Influence of Turkey Bone Particulate on Corrosion Resistance of Cast Aluminium Brass

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ABSTRACT

This research investigates the effects of varying turkey bone particulate on the corrosion resistance of cast aluminum brass alloy. The study employed a systematic approach by preparing composite samples with turkey bone particulate contents of 0%, 1%, 2%, 3%, and 4% and subsequently performing comprehensive corrosion tests. Corrosion resistance was evaluated using an immersion method, in which the samples were immersed in 1.0 M, 1.5 M and 2.0 M of sulphuric acid and sodium hydroxide for a testing period of 195 hours. The samples were carefully observed and their mass loss were recorded every 3 hours. For the acidic medium, the mass loss of sample A (the control sample) is 0.7 g while that of sample D (with 3% turkey bone) is 0.4 g when immersed in 1.0 M of sulphuric acid. Other samples show more susceptibility to corrosion. For basic medium, samples A, B, C and D show higher values of mass loss when immersed in all the three concentrations of sodium hydroxide. Sample E (with 4% turkey bone) shows no mass loss when immersed in 1.5 M of sodium hydroxide. Therefore, addition of turkey bone particulate has a significant effect on sample E when immersed in 1.5 M of sodium hydroxide. The mass loss of sample A when immersed in 2.0 M of sodium hydroxide is 0.007 g while that of sample B is 0.002 g. Sample D shows highest corrosion resistance in sulphuric acid while sample E shows highest corrosion resistance in sodium hydroxide. Notably, the incorporation of 3 to 4 % of turkey bone particulate significantly influences the corrosion behaviour of the composite yielding an enhanced corrosion resistance. The study demonstrates that the incorporation of turkey bone particulate up to an optimal level can improve the corrosion resistance of cast aluminum brass, highlighting the potentials of turkey bone particulate (an agricultural waste) as a suitable and sustainable reinforcement material for aluminium composite..

Keywords: Aluminium brass, turkey bone particulate, immersion time, corrosion resistance

INTRODUCTION

Aluminum brass is primarily composed of copper (Cu), aluminum (Al), and zinc (Zn), with small amounts of other elements such as iron (Fe), nickel (Ni), and manganese (Mn). Aluminum brass alloys are widely utilized in various industries. The precise composition may vary based on specific manufacturing requirements and standards. In recent years, significant attention has been given to improving the properties of metallic alloys by adding reinforcing materials. Traditionally, synthetic materials such as ceramics or other metallic elements have been used as reinforcements to enhance mechanical properties, corrosion resistance, and wear performance of different engineering materials. However, these reinforcements can be expensive, energy-intensive to produce and may not be environmentally sustainable.

With the growing concern for sustainable development and environmental protection, there has been increasing interest in using bio-based reinforcements derived from natural and agricultural waste. One such material is turkey bone, a type of agricultural waste rich in calcium phosphate [1], which has been shown to have potential in reinforcing metal alloys. The utilization of turkey bone, which is often discarded as waste, offers an eco-friendly and cost-effective alternative to synthetic reinforcements. Its organic nature makes it a promising candidate for enhancing the properties of metallic materials while also addressing environmental concerns related to waste disposal.

Many researchers have used non-synthetic materials to reinforce metal alloys, for better properties and performance. Saravanan and Kumar carried out an experimental study in order to determine the likelihood of improving the mechanical properties of Aluminum silicon magnesium alloy (ALSi10Mg) by reinforcing it with rice husk ash (RHA) which is relatively cheap and locally available. Rice husk ash was used as the particulate for the experiment. The quantity of the rice husk ash that are in different percentages (such as 3%, 6%, 9%, and 12% per unit weight), as the reinforcement in the metal composite with the aid of liquid metallurgy. The RHA particles were well spread in the aluminum matrix, and thus the hardness and the tensile strength of the composite were improved [2]. Hayajneh *et al.*, observed an increase in wear resistance by 65% for the composites reinforced with 3 to 4 % by weight of eggshells. The lowest value of COF was obtained for a variant with 4 % of filler. However, in the case of higher waste contents, a negative effect was observed, which was explained by the increase in porosity and agglomeration of particles [3]. In another study, Dwiwedi *et al*. investigated the influence of eggshell reinforcement (0–10 % by weight) on the composites based on the Al6061 aluminum alloy matrix [4] . The lowest wear rate was observed for the variants with maximal filler content (10 % by weight). Furthermore, Dwivedi et al. incorporated waste carbonized eggshell (0–12.5 % weight) and silicon carbide (SiC, 0 – 12.5 % by weight) into AA2014 aluminum alloy to create green composites with superior tribological properties [5]. The authors showed that regardless of the waste content in the matrix, the wear rate remained similar for all of the studied variants. Ochieze et al., experimentally studied the wear parameters and their effects on the wear characteristics of an A356 alloy that is fully reinforced with cow horn particulate. The cow horn particles were produced via the sintering of the spark plasma. The Tahuchi's (L9) technique was used to carry out the experimental investigation. The wear test was done with the aid of a tribometer and the microstructural test was carried out with the use of a scanning electron microscope. It was discovered that the reinforced A356 alloy exhibited a better sliding resistance to the wear compared with the virgin material (unreinforced A356 alloy) [6]. Atuanya and Aigbodion used the ash from bean pods to reinforce the Al–Cu–Mg alloy through the double layer feeding stir casting method. The study was focused on the microstructural and properties evaluation of the bean pod ash (BPA) particulate reinforced aluminum alloy. The nanoparticles were used within the variance of 1 to 4 wt % in order to produce the aluminum matrix composite. The evaluation was done in order to know the hardness, impact strength, and tensile strength of the reinforced composite using SEM and XRD. The outcome of the experiment showed that the interphase bonding was achieved and robust, with a substantial increase in the hardness and tensile strength at 4 %, by 44.1% and 35% by weight respectively [7]. They also studied the properties and the microstructural characterization of an Al–Si–Fe alloy reinforced with ash from breadfruit seed hull as particulate composites. A 500 nm particulate size was examined, with an investigation of six varying fractional weights of the ash particles from the breadfruit seed hull. There was a very good bonding between the aluminium matrix metal composite (AMMC) and the breadfruit seed hull ash particulate, resulting in improved mechanical properties of the composite, except for a very slight decrease in the impact strength [8]. Alaneme et al. presented experiment carried out on the study of the fracture, mechanical, and microstructural properties of silicon carbide and groundnut shell ash particle reinforced aluminum metal matrix composites (AMMCs). The phase of reinforcement was constituted by 6 and 10 wt % of the particulate mix ratio. The results show that there was an improved percentage elongation and fracture toughness [9]. Alaneme and Olubambi studied the wear and corrosion behavior of an Al–Mg–Si alloy matrix as a hybrid composite reinforced with alumina and rice husk ash particulate. The corrosion behavioral analysis was done using a potentio-dynamic polarization measurement and open circuit corrosion potential (OCP). The wear behavioral study of the composite was carried out using the coefficient of the friction parameter. The study showed that there was a superior resistance to corrosion from the reinforced composite (Al–Mg–Si) with 10% Al_2O_3 to that of the hybrid composite in a solution of 3.5% NaCl [10]. Mishra et al. observed the mechanical properties of aluminum alloy (LM6) as a metal matrix composite reinforced with rice husk. A rice husk ash (RHA) particulate of 6% was used as the reinforcing constituent, and the aging process was artificially carried out at varying temperatures (135 ◦C, 175 ◦C, and 225 ◦C). The metal matrix composites (MMCs) were developed via the stir casting method. The results showed an improvement on the hardness value in the as cast form, from 54.8 HRB to 78.4 HRB for the composite at 175 ◦C [11]. The influence of reinforcing sand mould with ashes of coconut pod on the mechanical properties and microstructure of aluminium brass was presented by Adeyemi et al. [12]. The mechanical properties of the aluminium brass increase at the quantity of the ashes is increased. Kolawole et al. studied the effect of calcined shell particulate on mechanical properties of aluminium-silicon alloy. It was shown that increase in the quantity of calcined snail shell particulate led to increase in the mechanical properties of the aluminium-silicon composite [13].

However, despite the varied applications of agricultural waste materials, none of these studies have explored the influence of turkey bone on aluminum brass alloys specifically. The justification for this study lies in the growing need for sustainable and cost-effective materials in various industries. Aluminum-brass alloys are widely used for their strong mechanical properties and corrosion resistance, but they still face challenges such as high costs and limited performance in certain applications. This study aims to investigate the effect of agricultural waste, specifically turkey bone (as an additive), on the corrosion and tribological properties (wear and friction) of cast aluminum-brass alloys. This will offer an eco-friendly and potentially cheaper solution to enhance the alloys' performance. Turkey bone, being a natural waste product, presents an opportunity to reduce environmental impact (such as harmful waste) while improving the corrosion resistance and wear properties of the alloy.

MATERIALS AND METHOD

Raw turkey bones were obtained from a food store in Ekiti State, while aluminium and zinc were sourced from Obafemi Awolowo University, Ile-Ife, Nigeria. Copper was obtained from copper windings purchased from the market. The turkey bones were thoroughly washed with hot water so as to remove any trace of marrow, blood and other substances that can serve as impurity in the composite and were subsequently sun-dried for about one month (Fig. 1(a)). The bones were then crushed into smaller pieces with hammer, and subsequently grinded using a grinding machine as shown in Fig. 1(b).

(a) (b)

Figure 1. (a) Sun-dried turkey bone and (b) grinded turkey bone particulates

Experimental procedure

The samples (aluminum brass composite with different quantity of turkey bone including the baseline sample) were prepared and cast in the Mechanical Foundry Workshop of Obafemi Awolowo University, Ile Ife, Nigeria. The samples were machined to the required standard measurement for the corrosion test in the Foundry Workshop. The wear and corrosion tests were conducted at the Mechanical Engineering Laboratory of Ekiti State University, Ado-Ekiti, Nigeria.

The samples were prepared using the sand casting procedure. Wooden patterns shaped like the samples were made. An integrated gating system was used to form the mould cavity inside the drag and cope assembly. Moulding sand, in its green state, was used to create sand mould, which was subsequently dried. The melting points of aluminium and zinc are 660.30°C and 419.50°C, respectively, whereas copper has the highest melting point of all the metals at 1085°C. The temperature of the molten metal in the crucible was measured by inserting the thermocouple through the opening in the furnace lid. Initially, the melting furnace was charged with copper, and a thermocouple was used. The pit type crucible furnace was pre-heated for about 10 minutes while copper, zinc, crushed turkey and aluminum are being weighed out. Copper was charged into the furnace

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pre-set at 1200 ºC and heated till it melts. Aluminum was added then allowed to dissolve in the molten copper for 6 minutes before zinc was added to dissolve in the molten for 3 minutes, lastly the turkey bone powder was added for 30 seconds and its was stirred properly to ensure homogeneity. The melt was manually stirred intermittently in order to ensure homogeneity and facilitate uniformity in the distribution of alloying element. The molten metal is being poured into the mould cavities and allowed to cool and solidify for about 30 minutes and then removed from the mould. The different samples produced were labelled sample A to E, respectively. The control sample which is a pure aluminium brass is labelled sample A. The total weight of each sample is 500 g and the percentage composition of each sample is shown in Table 1.

Table 1 Weight and percentage composition of each sample

Sample	Copper	Turkey-bone particulate	Aluminium	Zinc
A (control sample)	440g (88%)	0g (0%)	50g (10%)	10g (2%)
B	435g (87%)	5g (1%)	50g (10%)	10g (2%)
C	430g (86%)	10g (2%)	50g (10%)	10g (2%)
D	425g (85%)	15g (3%)	50g (10%)	10g (2%)
E	420g (84%)	20g (4%)	50g (10%)	10g (2%)

Microstructural Test

Microstructural examination was carried out on the specimens (Fig.2) at EMDI. The specimens were grinded to have flat and smooth surface. Silicon carbide papers of grit size 220 µm, 320 µm, 400 µm and 600 µm were placed on the grinding machine. The grinding process was done under running water to wash away the grits and also to avoid overheating. The specimens were rotated 90° between each grinding step to avoid scratches. Thereafter, a polishing cloth was placed on the polisher for the initial polishing, swamped with solution of one micron of silicon carbide. The final polishing stage was done using polishing cloth swamped with solution of 0.5 µm silicon carbide until the surface of the specimen became a mirror-like. It is then washed and dried.

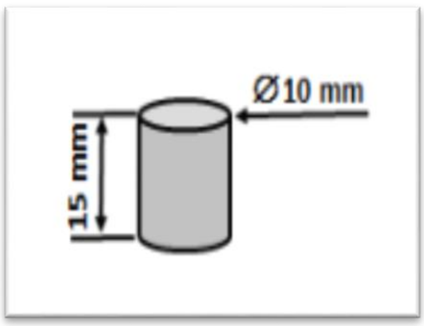

Figure 2. Specimen for microstructural test

Finally, the mirror-like surface specimens were etched in 2% NaOH, then put in a desiccator. They were viewed with optical metallurgical microscope (OMM) in order to reveal their internal structure.

Procedure for Corrosion Test

The cast brass aluminum brass samples were thoroughly cleaned with acetone to remove any surface contaminants. The samples were cut into a smaller quantity with the use of ark saw for the immersion process. Measurements were then taken in multiple locations using a digital weighing balance (at least three times) for each dimension to account for any irregularities (Fig.3). Each specimen was labeled with a unique identifier using a non-reactive marking method (e.g. the beakers were labeled with a tape for easy identification). Each container was thoroughly cleaned and dried before use. The volume of the solution was calculated based on the specimen surface area. Diluted 1.0 M, 1.5 M and 2 M of sulphuric acid were poured into each container. Diluted 1.0 M, 1.5 M, 2 M of aqueous sodium hydroxide were poured into each container. Each specimen was then carefully immersed in the container containing the solution. Containers were then sealed with a lid to minimize evaporation and contamination (Fig.4).

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Each sample was tested for a period of 195 hours. All the five samples were divided into 6 (3.3 mm) each and immersed into 30 solutions. Each container was labeled clearly with specimen number. A detailed testing schedule and checklist were created to ensure timely removal and processing. Solution levels were checked every 3 hours. Visual changes in the sample appearance or solution colour were noted. At each time point (every 3 hours), the specimens were carefully removed for testing. Tweezers were used to avoid scratching or damaging the sample surface. The samples were pat dry with lint-free tissue paper to ensure accurate measurement. A detailed logbook was maintained to record all observations, measurements and actions taken. Records include date, time and mass. And digital spreadsheet was used to ensure consistent data collection across all specimens. The experiments were carried out at normal room temperature

Determination of Corrosion Rate from Weight Measurement

The corrosion rate was obtained using the relation in Equation 1

$$R = \frac{W}{A} \times \frac{T}{365} \qquad (1)$$

where,

$R =$ Corrosion rate (mg/mm^2/year); W = weight loss/gain (i.e. weight difference);

$A =$ Area of the specimen; $\frac{T}{365} =$ Exposure time in days extrapolated to year

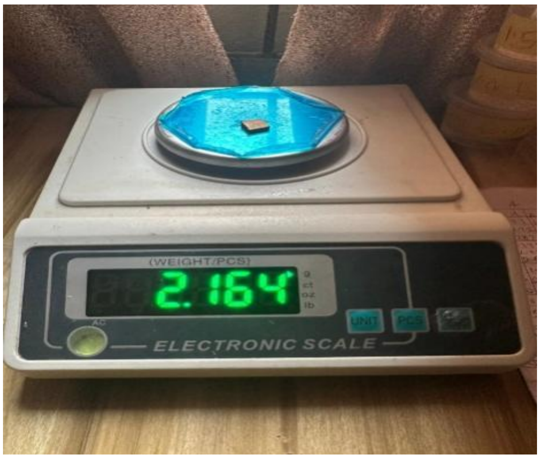

Figure 3. A digital weighing balance for measurement of samples

Figure 4. Different samples inside containers

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RESULTS AND DISCUSSION

Microstructural Analysis

The microstructure plays an important role for analyzing the distribution of distinct phases in an Aluminium composite. The microstructure was studied by using optical metallurgical microscope OMM as presented in Fig. 5 with magnification of $\times 100$. The microstructural analysis of aluminium brass specimen with varying proportions of TBp reveals a significant impact on the material's microstructure. As TBp increases from 1% to 4%, the particulate distribution becomes more pronounced, with a notable increase in particulate size.

Fig. 5 (a) shows the microstructure of aluminium brass without TBp. The β-phase (dark region) is distributed around the $\propto$-phase (light region) such that they are not uniformly distributed. The dark region is more pronounced in Figs 5 (b) and (c) when 1% and 2 % of TBp were added respectively but slightly different in (d) when 3% of TBp was added. The presence of dark region indicate low overall ductility of the composite [14]. Fig. 5 (d) shows a significant change in microstructure with particle growth, finer grains such that particles start clustering together. Fig. 5 (e) shows the microstructure of the Aluminium composite when 4% of TBp was added. This reveals a microstructure where both the $\propto$ and β phases are more distinct, pronounced and uniformly distributed. The hardness of the reinforced aluminium brass increased due to increment in the TBp atoms reducing the mobility of copper atoms. There is a substantial increase in particulate size and density. It contains fine and packed grained structure, resulting in enhanced strength and distinct brass color.

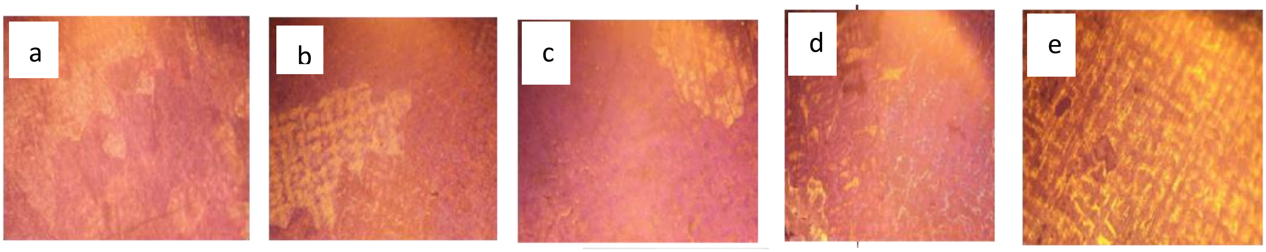
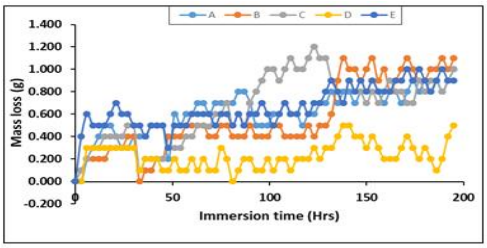


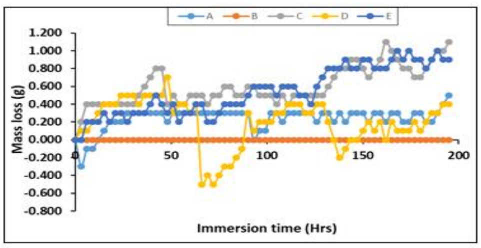
Figure 5. Microstructures of (a) sample A (b) sample B (1% TBp) (c) sample C (2% TBp) (d) sample D (3% TBp) and (e) sample E (4%) TBp).

Corrosion Test Analysis

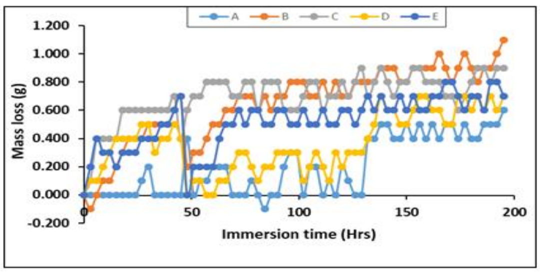
The mass loss of different samples in different concentrations of sulphuric acid are shown in Figs. 6 (a), (b) and (c).



(a)



(b)



(c)

Figure 6. Mass loss of samples in (a) 1.0 M (b) 1.5 M and (c) 2.0 M of sulphuric acid

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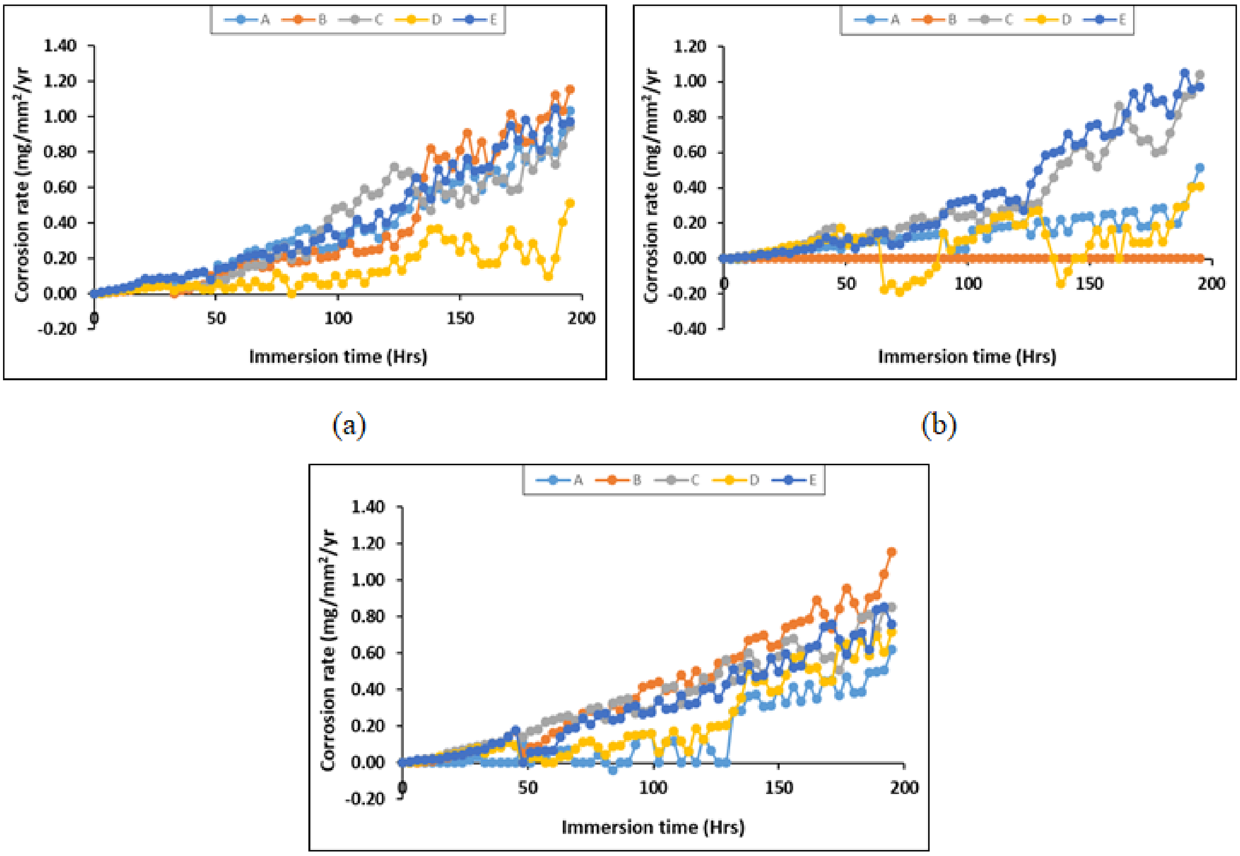
For samples in 1.0 M of sulphuric acid (Fig. 6 (a)), all samples initially show a slight reduction in mass due to the formation of a protective oxide layer. The mass loss increases progressively as the protective layer breaks down. Sample D (3% bone) exhibits the least mass loss, indicating superior corrosion resistance. Sample C (2% turkey bone) has the highest mass loss, suggesting that 2% turkey bone weakens the alloy's corrosion resistance. Samples A, B, and E show moderate corrosion trends between these two extremes.

For samples in 1.5 M of sulphuric acid (Fig. 6 (b)), corrosion rates generally increase due to the higher acid concentration. Sample B (1% turkey bone) shows almost no mass loss, which is unexpected and may require further investigation. Sample D (3% turkey bone) fluctuates but still maintains the lowest corrosion rate, reinforcing its protective effect. Sample C (2% turkey bone) continues to show high corrosion rates, confirming its susceptibility to acidic attack. Samples A and E follow a steady mass loss trend, with moderate corrosion.

For samples in 2.0 M of sulphuric acid (Fig. 6 (c)), corrosion is most aggressive at this concentration. Sample C (2% turkey bone) experiences the highest mass loss, indicating its poor resistance to corrosion. Sample D (3% turkey bone) still shows the lowest mass loss, suggesting it has the most optimal capacity for corrosion resistance. Samples A, B, and E exhibit increasing corrosion rates, with E (4% turkey bone) showing slightly higher corrosion than A and B.

The corrosion rates of all the five samples are shown in Fig. 7 (a), (b) and (c). Samples A, B, C, and E show moderate corrosion but increase steadily over time. It shows that the corrosion rate of sample D at 195 hours (0.4 $mg/mm^2/yr$) is the lowest in 1.0 M sulphuric acid (Fig. 7 (a)). Also, sample D has lowest corrosion rate of 0.38 $mg/mm^2/yr$ at 195 hours when the concentration is 1.5 M (Fig. 7 (b)). For 2.0 M of sulphuric acid, the corrosion rates of sample A (the control sample) is the lowest followed by that of sample D (Fig. 7 (c)). This further reveals that sample D has high corrosion resistance than all the samples in acidic medium except for 2.0 M of acid where sample A has a slightly higher corrosion resistance.



(a) (b) (c)

Figure 7. Corrosion rates of different samples immersed in (a) 1.0 M (b) 1.5 M (c) 2.0 M of sulphuric acid

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The mass loss of the specimen when immersed in different concentrations of sodium hydroxide is shown in Fig. 8.

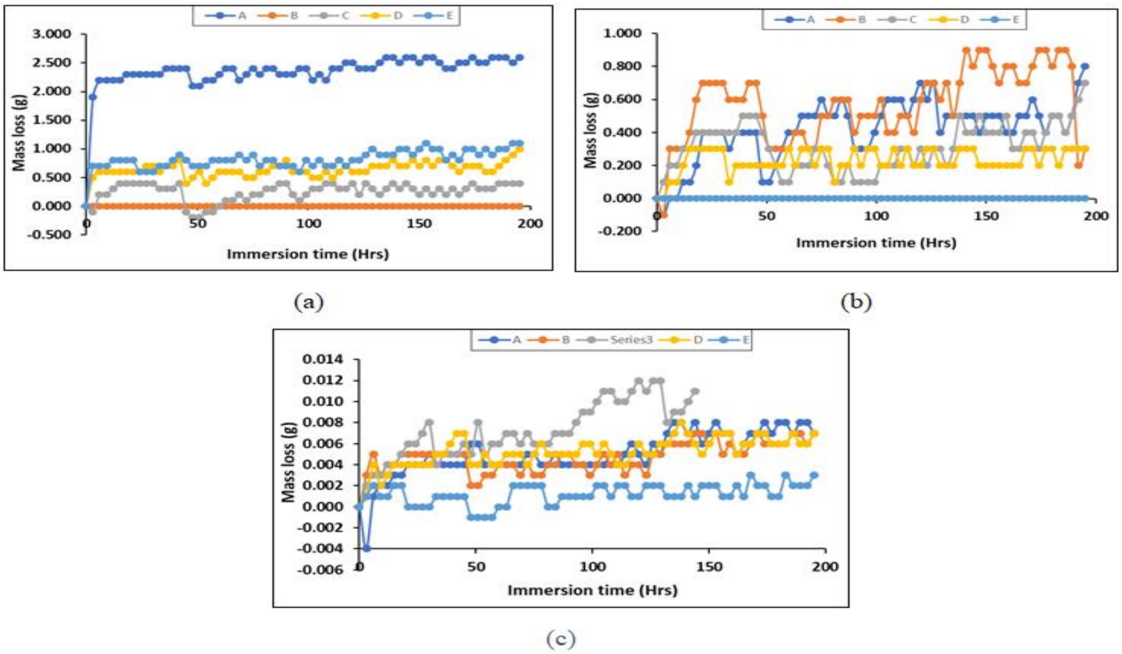

Figure 8. Mass loss of samples in (a) 1.0 M (b) 1.5 M (c) 2.0 M of sodium hydroxide

All samples remain almost constant considering their initial values of mass loss when immersed in 1.0 M of sodium hydroxide except sample A that increased from o to 2.5 g. Therefore, no significant loss of masses of samples in 1.0 M of sodium hydroxide except for sample A. This suggests strong protection against corrosion in 1.0 M of sodium hydroxide (Fig. 8 (a)). For 1.5 M of sodium hydroxide, sample B exhibits highest mass loss between 20 to 50 hours of immersion and 130 to 190 hours of immersion. Sample A also shows a significant loss of mass at 195 hours of immersion (Fig. 8 (b)). Sample E which has the highest percentage of turkey bone (Table 1) has lowest mass loss (when immersed in 1.5 and 2.0 M of base), while samples C and D do not exhibit significant loss of mass (Fig. 8 (b)). Figure 8 (c) shows that samples B and C are the most susceptible to corrosion in 1.5 and 2.0 M of sodium hydroxide respectively. Summarily, sample E shows the lowest mass loss over a wide range of immersion period.

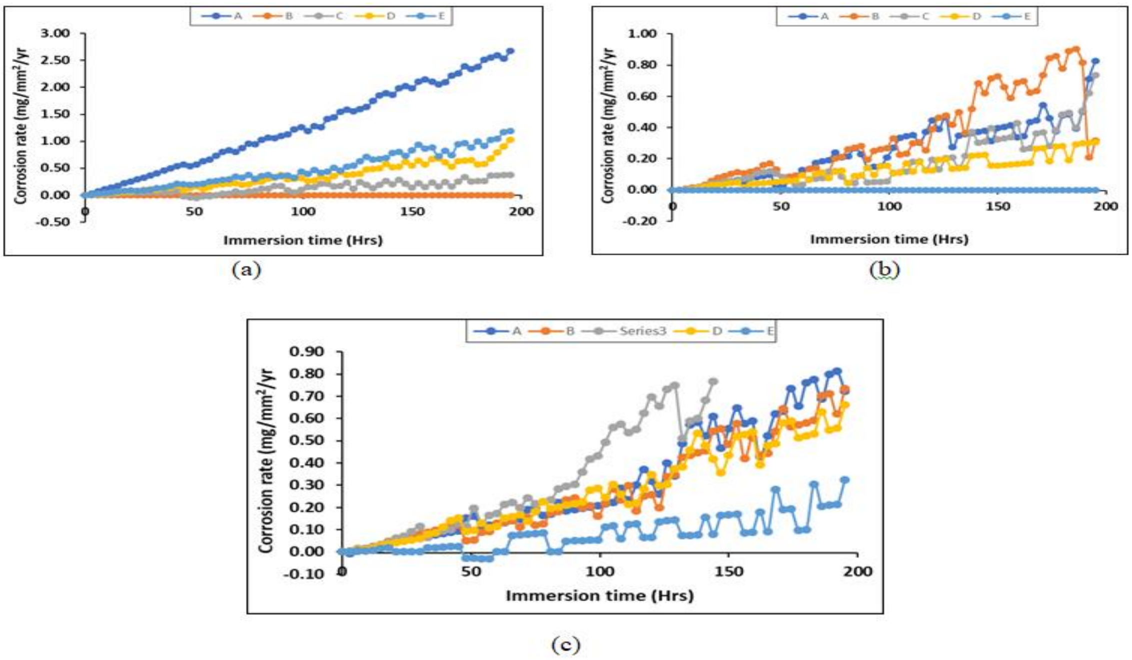

Figure 9. Corrosion rates of different samples immersed in (a) 1.0 M (b) 1.5 M (c) 2.0 M of sodium hydroxide.

Figures 9 (a), (b) and (c) show the corrosion rates of all the samples immersed in different concentrations of sodium hydroxide. The corrosion rate generally increases with immersion time in all base concentrations except for sample E immersed in 1.5 M of sodium hydroxide. Fluctuations in the corrosion rate curves indicate periods of passivation (temporary stability) followed by renewed degradation.

Sample A exhibits the highest corrosion rate when immersed in 1.0 M of sodium hydroxide, peaking near 2.6 $g/mm^2/yr$ indicating high susceptibility to corrosion (Fig. 9 (a)). Sample E experiences a steadily increasing rate lower than A, indicating a more resistance to corrosion. For the case 1.5 and 2.0 M of sodium hydroxide are the corrosive media, sample E shows insignificant and least rate of corrosion compared to all the samples.

In general, sample E consistently demonstrates the best corrosion resistance in sodium hydroxide, most especially in 1.5 and 2.0 M of sodium hydroxide. Samples A, B and C are susceptible to corrosion, with its increasing rate at higher sodium hydroxide concentration.

CONCLUSIONS

Investigation has been conducted on the corrosion performance of cast aluminum brass alloy reinforced with varying amounts of turkey bone particulate. The effects of TBp on the corrosion resistance and microstructure of Aluminium were considered. The Microstructural analysis reveals the presence of turkey bone particulate without the formation of any other inter-metallic compounds. It also reveals the absence of agglomeration of TBp in the metal matrix and good bonding between TBp and the aluminium brass when 4% turkey bone was added.

For a case where sulphuric acid is used as a corrosive medium, sample D (3% turkey bone particulate) has the highest corrosion resistance while sample C (2% bone) exhibits the lowest corrosion resistance. Sample E (4% turkey bone particulate) has the highest corrosion resistance while sample C exhibits the lowest corrosion resistance when the corrosive media is sodium hydroxide.

The study indicates that an optimal quantity of turkey bone particulate at both 3% and 4 % of aluminium brass composite can enhance corrosion resistance. In summary, these findings show the potential of utilizing turkey bone particulate as a suitable and sustainable reinforcement material in aluminium brass.

RECOMMENDATIONS

Based on the results obtained in this study, the following recommendations are made for future study:

The effect of environmental parameters such as temperature and humidity should be investigated on the composite in order to determine the kind of environment and application where the composite can perform optimally. The influence of the particle size (coarse and fine) of turkey bone particulate on the corrosion resistance of the composite should be investigated. Similar studies should be extended to other aluminum alloys such as aluminium bronze to determine if turkey bone can improve their corrosion resistance. Also, the wear test should be conducted on the composite to determine the tribological performance.

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