flexibility. Cold deformation of various degrees and heat treatments—solution heat treatment, normalizing, and aging were applied to the cast brass to influence its mechanical properties. Results indicated that normalizing provided the optimal mix of mechanical properties, including ultimate tensile strength, elongation, and Rockwell hardness, making the brass a suitable alternative to steel in low/medium strength structural applications.

Copper, with the highest melting point of 1083°C, was first charged into the melting furnace. Once it reached a fluidity level, aluminium (660.3°C) and zinc (419.5°C) were introduced according to their melting points. The temperature of the molten metal was measured using a furnace thermocouple inserted through a hole in the furnace lid into the molten metal in the crucible.

It should be noted that the furnace temperature was adjusted to melt materials with lower melting points without causing evaporation. Copper, aluminium, and zinc were added in lumps and stirred with a rod before being poured into prepared moulds. This procedure was repeated for all cast specimens. After solidification, the specimens were prepared for microscopic examination and mechanical properties testing.

Table 1: Percentage compositions of the specimen

| Specimen | Cow-bone particulate (%) | Cow-bone particulate (kg) | Cu (%) | Cu (g) | Al (%) | Al (g) | Zn (%) | Zn (g) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 88 | 440 | 10 | 50 | 2 | 10 |
| 2 | 1 | 5 | 87 | 435 | 10 | 50 | 2 | 10 |
| 3 | 2 | 10 | 86 | 430 | 10 | 50 | 2 | 10 |
| 4 | 3 | 15 | 85 | 425 | 10 | 50 | 2 | 10 |

**Characterisation**

The samples were prepared for micro-examination through several processes. First, sample preparation involved grinding, polishing, and etching before examination under a metallurgical microscope. Grinding aimed to produce a flat, smooth surface using silicon carbide papers of grades 220, 320, 400, and 600, progressing from coarse to fine under running water to prevent overheating and remove grits. The samples were rotated 90° between grits to counteract scratches from previous stages, performed at Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Polishing involved using a universal polishing machine with a selvyt cloth. Initial polishing used a solution with one micron of silicon carbide, followed by final polishing with a 0.5µm silicon carbide solution to achieve a mirror-like finish. The sample was then washed and dried. Etching was done to reveal the microstructure, selectively attacked grain boundaries. Polished samples were etched with 2% NITAL for ferrous materials and Sodium Hydroxide for non-ferrous materials, then washed, dried, and examined under a metallurgical microscope (Accu-scope, 400x and 800x magnification).

The tensile property was determined by the Universal Tensile Testing Machine as per ASTME 8 standard, while the Hardness Property was determined by Brinell Hardness Testing Machine.

## RESULT AND DISCUSSION

Table 2 presents data on the tensile and hardness properties of aluminium brass samples reinforced with varying percentages of cow bone particulate.

As documented in Table 2, the stress recorded shows a clear trend with the addition of cow bone particulate. For the samples, stress values increase with the percentage of cow bone particulate: 2.2123 N/mm² for 0% cow bone, 2.5072 N/mm² for 1% cow bone, 3.1396 N/mm² for 2% cow bone, and 3.9951 N/mm² for 3% cow bone. This increase in stress capacity indicates that cow bone particulates improve the material's ability to withstand higher loads before failure. The enhanced stress resistance can be attributed to the hydroxyapatite and collagen in the cow bone, which provide a rigid reinforcement phase, effectively distributing the applied load more efficiently. Similar observation has been observed in the literature for epoxy resin composite [19], [20]

The strain on the other hand shows an inverse trend with the addition of cow bone particulate. The strain values decrease as the percentage of cow bone particulate increases: 16.8% for 0% cow bone, 15.24% for 1% cow bone, 14.57% for 2% cow bone, and 13.26% for 3% cow bone. This reduction in strain suggests that the material becomes less ductile and more brittle with increasing cow bone particulate. The rigid structure of the cow bone particulates likely restricts the overall flexibility of the composite, leading to reduced capacity for deformation under load.

The elongation at yield shows a mixed trend with varying cow bone particulate content. For the samples, elongation at yield values are 1.5650 mm for 0% cow bone, 2.8462 mm for 1% cow bone, 1.7760 mm for 2% cow bone, and 1.8280 mm for 3% cow bone. There is an initial increase in elongation at 1% cow bone particulate, followed by a decrease at higher percentages. This suggests that small amounts of cow bone particulate might initially enhance the elongation due to better load distribution. However, as the particulate content increases further, it begins to restrict the material's ability to elongate, reducing its ductility.

Table 2: Tensile and hardness properties

| Sample | Cow-bone particulate (%) | Stress ($N/mm^2$) | Strain (%) | Elongation at yield (mm) | Brinell Hardness (BHN) |
|---|---|---|---|---|---|
| 1 | 0 | 2.2123 | 16.8 | 1.5650 | 52.98 |
| 2 | 1 | 2.5072 | 15.24 | 2.8462 | 82.78 |
| 3 | 2 | 3.1396 | 14.57 | 1.7760 | 91.48 |
| 4 | 3 | 3.9951 | 13.26 | 1.8280 | 103.63 |

The Brinell hardness values show a significant increase with the addition of cow bone particulate: 52.98 BHN for 0% cow bone, 82.78 BHN for 1% cow bone, 91.48 BHN for 2% cow bone, and 103.63 BHN for 3% cow bone. This increase in hardness demonstrates that cow bone particulates significantly enhance the hardness of aluminium brass, making it more resistant to surface deformation. The improved hardness is beneficial for applications that require higher wear resistance.

**Error! Reference source not found.** provides information on the impact resistance of aluminium brass samples reinforced with varying percentages of cow bone particulate. Impact resistance, measured in joules, indicates the energy absorbed by the material before failure under a sudden load. The baseline sample, which contains no cow bone particulate, exhibits the highest impact resistance at 43.52 joules. This suggests that unreinforced aluminium brass is more capable of absorbing energy from sudden impacts compared to the reinforced samples. As the percentage of cow bone particulate increases, the impact resistance consistently decreases. Specifically, the impact resistance drops from 43.52 Joules in the baseline sample to 32 Joules in the sample with 3% cow bone particulate. The reduction in impact resistance is gradual from 0% to 2% cow bone particulate but becomes more pronounced at 3% of cow bone particulate.

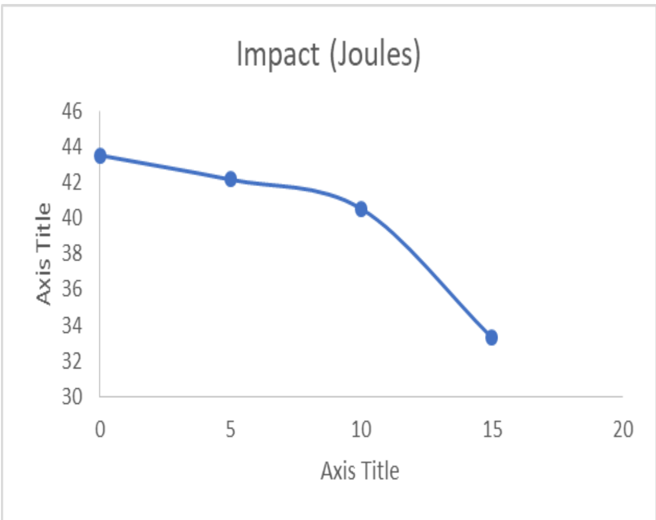


Figure 1. Graph of Impact (J) against CBp (g).

The decrease in impact resistance with increasing cow bone particulate content can be attributed to the inherent properties of the particulate. Cow bone, while adding strength and hardness, also introduces brittleness to the composite material. The rigid structure of hydroxyapatite, a major component of cow bone, reduces the material’s ability to deform plastically under sudden loads. This rigidity leads to lower energy absorption and

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higher susceptibility to fracture. While cow bone particulate enhances certain mechanical properties like hardness and tensile strength, there is a trade-off in terms of impact resistance.

**Error! Reference source not found.** shows micrographs of brass with varying percentages of cow bone particulate (CBP) incorporated by weight. In **Error! Reference source not found.** (a), the micrograph displays full coverage with a few pores, which might be due to the uneven surface or the presence of impurities. **Error! Reference source not found.** (b) to **Error! Reference source not found.** (d) reveal clear grain boundaries with the presence of larger pores, likely attributed to the amorphous nature of the cow bone particulate. It was further observed that increasing the CBP content above 5% by weight results in comparatively smaller grain sizes with tube-like grains. The micrographs clearly indicate that the CBP particles are present both as clusters and as fine isolated particles within the matrix. The fine CBP particles tend to occupy the grain boundary sites, while the larger particles of the reinforcement are embedded within the metal matrix.

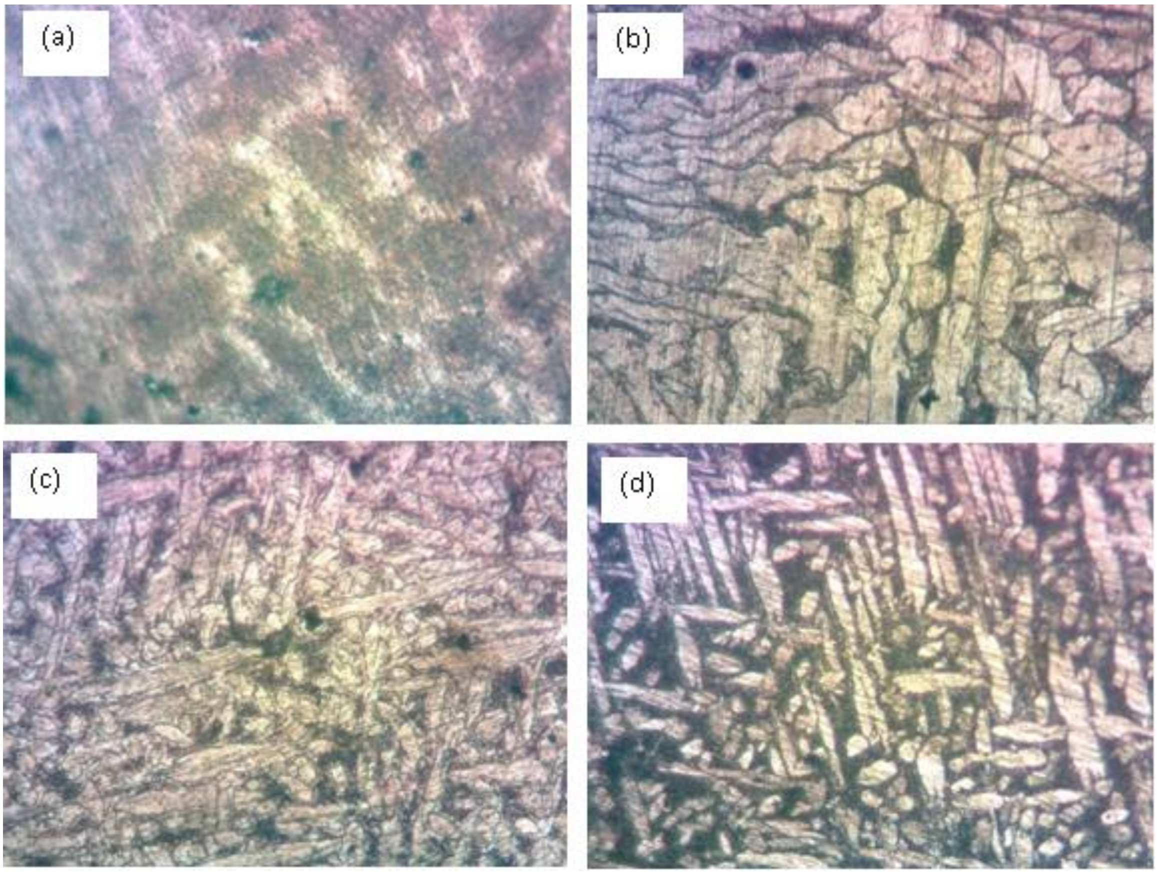


Figure 2: Microstructure of (a) Control sample without CBp, (b) Aluminium brass + 1% of CBp, (c) Aluminium brass + 2% CBp and (d) Aluminium brass + 3% of CBp.

The arrangement of the grains, inclusions, and substitutions significantly influences the mechanical properties of the alloy. The distribution and size of the CBP particles within the brass matrix contribute to the observed variations in the strength values of the alloy. The presence of CBP as both clusters and fine particles suggests a complex interaction at the microscopic level, where the fine particles enhance the grain boundary strength, and the larger particles provide additional reinforcement within the matrix. This intricate microstructural arrangement is responsible for the enhanced mechanical properties, such as increased hardness and strength, observed in the CBP-reinforced brass alloy.

This study further reveals the potentials of animal bones which are considered as wastes. It shows that they can be useful additives to improve properties of already existing engineering materials and make them more suitable for a specific application. For example aluminium brass is a useful material suitable in production of components used in marine, aerospace and automotive industries. The study shows that the properties of aluminium was improved when cow bone was added.

## CONCLUSION

The effects of cow bone particulate on the mechanical properties and microstructure of aluminium brass have been studied. The incorporation of cow bone particulate (CBP) into aluminium brass significantly influences its mechanical properties and microstructure. The experimental results indicate that increasing the percentage of CBP enhances the stress capacity and Brinell hardness of the composite material. Specifically, stress values increased from 2.2123 N/mm² for the 0% CBP sample to 3.9951 N/mm² for the 3% CBP sample, and Brinell hardness improved from 52.98 BHN to 103.63 BHN over the same range. This enhancement in strength and hardness can be attributed to the rigid nature of the hydroxyapatite and collagen in cow bone, which effectively reinforces the aluminium brass matrix. However, the addition of CBP also results in a decrease in ductility, as indicated by the reduction in strain from 16.8% for the 0% CBP sample to 13.26% for the 3% CBP sample. Similarly, impact resistance decreases with higher CBP content, from 43.52 Joules in the baseline sample to 31.55 joules in the 4% CBP sample. This reduction in ductility and impact resistance suggests that the material becomes more brittle with increasing CBP content, likely due to the rigid and amorphous nature of the CBP particles.

Microstructural analysis reveals that the addition of CBP affects the grain size and distribution within the brass matrix. Higher CBP content results in smaller, tube-like grains and the presence of both clusters and fine isolated CBP particles. The fine particles predominantly occupy the grain boundary sites, enhancing boundary strength, while larger particles are distributed within the matrix, contributing to overall reinforcement. While the addition of cow bone particulate to aluminium brass improves its hardness and stress resistance, it also makes the material more brittle and less capable of absorbing sudden impacts. The microstructural changes observed with increasing CBP content are consistent with the mechanical property variations.

## RECOMMENDATIONS

For further investigation on this study, the following are recommended:

- The effect of adding cow bone particulate to aluminium brass should be studied on the tribological, thermal and damping properties in order to determine specific area of application of the composite.
- More materials that are considered as waste should be used added to the aluminium alloy and their effects on the mechanical properties and microstructure should be investigated.

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