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Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite

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ABSTRACT

The microstructural characteristics, mechanical and wear behaviour of Aluminium matrix hybrid composites reinforced with alumina, rice husk ash (RHA) and graphite were investigated. Alumina, RHA and graphite mixed in varied weight ratios were utilized to prepare 10 wt% hybrid reinforced Al-Mg-Si alloy based composites using two-step stir casting. Hardness, tensile properties, scanning electron microscopy, and wear tests were used to characterize the composites produced. The results show that Hardness decreases with increase in the weight ratio of RHA and graphite in the composites; and with RHA content greater than 50%, the effect of graphite on the hardness becomes less significant. The tensile strength for the composites containing o.5wt% graphite and up to 50% RHA was observed to be higher than that of the composites without graphite. The toughness values for the composites containing 0.5wt% graphite were in all cases higher than that of the composites without graphite. The % Elongation for all composites produced was within the range of 10–13% and the values were invariant to the RHA and graphite content. The tensile fracture surface morphology in all the composites produced was identical characterized with the presence of reinforcing particles housed in ductile dimples. The composites without graphite exhibited greater wear susceptibility in comparison to the composite grades containing graphite. However the wear resistance decreased with increase in the graphite content from 0.5 to 1.5 wt%.

1. Introduction

The development of Aluminium matrix composites (AMCs) reinforced with agro and industrial waste derivatives have gathered a lot of interest in recent years [1,2]. These grades of composites offer the benefits of significant processing cost reduction, satisfactory physical properties (such as low density and thermal coefficient of thermal expansion); and useful in thermal management, semi-structural and mild stress-bearing applications [3]. In service applications where high strength and wear resistance are of prime importance, these grades of AMCs have been found to have fairly limited use. This is primarily due to the relatively lower strength and wear characteristics of the agro and industrial waste derivatives used as reinforcements in comparison with conventional reinforcement materials like silicon carbide and alumina [4]. In order to harness the low cost and physical property benefits offered by these waste derived reinforcing materials, there are current efforts to complement them with conventional synthetic reinforcing materials such as silicon carbide and alumina. The use of these so called hybrid reinforced composites has been well received and continues to attract interest from researchers [5,6]. Improvements in toughness, ductility, corrosion resistance and competing specific strength levels at par with that of single conventional reinforced AMCs have been reported [6]. Literatures are currently available for hybrid composites systems reinforced with combinations of silicon carbide/rice husk ash, alumina/rice husk ash, silicon carbide/bamboo leave ash, silicon carbide/groundnut shell ash, alumina/ groundnut shell ash, silicon carbide/ fly ash, alumina/fly ash, alumina/ red mud, silicon carbide/ graphite, alumina/graphite, silicon carbide/corn cub among others [2–4,7]. The performance levels derived from these hybrid composite

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systems have been reported to be dependent on the type of reinforcements combined, the weight ratio of both reinforcing materials in the composite, wettability between the reinforcements and the matrix, processing route selected, and the metallurgical characteristics of the matrix material [8]. In the case of alumina and rice husk ash hybrid reinforced AMC promising levels of ductility and fracture toughness comparable to that of single alumina reinforced composites were observed [9]. However, findings on potential improvements in strength characteristics and wear performance are still inconclusive and worthwhile subject for further investigations. In the present study, the use of graphite as a reinforcing addition to alumina and rice husk ash for development of AMCs was investigated. Graphite is a well recognized solid lubricant which also has the advantage of low density [10]. In graphite reinforced AMCs, graphite serves as a solid lubricating layer between the composite and rubbing surface helping in reduction of composite wear without the need for traditional solid and liquid lubrication [11]. Graphite has also been used as hybrid reinforcement with alumina and silicon carbide in AMCs with property improvements in strength and wear properties recorded [12] but its use as part of a trident hybrid reinforcing system for AMCs has not been reported in literature. The effects of varied weight ratios of the three reinforcing materials namely, alumina, rice husk ash, and graphite on the microstructure, mechanical and wear behaviour of Al-Mg-Si alloy matrix was the subject of this investigation.

2. Materials and method

2.1. Materials

Al-Mg-Si alloy (AA 6063) with chemical composition presented in Table 1 was selected as matrix for the composite production. Alumina of average particle size of 30 μm, rice husk ash and graphite with particle sizes (<50 μm) were selected as reinforcing materials. The rice husk was sourced locally from a rice processing plant located at Igbemu Ekiti, Ekiti State, Nigeria. The rice husk ash was obtained by burning the rice husks completely in an incinerator, heat-treating in a furnace, and then sieving following procedures explained in details by Alaneme et al. [4]. The chemical composition of the rice husk is presented in Table 2.

2.2. Composites production

Liquid metallurgy route using two step stir casting process was adopted for the production of the composites. The process commenced with the determination of the quantities of rice husk ash (RHA), alumina and graphite required to produce 10wt% particle reinforced composites having weight ratios of the reinforcing materials as presented in Table 3. The rice husk ash, graphite and alumina particles were initially preheated separately at a temperature of 250 °C to eliminate dampness and improve wettability with the molten Al-Mg-Si alloy [13]. The Al-Mg-Si alloy were charged in gas-fired crucible furnace (fitted with a temperature probe), and heated to a temperature of 720 °C ± 30 °C (above the liquidus temperature of the alloy) to ensure the alloy melts completely. The liquid alloy was cooled in the furnace to a semi solid state at a temperature of about 600 °C. The preheated rice husk ash, graphite and alumina particles were charged into the semi-solid melt at this temperature (600 °C) and stirred manually for 10 min. The semi-solid composite mixture was super heated to 780 °C ± 30 °C and stirred using an automated mechanical stirrer. The mechanical stirring was performed at 400 rpm for 10 min before casting into sand moulds inserted with metallic chills. Representative sizes of as-cast composites produced from the two step stir casting process are presented in Fig. 1.

Table 1
Elemental composition of Al-Mg-Si alloy.

Element	wt%
Magnesium (Mg)	0.48
Silicon (Si)	0.52
Manganese (Mn)	0.073
Copper (Cu)	0.068
Zinc (Zn)	0.11
Titanium (Ti)	0.015
Iron (Fe)	0.058
Sodium (Na)	0.003
Aluminium (Al)	balance

Table 2
Chemical composition of the rice husk ash.

Compound/element (constituent)	wt%
Silica (SiO_2)	91.56
Carbon	4.8
Calcium oxide, CaO	1.58
Magnesium oxide, MgO	0.53
Potassium oxide, K_2O	0.39
Hematite, Fe_2O_3	0.21
Others	0.93

2.3. Mechanical properties

The hardness values of the composites were evaluated on a hardness testing machine using the Vickers hardness scale. The sample preparation and testing procedure was performed in accordance with ASTM E-92 standard [14]. Seven hardness indents were made on each specimen and readings within the margin of ±2% were taken for the computation of the average hardness values of the specimens.

The tensile properties of the composites produced were evaluated by tensile testing using an Instron universal testing machine. Specimens for the test were machined from the as-cast composite cylindrical rods of 15 mm diameter and 15 cm length to tensile test specifications of 5 mm diameter and 30 mm gauge length. The

Table 3
Sample designation and reinforcement weight ratio.

Sample designation	Composition of reinforcing materials
A0	(100%Al_2O_3 + 0%RHA+ 0% graphite)
A1	(99.5%Al_2O_3 + 0%RHA+ 0.5% graphite)
A2	(99%Al_2O_3 + 0%RHA+ 1.0% graphite)
A3	(98.5%Al_2O_3 + 0%RHA+ 1.5% graphite)
B0	(75%Al_2O_3 + 25%RHA + 0% graphite)
B1	(74.5%Al_2O_3 + 25%RHA + 0.5% graphite)
B2	(74%Al_2O_3 + 25%RHA + 1.0% graphite)
B3	(73.5%Al_2O_3 + 25%RHA + 1.5% graphite)
C0	(50%Al_2O_3 + 50%RHA + 0% graphite)
C1	(49.5%Al_2O_3 + 50%RHA + 0.5% graphite)
C2	(49%Al_2O_3 + 50%RHA + 1.0% graphite)
C3	(48.5%Al_2O_3 + 50%RHA + 1.5% graphite)
D0	(25%Al_2O_3 + 75%RHA + 0% graphite)
D1	(24.5%Al_2O_3 + 75%RHA + 0.5% graphite)
D2	(24%Al_2O_3 + 75%RHA + 1.0% graphite)
D3	(23.5%Al_2O_3 + 75%RHA + 1.5% graphite)
E0	(0%Al_2O_3 + 100%RHA + 0% graphite)
E1	(0%Al_2O_3 + 99.5%RHA + 0.5% graphite)
E2	(0%Al_2O_3 + 99%RHA + 1.0% graphite)
E3	(0%Al_2O_3 + 98.5%RHA + 1.5% graphite)