Silicon Nitride-based Ceramic Material as a Reinforcement with Corrosion Resistance Properties in High Grade Aluminium (AA8011) Metal Matrix Composites

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Abstract-
The impact of silicon nitride particulates as a ceramic reinforcement material on the corrosion mitigation of AA8011 in 0.5 M H2SO4 was Experimented with potentiodynamic polarization technique, and the microstructural evolution was keenly observed with TESCAN scanning electron microscope (SEM). The findings from the research show the enhancement in the corrosion performance of the developed composites in relation with the unreinforced AA8011 alloy. The corrosion rate was observed to decrease drastically at higher percentage reinforcement of 20% Si3N4 with 66.78% efficiency. The scanning electron micrographs present a pitting form of corrosion, the pit was seen to be more pronounced in the unreinforced alloy than the developed composites.

Keywords: Si3N4; Stir casting; AA8011; Metal Matrix Composites; Corrosion resistance; Microstructure

1. Introduction

The massive demand for aluminium and its alloy over some decades now has been on the progression and this has in turn, raise the yearly gross sales to about 26 million tonnes, making aluminium the giant non-ferrous metals that are richly required in virtually all engineering applications ranging from construction, medical, electrical, aerospace, textile and not limited to automotive applications, etc [1-4].

The increasing demand for aluminium as a structural primary material utilized in most important applications can be attributed to its inherent properties of light weight to strength ratio, coupled with the corrosion resistance and high ductility. However, there exist some limitations in the utilization of aluminium alloy in some applications and these structural defects attract the interest of the researchers to find the lasting remedy to the deficiency [5]. The low melting temperature, low hardness, and strengthening mechanism are major problems that restrict its usage in some component part of the automobile and other industrial applications where high-temperature resistance and excellent strengthening mechanism material is highly needed. In the process of finding ways to harness the essential properties of aluminium alloy, interest was geared towards composite development where materials with better-improved properties are meant to complement the gaps found in aluminium alloy usage. So far, ceramic materials such as silicon carbide, alumina, titania, zirconia, and other oxides, carbides, nitrides have greatly been employed [3-5]. Nevertheless, the incorporation of some ceramic materials as an enhancer in the aluminium metal composite sometimes tradeoff the intrinsic properties of aluminium alloy such as the ductility and corrosion resistance. Hence, the careful measure is essential in selecting the second reinforcement phase (ceramic) that will improve the properties of aluminium alloy rather than creating more sites...
of deterioration in aggrieved and toxic environments. Meanwhile, this research focus on the efficiency of silicon nitride additives as a reinforcement material on the corrosion resistance of the high-grade (AA8011) metal matrix composite in an acidic environment. Potentiodynamic polarization technique was employed to evaluate the corrosion response of the composite, while the SEM was utilized to reveal the microstructure of the corrosion type that was observed.

2. Materials and Experimental Procedure

AA8011 alloy was procured from aluminium rolling mill, Ogun state, Nigeria and the silicon nitride (Si₃N₄) Nano-powder was obtained from the Hongwu international group, China. Si₃N₄ was employed as a second discontinuous phase at 0 to 20% weight fractions. AA8011 was initially melted in a graphite heating furnace for 30 minutes and conditioned to 700°C to achieve complete melting above the liquid temperature of AA8011. Si₃N₄ additives were conditioned to about 450°C to remove the impurities which might create a void and then incorporated into the molten AA8011, the mixture was stirred mechanically to avoid agglomeration and clustering before casting into sand moulds. The fabricated composites (AA8011/Si₃N₄) were subjected to machining, grinding, polishing and cleansed with reagents like acetone, ethanol and deionized water. The prepared representative samples were preserved in the desiccator for corrosion analysis to avoid moisture contamination [5].

2.1 Potentiodynamic Polarization Analysis

Corrosion behavior of both unreinforced alloy AA8011 and reinforced AA8011/Si₃N₄ composites were examined at a room temperature of 25°C using potentiodynamic polarization technique, this was done by employing three electrode systems namely; working electrode, a reference electrode and the counter electrode. The electrochemical investigation was performed in 100 ml of 0.5 M H₂SO₄ aggrieved environment using auto lab potentiostat coupled with 3D NOVA software of 1.9 version. Tafel extrapolation was used to extrapolate the cathodic and anodic branch curve that was polarized at a scan rate 0.0015 V/s between potential of -0.15 and +1.5 V. from the extrapolation, the basic corrosion parameters were achieved as seen in table 1.

\[
Cr = 3.27 \times 10^{-3} \times j_{\text{Corr}} \times E_{\text{eqv}}/D \tag{1}
\]

\[
(1 - j_{\text{Corr}}/j_{0\text{Corr}}) \times 100 \tag{2}
\]

\[
\theta = (1 - j_{\text{Corr}}/j_{0\text{Corr}}) \tag{3}
\]

Cr is the corrosion rate (mm/yr), \(j_{\text{Corr}}/j_{0\text{Corr}} \text{ (A/cm}^2\) is the corrosion current density in each composite (AA8011/Si₃N₄), and in as-cast AA8011 respectively, Eqv. is the equivalent weight of the samples, D is the experimental density (g/cm)³, \(\theta\) is the surface coverage, I.E is the inhibition efficiency of the particulates.

2.2 Scanning Electron Characterization
The microstructural evolution of the unreinforced AA8011 and the reinforced (AA8011-Si₃N₄) after the electrochemical test was characterized to evaluate the surface morphologies of corroded regions using TESCAN-SEM.

3. Results and Discussion

3.1 Corrosion Performance of AA8011-Si₃N₄.

Table 1 and figure 1 present the result of the Tafel extrapolation from the cathodic and anodic branch of the polarized curve. The table clearly display; the improved polarization resistance of the reinforced composites in an acidic environment, decrease in corrosion rate in relative to the increase in the potential of the reinforced composites and finally decrease in the current density as the percentage fraction of the particulates in the composite increases. As shown in figure 1, the shift in the potential towards a positive region as the weight fractions of the silicon nitrides increases depicts better cathodic protection of the composites. This shows that the potency of the Si₃N₄ reinforcement in the AA8011 metal matrix has been observed to support the thin film protective layer resulting in high cathodic protection obtained by all the developed composites. The adhesion of the Si₃N₄ nanoparticles in the grain boundaries refinement of AA8011 rendered stability to the material against corrosion attack [6-8]. However, the unreinforced AA8011 alloy revealed a low oxide thin film deposited on its surface, this deficiency in the protective layer of the alloy permit an intense attack by the sulphate ion (SO₄²⁻) with corrosion potential of -0.88V. The corrosion density decreases from 3.37x10⁻⁴ A/cm² for 5% Si₃N₄ to 1.67x10⁻⁴ A/cm² mm/yr for 20% Si₃N₄ and the corrosion rate decreases from 3.9120 mm/yr to 1.9382 mm/yr. The magnitude of polarization resistance is 4>3>2>1>0.

Table 1: Tafel Extrapolation Outcome of AA8011-Si₃N₄

| Specimen          | Corrosion Potential (V) | Corrosion Density (A/cm²) | L Rp (Ω) | Corrosion rate (mm/yr) |
|-------------------|-------------------------|---------------------------|----------|------------------------|
| 1-AA8011 (as-cast)| -0.8797                 | 5.02x10⁻⁴                 | 76.028   | 5.8336                 |
| 2-AA8011-5% Si₃N₄| -0.5398                 | 3.37x10⁻⁴                 | 151.29   | 3.9120                 |
| 3-AA8011-10% Si₃N₄| -0.5119                 | 2.84x10⁻⁴                 | 174.20   | 3.2991                 |
| 4-AA8011-15% Si₃N₄| -0.4633                 | 2.05x10⁻⁴                 | 278.59   | 2.3848                 |
| 5-AA8011-20% Si₃N₄| -0.3107                 | 1.67x10⁻⁴                 | 2022.5   | 1.9382                 |
3.2 Scanning Electron Characterization

The microstructural evolution of the as-cast AA8011 and the developed composites of AA8011-Si₃N₄ with various composition after electrochemical analysis in corrosive acidic (H₂SO₄) environment is presented in figure 2 and 3 below respectively. From the microstructure, the micrograph in figure 2 which represent the unreinforced alloy clearly revealed a more severe pit and cracks due to the acidify corrosion attack. In figure 3, the material loss decreases with an increase in the weight percentage Si₃N₄ as shown in figure 3a-d, though pitting corrosion was observed but it was localized mostly in 20% Si₃N₄ particulates. In summary, Si₃N₄ plays a vital role in improving the corrosion resistance of the continuous phase of AA8011 alloy in an acidic environment rather than creating more site of corrosion attack.
4. Conclusions

From the evaluation of the corrosion behavior of silicon nitride as a reinforcement material for AA8011 alloy in 0.5 M H$_2$SO$_4$, it can be deduced that silicon nitride performed efficiently as a corrosion resistance material in AA8011 and the efficiency progresses as the weight percentage of particulates increases. The cathodic and anodic branch polarization curve shows that the silicon nitride truly acts as cathodic protection thereby reducing the anodic metal dissolution. The
microstructure clearly revealed a pitting form of corrosion on the material surfaces, this pitting and cracks become localized and insignificant with the incorporation of silicon nitrides.

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