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Microstructure, mechanical and fracture properties of groundnut shell ash and silicon carbide dispersion strengthened aluminium matrix composites

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Abstract The mechanical properties of aluminium hybrid composites reinforced with groundnut shell ash (GSA) and silicon carbide was investigated. GSA and silicon carbide with different mix ratios (10:0, 7.5:2.5, 5.0:5.0, 2.5:7.5 and 0:10) constituted 6 and 10 wt.% of the reinforcing phase, while the matrix material was Al–Mg–Si alloy. The hybrid composites were produced via a two-step stir casting technique. Microstructural examination, hardness, tensile and fracture toughness testing were carried out to appraise the mechanical properties of the composites. The results show that with increasing GSA in the reinforcing phase, the hardness, ultimate tensile strength (UTS) and specific strength of the composites decreased slightly for both 6 and 10 wt.% reinforced Al–Mg–Si based composites owing to the amount of the oxides of Al, Si, Ca, K_2 and Mg present in the composition of GSA. However, the percentage elongation improved marginally and was generally invariant to increasing GSA content while the fracture toughness increased with increasing GSA content. GSA offered a favourable influence on the mechanical properties of Al–Mg–Si hybrid composites comparable to that of rice husk ash and bamboo leaf ash.

1. Introduction

Materials with good strength to weight ratio are becoming very essential in modern engineering designs especially for automotive and aerospace applications where improved machine efficiency and reduced fuel consumption are critical requirements to be satisfied. Also, modern infrastructures, equipment and machineries that are currently developed require materials that have a good combination of properties to match service demands. Aluminium matrix composites

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(AMCs) represent a class of materials that offer a wide range of properties that can measure up with the design requirements of some of the aforementioned applications (Surappa, 2003). AMCs are primarily reinforced with fibres or particulates which are usually ceramic materials (SiC, Al_2O_3, WC, B_4C, TiO_2, BN). They can be produced via solid route processing (such as powder metallurgy) and liquid metallurgy processing routes (rheocasting, compocasting, liquid infiltration, stir casting are a few examples) (Shabani et al., 2012; Kala et al., 2014). Without disregard to the technical competence of other processing routes available, stir-casting remains the most utilised technique due to its simplicity, flexibility, low cost acquiescence and commercial viability (Kala et al., 2014). Over the years, single reinforced composites have been mostly developed for use in several applications but have been observed to have some material property and cost related limitations (Dharmalingam et al., 2010). Efforts to optimise the performance of single reinforced MMCs and also to reduce the processing cost have paved way for the development of hybrid reinforced AMCs (Dharmalingam et al., 2010; Alaneme et al., 2014a).

In recent times, hybrid reinforced AMCs have attracted the interest of researchers and different design concepts have been adopted to select the appropriate combination of reinforcing materials (Alaneme et al., 2014b; Pandi and Muthusamy, 2012; Alaneme and Ajayi, 2015; Bodunrin et al., 2015). The combination of reinforcing materials has been noted to have an influence on the properties and processing cost of the composites. For example Iqbal et al. (2014), in their studies on the fatigue crack growth mechanism in cast aluminium hybrid composites reinforced with silicon carbide and alumina observed superior crack growth resistance in the lower stress intensity factor range for the composites containing both silicon carbide and alumina in comparison with aluminium matrix composite containing alumina alone. Siddesh Kumar et al. (2014), obtained superior wear resistance in MoS_2 and B_4C hybrid reinforced aluminium composites as compared to the single reinforced aluminium/B_4C composite. Montalba et al. (2015) reported that an increase in piezoelectric lead lanthanum zirconate titanate (PLZT) led to an improvement in the damping properties of aluminium based hybrid composites containing silicon carbide (SiC) and PZLT. Several other reports on property optimisation in metal matrix composites (MMC) using hybrid reinforcements are available in the literature (Dolata et al., 2012; Lei et al., 2014; Poovazhagan et al., 2013; Prasad et al., 2014). It can be noted from the above cited literature that synthetic reinforcements which are known to be relatively expensive and not readily available in most developing countries were used. Notwithstanding the attainment of improved properties in the respective cases, the problem of high processing cost was not addressed.

Alaneme et al. (2013a), Prasad (2006) and Escalera-Lozano et al. (2007) are among researchers that have considered the development of less expensive AMCs by using industrial and agro waste derivatives as reinforcing materials in hybrid reinforced AMCs. This class of AMCs is referred to as low-cost high performance composites since the incorporation of these reinforcing materials did not only reduce the cost of the composites but in most cases had a positive effect on the performance of the composites provided the mix ratio is monitored (Alaneme et al., 2014a). Among the most investigated industrial and agro waste derivatives that have been used as reinforcing materials in AMCs include coal fly ash (FA), red-mud, rice husk ash (RHA), bamboo leaf ash (BLA) and bagasse ash (Bahrami et al., 2015; Lancaster et al., 2013; Loh et al., 2013; David Raja Selvam et al., 2013; Soltani et al., 2015). These reinforcing materials (BLA-0.36 g/cm^3 and RHA-0.31 g/cm^3) usually have lower densities than the synthetic reinforcing materials (silicon carbide-3.18 g/cm^3 and alumina-3.96 g/cm^3). They are also readily available as wastes and from chemical analysis observed to contain refractory oxides such as aluminium oxide, iron oxides and silicon oxides that make them attractive as reinforcing materials. GSA obtained from combustion of groundnut shell is another agro waste derivative that should be considered as potential reinforcing material in composite development. Although, articles published on the use of GSA as reinforcement in aluminium matrix composites are sparse, there are strong reasons for its advocacy. Firstly, nominal chemical compositions of GSA from the literature show a high alumina and silica content which are known to function as reinforcing materials (Alaneme et al., 2015). Unlike the other agro waste derivatives (RHA and BLA) that have been investigated in the past, the silica content in GSA is slightly lower while the alumina content is higher when compared to RHA and BLA. Secondly, Nigeria is one of the largest producers of groundnut in the world producing, 2,962,760 tons after China (16,114,231 tons) and India (6,933,000 tons) in 2011 (Ibrahim et al., 2013). There is current effort to increase production capacity by additional 120,000 metric tons in the next few years. This implies that groundnut shells will contribute significantly to the solid waste in the country. Ground nut shell can potentially be processed for use as reinforcing material in AMCs, thus contributing to reduction in current environmental waste management challenges.

In this research work, we considered the use of groundnut shell ash (GSA) and silicon carbide as hybrid reinforcements in the development of Al–Mg–Si based composites. The microstructural features, density measurements and mechanical properties were investigated to ascertain the viability of using GSA as a reinforcing material in the development of aluminium matrix composites.

2. Materials and methods

2.1. Materials

Al–Mg–Si alloy billets with chemical composition: Al (98.71 wt.%), Si (0.45 wt.%), Fe(0.22 wt.%), Cu(0.02 wt.%), Mn (0.03 wt.%), Mg (0.50 wt.%), Cr (0.03 wt.%), Zn (0.02 wt.%), and Ti (0.02 wt.%); determined using spark spectrometric analysis, was selected as aluminium matrix for this investigation. Silicon carbide (SiC) and groundnut shell ash (GSA) were selected as reinforcing materials for the development of the hybrid composites. The silicon carbide procured was of high chemical purity with average particle size of 28 μm while groundnut shell was obtained from the dump site of an open market within Akure metropolis. The groundnut shell was processed by burning to obtain groundnut shell ash following procedures explained in detail by Alaneme et al. (2015). Briefly, dried groundnut shell was placed in a metallic drum and burnt in open air. The ash was collected after 24 h and then subjected to conditioning in a muffle furnace at a

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