

# **Original Research Article**

### Corrosion Resistance of Al-Si-Mg/SiC Composite in Inoculated Oily-HCl Solution

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# ARTICLE INFORMATION

# ABSTRACT

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The influence of Jatropha curcas oil on the corrosion resistance of Al-Si-Mg/SiC composite in 0.5HCl solution was investigated using weight loss method. Al-Si-Mg with SiC (equivalent to 10% of the total weight of the molten metal) was produced and cast into cylindrical test bar of length 30cm and diameter of 1.5cm. After casting, the bars were cut into coupons of  $15 \times 10$  mm dimension for corrosion test. They were immersed in 0.5M HCl with and without Jatropha curcas oil in order to determine the corrosion rate. The study was carried out at different Jatropha curcas oil concentrations; 1.5, 3.0, 4.5, 6.0 and 7.5% v/v, and varying exposure time and temperature. The result obtained revealed that Jatropha curcas oil was able to reduce the corrosion rate of Al-Si-Mg/SiC at a concentration of 7.5%v/v at room temperature. The inhibition was attributed to the adsorption of Jatropha curcas oil onto the surface of the composite at room temperature which prevents the breakdown of the passive film, hence, preventing the corrosion of the composite (Al-Si-Mg/SiC). Furthermore, the microstructure contains thin layers of the inhibitors molecules which protect the metal against corrosion attack at room temperature.

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# **1. INTRODUCTION**

Corrosion is a destructive attack of a material by reaction with its environment. The serious consequences of the corrosion process have become a problem of worldwide significance (Pierre, 1999). Most materials, to one degree or another, experience some kind of interaction in a large number of diverse environments. Often times, such interactions with the environment impair a material's usefulness as a result of the deterioration of its mechanical properties, such as ductility and strength (Obassi, 2014). Furthermore, despite active research by corrosion engineers, a visit to the scrap yard proves that large quantities of domestic appliances and car body parts still fail because of corrosion (Kakani, 2004).

Aluminium matrix composite (AMCs) have shown high mechanical properties such as high strength, high stiffness, wear resistance and good elevated temperature properties when compared to the unreinforced

matrix alloy, which has led to the use of aluminum matrix composite in electronic heat sinks, automotive drive shaft, ground vehicles brake rotors, jet fighters, air craft firms, electronic instrument racks and satellite struts (Szklarska-Smialowska, 1999; Rushing and Edwards, 1999; Gouveia-Caridade *et al.*, 2004; Ahlatci *et al.*, 2006; Hassan *et al.*, 2007; Kiourtsidis and Skolianos, 2007).

Corrosion is an undesirable process whose result may not be limited to the damage it does to the materials or engineering properties. The spontaneous process of corrosion occurs predominantly without the application of external current, and this feature of corrosion is easy to understand considering that these metals (ferrous and non-ferrous) are usually subjected to corrosion which occurs in nature as mineral or ores, and not in native state. For example, gold and platinum usually do not corrode under conditions which do not differ materially from those existing in nature (Pierre, 1999). It should be noted that, the materials affected by corrosion are not limited to metals, but also include plastics, rubbers, wood, bricks, paint etc. Corrosion of metals applies specifically to chemical or electrochemical attack. The deterioration of plastics and other non-metallic materials which are susceptible to swelling, cracking, softening and so, on, is essentially physicochemical rather than electrochemical in nature. Corrosion commonly occurs at metal surface in the presence of oxygen and moisture, involving electrochemical reactions (Szklarska-Smialowska, 1999; Omotioma and Onukwuli, 2015). Naturally, some metals have the ability to form tenacious oxide films when they come in contact with certain corrosive media and these films provide some protection against corrosion to the entire metal matrix (Olawale *et al.*, 2017). However, most of the films are very thin, of low mechanical strength and high porosity and therefore have little or no practical applications (Kiourtsidis and Skolianos, 2007).

Composite materials are emerging chiefly in response to demands from technology due to rapidly advancing activities in aircrafts, aerospace and automotive industries (Rao et.al., 2012). These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials such as metals (Jitendra *et al.*, 2016). As a result of intensive studies into the fundamental nature of materials and better understanding of their structural property relationship, it has become possible to develop composite materials with improved physical and mechanical properties (Mohammed *et al.*, 2013). Composite materials have attracted many researches throughout the globe (Chawla, 2012). Success in these researches has opened new findings on their corrosion, physical and mechanical properties and methods of fabrication. The use of inhibitors for the control of corrosion of aluminium-based composite which are in contact with aggressive environment has gained an accepted recognition. Large numbers of organic compounds were studied to investigate their corrosion inhibition potential (Mohammed *et al.*, 2013).

Aluminium matrix composite are generally reinforced either with short fibers, continuous fiber, ceramic particles or monofilament. Early research on metal matrix composite concentrated on continuous fibers but fabrication techniques have reduced their used in areas where the end justified the means. This had foster growth in the development of a low-cost particle reinforced composite. The reinforcement of aluminum alloys with silicon carbide (SiC), aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), silicon oxide (SiO<sub>2</sub>), carbon (C) and zirconium tetra-oxosilicate (ZrSiO<sub>4</sub>) particulates has led to a new generation of engineering materials, which offer some advantages over conventional materials such as aluminium-based alloys (Okafor, 2008).

One of the main obstacles in the use of metal matrix composites (MMC) is the influence of reinforcement on corrosion resistance. This is particularly important in aluminium alloy-based composite, where a protective oxide film imparts corrosion resistance. The addition of a reinforcing phase can increase the frequency of discontinuities in the film, thereby increasing the number of sites where corrosion can be initiated and rendering the composite liable to severe attack (Abdulwahab *et al.*, 2011). Corrosion is a major problem in aluminum-based metal matrix composites (AMMCs). Crevice attack at the matrix/reinforcement interfaces and localized attack on structural and compositional inhomogeneities can also occur within the matrix. In general, incorporation of reinforcements increases susceptibility to corrosion attack of the metallic matrices especially in the presence of air (Bobic *et al.*, 2010).

Therefore, the present study is an attempt to investigate the corrosion behavior of Aluminium-based alloys and composites reinforced with silicon carbide (SiC), using *Jatropha curcas* oil as corrosion inhibitors for Al-0.91%Si-0.51%Mg/10%SiC metal matrix composite in 0.5M HCl solution under different temperatures and concentrations using weight loss method.

### 2. MATERIALS AND METHODS

### 2.1. Materials and Equipment

The materials used in this research include pure aluminum electrical wires obtained from Northern Cable Company (NOCACO) Kaduna. Silicon, Magnesium, Silicon carbide powder, Hydrogen chloride and ethanol were purchased from Sabon-Gari market, Zaria, Kaduna State. *Jatropha curcas* oil was collected from National Research Institute for Chemical Technology (NARICT), Zaria. Etchant, Grit papers (320, 400, 600 and 800), polishing powder (Alumina) and distilled water were also used. The equipment used in this work include water bath, digital weighing balance, measuring cylinder, beakers, stopwatch, conical flask, desiccator, grinding and polishing machine, metallurgical microscope with in-built camera, brush, crucible, cylindrical metal mould, sponge, masking tape, thread, syringe, mechanical stirrer, electrical resistance furnace, pyrometer, moulding box and retort stand.

### 2.2. Production of Composite

The aluminum metal-matrix composite that was used in this study was produced using the chill casting method (Hiremath and Hemanth, 2017), at the foundry shop of the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria. Pure Aluminium wires were used as a source of aluminum which was cut to chargeable size, placed in the crucible and fired to melting. Silicon and magnesium equivalent to 0.91% and 0.51% respectively of the total weight of the molten metal were added to the melt. The melt was thoroughly stirred while melting was still in progress. Stirring was continued until a homogenous molten material was obtained. Silicon carbide particles (equivalent to 10% of the total weight of the molten metal) was preheated and introduced into the homogenous molten metal. Cylindrical metal moulds of approximate length 30cm and diameter of 1.5cm were prepared, after which the molten alloy and the Silicon carbide were poured into the prepared mould. After solidification the samples were machined to dimension of 15 mm  $\times$  10 mm.

### 2.3. Corrosion Measurement

Using the weight loss method, samples of dimension ( $15 \text{ mm} \times 10 \text{ mm}$ ) were degreased in ethanol, dried, weighed and stored in a desiccator. A water bath was filled with water above the heating element, and then switched on and set to the desired temperature level needed for about 1 hour. The heated water was then stirred thoroughly to ensure a homogeneous temperature level in the water bath. The beaker containing 0.5M HCl solution was put in the water bath and allowed for 10 minutes to ensure a homogeneous temperature in the beaker after which some of the samples were inserted in the beaker for the test. The first corrosion test was conducted at a temperature of 30°C and exposure time of 2-10hrs (i.e. after every two hours a sample is removed and weighed and the difference in weight was noted and recorded). The above procedures were repeated with varying inhibitor concentration of 1.5, 3.0, 4.5, 6.0 and 7.5%v/v at temperatures of 30°C, 50°C and 70°C. The weight losses, the corrosion rates and inhibitor efficiencies were then calculated. The activation energies were also computed.

### 2.4. Microstructural Examination

The sample for metallographic examination was ground using series of SiC grades impregnated emery paper (320-800grits), with water as coolant. Polishing was done in two steps; first, rough polishing was done using a 1.0  $\mu$  size alumina polishing powder suspended in distilled water. Secondly, fine polishing was done using 0.5  $\mu$  alumina powder on a rotating disc of propriety nap cloth. The polished samples were etched using Hydrofluoric acid, followed by nitric acid. The microstructure was then captured by an optical metallurgical microscope with an in-built camera.

#### 2.5. Determination of Corrosion Rate (mpy) and Percentage Inhibitor Efficiency

The weight loss was determined by finding the difference between initial weight of the samples and the final weight after each exposure time using the relationship;

$$W = Wo - Wf \tag{1}$$

Where:

W =weight loss (mg) Wo =initial weight (mg) Wf =final weight (mg)

The standard expression for measurement of corrosion rate in miles per year (mpy) was used which is given as follows:

$$Corrosion rate (mpy) = \frac{534w}{DAT}$$
(2)

mpy = miles per year W = weight loss (mg) D = density of the materials (g/cm<sup>3</sup>) T = time of exposure (hours) A = surface area (in<sup>2</sup>)

The inhibitor efficiency was computed using the relationship:

Inhibitor Efficiency = 
$$\frac{W_{o} - W}{W_{o}} \times 100\%$$
 (3)

Where, W and W<sub>o</sub> are the corrosion rate with and without inhibitors respectively.

#### 2.6. Thermodynamic Models

The activation energy (Ea) of the corrosion reaction was calculated using Arrhenius equation given by:

$$Log \frac{R1}{R2} = -\frac{Ea}{2.303R(\frac{1}{T_1} - \frac{1}{T_2})}$$
(4)

Where, R<sub>1</sub> and R<sub>2</sub> are the corrosion rate at any given two different temperatures.

### **3. RESULTS AND DISCUSSION**

#### 3.1. Effect of Inhibitor Concentration and Time on Corrosion Rate

Figures 1-3 show the variation of corrosion rates with exposure time of (2-10 hours) at temperatures of 30°C, 50°C and 70°C using Jatropha curcas oil as corrosion inhibitors in 0.5M HCl solution. It was observed from Figure 1 that there was a decrease in corrosion rate with increase in inhibitor concentration from 4.5% v/v to 7.5% v/v. This may be due to the increased protection offered by the inhibitor as concentration increases, thereby preventing the breakdown of the passive films leading to an increase in the corrosion resistance of the composite compared with the uninhibited samples (Adams et al., 2016). Corrosion rate was noted to be high in the inhibitor free solution, while the introduction of the inhibitor generally reduced the corrosion rates. The least value of corrosion rate was obtained at 30°C, in 7.5%v/v concentration and exposure time of 6 hours. In Figure 2, corrosion rate was higher in the control solution (0% v/v), followed by 1.5%v/v, and next 3.0%v/v. This was also in agreement with the report of Adams et al. (2016). It further decreases at 7.5%v/v (in which case, at exposure time of 2 hours, the corrosion rate was very low, and then increasing steadily at 6 hours). This further increase in corrosion rate with increase in time may be attributed to the breakdown of some passive films (Hari et al., 2016), leaving parts of the sample to have direct contact with the acid. Figure 3 showed that the corrosion rates decreased with increase in concentration of *Jatropha curcas* oil from 1.5-7.5% v/v. The least value was obtained at 4.5% v/v at exposure time of 2 hours. The negative corrosion rates observed at 30°C were as a result of increase in weight of some samples after exposure to the acidic medium. This was as a result of the deposition of the corroded products onto the samples.



Figure 1: Variation of corrosion rates with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 30°C



Figure 2: Variation of corrosion rates with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 50°C

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Figure 3: Variation of corrosion rates with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 70°C

#### 3.2. Effect of Inhibitor Concentration and Time on Inhibitor Efficiency

Figures 4-6 showed the variation of inhibitor efficiency with time for the various inhibitor concentrations. The inhibition efficiency increased with increase in the concentration of *Jatropha curcas* oil. At a temperature of 30°C, maximum inhibition efficiency of 100% was obtained at 7.5% v/v inhibitor concentration and exposure time of (2-8 hours), No considerable change in inhibition efficiency was observed after this concentration. Inhibitor efficiency of 77.78% at the same concentration of inhibitor and at temperature of 50°C, 4 hours exposure time was observed. The reduction in inhibition efficiencies at 50°C and 70°C can be attributed to the acceleration of the breakdown of the passive films at higher temperature. At lower concentration of inhibitor (4.5%v/v), maximum inhibition efficiency of 83.33% was observed at temperature of 70°C and 4 hours. Better inhibition efficiencies were achieved at lower temperature of 30°C and higher inhibitor concentration of 7.5%v/v for lower time of 2-8 hours respectively.



Figure 4: Variation of percentage inhibitor efficiencies with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 30°C

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Figure 5: Variation of percentage inhibitor efficiencies (IE %) with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 50°C



Figure 6: Variation of percentage inhibitor efficiencies (IE %) with time for Al-Si-Mg/SiC composite in 0.5M HCl solution at 70°C

#### 3.3. Activation Energy

The results for the activation energies are presented in Table 1. From Table 1, it could be seen that, the activation energy of the control (0.0%v/v) solution was low. When the inhibitors were introduced, higher values of activation energy were generally obtained. This shows that corrosion will occur more easily in the absence of inhibitors. But with the inhibitors, the corrosion reaction needs to overcome higher activation energy values before it can occur.

Table 1. Activation chergies (KJ/mol) for Al-SI-Mg/Sie composite in 0.5W fiel solution					
Inhibitor conc. (%v/v)	Activation Energy (kJ/mol) at different temperatures (50°C-70°C)				
	2hr	4hr	6hr	8hr	10hr
0.0	70.93	16.50	31.22	10.01	37.83
1.5	25.78	22.76	17.19	32.69	40.47
3.0	38.99	21.30	14.15	20.38	2.55
4.5	145.04	39.72	32.27	9.82	42.60
6.0	97.11	27.69	14.36	17.3	14.81
7.5	69.05	25.41	44.66	21.4	49.40

Table 1: Activation energies (kJ/mol) for Al-Si-Mg/SiC composite in 0.5M HCl solution

### **3.4.** Microstructural Examination

The microstructure of the produced composite is given in Plate 1 while Plate 2 and 3 show the micrograph of the corroded samples. From Plate 1, it was observed that, the structure of the as-cast sample contains uniform distribution of the reinforcement within the matrix phase. The micrograph shows the matrix phase (white) and the reinforcement as dark patches in the fine grain boundaries of the as-cast composite (x100). Plate 2 and 3 show increased in distribution of the reinforcement and corrosion product within the matrix phase. The dark patches are more pronounced at the grain boundaries which indicate corrosion products. Plate 2 shows the micrograph of the most corroded sample (uninhibited) with several micro cracks and pits due to the corrosive effect of the acid (HCl). Plate 3 shows the microstructure of the least corroded sample (inhibited). It can be observed from Plate 3, the formation of thin passive films which covered the entire surface of the sample, thereby preventing the composite from further attack by the corrosive medium.





Plate 1: Micrograph of Al-Si-Mg/SiC composite (x100)

Plate 2: Micrograph of Al-Si-Mg/SiC composite (x100)



Plate 3: Micrograph of Al-Si-Mg/SiC composite (x100)

# 4. CONCLUSION

From the results of weight loss of corrosion rate of Al-0.91%Si-0.51%Mg/10% SiC composite in 0.5M HCl solution using *Jatropha curcas* oil as corrosion inhibitor, the following conclusions were drawn:

- 1. The extract of Jatropha curcas oil flower can be used as inhibitor for Al-Si-Mg/SiC composite.
- 2. *Jatropha curcas* oil is an effective corrosion inhibitor for Al-Si-Mg/SiC composite in 0.5M HCl solution at an optimum concentration of 7.5%v/v at 30°C. The inhibitor efficiency also decreased with temperature increase.

# **5. CONFLICT OF INTEREST**

There is no conflict of interest associated with this work.

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