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Investigating Effect of Zinc Content on the Mechanical and Corrosion Responses of Al6063-SiC Composite

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Authors' contributions

This work was carried out in collaboration between all the five authors. Author OOA conceived the research idea and carried out extensive literature study on the subject matter in order to establish a gap and formulate a problem statement. Author OOA discussed the idea with author AOO, It was jointly agreed by these two authors that a study should be carried out in order to provide explanations that can further enrich the literature on effect of zinc content on the mechanical and corrosion responses of aluminium based composites. Experimental procedures were jointly formulated by authors OOA and AOO, while laboratory experimental works were carried out by author AOO under the guidance of author OOA. Results obtained were used to prepare first draft of the manuscript for rigorous pre-review of authors TAOS, OSI and OMO, who were senior colleagues and more experienced research authors. Useful critics and suggestions offered in the pre-review process were jointly adopted by all authors to revise and produce the manuscript submitted to the journal for peer review processing. Response to CJAST reviewers' comments were jointly handled and approved by all the five authors.

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ABSTRACT

Corrosion susceptibility of Al6063-SiC based composites is attracting unceasing concerns among researchers. The motive of this work was to investigate the influence of zinc content on the corrosion resistance and mechanical responses of Al6063-SiC composites. Zinc was incorporated into the composite at 2, 4, 6, 8 and 10% volume fractions using the Two-step stir casting method.

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Thereafter, mechanical response, optical microscopy and corrosion tests were carried out. The hardness tests revealed a general decrease pattern in the Brinell Hardness Number (BHN) of Al6063-SiC-Zn composite as the percentage of zinc increased. However, the Impact and tensile strengths of Al6063-SiC-Zn composite increased as the volume fraction of Zn increased. The relative enhancement in the mechanical responses of Al6063-SiC-Zn composites can perhaps be attributed to the manifestation of thickened and dense grain lines observed in the micrographs as the concentration of zinc in the composite increased. Corrosion tests in both sulphuric and saline media revealed a good influence of zinc on the composite. Therefore, the choice of zinc alloying element has potential for enhancing corrosion resistance of Al6063-SiC-Zn composites in brine and acid based environments with satisfactory contributions to their mechanical behaviours.

Keywords: Mechanical response; corrosion; microstructure; zinc and aluminium 6063.

1. INTRODUCTION

The unprecedented research interests in the development and characterisation of Metal Matrix Composites (MMCs) with special focus on Aluminium Metal Matrix Composites (AMCs) is gaining prominence due to its high strength-to-weight ratio and the overall improvement in mechanical properties. This is equally responsible for the quantum leap in the choice of AMCs as potential composite material for engineering critical components, power electronic modules, space systems [1], equipment and structures in industries (oil and gas, automobiles, telecommunication, transportation, e.t.c).

Aluminium 6063 (Al6063) is one of the leading alloy materials for industrial applications. It has eight alloying elements namely: Silicon (Si), Iron (Fe), Copper (Cu), Manganese (Mn), Magnesium (Mg), Zinc (Zn), Chromium (Cr), Titanium (Ti) and finally the base metal, Aluminium (Al).When Silicon carbide is embedded in aluminium, the composite becomes a potential structural material for high temperature and aerospace applications due to its ability to increase service temperature and specific mechanical properties. Prominent example of aluminium-silicon carbide (Al/SiC) based composites application is its use in automobile engine components [2] such as valves, camshafts, gear parts, suspension arms e.t.c.

Laudable efforts have been made on the characterisation of mechanical properties of Al6063-SiC composites and the outcomes of researchers' studies have been tremendously promising. [3] examined the mechanical properties of Al6063-SiC by varying weight fractions of SiC. It was reported that the tensile strength and ultimate break load increased with rising weight fraction of SiC reinforcement. A study on the evaluation of the mechanical properties of coconut shell ash reinforced aluminium alloy composites was carried out by [4]. The incorporation of coconut shell ash in the composites was found to significantly improve its hardness and ultimate tensile strength properties. [5] characterised mechanical behaviour of stir cast Al6063-SiC reinforced composites. While addition of SiC was found to increase hardness and tensile strength, ductility experienced a significant decrease. Experimental analysis of mechanical properties of Al6063-SiC composite carried out by [6] showed noteworthy improvement in hardness and tensile strength of the composites as the volume fraction of SiC reinforcement increases. Mechanical behaviour of Al6063-SiC was studied by [7]. Experimental results obtained showed that impact strength, hardness, shear and tensile strengths attained maximum value at 15% SiC. The increase in addition of SiC as reinforcement particles in Al6063 based metal matrix composites was observed to influence its hardness and tensile strength [8].

Although Al6063-SiC is a good choice of material in several applications, major limitation has been attributed to its high corrosion susceptibility as the volume fraction of SiC content increases. Except on few instances where the incorporation of SiC promotes corrosion resistance of aluminium based composites [9-11], it has been generally observed to affect AMCs corrosion behaviours immeasurably [12-16]. AMCs tend to corrode in a localized manner. Possible mechanisms for this include micro-galvanic coupling between the matrix and reinforcement or between the matrix and inter-metallic atoms as well as failure of the protective oxide film due to micro segregation of the alloying elements or micro crevices at the matrix reinforcement interface. Several additional research works have been conducted on the corrosion challenges of using SiC as reinforcement particles in Al6063 composites. [17] examined the corrosion behaviour of silicon carbide metal matrix composites in sodium chloride solutions. Their experimental data revealed a monumental loss in weight of composites resulting in formation of deeper pits and microcrevices at higher volume fraction of SiC. The influence of SiC volume fraction on the corrosion behaviour of Al6063 and its monolithic alloy in NaCl solution was studied by [18]. Results obtained showed clearly that the corrosion susceptibility of Al6063-SiC_p composites was much higher than the monolithic alloy. [19] investigated the corrosion behaviour of Al6063-SiC in NaCl and H_2SO_4 media. Results obtained prior to solution heat treatment revealed that corrosion rates were more aggravated in both media at higher exposure time. However, thermomechanical treatment of the composites manifested enormous corrosion resistance ability in H_2SO_4 environment. The corrosion behaviour of hybrid reinforcement of silicon carbide and groundnut shell particles in Al-Mg-Si alloy matrix was investigated in salt and acid solutions [20]. It was found that hybrid ratio with much higher silicon carbide showed a very low corrosion resistance in the media when compared to ratio with higher content of groundnut shell ash. In another work [21], the high corrosion susceptibility of SiC as reinforcement was found to be slightly subdued by the incorporation of corn-cob ash as hybrid reinforcement in Al-Mg-Si composite.

The adoption of zinc as alloying element has been found to be beneficial to the mechanical responses [22-24] and corrosion resistance characteristics of non-ferrous based alloys (most especially magnesium based alloys). The effect of zinc concentration on the corrosion behaviour of Mg-Zn-Mn alloys was investigated by [25]. The outcome of the study showed that zinc content enhances the anti-corrosion property of the alloy. The best anti-corrosion property was achieved with 1% Zn. [26] studied the influence of zinc on the corrosion behaviour of Mg-Zn alloys. Results indicated significant improvement on the mechanical properties and corrosion resistance at 5% weight fraction. Zinc was observed to form a protective film on the surface of the alloys thus exhibiting anti-corrosion property. The influence of zinc content on corrosion behaviour of ternary alloy Mg-Zn-Ca in a body fluid was examined by [27]. Results showed that the Mg-Zn-Ca alloy with 4% zinc content has the best corrosion resistance when compared to the alloy at no or lower zinc volume fraction.

Sequel to the foregoing, this work was an attempt to investigate the effect of zinc addition on the corrosion resistance ability of Al6063-SiC composite without compromising its mechanical properties. The choice of zinc as a reinforcing alloying element was motivated from the fact that it is unaffected by dry air; its excellent corrosion resisting characteristics and satisfactory potentials for improving tensile strength properties of non-ferrous alloys.

2. METHODS AND MATERIALS

2.1 Composite Production

Aluminium 6063 alloy was used as the matrix metal for the composite. The chemical composition analysis showed that the alloy has Si(0.4806%), Fe(0.2907%), Cu (0.008%), Mn(0.168%), Mg(0.4741%), Zn (0.001%), Cr(0.0005%), Ti(0.003%) and finally the base metal, Al(98.58%). The volume percentage by weight of Silicon carbide was 10% for all samples. Zinc was incorporated into Al6063-SiC composite at levels of 2, 4, 6, and 10% using the liquid metallurgy route (Two-Step stir casting technique) to produce Al6063-SiC-Zn composite. The Aluminium 6063 alloy having 82, 84, 86, 88 and 90 percents by weight, according to charge calculations were initially heated to 300℃ for 45 minutes to aid the wettability of the alloy. The silicon carbide powder particles were also preheated to 1100℃ and the zinc powder was preheated to 250℃ further aid wettability of the alloy. Thereafter, the Al6063 particles were charged into a furnace at a temperature of 780°C and allowed to dissipate heat till the alloy was in a semi-solid state at about 600℃. During the semi-solid phase of the Al6063 alloy, the already preheated Silicon Carbide powder particles and Zinc powder particles were introduced into the alloy and it was stirred manually for 5 minutes.

2.2 Mechanical Testing

2.2.1 Brinell hardness test

The various specimens of the composite Al6063-SiC-Zn were reduced to cylindrical shapes with a length of 30 mm and diameter 8 mm. A Brinell hardness tester was used to determine the hardness of the specimens.

2.2.2 Tensile strength test

The tensile strength test was carried out using a tensometer. A lathe machine was used to machine the specimen, thereafter it was shaped into the standard test piece size, a cylindrical shape of diameter 5 mm and length 30 mm with dog bone-shaped ends. The initial length (L_0) and the initial diameter (d_0) of the specimen were measured before the test began. Thereafter, the fractured specimens were arranged together and the final length (L_f) and diameter (d_f) of each specimen were measured.

2.2.3 Impact strength test

The Impact Strength of the various samples was determined using a pendulum-type Impact strength testing machine. Each specimen was cut and reduced to a standard test piece size of diameter 10 mm and length 120 mm. A groove of 2 mm was notched on each specimen to help the specimen fit into the machine.

2.3 Metallographic Test

The samples were grinded, polished and etched. Silicon Carbide paper of different grades used in the order 220, 320, 400 and 600 (i.e. coarse grade to fine grade) were placed on the grinding machine. A polishing cloth (selvt cloth) was swamped with a solution containing one micron of Silicon Carbide. Final polishing was performed by swamping the selvt cloth with 0.5 micron of Silicon Carbide until a mirror-like surface was attained. The mirror-like polished surface was etched in a solution containing 2% sodium hydroxide for 45 seconds.

The samples were viewed using an Accuscope microscope coupled with camera (Serial no. 0524011, Maker: Princeton, US) with magnification 400x.

2.4 Corrosion Test

The corrosion test was carried out in 3.5wt% NaCl (pH 6.7) and 0.3M H_2SO_4 (pH 0.71) solutions which were prepared following standard procedures. The specimens for the test were machined to a cylindrical shape with a diameter of 3 mm and height 8.2 mm and then mechanically polished with emery paper. The samples were then degreased with acetone and thereafter rinsed in distilled water. Finally, they were immersed into the prepared solution. The samples were exposed in the acidic and salt water environments for 30 days during which the pH, temperature and weight of each sample was recorded severally and systematically during the 30-day period. A pH meter having a thermometer was used to take the pH and temperature simultaneously. Mass loss was evaluated for each sample in accordance with standard recommended practice ASTM G31 using a 4-digit accuracy weighing balance.

3. RESULTS AND DISCUSSION

3.1 Hardness Test

As shown in Fig. 1, the composite Al6063-SiC-Zn had the highest hardness number of 26.2 on the Brinell Hardness Machine when it contained 2%

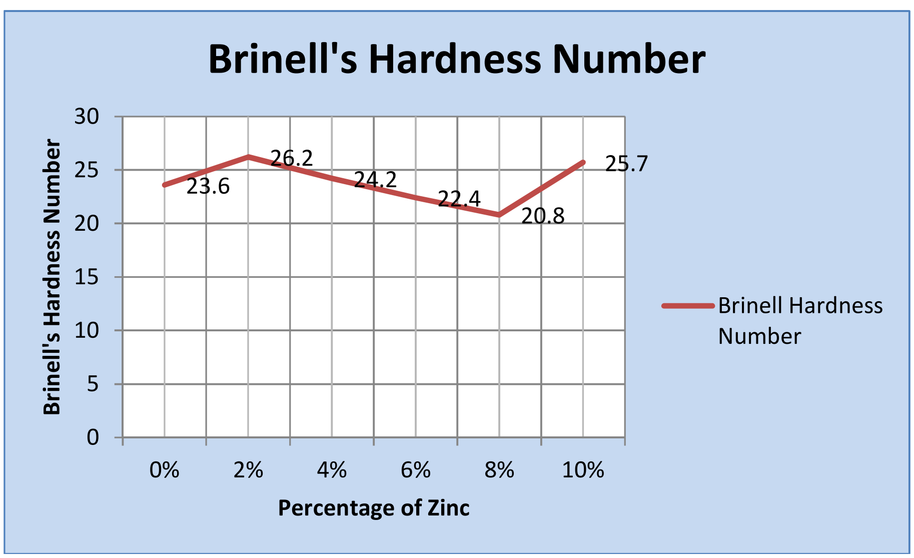

Fig. 1. Relationship between the percentage of Zinc in Al6063-SiC-Zn and the Brinell's Hardness number of the composite

zinc. With increasing percentage of Zinc in the composite, the hardness number reduced to a minimum value of 20.8. Interestingly, the composite hardness picked up again at 8% zinc and increased up to 10% Zinc.

3.2 Impact Strength Test

Fig. 2 shows that as the percentage of zinc in the composite increased, the impact strength also increased. Initially, when no zinc was added, it had an Impact Strength of 7.888 Joules, but had the lowest Impact Strength of 6.732 Joules when it contained 2% zinc. The Impact Strength kept increasing and reached its peak at a value of 9.52 Joules when it contained 8% zinc, and then decreased again to 8.024 J at 10% zinc. This significant reduction perhaps can be attributed to the fact that excessive additions of soft metals such as zinc with 10% volume fraction or more has a reasonable potential for degrading the impact behaviour of aluminium based composites. This assertion can be corroborated by [28].

3.3 Ultimate Tensile Strength Test

Fig. 3 shows the effect of increasing percentages of zinc on the tensile strength of the composite. A close look at Fig. 3 reveals that generally, the Ultimate Tensile Strength (UTS) increased with increasing percentage of zinc in the composite. However, when the composite contained 6-8% zinc, the tensile strength remained the same. This further goes to confirm previous reports that zinc does in fact increase the tensile strength of aluminium alloy. The maximum UTS was reached when the composite contained 10% zinc with a value of 110 MPa.

3.4 Metallographic Examination

Plate a shows the micrograph of Al6063-SiC composite containing no zinc; the microstructural studies revealed a fairly uniform distribution of SiC particles and slight macro-segregation of particles in some places.

Plate b shows the micrograph of Al6063-SiC composite containing 2% Zinc. A close look at the microstructure revealed the presence of agglomerated particles of SiC in the composite. These clusters of SiC are likely to be responsible for the increased hardness in the composite containing 2% Zinc. The impact strength was lowest at this percentage and the UTS was lowest at this point also due to the agglomeration of the SiC particles.

Plate c shows the micrograph of Al6063-SiC composite containing 4% Zinc. The microstructure revealed the presence of rather thick grain boundary lines. The agglomeration of SiC is not as pronounced as the samples containing 2% Zinc. Generally, the sample showed good mixability of the matrix and the fibres added. Perhaps, the proper incorporation of zinc at this percentage is accountable for the reduced hardness as zinc is a soft metal.

Plate d shows the micrograph of Al6063-SiC composite containing 6% zinc. Clearly observed

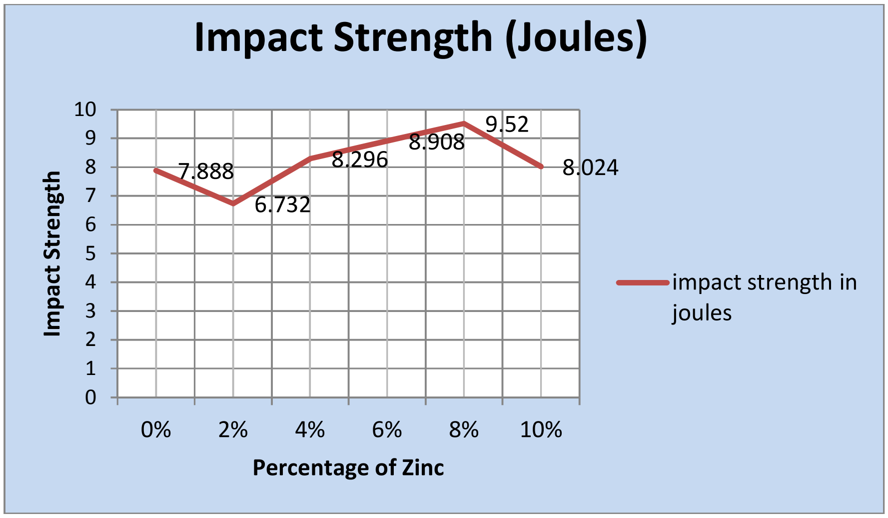

Fig. 2. Relationship between the percentage of Zinc in Al6063-SiC-Zn and the Impact Strength of the composite

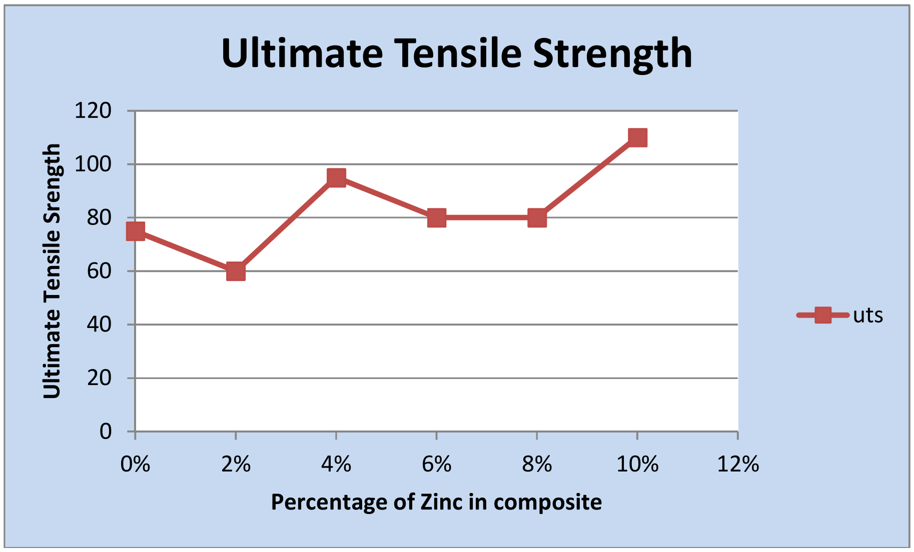

Fig. 3. Relationship between the percentage of Zinc in Al6063-SiC-Zn and the Tensile Strength of the composite

from the micrograph is the good spread of zinc and SiC along the matrix. This implied that increasing the percentage of zinc reduces hardness while increasing impact strength. The UTS was also found to increase tremendously.

Plate e shows the micrograph of Al6063-SiC composite containing 8% Zinc. A very good incorporation of the reinforcement particles into the matrix was observed. Only a small portion showed a ring of agglomeration. The Hardness further reduced at this percentage while impact strength reached a maximum value at this point.

Plate f presents the micrograph of Al6063-SiC composite containing 10% Zinc. Formation of thick grain lines and a thick agglomeration of the reinforcement particles were observed. At this percentage, the mechanical properties took a different turn. The hardness began to increase while the impact strength reduced at this percentage. However, the ultimate tensile strength kept increasing and had a maximum value at this point. This observed reversal of trends could be due to the oversaturation of the composite at this percentage with reinforcement particles as strong agglomerations was formed rather than being dispersed evenly.

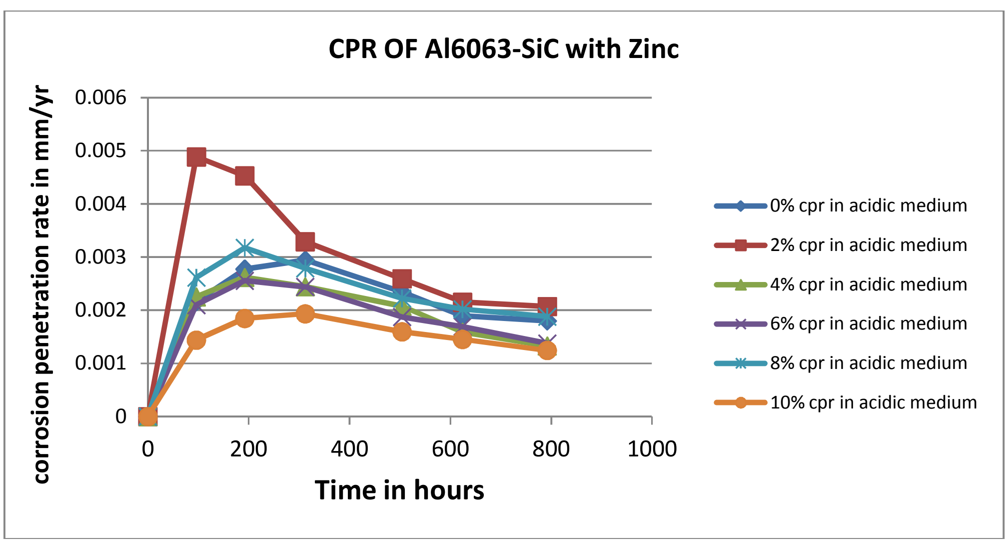

Fig. 4. Corrosion penetration rate of Al6063-SiC composite with zinc in an acidic medium

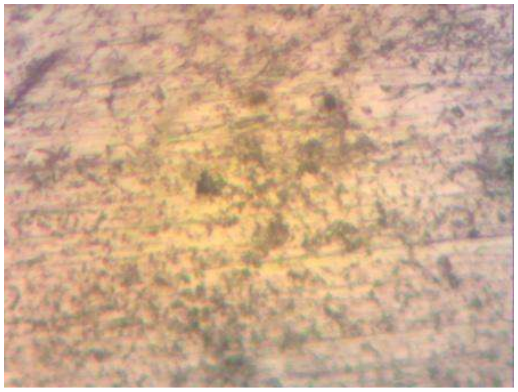

Plate a. Al6063-SiC (no Zinc)

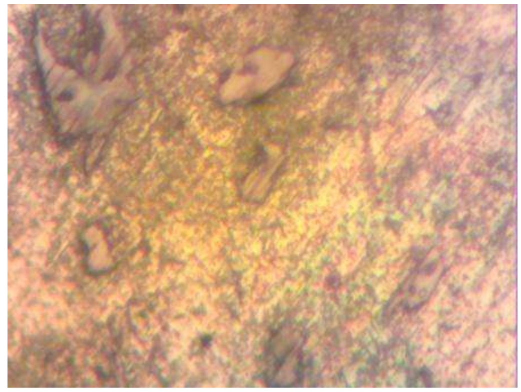

Plate b. Al6063-SiC (2% Zinc)

Plate c. Al6063-SiC (4% Zinc)

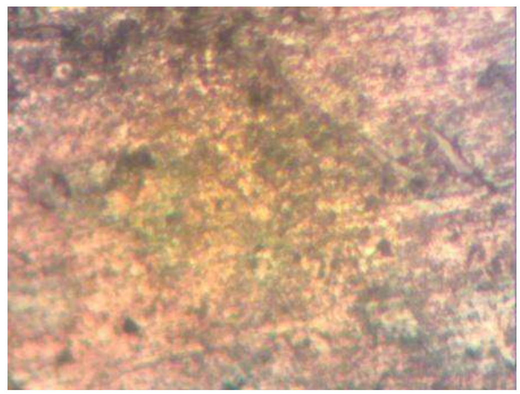

Plate d. Al6063-SiC (6% Zinc)

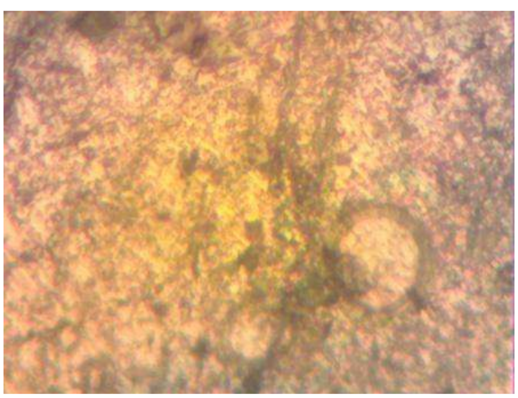

Plate e. Al6063-SiC (8% Zinc)

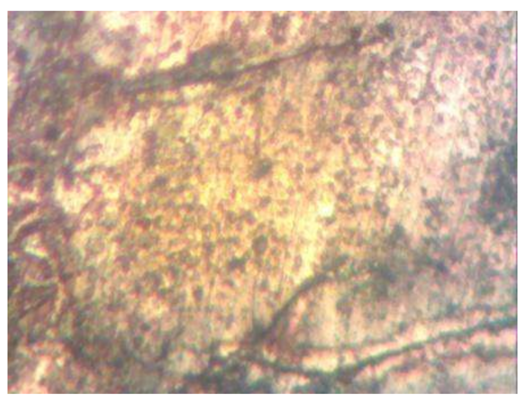

Plate f. Al6063-SiC (10% Zinc)

3.5 Corrosion Test

Fig. 4 shows the results of the corrosion test both in an acidic medium. In the acidic medium for all samples containing increasing percentages of zinc, the Corrosion Penetration Rate (CPR) initially increased and peaked at a point before gradually reducing. The corrosion penetration rate was highest in the sample containing 2% Zinc with a CPR of 0.005 mm/yr, while the sample with the least CPR was the sample containing 10% Zinc with a CPR of 0.0019 mm/yr. The results indicated that Zinc does reduce the rate of corrosion in Al6063-SiC composite. Pitting was the major form of corrosion in all samples immersed in the acidic solution as illustrated in Fig. 5.

Fig. 5. Pitting corrosion of sample in acidic medium

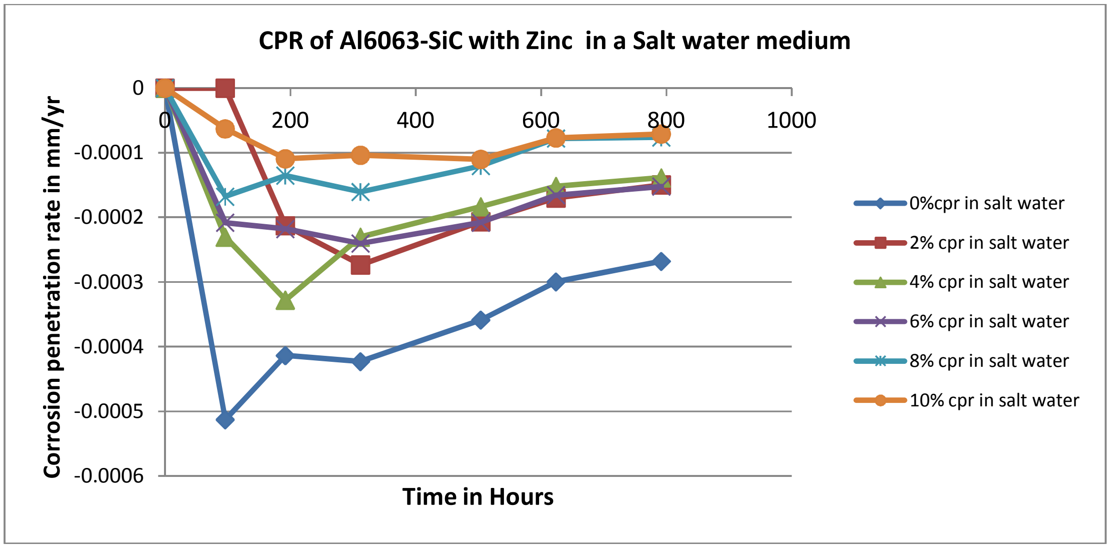

Fig. 6. Corrosion Penetration Rate of Al6063-SiC composite with Zinc in an acidic medium

However, the samples in the salt water medium experienced a negative CPR as shown in Fig.6. This was because rather than lose weight, all samples gained considerable weight during the period of the test. The weight gain was most pronounced in the sample containing no Zinc. Weight gain during corrosion test could be due to the formation of a thin film of salt on the samples. These results again indicate that generally, the addition of Zinc in Al6063-SiC composite does not cause harm due to corrosion in a saline solution.

4. CONCLUSIONS

In this investigative study, the following conclusions can be drawn:

- When Zinc is added to Al6063-SiC composite, the hardness of the composite reduces from 2-8% with increasing percentage of zinc but increases from 8%.
- The Impact Strength of Al6063-SiC composite is improved when zinc is added and it increases with increasing percentage of Zinc.
- The tensile strength of Al6063-SiC composite increases as the percentage of zinc added to it increases.
- Corrosion tests showed that increasing the percentage of zinc in Al6063-SiC composite improved the corrosion resistance in an acidic medium while in the Salt water medium there was no mass loss due to corrosion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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