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Characteristics of Al-Alloy/Seashell (S_ES_B) Composites in Acidic and Alkaline Environments

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***Abstract*:** The corrosion behaviour of Al-alloy/Seashell (S_eS_h) composites in the acidic and alkaline environment was investigated in this study. Fifteen Aluminum alloy composites samples were produced using stir casting technology by varying the amount of reinforcement (1.5, 3.0, 4.5, 6.0, 7.5 wt%) and particle size (100, 150, 200 µm) of milled S_eS_h in the Aluminium alloy matrix. The corrosion rate was determined using a weight loss technique after 18 days of immersion at an interval of 72 hours. It was observed that 6.0 wt% of the 100 µm reinforced Aluminium alloy had the best corrosion resistance in acidic and alkaline environments. In general, the reinforced Al-alloy had better corrosion resistance when compared with the unreinforced samples. Analyses of the results show that aluminum alloy seashell composites exhibited better resistance to corrosion in the alkaline environment than the acidic environment.

Keywords: Aluminium Alloy; Composites; Corrosion Resistance; Metal Matrix; Seashell

1. Introduction

Wear and tear as machine components ages could result in a breakdown, and these might be as a result of the environment in which the machines are being operated [1]. Failure can occur from the vibration of a machine components, improper lubrication, high operating temperature, and corrosion of machine components, which might eventually lead to total replacement of the parts. Due to several factors such as longer shipping time, cost of purchase, and shipping of parts, among other factors necessitated the need to seek an alternative way of producing parts from locally available materials [2-4]. Studies have shown that the physical and mechanical properties of a machine component can be improved by having them in composites form [5-7]. A composite is a material made from two or more constituent materials with different compositions. When the materials are combined, it does not dissolve or unite completely with each other. However, they still perform optimally [4][8]. Base on matrix constituents, composites materials can be classified into three, these are Metal Matrix Composites (M.M.C.s), Polymer Matrix Composites (P.M.C.s), and Ceramic Matrix Composites (C.M.C.s) [4][8].

Globally, there is renewed interest in materials that can exhibit good mechanical properties, in which M.M.C.s have been proved to be one of such material [3][9]. M.M.C.s consists of a matrix (metal) and reinforcement (particles); the matrix holds the reinforcement to form the desired composite while the reinforcement improves the mechanical properties of the matrix [8], [10-11]. Several technologies have been developed for producing parts. Among these technologies are casting, forging, rolling, and machining [7], [12-13]. Many research works have been carried out on the development of low-density composites using locally available reinforcement from biological wastes. M.M.C.s produced using biological wastes (Eggshells, Coconut shells, and Seashells) as reinforcement helps in reducing environmental pollution as well as improving the properties of the M.M.C.s [11][14-18]. Also, the utilization of waste materials for the value-added product will promote a green environment and healthy living [10]. Several advantages had been identified with M.M.C.s. However, studies had also itemized some disadvantages associated with reinforced M.M.C.s. One critical limitation of M.M.C.s that needs urgent attention is the influence of reinforcement on the corrosion rate of M.M.C.s. This is a slow and progressive degradation of the physical and mechanical properties of the metal.

Studies on the corrosion behaviour of M.M.C.s, such as Aluminium Metal Matrix Composites (AMMCs) in different environments, are becoming popular because of its potential for a wide range of industrial applications. This corrosion behaviour will be part of the assessments required in establishing the composite's performance and its suitability in several service environment [1][19-20]. AMMCs could be exposed to a range of corrosive environments, which could be generally classified into alkaline or acidic during its service life.

Among the studies carried out on the composites metal alloys in a corrosive environment is the work of Arun *et al.* [21], they experimentally investigated the effect of corrosion on Aluminium alloy composites. The experiment was conducted on a weight percentage basis with 6 % and 9% SiC, 15 % constant fly ash, and Al6061T6 alloy as the matrix material. Results showed that the composites are hard, rigid, and tough with good mechanical properties and better resistance to corrosion.

Saravanan *et al*. [22] worked on the mechanical properties of metal matrix composites reinforced with rice husk ash (R.H.A.) particles of 3, 6, 9, and 12 % by weight. The M.M.C.s was developed using a liquid metallurgy route. They concluded that the tensile strength increased with an increase in the weight percentage of rice husk ash. Anilkumar *et al.* [5] produced three sets of Al (Al6061) M.M.C.s reinforced with fly ash of particle sizes of 75-100, 45-50, and 4-25 µm and weight fractions of 10, 15 and 20%. It was reported that tensile strength, compression strength, and hardness increased with an increase in the weight fraction of reinforced fly ash and decreased with an increase in particle size of the fly ash. The ductility of the composites decreased with an increase in the weight fraction of reinforced fly ash and decreased with an increase in particle size of the fly ash.

Synthesis hybrid micro and nanomatrix reinforced Aluminum matrix by sintering process were carried out by Ravinder *et al.* [23]. An atomized 99.5% pure Aluminum powder was used as matrix alloy and micro silicon carbide (SiC 10% wt.) particles and nano copper oxide (CuO 0-2% wt.) particles as hybrid reinforcements. Characterization was done by a fixed weight percentage of microparticle and by varying nanoparticles. Sintering was also done in an electric muffler by cold pressing at a pressure of 55 - 66 N/m^2. It was concluded that nano CuO particles in the A.M.C. improved the structure and property of the composites materials.

The interest in composites with improved mechanical and corrosion properties for industrial and domestic applications is growing as new technologies emerge. Researches have shown that these composites with desired properties can be produced locally. Therefore, this study seeks to investigate the corrosion behaviour of machined AMMCs in alkaline and acidic environment.

2. Materials and Methods

2.1 Materials

Already prepared Aluminium alloy 6063 with the composition shown in Table 1 was used as the metal matrix. In contrast, Oyster *(SeniliaSenilius)* Seashells (S_eS_b) was used as reinforcement materials to produce Aluminum alloy/S_eS_b composites. Sulphuric acid (H_2SO_4) and Sodium hydroxide (NaOH) solutions were the acidic and alkaline environments respectively used for the investigation.

Table 1 Elemental Composition of the Aluminium Alloy 6063 used

Element	Mg	Si	Fe	Cr	Cu	Ti	Mn	Zn	A
Wt.%	0.45- 0.90	0.20- 0.60	0.35	0.10	0.10	0.10	0.10	0.10	Balance

2.2 METHODS

2.2.1 Production of Aluminium Metal Matrix Composites (AMMCs)

The different particle sizes of the reinforcement used were 100, 150, and 200 µm, while the amount of the reinforcement in aluminum alloy composites was varied in order of 1.5, 3.0, 4.5, 6.0, and 7.5% compositions by weight.

The metal matrix reinforcement composites were produced using a double stir casting method due to its economical way of materials processing [3], [19] [25]. The reinforcing particles were added into the molten material and stirred thoroughly to form a homogenous mixture with the matrix alloy. The molten composites slurry was poured into the prepared mould and allowed to solidify, and then machined on the lathe to 20 mm diameter rods. The machined samples were then cut into 20 mm long (i.e., 20 mm diameter by 20 mm length). The samples were grinded using emery cloth of 120 – 640 grit sizes before they were degreased and cleaned using acetone and ethanol solutions, respectively. The samples were allowed to dry in still air for 5 minutes before immersion into the prepared media [3].

2.2.2 *Preparation of Alkaline Solution*

The Alkaline solution of 0.1 M NaOH was prepared by dissolving 4 g of solid NaOH in 1 dm^3 of distilled water in accordance with Equation (1).

$$Mole = \frac{Mass}{Molar\ mass} \qquad (1)$$

For every 1 dm^3 of distilled water, 4 g of NaOH was used during the dilution process; this was done with a flat bottom flask. After dilution, 0.1 M of NaOH solutions were poured into plastic containers of 2.5 L.

2.2.3 Preparation of Acidic Solution

0.3 M of H_2SO_4 with a percentage purity of 98% was prepared for the study. The volume of the solution in cm^3 was calculated using Equation (2).

$$Volume = \frac{Molar\ mass}{Specific\ gravity} \div Percentage\ purity \times Molarity$$

(2)

The solution was prepared using a flat bottom flask and stored in 2.5 L plastic containers for the investigation.

2.2.4 *Suspension of Samples in Corrosive Environment*

The samples were suspended in the corrosive environments (prepared solutions) by drilling four holes at the top edges of the plastic containers (two holes directly opposite each other). Sticks were inserted into the drilled holes, in other to hold two threads each, whose ends were tied around a sample (Figure 1).

The samples were suspended in the medium in such a way that none has contact with each other or with any part of the container wall. This was done in other to expose the samples to the medium. The setup was completed by covering the container to avoid interaction with the environment. Figures 1A and 1B show the picture of the experimental setup.

Figure 1: Suspension of samples in a corrosive environment- (A) plan view and (B) side elevation

2.2.5 Corrosion Test

The method adopted in this study was the static immersion weight loss method. Mass loss and corrosion rate measurements were the bases for the investigation [21][25]. The initial weight of each sample was measured and recorded before and after they were immersed in acidic and alkaline solutions. Samples were immersed at room temperature of 25 ^{o}C. Figures 2 (B) and 2(A) show the samples before and after immersion in the test environment. The weight of the samples was measured at an interval of 72 hours for 18 days in accordance with the ASTM G31-12 standard [26].

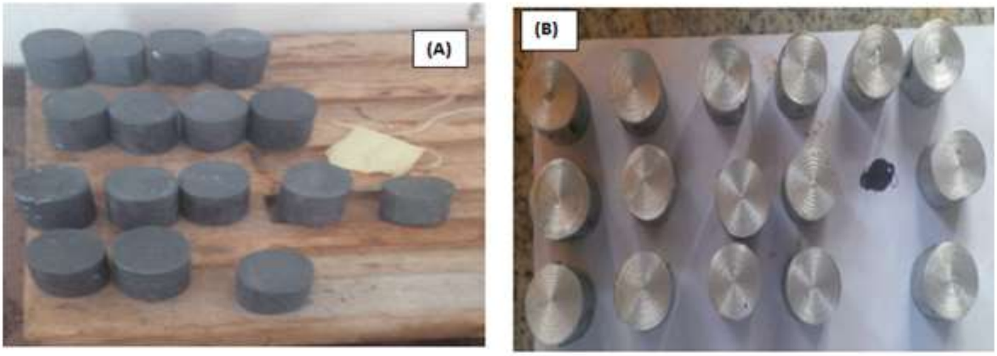

Figure 2: Prepared A.M.C. samples: (B) Before immersion and (A) After immersion in the test medium

The samples mass loss to weight ratio (mg/cm^2) was evaluated in accordance with ASTM standard using Equation (3).

$$M = \frac{CW}{A} \tag{3}$$

Where M = mass loss (mg/cm^2)

CW = cumulative weight loss (mg)

A= the total surface area of the sample (cm^2).

The corrosion rate was calculated using Equation (4)

$$C.R = \frac{KW}{\rho AT}$$

(4)

But $W = W_i - W_f$

(5)

where $C.R$ is the corrosion rate (mm/y), ρ density (g/cm^3), A area, W weight loss, W_i initial weight (g), W_f final weight (g), T time (hours) and K is a constant equal to 87500 [17].

3 Results and Discussion

Figures 3 (A) and (B) show the variation of corrosion rate in acidic and alkaline medium, respectively, for the samples of 100 µm particle size. It can be observed that the corrosion rate was more intense and eventually got to the peak on the 3rd to 4th day of immersion for all the samples. The cause of the high corrosion rate may be as a result of the formation of the Al-alloy matrix composites intermetallic precipitation or s of alloying elements at the i the samples. Also, the formation of oxide film been perforated locally made the Al-alloy matrix composites to be attacked more rapidly than the oxide layer at a passive state. The 6.0 wt% sample had the best corrosion rate of all the samples in the acidic environment, as shown in Figure 3(A). This shows that a 6.0 wt% sample of 100 µm particle size as reinforcement corroded minimally in the acidic environment. Figure 3 (B) also shows that Al-alloy/4.5 wt% composites sample had the highest corrosion rate, followed by the 6.0 wt% S_eS_b reinforced matrix. It can equally be observed that the 6.0 wt% had the peak negative (Figure 3B), indicating superior corrosion resistance. It was observed that the unreinforced sample had the least corrosion rate compared with the 4.5 wt% and 6.0 wt% particulate samples. Despite the poor corrosion resistance within the first 6 days of immersion, samples showed resistance to corrosion from the 6th day to the 12th day owing to the formation of the oxide film across the surface of the Al-alloy composites which prevented further corrosion of the samples.

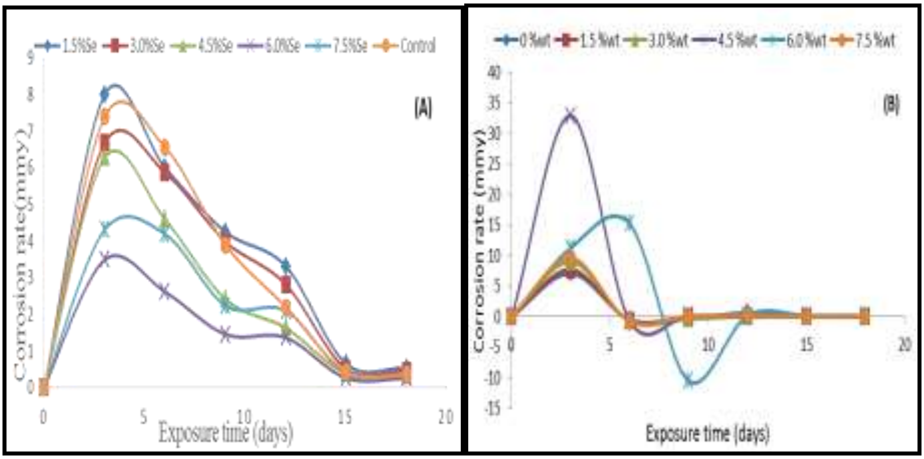

Figure 3: Variation of corrosion rate for 100 µm samples in (A) Acidic medium and (B) Alkaline medium

From Figure 4 (A), it could be seen that the sample with 1.5 wt% had the highest peak mass loss, and this is an indication of a higher rate of corrosion. A similar trend was reported by Bodunrin *et al.* [27].

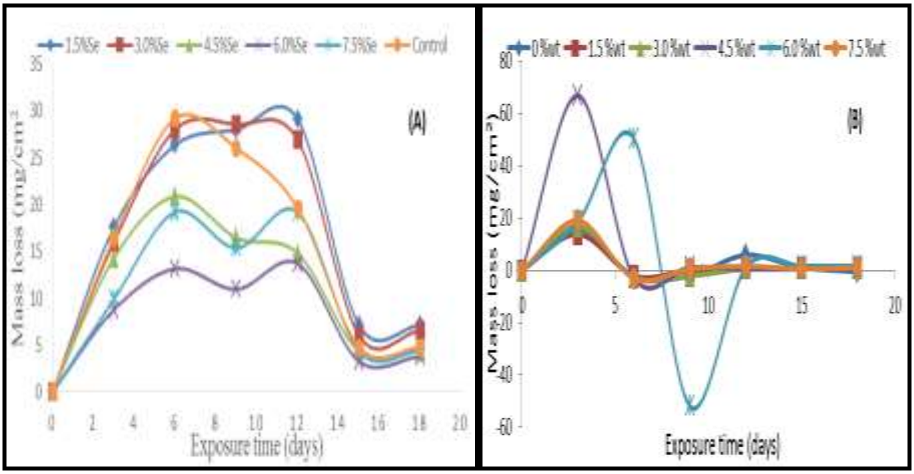

Figure 4: Variation of mass for 100 µm samples in (A) Acidic medium and (B) Alkaline medium

The variation of corrosion rate in acidic and alkaline media for a 150 µm sample is shown in Figure 5. The corrosion rate in the acidic medium does not follow the regular pattern when compared with other particle sizes. However, the mass loss for the reinforced samples was still lesser than that of the unreinforced sample except for the 1.5 wt% sample. This is an indication of improved corrosion resistance characteristics of the reinforced samples when compared with the unreinforced sample. Figure 5 (B) revealed that the corrosion rate was more intense within the first 5 days in the passive state due to aggressive alkaline solution on the Al-alloy matrix composites. However, with the poor corrosion resistance within the first 6 days of immersion, samples showed resistance to corrosion from the sixth day due to the formation of a protective film, which causes corrosion to cease. From the 9th-12th day, the protective film undergoes rupture when the oxide film breakage was faster than the rate of passivation. This leads to a relatively constant corrosion rate from the 12th day to the last day of the experiment. The particulate sample of 7.5 wt% S_eS_b reinforced Aluminium alloy matrix had the peak corrosion rate and highest negative corrosion resistance compared to the unreinforced particulate samples. It implies that the unreinforced particulate sample had better corrosion resistance than those of 7.5 wt% of the reinforced particulate sample.

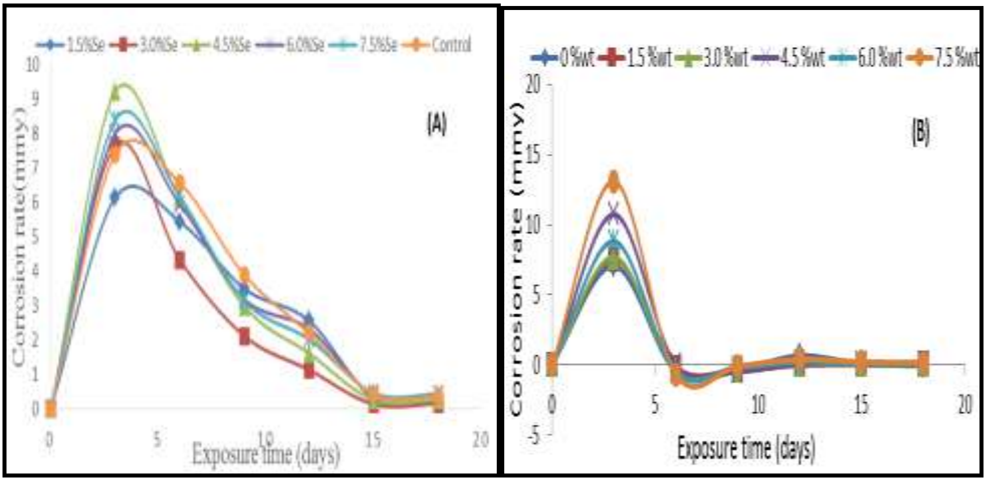

Figure 5: Variation of corrosion rate for 150 µm samples in (A) Acidic medium and (B) Alkaline medium

From Figure 6 (A), it could be observed that mass loss was significantly lesser in the 3.0 wt% compared to other reinforced samples, and this could be a result of reduced pitting corrosion formed on the samples. The 1.5 wt% and unreinforced sample displayed the highest mass loss, and this was due to cracks and pits that were formed on the samples as well as the severe acidic environment in which the samples were exposed to. From Figure 6 (B), the maximum and minimum mass loss was observed with the 7.5 wt% and 1.5 wt% reinforced samples, respectively, and Figure 6 (B) further shows the reason these samples had the peak and least resistance to corrosion. This was due to the reinforcement that acted as an inert physical barrier to the initiation and development of pits corrosion. It also modifies the microstructure of the matrix material, hence, reduces the rate of corrosion [25] [28].

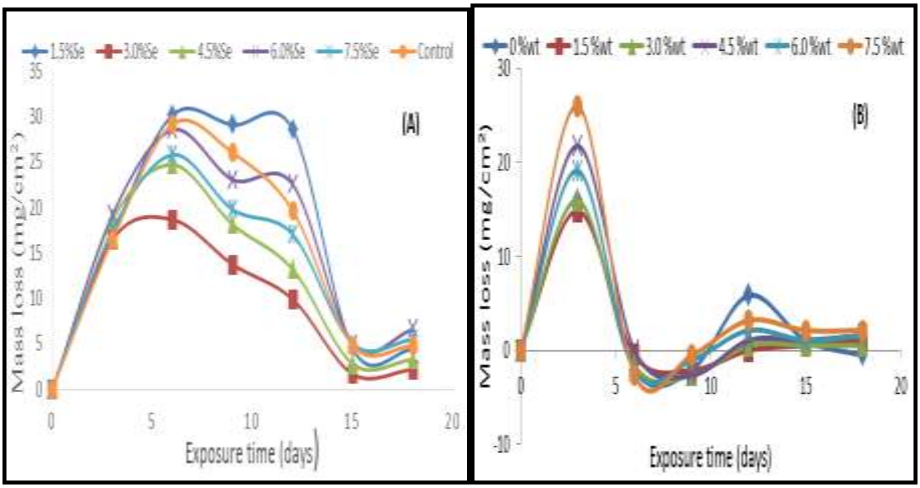

Figure 6: Variation of mass loss for 150 µm samples in (A) Acidic medium and (B) Alkaline medium

It can be observed from Figure 7 (A) that the corrosion rate increases steadily with exposure time before it reaches the peak on the 5th day, after which the corrosion rate began to fall for all samples. The corrosion rate of the reinforced samples could be seen to be considerably less than that of unreinforced samples. This shows that the Seashell reinforcement had improved the corrosion resistance of the reinforced samples making them have better resistance to corrosion than the unreinforced sample. The 1.5 wt% reinforced sample had a peak corrosion rate followed by 4.5 wt% when compared with other reinforced samples. This means that samples of 200 µm particle sizes had the least corrosion resistance at 1.5 wt%. This observation may be due to the formation of cracks and pits within these samples. Cracks and pits were more pronounced on the unreinforced samples in 1.5 wt% and 4.5 wt% samples, which makes it to be more susceptible to pitting corrosion. Figure 7 (B) shows that Al-alloy composites corrosion susceptibility was highest with 6.0 wt% reinforcement addition. The 6.0 wt% particulate reinforced sample was severely affected compared to other samples. It could also be observed that the particulate sample with 1.5 wt% of reinforcement had the highest negative peak corrosion resistance, which implies that 1.5 wt% reinforced sample exhibited better corrosion resistance compared to other samples. Thus, S_eS_b reinforcement acts as a relatively inert physical barrier to the initiation and development of pit corrosion, hence reduction in corrosion rate. This observation is in line with the work of Analeme *et al.* [3].

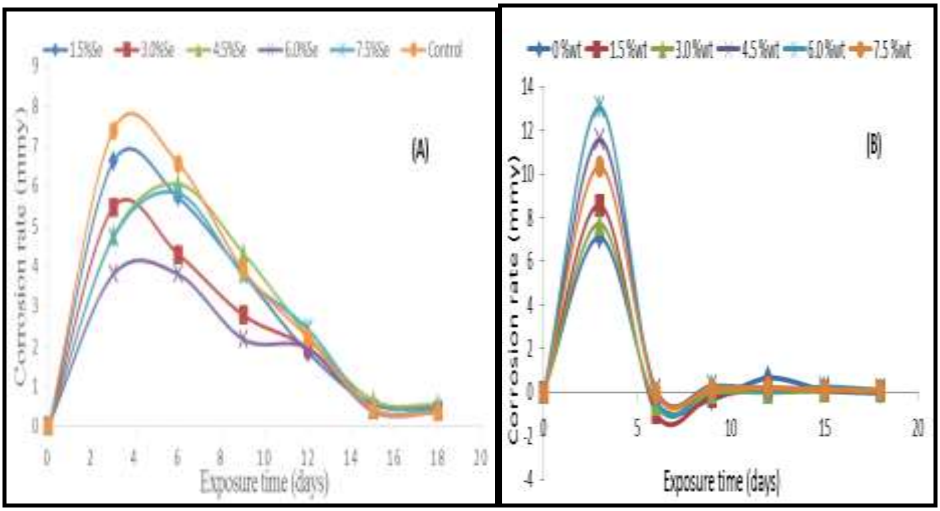

Figure 7: Variation of corrosion rate for 200 µm samples in (A) Acidic medium and (B) Alkaline medium

In Figure 8, it can be seen that the trend in the plots of mass loss is generally similar to that of the corrosion rate. It can be observed from Figure 8 (A) that reinforced samples with 4.5 wt% had the peak mass loss followed by the unreinforced matrix. The severe attack of the acid on the samples induced cracks formation on the surface, which resulted in pits formation and causing loss of material. It could be observed in Figure 8 (B) that a 6 wt% sample had the highest mass loss. This means that the sample particles could not resist the attack from the acidic environment as much as the other reinforced samples.

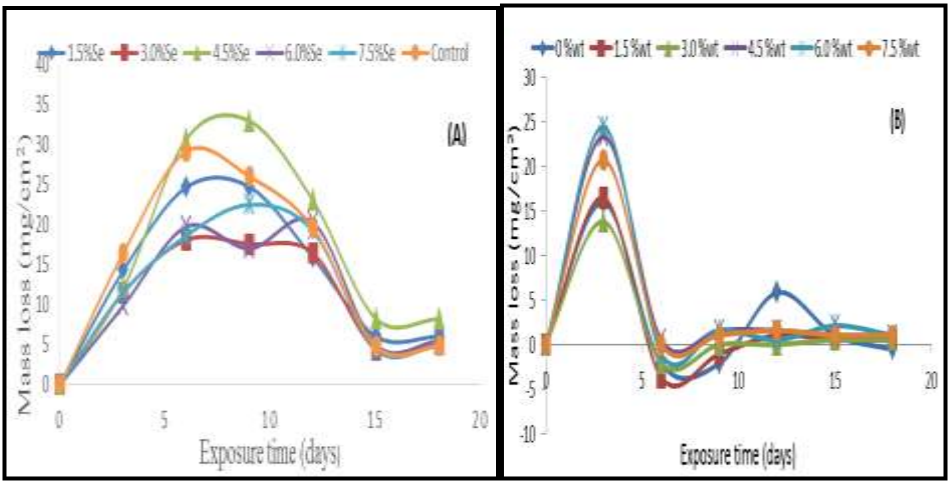

Figure 8: Variation of mass loss for 200 µm samples in(A) Acidic medium and (B) Alkaline mediu

The sample with the optimum corrosion resistance for each particulate size in acidic medium is shown in Figure 9 (A). The 6.0 wt% of 100 µm particle-sized reinforced samples displayed the best corrosion rate when compared with other reinforced samples. This shows that a reduction in the size of the particle of the Aluminum alloy Seashell composites improves its corrosion resistance in an acidic environment. The 150 µm particle reinforced sample displayed the worst corrosion behaviour in acidic medium. Figure 9 (B) shows the corrosion behaviour of samples with the optimum resistance to corrosion in alkaline medium at different particulate sizes. It can be observed that the 6.0 wt% of 100 µm reinforced samples had the highest corrosion resistance, while the 1.5 wt% of 200 µm reinforced samples had the least corrosion resistance. The improvement in corrosion resistance was observed with the addition of 1.5 wt%. This observation can be attributed to the presence of Magnesium, which is the primary constituent of S_eS_b. According to Alaneme and Bodunrin [24], Magnesium had been reported to inhibit the formation of the Al2024 phase, which forms interfacial reaction between the matrix and Egg-glass and fly ash during the production process. The corrosion rate of the reinforced sample was also seen to have its peak with 100 µm samples. This indicates that corrosion resistance improved with an increase in Seashell concentration; this is because they act as physical barriers to the corrosion process.

Hiroshi *et al*. [28] reported that the reason for a decrease in the corrosion rate is the inter-metallic region, which is the site of corrosion, forming crevice around each particle. This may be due to the formation of Magnesium inter-metallic layer adjacent to the particle during the production of hybrid M.M.C.s. Pitting in the composites is associated with the particle-matrix interface because of the higher Magnesium concentration in this region [24-26].

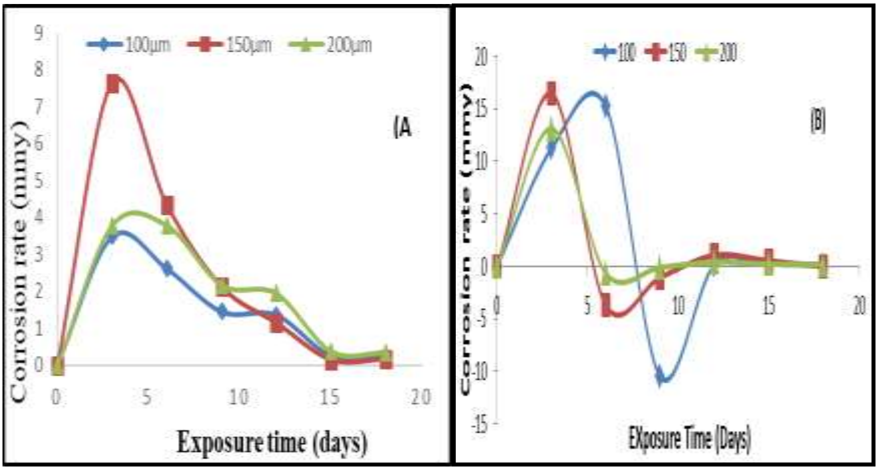

Figure 9: Variation of corrosion rate with exposure time for the Seashell (S_eS_b) reinforced Aluminium composites in (A) Acidic medium and (B) Alkaline medium at different particulate sizes

4. Conclusions

Corrosion rate on Seashell reinforced Aluminium alloy composites in acidic and alkaline environments had been investigated in this study, and the following conclusions can be drawn:

1. The use of Seashell (SeS_b) as reinforcement in Aluminium composites relatively improved the corrosion resistance of the composites.
2. The 6.0 wt% of the 100 µm particle size reinforced samples had the best corrosion resistance in both acidic and alkaline media.
3. The results show that stir-cast Aluminium alloy/Seashell composites exhibited better corrosion resistance characteristics in an alkaline medium than in acidic medium.

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