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RESEARCH ARTICLE OPEN ACCESS

ENHANCING MECHANICAL AND CORROSION PROPERTIES OF BRASS COMPOSITES WITH CARBONIZED COCONUT SHELL ASH

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ABSTRACT

This study investigates the mechanical properties and corrosion behavior of brass (Cu-Zn alloy) reinforced with carbonized coconut shell ash (CSA) composites. The coconut shells were obtained, sun-dried, crushed, carbonized at 500 °C and sieved. The resulting CSA was then incorporated into molten brass scrap, which was first preheated to 950°C. For reproducibility purposes, several samples were prepared with varying CSA weight fraction (0wt%, 5wt%, 10wt%, and 15wt%). The samples were characterized by using metallurgical microscopes to assess their microstructure and homogeneity. The mechanical properties, including: ultimate tensile strength (UTS), hardness, impact energy, and compressive strength, were evaluated. The corrosion analysis was carried out by attaching the respective samples to a holder in the electrolytic streams of the acid and chloride solution in the constructed sand slurry pot using potentio-dynamic polarization. X-ray fluorescence was used to determine the elemental composition of the brass scraps. The results indicated that increased CSA content improved UTS, hardness, and compressive strength. However, a reduction in impact energy was observed. The sample with 15wt% weight fraction of CSA, exhibited the highest UTS (326.32 N/mm²), hardness (281.67 HRB), and compressive strength (198.3 MPa). Nevertheless, sample A with 0wt% weight fraction of CSA, showed the highest impact energy (35.59 J). Corrosion rates varied, with sample A showing the moderate rate of corrosion resistance, sample B is prone to high rate of corrosion, sample C has the poorest corrosion resistance, while sample D exhibited the best overall corrosion resistance. This study demonstrates that CSA reinforcement enhances the mechanical properties of brass composites, making them suitable for various engineering applications.

I. INTRODUCTION

Brass (Cu-Zu) alloy is a formidable material for aerospace, valves, channels, and automobile applications due to their excellent corrosion resistance, low-friction coefficient, non-magnetism, forgeability, machinability, tensile strength, and hardness [1]. In categories, brass is useful where high corrosion resistance is needed, moderate mechanical strength is required, and electrical/thermal conductivity is desired [2]. Factors, such as: weight percentage of copper in brass alloy, and process temperature, determine the brass alloy type and applications area. For instance, bronze, gold, color brass alloys can be obtained, by 10:90; 15:85; and 38:62 zinc and copper weight ratios [3]. Based on structure, brass has been divided into alpha (α) and alpha-beta ($\alpha + \beta$) brass. There are also leaded brasses. Leaded brass is a brass alloy, which contains a small proportion of lead for the purpose of easy machination while maintaining the corrosion and mechanical properties integrity of the brass alloy [4]. Of course, lead is an environmental pollutant, and when it is leached in drinking water via plumbing systems, it becomes harmful substance, leading to the cause of neurological disorder and threat to pregnancy [5].

To enhance the mechanical properties of brass alloy and also reduce the negative impact of lead in brass, literature has reported alternative alloying elements [6]. For example, the addition of small amounts of elements, such as: aluminum, manganese, or silicon in brass, can improve the strength, corrosion resistance, and durability of brass without relying on lead. Casting, infiltration, diffusion bonding, spark plasma sintering, and extrusion are examples metal matrix composite of production methods [7]. Metal matrix composites have metal as the matrix and other material (e.g., non-metals) as the reinforcement. They possess excellent mechanical strength, low density, lightweight, conductivity, hardness, stiffness, wear, and abrasion resistance [8], [9]. The ultimate characteristics of a metal matrix composite (MMC) are influenced by several key factors, such as: the specific alloying elements used in the matrix, the choice of reinforcement materials, and the synthesis technique employed. The method of synthesis—whether it be casting, powder metallurgy, or another technique—plays a crucial role in determining the uniformity, bonding quality, and overall performance of the composite. Ceramic compounds, such as: silicon-carbides, aluminum-oxides, and carbon allotropes, have been used to reinforce metals, such as: aluminum, magnesium, copper, and alloys [10]. Despite the plethora of advantages of metal matrix composite with nonmetallic materials (e.g., ceramic, silicon nitride, graphite), high processing cost, low wettability of ceramic-nanoparticles, non-uniform dispersion, and availability problems, are disadvantaged to metal matrix composites with nonmetallic materials [11].

Therefore, this study is concerned with metal matrix composite having agro-waste as reinforcement. Processed agro-waste into powder form has the reinforcing potential for metal matrix mechanical properties. Examples of the commonly used agro-waste for metal matrix composite, include: coconut shell, groundnut shell, rice husk, palm kernel shell, maize stalk ash, breadfruit, seed hull-ash, aloe vera, bean pod ash, cow-horn, and bagasse ash. Owing to the natural benefits of organic waste, such as: environmental benignity, availability, easy processing, low cost, and low weight, their use as reinforcing material for the synthesis of brass matrix, is promising [12]. In the study presented by [13], waste rice husk ash was used as a reinforcing material for aluminum alloy. The aluminum alloy was obtained from car scrap. The scrap aluminum alloy was first melted in a muffle furnace of graphite crucible. The rice husk ash was preheated at a temperature of about 300 °C to form good wettability with the aluminum matrix. The mixture of the metal and the waste organic material was obtained at a temperature of ∼680 °C and stirred at 200 rpm for 5 minutes. The fabricated metal matrix composite in the presence of alumina catalyst as secondary reinforcing agent, has excellent hardness, ductility, compressive, and tensile strengths properties. In another study [14], groundnut shell ash and hemp fiber ash have been used to reinforce aluminum to produce metal matrix composite. According to, [15], carried out an experimentation on aluminum and agro-waste composite. In the study, fly ash and aloe vera were engaged to reinforce aluminum matrix and the results showed aluminum matrix composite possessing significant improved mechanical properties.

It is therefore envisaged in this study that agro-waste can be beneficial as a significant reinforcement for brass alloy. In this study, due to the easy availability, low cost, low density, and environmental benignity of coconut shell ash (CSA), it is chosen as the reinforcing material for brass alloy. The study focuses on the characterization of the brass alloy/coconut shell ash composite. Therefore, the investigation carried out in this study principally involved the mechanical characterization of brass scraps reinforced with carbonized-CSA

II. MATERIALS AND METHOD

The major raw materials used in this study, are brass scraps and Coconut shell. The equipment used includes a sieve shaker 1.18mm, Crusher, metallurgical microscope model number, NJF-120A, disc grinder, sensitive weighing machine, charcoal-fired crucible furnace, ladle, Vernier caliper, lathe machine, meter rule, crucible pot, Mansoto Tensometer, Izod impact testing machine, computer-controlled hardness testing machine and energy dispersion XRF machine.

II.1 THE REINFORCING COCONUT SHELL ASH

The coconut shells used in this work were obtained from Ilorin, Nigeria. Thereafter, the shells were cleaned and sun-dried. To obtain the power form of the coconut shells, the dried shells were subjected to crushing and grounding processes. The powdered shells were packed in a crucible pot and carbonized in the furnace at the temperature of 500 °C to form a CSA. The carbonized CSA was cooled and sieved by using 1.18 mm mesh. Figure 1 shows the coconut shell, crushed coconut shell and coconut shell powder, respectively.

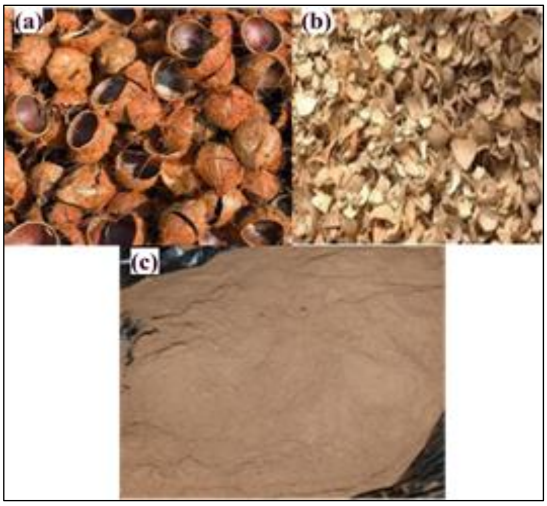

Figure 1: The reinforcing coconut shell organic waste (a) uncrushed (b) crushed, and (c) powder.
Source: Authors, (2024).

II.2 THE METAL MATRIX

The enumerations of citations in the body of the article must be sequenced in the order in which they appear, according to the example shown below.

II.3 THE BRASS ALLOY/CSA METAL MATRIX COMPOSITE

The homogenous mixture of the carbonized-CSA and the molten metal was obtained by continuous stirring. The composite of the metal matrix/CSA in molten form, was afterward poured into a mould cavity and allowed to solidify. The fabricated brass alloy/CSA composite was machined by using the lathe machine. For repeatability purposes, various samples were prepared by varying the volume fraction of the matrix and reinforcing materials. Table 1 shows the composition of the fabricated metal matrix/CSA composites.

Table 1**:** Sample preparation of the developed composites

Samples	Brass (%)	CSA (%)
A	100	0
B	95	5
C	90	10
D	85	15

Source: Authors, (2024).

II.4 CHARACTERIZATION

II.4.1 the Mechanical Properties of Brass Alloy/CSA Composites

The mechanical properties characterizations were carried out according to ASTM E18-19, ASTM E8, and ASTM A370. The hardness test was performed on a standard computerized Vickers Hardness Testing Machine, Model MV1-PC with a load of 0.3kgf, max/min limit of 500/300HV. The tensile test was carried out on a standard method by using the Monsanto Tensometer, type W Serial No. 9875. The samples were gripped in the chucks of the Tensometer and load was applied with the aid of load handle until the samples fracture. The impact test was carried out by using Izod Impact Testing Machine with V-notches of depth of 0.5mm. Scanning electron microscope (SEM) model SIRIUS50/3.8 (ASPEX 3020) was used to examine the morphology of the samples. The corrosion analysis was carried out by attaching the respective samples to a holder in the electrolytic streams of the acid and chloride solution in the constructed sand slurry pot by using potentio-dynamic polarization at a revolution of 960 rev./min for 120 minutes in each case. The slurry was prepared by adding sand in the proportion of 10 g per 10 litres of tap water. The surfaces of the samples were prepared by polishing with emery papers of 60D, 320D, 600C, 800C 100C and 1200C, respectively. This was done to eliminate scaling, surface contaminants, and oxide film on the metal surface. Followed by the elimination of scaling, surface contaminants, and oxides film from the metal surface is the de-greasing of the samples with acetone to remove grease, dirt, or dust in order to avoid error in experimentation, and subsequent corrosion rate measurement. The de-greased surface was thereafter air-dried prior to immersion; and their initial weights were obtained by using weigh balance. All the experiments were repeated in triplicate to ensure good reproducibility of the results. The elemental composition analysis of the scrap brass was obtained by using X-ray fluorescent analyzer (XRF, model: minipal 4 No. DY 1055) [16].

III RESULTS AND DISCUSSION

Table 2 shows the various elements of the scrap brass with their percentage weight in the metal composition. The major elements are copper (56.81%) and zinc (37.4%). The metal scrap can be classified as Alpha (α) brass.

Table 2: Elemental composition of scrap brass.

Elements	Wt(%)
Si	0.70
Ca	0.51
Ca	56.81
Zn	32.04
Ti	0.02
Mn	0.04
As	0.28
Nb	0.30
Fe	1.00
Sb	0.80
Ni	1.50
Pb	6.00

Source: Authors, (2024).

The micrograph presented in Figure 2 for samples B, C, and D shows that the carbonized coconut shell ash is evenly distributed as reinforcement within the brass matrix. Homogeneity was achieved through continuous stirring of the carbonized-CSA with varied compositions into the brass matrix, as evidenced by the absence of agglomeration or segregation of the carbonized CSA in each of the samples. The microstructure also reveals that the brass matrix and carbonized-CSA are interfacially bonded. This result is consistent with literature [9],[17],[18].

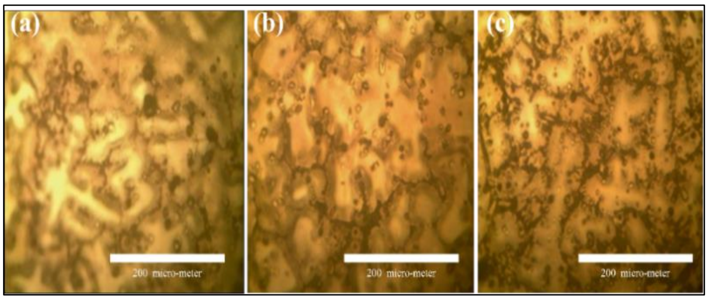

Figure 2: SEM micrograph for: (a) sample B (b) sample C, and (c) sample D.
Source: Authors, (2024).

Figure 3 illustrates the variation in ultimate tensile strength among the fabricated samples. It is evident from Figure 3 that Sample D exhibits the highest tensile strength at 326.32 N/mm². This result indicates that the tensile strength of the brass alloy increases with a higher volume fraction of the reinforcing carbonized coconut ash (CAS). Following Sample D, the tensile strengths of the samples decrease in the order of Sample C, Sample B, and Sample A. The observed trend of increasing tensile strength from Sample A to Sample D suggests an enhancement in the tensile properties, likely due to variations in their composition and the effective diffusion of the carbonized CAS within the matrix. Consequently, the formation of stronger bonds and intermolecular attractions in the resulting composite is most pronounced in the metal alloy containing the highest proportion of the agro-waste filler.

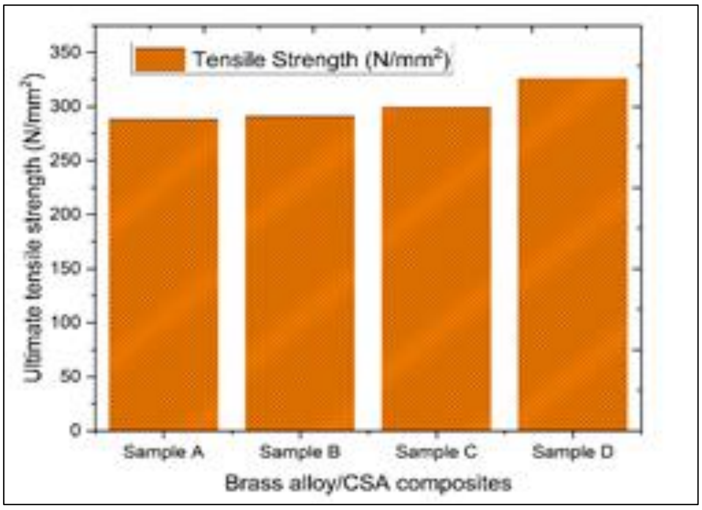

Figure 3: Variation of ultimate tensile strength of brass reinforced carbonized CSA samples.
Source: Authors, (2024).

The brass matrix composite, as presented in Figure 4, shows a significant enhancement with the addition of carbonized-CSA reinforcement. The hardness values exhibit a clear upward trend from Sample A to Sample D. Specifically, Sample D achieves the highest hardness value of 281.67 HRB. This increase in hardness indicates that Sample D is the most resistant to indentation and deformation among the tested samples. Higher hardness values typically correlate with enhanced material strength and reduced ductility, suggesting that Sample D possesses superior mechanical properties compared to the other samples. The proportional increase in hardness values from Sample A to Sample D highlights the beneficial impact of increasing the volume fraction of carbonized-CSA reinforcement within the brass matrix. As the proportion of CSA increases, the composite material becomes more resistant to wear and deformation, contributing to its overall durability and robustness. The underlying reason for this improvement can be attributed to the effective dispersion and bonding of the carbonized-CSA within the brass matrix. The CSA particles act as reinforcement, impeding dislocation motion and enhancing the material's load-bearing capacity. This leads to a more rigid and structurally sound composite, capable of withstanding higher stress without undergoing significant deformation. Furthermore, the consistent increase in hardness values suggests a possible enhancement in the structural integrity of the material. This observation aligns with previous findings reported by sources [9],[19], which indicate that the addition of carbonized CSA reinforcement can significantly improve the mechanical properties of metal matrix composites.

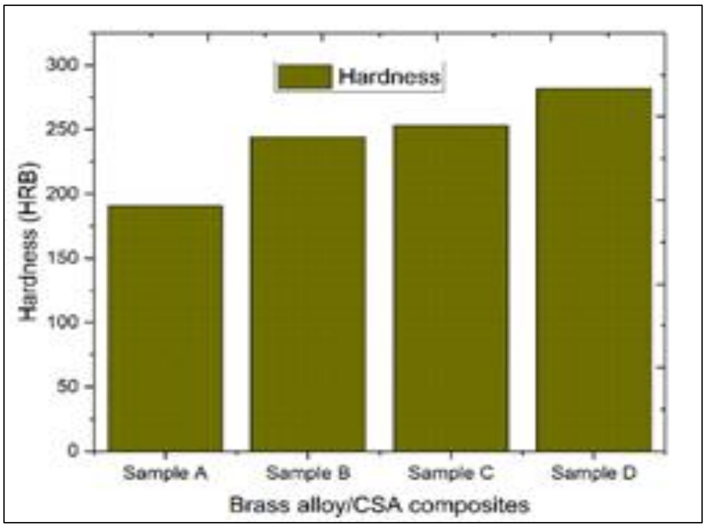

Figure 4: Variation of hardness of brass reinforced carbonized-CSA composites.
Source: Authors, (2024).

The compression strength results depicted in Figure **5** show that the addition of carbonized-CAS as reinforcement significantly improves the strength of brass matrix materials. The compressive strength increases from Sample A to Sample D, with Sample D exhibiting the highest compressive strength at 198.3 MPa. This indicates that Sample D is the most resistant to compressive forces, which is consistent with its higher ultimate tensile strength and hardness values. The trend suggests that the modifications made to each successive sample have enhanced their ability to withstand compressive loads. This result is in line with findings reported by [20]. Moreover, the correlation between the compressive strength, ultimate tensile strength, and hardness values further validates the reinforcing capability of CSA. As compressive strength is a critical parameter for materials subjected to heavy loads, the enhanced values indicate that the brass matrix composite with CSA reinforcement is more durable and capable of sustaining higher loads without collapsing or deforming. This enhancement is particularly beneficial for applications in structural components, automotive parts, and other areas where materials are regularly exposed to significant compressive forces.

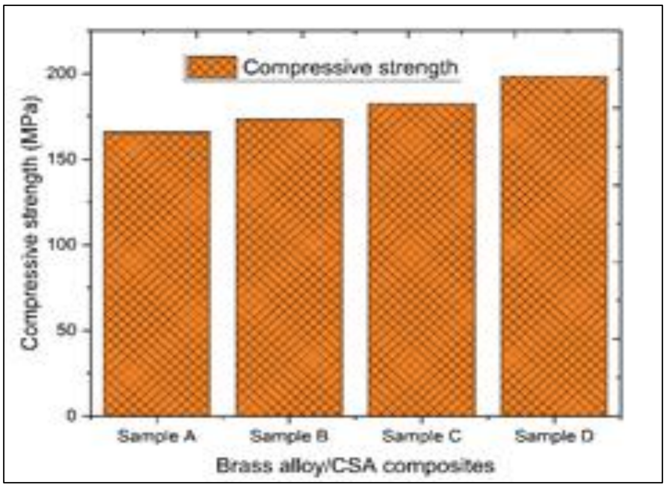

Figure 5. Variation of Compressive strength of brass reinforced carbonized CSA composites.
Source: Authors, (2024).

On the contrary, Figure 6 illustrates the decrease in impact energies of the brass metal composite with an increasing volume fraction of carbonized coconut shell ash (CSA) addition. Impact energy decreases from Sample A to Sample D, with Sample A exhibiting the highest impact energy at 35.59 J. This suggests that Sample A can absorb more energy before fracturing, indicating better toughness compared to the other samples. This reduction in impact energy, coupled with the increase in hardness and ultimate tensile strength (UTS), indicates a trade-off between toughness, compressive strength, and ultimate tensile strength. Essentially, this result shows the possibility that materials fabricated with excellent hardness and tensile strength may possess low impact energy (or, impact toughness). This result is in agreement with the study conducted by [21]. Furthermore, the elongation as shown in Figure **7** also decreases as the carbonized-CSA volume fraction increases. However, sample B showed a higher elongation than the other samples. This inconsistency in the elongation trend may be as a result of measurement error. This result agree with literature [22].

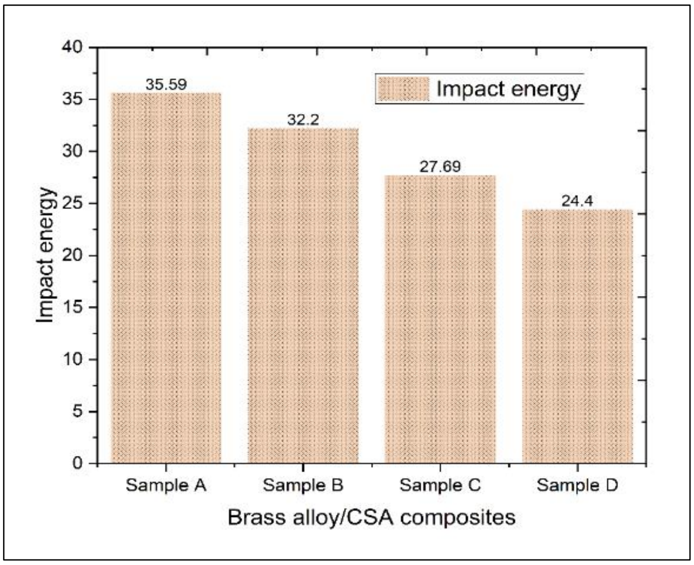

Figure 6: Variation of Impact energy of brass reinforced carbonized-CSA composites.
Source: Authors, (2024).

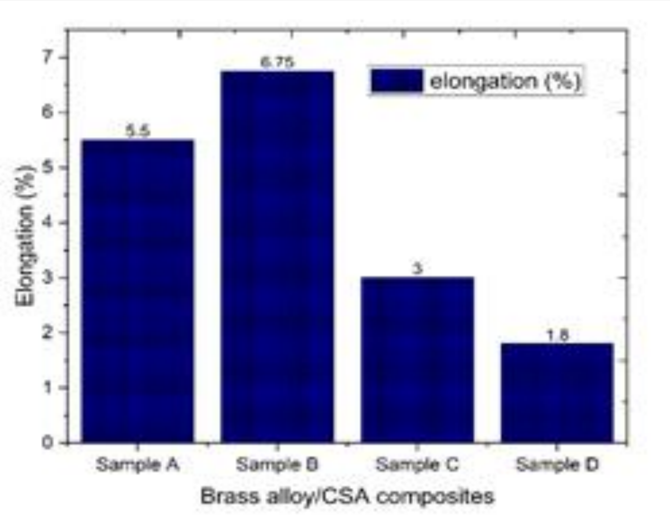

Figure 7: Variation of elongation of brass reinforced carbonized-CSA composites.
Source: Authors, (2024).

III.1 THE CORROSION PROPERTIES OF BRASS ALLOY/CSA COMPOSITES

The corrosion analysis was carried out by attaching each of the respective samples to a holder in the electrolytic streams of acid and chloride solution in the constructed sand slurry pot by using potentio-dynamic polarization method. The potentio-dynamic polarization curves of the samples are shown in Figure 8. The corrosion potential (E_{Corr}), corrosion current density (I_{Corr}), tafel slopes (βc and βa) values, are measured. The results showed diverse variation in corrosion potential and the corrosion current densities of the samples. The corrosion current density and corrosion potential of the brass alloy are: -4.433 μA/cm^2 and 301.20 mV.

The brass alloy/CSA composite containing 5wt% (Sample B), showed a -218.75 mV, corrosion potential and 4.911 μA/cm^2 corrosion current density. Even though the corrosion potential of the composite of sample B is more positive than sample A, however, its high corrosion current density compared sample A, depicted a high corrosion rate. Moreover, sample C showed the worst corrosion performance with the highest corrosion potential and corrosion current density (534 mV and 6.396 μA/cm^2). Nevertheless, sample D exhibits the lowest corrosion current density and moderate corrosion potential (327.40 mV and 3.494 μA/cm^2). Furthermore, the improvement in the corrosion resistance of the metal matrix is also observed from the anodic and cathodic values measured from the Tafel curves. As shown in Table 3, sample D has the least negative cathodic value compared to other samples. This least negative cathodic and moderate anodic values, corroborate the corrosion current density and corrosion potential values previously presented. The general observation from the corrosion results is that the corrosion rate of the composites increases as the content of carbonized-CSA increases to 10% volume fraction. However, further addition of the carbonized-CSA, led to the reduction in the rate of corrosion, as evident in sample D. This result agrees with literature [23, 24].

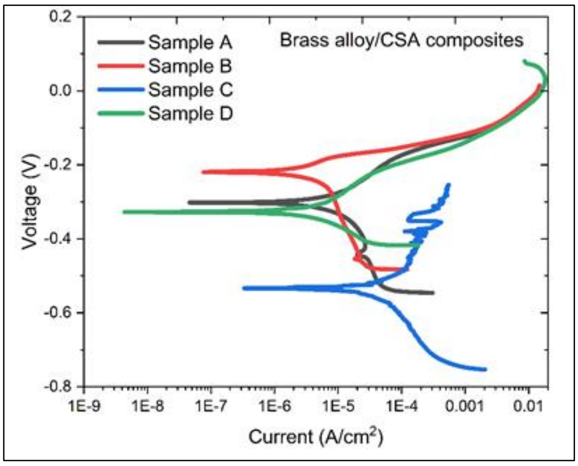

Figure 8: Potentio-dynamic polarization curves of the fabricated brass alloy/CSA composites.
Source: Authors, (2024).

Table 3: Brass alloy/CSA composites corrosion analysis parameters.

Sample	Corrosion potential (mV)	Corrosion current density (μA/cm^2)	Anodic value (mV/dec)	Cathodic value (mV/dec)	Remarks
A	-301.20 This is a moderate corrosion potential, since the value is more positive than the corrosion potential of samples C and D.	4.433 The low corrosion current density of this sample, when compared to sample B and C, shows a moderate corrosion resistance.	0.0987 This is a moderate rate of oxidation reaction.	-0.1173 The cathodic value indicates moderate rate of reduction.	Moderate corrosion resistance
B	-218.75 When compared to other samples, this corrosion potential shows the best electrochemical stability and probably, a more resistant to corrosion.	4.911 This is a high corrosion current density, indication a higher corrosion rate than sample A.	0.0321 This is the lowest anodic value, indicating a slower rate of metal dissolution.	-0.3858 This is the highest negative cathodic values, indicating a high corrosion current density.	Prone to corrosion due to high corrosion current and cathodic value
C	-534.00 This is the most negative corrosion potential; therefore, the sample probably has the poorest corrosion resistance.	6.396 This is the highest corrosion current density, indication that this sample is more subjective to corrosion.	0.2647 The highest anodic value, indicating a rapid rate of oxidation or metal dissolution.	-0.2317 Relatively moderate rate of reduction.	Poor resistance to corrosion
D	-327.40 This is a moderate corrosion potential; however, it is more negative than sample A and B.	3.494 This sample exhibits the lowest corrosion current density, indicating the best overall corrosion resistance among the samples.	0.1178 Relatively moderate rate of oxidation or metal dissolution.	-0.0912 The least negative cathodic value. This value indicates the slowest rate of reduction and excellent corrosion resistance	Overall best resistance to corrosion. This is due to the balance between anodic and cathodic reaction. In addition, the sample has the lowest corrosion current density and moderate corrosion potential.

Source: Authors, (2024).

IV CONCLUSION

Carbonized coconut shell ash (CSA) has been used to enhance the mechanical properties and corrosion resistance of brass. The experimental investigation has demonstrated significant enhancements in mechanical properties with increasing CSA content. An addition of CSA significantly increased the UTS of the composites, with Sample D (15% CSA) exhibiting the highest UTS of 326.32 N/mm². This suggests improved resistance to tensile stress due to the strong interfacial bonding between the brass matrix and CSA. Hardness of the composites increased with CSA content, with Sample D achieving the highest hardness value of 281.67 HRB. This indicates enhanced resistance to deformation and indentation. Compressive strength also improved with higher CSA content, with Sample D showing the highest compressive strength of 198.3 MPa. This reinforces the material's capability to withstand compressive loads. The impact energy decreased with increasing CSA content, with Sample A (0% CSA) having the highest impact energy of 35.59 J. This trade-off suggests a reduction in toughness with increased hardness and tensile strength. Corrosion tests revealed that sample A had a moderate rate corrosion resistance, sample B is prone to high rate of corrosion, sample C has the poorest corrosion resistance, while sample D exhibited the best overall corrosion resistance.

Declaration of competing interests: The authors have no competing Interest to declare that are relevant to the content of this article.

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Data Availability:
'The raw/processed Data required to produce these findings cannot be shared at this time due to technical and time limitations'.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Methodology: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Investigation: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Discussion of results: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Writing – Original Draft: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Writing – Review and Editing: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Resources: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Supervision: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.
Approval of the final text: Mathew Olurotimi Adeoti, Prof. Tamba Jamiru and Taoreed Adesola Adegbola.

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