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Chapter

Conversion of Environmental Waste to Engineering Wealth: Eggshell Particulates as a Reinforcement Agent in Al-6063

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Abstract

In the quest to improve on some properties of aluminum alloy for better engineering application, eggshell particulate was used to reinforce the alloy at various percentages in this research. The reinforcement was carried out at a superheated temperature of 700°C in order to have homogenous mixture prior to casting. Micro hardness, impact and microstructure were evaluated. It was observed that eggshell particulates has positive impact on the mechanical properties of aluminum with sample X₂ reinforced with 4% eggshell particulate possessing the highest hardness value of 187.1 Hv in comparison with the control sample X₀ showing the least value of 100.7 Hv. The impact result complemented the hardness results with samples X₁ and X₂ reinforced with 2% and 4% respectively of eggshell particulates exhibiting the highest impact value of 4.7 J each. This thus indicates that eggshell particulate can be considered as an alternative reinforcing agent in improving the mechanical properties of aluminum 6063. The particulate however dampens the corrosion resistance of Al6063 to deterioration in saline environment with the control sample X₀ showing the least corrosion rate (0.15711 mpy), corrosion density (−0.01221 A/cm²) and the highest corrosion potential (0.99186 V). Thus, indicating that the material is not recommended for use in such environment. However, more percentage of the particulates is recommended in order to affirm the optimum ratio to which Al6063 would yield better properties.

Keywords: particulates, Al-6063, micro hardness, corrosion, mechanical properties

1. Introduction

The demand for light weight and cost-effective engineering materials with high strength most especially in automobile, aerospace and structural applications to enhance performance are on the increase. Interestingly, aluminum and its alloy with matching characteristics of light weight, low cost, good thermal and electrical properties desirable in various engineering applications had stimulated research interest. These good properties as well as the recyclability of aluminum had made it a promising candidate for engineering application. Recently, it is used in all sector of human
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endeavor today which is not limited to just structural and automobile applications but also in cooking utensils household furniture, electrical industries, etc., are making use of aluminum either pure or its alloyed form. However, the global increasing demand for light weight material with enhanced mechanical properties over the conventional alloys in the emerging industrial applications and requirement has recently fueled the curiosity of researchers on advanced engineering material (metal matrix composites) developments [1].

Reinforcing a metal matrix phase resulted in metal matrix composite with processing techniques serving as major hub for tailoring the resulting properties into the desired application. Reinforcement material can simply be regarded as strength enhancer or bad carrying member in MMCs. It is usually a non-metallic in nature including ceramic, egg shell waste, agro and bid shell waste [2, 3].

Reinforcement material can simply be regarded as strength enhancer or bad carrying member in MMCs. It is usually a non-metallic in nature including ceramic, egg shell waste, agro and bid shell waste. Metal Matrix Composite (MMCs) was dated back two decades ago. This was to improve physical, mechanical properties and weight serving advantages associated with matrix composite compared to unreinforced alloy [4, 5].

Various viable industrial and agro waste that has been investigated in aluminum alloy matrix include agricultural (rice husk, bamboo leaves, eggshell, animal bone, coconut shell, etc.) waste and industrial (quarry dust) waste material. His investigation shows that agro and industrial waste can be used as aluminum matrix reinforcement material due to their promising properties enhancement [6, 7].

There are various available processing routes for processing of MMCs includes squeeze casting, infiltration powder metallurgy and stir casting technique. However, stir casting process has widely been reported to be most viable and economical route for particle reinforced metal matrix composite (PMMCs) processing and production [8, 9].

Egg shell is an agro-based waste product (after consumption) that is readily available in any society; and its major constituent is calcium carbonate which makes it useful as reinforcement for aluminum 6063. In view of areas of application of aluminum alloys, this research becomes imperative to improve the performance of the material.

2. Experimental procedure

Aluminum alloy 6063 with known chemistry (Table 1) was used as base material and eggshell powder used as the reinforcing agent.

The eggshell was sourced from the local tea vendor in Okene, Nigeria. The collected eggshells were rinsed and cleaned thoroughly with fresh water to remove the accompanied dirty and the inner membrane of the shell. It was then dried in sunlight for 7 days to completely remove the moisture. Grinding and pulverization was then carried out to convert the eggshell into powder, this is essential to increase the surface

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Mg</th>
<th>Cu</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Zn</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>89.22</td>
<td>8.36</td>
<td>0.76</td>
<td>0.14</td>
<td>1.19</td>
<td>0.20</td>
<td>0.01</td>
<td>0.05</td>
<td>0.32</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of Al-Mg-Si alloy.
area of the particulate for effective interaction in due course of melt mixture. The pulverized powder was later fed into the set of vibratory sieve shaker arranged in decreasing order of mesh sizes. This classification yielded a very fine particulate, using 70 mesh size to produce, a particle size equivalent to 0.000212 μm (Table 2).

2.1 Preparation of the casting process

In the preparation of the casting process, charcoal, crucible pots and molding sand was sourced. This process involves the use of molten material usually metal poured into a mould cavity that takes the form of the finished parts. The mold material then cools with heat generally being extracted via the mold, until it solidifies into the desired shape.

A plastic pattern of cylindrical shape diameter of 6 mm and length of 30 mm was used. Adequate shrinkage allowance was provided. Silica sand was gotten and mixed manually with bentonite (as a binder) and water to ensure mouldability.

2.2 Specimen preparation and analysis procedure

The furnace was charged and fired to a superheated temperature of about 700°C. While waiting for the furnace to increase in temperature the eggshell was being weighed on the weighing balance in grams gotten from the charge calculation representing 2%, 4% and 6%. The Al-6063 alloy was charged into the crucible pot and placed in the furnace. The alloy turned liquidus at a temperature of 660°C but was left to super heat so as not to turn solidify upon removal. 2% eggshell particulate, as weighed, was added to the melt and stirred for about 60 s and the combined charge was left to stay in the furnace for about 10–15 min before it was removed and poured inside the mould for solidification. This process was repeated for 4% and 6% eggshell particulates. A control sample was also cast without reinforcement.

The first casting was labeled X₀ representing Al-6063 without reinforcement. This serves as the control sample; X₁ representing 2% of eggshell particulate; X₂ representing 4% of eggshell particulate; and sample labeled X₃ representing 6% of eggshell particulate (Table 3).

The hardness of the sample was evaluated using vicker’s micro hardness testing machine to determine its ability to resist indentation when subjected to load of 300 g
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for a dwell time of 10 s using standard procedure (ASTM E-384-17). As a complement, Impact testing of metals was performed to determine the toughness of both reinforced and unreinforced Al-6063 by calculating the amount of energy absorbed during fracture (ASTM A-370).

The surface of the developed composite was examined using a scanning electron microscope (SEM). The scanning electron microscope uses a focused beam of high energy electron to penetrate a variety of signals at the surface solid specimen. The signal that is derived from the electron sample interactions was reveal the information about the sample including the external morphology, texture, chemical composition, crystalline structure and the orientation of the material that makes up the samples.

3. Results and discussion

3.1 Effect of eggshell particulate on the hardness

Figure 1 shows the average hardness plot of the hardness of reinforced Al6063 with eggshell. Micro hardness testing machine was used to evaluate this property. In the course of conducting the test, a test load of 4.904 N was used over a dwell time of 10 s. Three indentations were made on each sample and the average calculated and documented. From the result, it was observed that there was a general increment in the hardness values of the reinforced samples. While there were gradual but rapid increase in the hardness value to the peak in sample X$_2$ reinforced with 4% eggshell particulates, a drop was observed in the X$_3$ sample (reinforced with 6% eggshell particulates). Generally, the reference sample was observed to display the least hardness value and the reinforced sample indicates that eggshell particulates are of much importance to Al alloy for better engineering performance where high strength is required. The excel model shows that the optimum hardness value of the composite can be attained at about 4.6% eggshell particulate reinforcement with a rank correlation coefficient of 1.

3.2 Effect of eggshell particulate on the impact energy

Like the hardness experiment, impact test was conducted at a room temperature of 25°C. The experiment was necessary in order to evaluate the toughness or the amount of energy the reinforced samples can absorbed prior to failure. From the result in Figure 2, it was observed that samples X$_1$ and X$_2$ reinforced with 2% and 4% of eggshell particulates exhibited the highest impact value with a sharp drop in sample X$_3$.

<table>
<thead>
<tr>
<th>Label</th>
<th>Weight of materials (kg)</th>
<th>% weight of particulate</th>
<th>Equivalent weight of particulate (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X$_0$</td>
<td>2.26</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>X$_1$</td>
<td>2.26</td>
<td>2</td>
<td>45.2</td>
</tr>
<tr>
<td>X$_2$</td>
<td>2.26</td>
<td>4</td>
<td>90.4</td>
</tr>
<tr>
<td>X$_3$</td>
<td>2.26</td>
<td>6</td>
<td>135.6</td>
</tr>
</tbody>
</table>

Table 3. Particulate mixture in Al-6063.
reinforced with 6%. This thus implies that Sample X₁ and X₂ displays a positive effect of the particulates and can be useful in a vibratory environment within the scope of other properties considered.

3.3 Effects of eggshell on the microstructure

Figure 3(a–d) shows the micro view of the structure of the aluminum alloy (both reinforced and as-cast). The image was captured at high resolution of 1000×, the resolution was ensured to be consistent in order to juxtapose the multi-images. From the displays, it shows that there was a metal flow in the sample X₀ reinforced (without reinforcement), the flow could be due to the absence of hardness enhancer. This limitation is taken care of in the reinforced sample (X₁, X₂ and X₃) which shows a display
of the eggshell particulates precipitates distributed round the structure of the material. This precipitates account for the significantly improved mechanical properties of the reinforced alloy under consideration. Also, the uniformly distributed particulate in the structure shows that there was thorough stirring, thus homogeneity, of the melt prior to casting.

3.4 Effects of eggshell particulates on the corrosion behavior

Machine designed to operate in marine environment are generally vulnerable to failure by corrosion. It is therefore imperative that the corrosion susceptibility of the materials used for such facility be investigated to establish the mechanism for its mitigation. The unreinforced and reinforced samples were subjected to potentiodynamic electrochemical measurement technique in accordance to ASTM G34 standard to determine its behavior in simulated saline environment.

Figure 4(a–c) show the extracted parameters from the linear polarization plots, results shows that the reinforced alloy generally displayed similar polarization curves and passivity characteristics. It was observed that in spite of the recorded improvement in the mechanical properties, the entire reinforced sample exhibited poor corrosion resistance in saline environment. The as-cast sample (without reinforcement)
has the lowest corrosion rate of 0.15711 mpy compare with those reinforced with 2.0 wt.% eggshell (0.85262 mpy), 4.0 wt. % eggshell (3.4385 mpy), and 6 wt.% eggshell particulate (1.6528 mpy). Correspondingly, the unreinforced sample has the
least corrosion current density of $-0.01221 \times 10^{-5}$ A/cm$^2$ and the highest corrosion potential of 0.99186 V compared with the reinforced sample exhibiting high current densities and potentials. From the above corrosion parameters obtained from the electrochemical test, it was discovered that the unreinforced Al6063 has the best corrosion resistance hence it has the least corrosion current density, lowest corrosion rate and the highest corrosion potential.

4. Conclusion

The mechanical properties of Al-6063 have been enhanced in this research owing to the adoption of eggshell particulates as reinforcing agent. The reinforcement was carried out at varied percentages and at a superheated temperature of 700°C in order to ensure homogeneity in the mixture prior to casting. Micro hardness, impact and the microstructural characterization were carried out under varied condition. From the results, it was observed that eggshell particulates have positive impact on the mechanical properties of Aluminum under consideration. While a significant rise in the hardness value was observed, the gradual increment in the impact result complement the hardness results. This thus indicates that eggshell, which ordinarily is considered a dangerous agro-waste, can be considered as an alternative reinforcing agent in improving the mechanical properties of Aluminum 6063. The particulate however dampens the corrosion resistance of Al6063 to deterioration in saline environment, indicating that the material is not recommended for use in such environment.
References


