ASSESSMENT OF MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF 
Al-3%Mg/SiC$_p$ COMPOSITE

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ABSTRACT
The research was aimed at developing silicon carbide (SiC$_p$) reinforced aluminium-magnesium (Al-Mg) matrix composite with better mechanical and microstructural properties than the conventional marine grade Al-Mg alloy presently used as structures in marine and coastal areas. Stir-casting process was used in developing the test materials with Al-3%Mg alloy having 0% SiC$_p$ used as control sample and compared with the performance of the samples containing 5% SiC$_p$, 10% SiC$_p$, 15% SiC$_p$, 20% SiC$_p$ and 25% SiC$_p$ reinforcements respectively. X-ray fluorescence (XRF), Scanning electron microscope (SEM) and energy dispersive x-ray (EDX) analyses of the materials have shown that the materials contain about 2-3% of Mg and also the reinforcement was found to be well distributed in the matrix without any serious flaws or cracks observed. Highest hardness value of 75.4 HRB was obtained on the sample containing 10% SiC$_p$ compared to the control sample with 53.8 HRB. Highest tensile strength of 108 N/mm$^2$ was recorded on sample with 15% SiC$_p$ as compared to the control sample with 93.2 N/mm and highest impact energy of 18.98 J was also obtained on the sample with 15% SiC$_p$ compared to the value of 9.97J as observed on the control sample. The composite materials developed are found to be of better mechanical properties than the marine grade matrix alloy under test condition.

Keywords: Aluminium alloy; Microstructure; Silicon carbide; Metal matrix composites; impact energy

1. INTRODUCTION

When selecting a material of construction for a particular application, that material must have certain physical, mechanical, and corrosion-resistant properties. Although many metals and alloys may be available to meet the criteria of the specific application but the cost involved must also be considered before selection. Development of metal matrix composites (MMCs) originated in the 1950s and early 1960s when engineers realized their good mechanical and physical properties when tested in harsh environments. The principal motivation was to dramatically improve the structural efficiency of metallic materials while retaining the advantages of high chemical inertness, high shear strength, and good property retention at high or low temperature (Zaki et al., 2011). It has been the emphasis of engineers in the field to reduce cost and even lost of lives especially in marine environments and aerospace industries. Apart from the mechanical properties corrosion is one of the major sources of accident which is also dependent on the materials property. It has been estimated that in the petroleum, pipeline and chemical industries, the cost due to corrosion is around $30 billion annually in the United States(US) alone while in developing countries like Nigeria it is assumed to be around $10 billion (SN Stress corrosion cracking tech news, August, 2001; Popoola et al., 2014). Aluminum (Al) has been identified as the second most abundant metal on earth. Unique qualities of
Al and its alloys such as low density, high specific strength, malleability, physical and mechanical properties and corrosion resistance, greatly grew the production and use of this metal and its alloys (Zohoor et al., 2012; Mahindru, and Mahendru, 2011). In material selection process, cost is also an important consideration. Although many alloys may be available to meet the criteria of the application, the cost of these alloys may be prohibitive (Musa, 2012). However, the proper selection of materials, product forms, and processes can have a major impact on the cost of the finished part (Campbell, 2010; Pech-Canul, 2011).

Al based metal matrix composites (AMCs) are of lightweight high performance material systems. Among the several types of Al alloys being used as matrix, Al-Mg series are extensively used in marine applications because of their superior corrosion resistance, excellent formability and good welding characteristics. The addition of reinforcement to aluminum matrix drastically alters mechanical, tribological and corrosion properties (Gaitonde et al., 2012). Al alloy reinforced with silicon carbide (SiC) have become a benchmark because of their improved properties compared to other composite materials in use (Pech-Canul, 2011).

In many cases, the performance of metal matrix composites is superior in terms of improved physical, mechanical, and thermal properties (Adeosun et al., 2009) but innovative thinking to develop new processes is essential for achieving this goal, and so is the work still in progress to gain a more thorough understanding of the available processes, allowing for consistent production of defect-free composites featuring optimized microstructures (Koczak et al., 1993; Wahab et al., 2009). Volume fraction, microstructure, homogeneity and isotropy of the system can also influence the properties of composites and these are strongly related to proportions and properties of the matrix and the reinforcement (Veeresh Kumar et al., 2011). This research work studied the quality and behaviour of the composite materials developed compared to the marine grade alloy and the impact of quantity of the SiCp reinforcement on the matrix alloy.

2. MATERIALS AND METHODS

2.1. Production of Al-3%Mg/SiC Composites

Stir casting process was used in development of the research materials. Al was melted at a temperature of about 660°C and mixed with up to 3% Mg using a stir casting process. The Al-3%Mg alloy was heated up to about 800°C and was allowed to remain above melting point to reduce the surface tension while adding the preheated SiCp for proper wetting of the reinforcement. The composite material was thoroughly mixed with stirrer and then allowed to cool in a mould of desired shape and size. The prepared SiCp was used to produce 5%SiC/Al-3%Mg alloy, 10%SiC/Al-3%Mg alloy, 15%SiC/Al-3%Mg alloy, 20%SiC/Al-3%Mg alloy and 25%SiC/Al-3%Mg alloy composites respectively for the research analysis.

2.2. Characterization of the Composite Material

The materials developed were fully investigated by studying their microstructure and the elemental analysis through the use of X-ray fluorescence (XRF), scanning electron microscope (SEM) and energy dispersive X-ray (EDX) spectra. The microstructure revealed the quality of the materials developed through stir casting process while the elements and impurities present were studied to confirm that the aim of the research conducted is averagely achieved.

2.3. Determination of Mechanical Properties

The samples for the mechanical test were prepared from the control alloy sample Al-3%Mg alloy and the composite samples with 5-25% of SiCp reinforcement according to the machine specifications. The Hardness Value, Impact Strength, Ultimate Tensile Strength (UTS) of the alloy and composites were determined and recorded.

2.3.1 Hardness test

Rockwell hardness testing machine was used to determine the hardness of the materials. The indenters are described as a diamond, a 1.6 mm diameter ball, and a diamond for scales A, B, and C, respectively, where the load applied is either 60, 100, or 150 kg. The hardness scale B was used in this research because the material is Al alloy composite. Minor load or preload of 10 kg was used to obtain the initial indent while 100 kg was used to observe the indent created by the manor load. The final position reached by the indenter after elastic recovery of the materials was also recorded. Measurement taken from difference between preload and major load position determines the hardness of the test samples. The test was conducted in the department of metallurgical
and materials engineering, Ahmadu Bello University (ABU) Zaria.

2.3.2 Impact test
Charpy Hounsfield Balanced Impact Testing Machine was used for this test. The machine is extraordinarily light and compact because, whereas in ordinary impact machines the mass of the anvil and the base should, theoretically, be infinitely great compared with that of the moving tup, in this machine the moving weight is equally divided between two tups moving in opposite directions. The weight at each centre of percussion is 5.44 kg, and as each mass falls through a vertical height of 0.6096 m, the energy stored is 65.1 J and the relative velocity is 6.92 m/s, which is equivalent to that of a weight having fallen from a height of 2.44 m. The samples used for the experiment were notched prior to the test. Considering the impact of these moving tups combined with the short test piece gives a very high angular velocity of bending. The experiment was conducted in the department of Mechanical Engineering ABU Zaria.

2.3.3 Tensile test
Tensile test is a basic and universal engineering test to achieve material parameters such as ultimate tensile strength, yield strength, % elongation, % area of reduction and Young’s modulus. These important parameters obtained from the standard tensile testing are useful for the selection of engineering materials for any applications required. The tensile testing was carried out in the department of mechanical engineering ABU Zaria using a Tensor-Meter developed by Kudale Instrument PVT Limited (K.I.P.L), Pune. Selected load cell for the experiment was 20400 N at a test speed of 25 mm/min. The force was applied during the test and observed the maximum tensile strength and extension of the material before failure. The applied tensile load and extension were recorded during the test for the calculation of stress and strain in the materials.

3. RESULTS AND DISCUSSION

3.1 Results
Table 1 shows the elements present in each of the developed samples as obtained by the XRF analysis. The quantity of Mg present in all the samples were confirmed to be averagely within the scope of work but Si is seen to be even higher than magnesium in the sample containing 15% SiCp.

Figures 1 - 6 below demonstrate the result of the SEM micrographs with the EDX spectra of the developed materials for microstructural investigation. In almost all the samples, the columnar grain structures are clearly seen in the micrographs with higher peaks of Mg observed from the spectra in conformity with the result of the XRF in Table 1.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Mg</th>
<th>Si</th>
<th>Al</th>
<th>Traces</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% SiC</td>
<td>2.55</td>
<td>0.759</td>
<td>95.302</td>
<td>1.3874</td>
</tr>
<tr>
<td>5% SiCp</td>
<td>2.37</td>
<td>1.90</td>
<td>94.859</td>
<td>0.8758</td>
</tr>
<tr>
<td>10% SiC</td>
<td>2.34</td>
<td>2.19</td>
<td>94.859</td>
<td>0.6791</td>
</tr>
<tr>
<td>15% SiC</td>
<td>2.11</td>
<td>5.31</td>
<td>90.860</td>
<td>1.7092</td>
</tr>
<tr>
<td>20% SiC</td>
<td>2.31</td>
<td>1.71</td>
<td>95.071</td>
<td>0.9068</td>
</tr>
<tr>
<td>25% SiC</td>
<td>2.32</td>
<td>1.99</td>
<td>94.756</td>
<td>0.9237</td>
</tr>
</tbody>
</table>
Figure 1: SEM Micrograph with EDX Spectra of Sample with 0% SiCp

Figure 2: SEM Micrograph with EDX Spectra of Sample with 5% SiCp
Figure 3: SEM Micrograph with EDX Spectra of Sample with 10% SiCp

Figure 4: SEM Micrograph with EDX Spectra of Sample with 15% SiCp
Figure 5: SEM Micrograph with EDX Spectra of Sample with 25% SiCp

Figure 6: SEM Micrograph with EDX Spectra of Sample with 25% SiCp
Figures 7 compare the results of the hardness values of the composite materials in comparison to the control alloy matrix. Figures 8 and 9 also compared the results of the tensile strength and the impact energy of the composites in relation to the control samples respectively.

3.2. Discussion of Results
The XRF analyses of the materials presented in Table 1 have shown that the major elements are within the range proposed for the research having the quantity of Mg around 2-3% but high quantity of silicon (Si) was also observed in the composite samples due to the addition of SiC\textsubscript{p} compared to the control samples without any reinforcement. The other traces of element present did not significantly affect the properties of the materials. Analyses of the SEM micrograph of the materials have shown a clear view of the grain arrangements. Evidence of dendritic formation of the alloy matrix coupled with the SiC\textsubscript{p} reinforcement is clearly visible in all the materials developed and also the grains were arranged properly with no serious dislocations observed. EDX spectra of the materials were also presented in Figures 1 to 6 to authenticate the results of the SEM micrographs presented in the same figures. The elements present in the materials are within the scope of the research as proposed and as compared to XRF results. The geometric arrangement of the grains and phases in the material are fairly okay and no visible formation of weak phases or pores discovered which is in line with the findings of Poovazhagan et al., (2013). The result of the hardness values of the materials tested was plotted in Figure 7. The hardness values of the developed composite materials are higher than that of the alloy sample as similarly observed by (Saravan et al., 2015; Venugopal and Manoharan, 2015) and it was also due to the addition of SiC\textsubscript{p} into the microstructure of the alloy. The formation of network of agglomerate phases and closeness of the grains gave the material high values of strength. Highest hardness value of 75.4 HRB was obtained in the sample with 10% SiC\textsubscript{p} as compared to control sample with hardness value of 53.8 HRB which was due to relatively high quantity of Si and Mg and
more composed microstructure as compared to the other developed composites.

The tensile properties of the materials are presented in Figures 8. The tensile strength was higher in the composites because they have fewer pores than the alloy as movement along grain boundaries are more restricted than in the alloy which is in line with the work conducted by Saravanan et al., (2015). Sample with 20% SiCp have the lowest value of tensile strength of 70.0 N/mm² compared to the control sample with 93.2 N/mm² which may be due to some challenges during casting or characterization of the materials but still the highest value of the tensile strength was obtained on sample with 15% SiCp which has a value of 108 N/mm². Generally, the composite materials were found to be stronger with better mechanical properties compared to the control sample with 0% SiCp.

The highest impact energy of 18.98 J was obtained in sample with 15% SiCp which is favourably better compared to the value of 9.97J as observed on the control alloy sample as presented in Figure 9. It is believed to be due to high quantity of Si as well as the Mg and no visible flaws or cracks were observed in the microstructure.

The mechanical properties tested have clearly shown that the reinforced alloy performed favourably well compared to the control sample. Most of the literatures surveyed have also shown that the composite materials are relatively better in terms of mechanical properties and majority of the result discovered were in agreement with the research conducted by many engineers including the work by Bodunrin et al., (2015) and Ravindran et al., (2013).

4. CONCLUSION

The research was able to prove that Al-3%Mg alloy and its composites reinforced with SiCp (5-25%) could be developed through stir casting process which is readily available and cost effective. The materials were also physically and chemically tested and confirmed to be within the scope of the research. The XRF result showed that the quantity of Mg is within 2-3%. SEM/EDX analysis indicated a fair distribution of the SiCp in the matrix with few agglomeration of the SiCp in some of the samples. Evidence of dendritic formation of the alloy matrix coupled with the SiCp reinforcement is clearly visible in all the materials studied.

According to the mechanical properties tested, the composite materials were averagely considered better compared to the marine grade alloy used as control sample. It was finally concluded that increase in percentage of SiCp improves the mechanical properties and microstructure of the composite material under the test condition and procedures followed in the research.

REFERENCES


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