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RESEARCH

# Influence of Rice Husk Ash – Silicon Carbide Weight Ratios on the Mechanical behaviour of Al-Mg-Si Alloy Matrix Hybrid Composites

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A B S T R A C T

*The influence of rice husk ash (RHA) and silicon carbide (SiC) weight ratio on the mechanical behaviour of Al-Mg-Si alloy matrix hybrid composites was investigated. RHA and SiC mixed in weight ratios 0:1, 1:3, 1:1, 3:1, and 1:0 were utilized to prepare 5, 7.5 and 10 wt% of the reinforcing phase with Al-Mg-Si alloy as matrix using two-step stir casting method. Density measurement, estimated percent porosity, tensile properties, fracture toughness, and SEM examination were used to characterize the composites produced. The results show that the composites were of good casting quality as the estimated porosity values were less than 2.5 % in all grades produced. For the three weight percent worked on, the tensile-, yield-, and specific strength decreases with increase in the weight proportion of RHA in the RHA-SiC reinforcement. However, the results show that the composites with composition of 1:3 weight ratio RHA:SiC (25% RHA: 75% SiC) offers comparable specific strength values with the single SiC reinforced Al composite grades. The strain to fractures was invariant to the weight ratio of RHA/SiC for all weight percent but the composite compositions containing RHA had improved fracture toughness compared with the single SiC reinforced Al composite grades.*



## 1. INTRODUCTION

Alternative sources of reinforcements that offer the potential of producing Aluminium matrix composites (AMCs) at reduced cost while maintaining high performance levels is attracting interests from researchers [1-2]. Compared to other engineering materials, AMCs are noted for the rare combination of properties they offer such as high specific strength and stiffness, good wear and corrosion resistance, low thermal coefficient of expansion, good high temperature mechanical properties, and excellent thermal management potentials among others [3-5]. Aluminium based matrices also have the advantage that they are the cheapest among other competing matrix materials (Copper, Titanium, Magnesium) for metal matrix composites (MMCs) development; and also are amenable to processing using techniques conventionally suited for the production of metals and alloys [6-7].

The unique properties of AMCs are derived from the material characteristics of both the matrix and the reinforcing phases [8]. The reinforcements are responsible for the improved mechanical, wear, and high temperature properties of the AMCs [9-10]. Thus the type of reinforcement and reinforcement parameters such as size, volume fraction, distribution, shape, and orientation often affect significantly the properties of AMCs [11]. The use of cheaper source of reinforcements such as industrial wastes (fly ash, red mud) [12-13] and agro wastes (rice husk ash, bamboo leaf ash, coconut shell ash) [14-15] for AMCs development is gaining popularity considering its advantage in solid waste recycling which has been a cause for major concern over the years. Additional to the advantages of low cost, availability in large quantities, and contributions to creation of a more eco-friendly environment; is lower densities which most of the agro and industrial wastes possess in comparison with the synthetic reinforcements such as silicon carbide (SiC) and alumina ($Al_2O_3$) [16]. The properties achieved with the sole utilization of these cheaper source reinforcements have been reported to be lower than that of the synthetic reinforced but with promise for use in semi-structural and thermal management applications [17]. The use of hybrid reinforcements utilizing SiC/$Al_2O_3$ and agro waste ashes as a means of improving the properties of AMCs has attracted interest recently with very encouraging results obtained [18-19].

The present work is aimed at investigating the influence of the weight ratios of rice husk ash and silicon carbide on the mechanical behaviour Aluminium matrix hybrid composites having varied weight percent of both reinforcements. The motivation for this work is to establish optimum RHA/SiC weight ratios required to achieve optimized performance of low cost AMCs developed with the use of rice husk. Literatures on the use of synthetic/agrowaste hybrid reinforcements for AMCs development are still very limited and there is currently none that the authors are aware of that discusses the use of RHA and SiC as hybrid composites in Al-Mg-Si alloy matrix.

## 2. MATERIALS AND METHOD

### 2.1 Materials

Al-Mg-Si alloy billets with chemical composition determined using spark spectrometric analysis (Table 1) was selected as Aluminium matrix for this investigation. For the hybrid reinforcing phases, silicon carbide (SiC) and rice husk ash (RHA) were selected. The silicon carbide procured was of high chemical purity with average particle size of 28 μm while rice husks utilized for the processing of rice husk ash was obtained from Igbemo-Ekiti, Ekiti State (a rice producing community in south western Nigeria). Magnesium for improving wettability between the Al-Mg-Si alloy and the reinforcements was also procured.

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

| Element | wt% |
|---|---|
| Si | 0.4002 |
| Fe | 0.2201 |
| Cu | 0.008 |
| Mn | 0.0109 |
| Mg | 0.3961 |
| Cr | 0.0302 |
| Zn | 0.0202 |
| Ti | 0.0125 |
| Ni | 0.0101 |
| Sn | 0.0021 |
| Pb | 0.0011 |
| Ca | 0.0015 |
| Cd | 0.0003 |
| Na | 0.0009 |
| V | 0.0027 |
| Al | 98.88 |

### 2.2 Preparation of Rice Husk Ash

The procedure adopted is in accordance with Alaneme et al [16]. It involves the use of a simple metallic drum with perforations as burner for the rice husk. Dry rice husks placed inside the drum was ignited with the use of charcoal. The husk was allowed to burn completely and the ashes removed 24 hours later. The ash was then heat-treated at a temperature of 650 $^oC$ for 180 minutes to reduce its carbonaceous and volatile constituents. Sieving of the bamboo leaf ash was then performed using a sieve shaker to obtain ashes with mesh size under 50 μm. The chemical composition of the rice husk ash from this process is presented in Table 2.

**Table 2.** Chemical Composition of the Rice Husk Ash.

| Compound/Element (constituent) | wt% |
|---|---|
| Silica ($SiO_2$) | 91.59 |
| Carbon, C | 4.8 |
| Calcium oxide CaO | 1.58 |
| Magnesium oxide, MgO | 0.53 |
| Potassium oxide, $K_2O$ | 0.39 |
| Haematite, $Fe_2O_3$ | 0.21 |
| Sodium, Na | trace |
| Titanium oxide, $TiO_2$ | 0.20 |

## 2.3 Composites Production

Two step stir casting process was utilized to produce the composites [20]. The process started with the determination of the quantities of rice husk ash (RHA) and silicon carbide (SiC) required to produce 5, 7.5, and 10 wt% reinforcement consisting of RHA and SiC in weight ratios 0:1, 1:3, 1:1, 3:1, and 1:0 respectively (which amounts to 0, 25, 50, 75, and 100 % RHA in the reinforcement phase). The rice husk ash and silicon carbide particles were initially preheated separately at a temperature of 250 °C to eliminate dampness and improve wettability with the molten Al-Mg-Si alloy. The Al-Mg-Si alloy billets were charged into a gas-fired crucible furnace (fitted with a temperature probe), and heated to a temperature of 750 °C ± 30 °C (above the liquidus temperature of the alloy) to ensure the alloy melts completely. The liquid alloy was then cooled in the furnace to a semi solid state at a temperature of about 600 °C.

**Table 3.** Composite Density and Estimated Percent Porosity.

| Sample Designation | Composition RHA: SiC | Theoretical density (g/cm³) | Experimental density (g/cm³) | % Porosity |
|---|---|---|---|---|
| A0 | 0 wt% | 2.700 | 2.655 | 1.67 |
| | 5wt% | | | |
| B1 | A (0:1) | 2.721 | 2.700 | 0.77 |
| B2 | B (1:3) | 2.691 | 2.650 | 1.52 |
| B3 | C (1:1) | 2.660 | 2.640 | 0.75 |
| B4 | D (3:1) | 2.630 | 2.590 | 1.52 |
| B5 | E (1:0) | 2.599 | 2.579 | 0.77 |
| | 7.5 wt% | | | |
| C1 | A (0:1) | 2.733 | 2.670 | 2.31 |
| C2 | B (1:3) | 2.689 | 2.640 | 1.82 |
| C3 | C (1:1) | 2.640 | 2.590 | 1.89 |
| C4 | D (3:1) | 2.595 | 2.570 | 0.96 |
| C5 | E (1:0) | 2.550 | 2.510 | 1.57 |
| | 10 wt% | | | |
| D1 | A (0:1) | 2.743 | 2.690 | 1.9 |
| D2 | B (1:3) | 2.680 | 2.650 | 1.11 |
| D3 | C (1:1) | 2.620 | 2.610 | 0.3 |
| D4 | D (3:1) | 2.560 | 2.50 | 2.34 |
| D5 | E (1:0) | 2.500 | 2.497 | 0.12 |

The preheated rice husk ash and SiC particles along with 0.1 wt% magnesium were then charged into the semi-solid melt at this temperature (600 °C) and stirring of the slurry was performed manually for 5-10 minutes. The composite slurry was then superheated to 800 °C± 50 °C and a second stirring performed using a mechanical stirrer. The stirring operation was performed at a speed of 400 rpm for 10 minutes before casting into prepared sand moulds inserted with chills. The designations used to represent each grade of the composites produced are presented in Table 3.

## 2.4 Density Measurement

The experimental density of each grade of composite produced was determined by dividing the measured weight of a test sample by its measured volume; while the theoretical density was evaluated by using the formula:

$$\rho_{Al\text{-}Mg\text{-}Si\,/\,RHA\text{-}SiCp} = wt._{Al\text{-}Mg\text{-}Si} \times \rho_{Al\text{-}Mg\text{-}Si} + wt._{RHA} \times \rho_{RHA} + wt._{SiC} \times \rho_{SiC} \qquad (2.1)$$

where, $\rho_{Al\text{-}Mg\text{-}Si\,/\,RHA\text{-}SiCp}$ = Density of Composite, $wt._{Al\text{-}Mg\text{-}Si}$ = Weight fraction of Al-Mg-Si alloy, $\rho_{Al\text{-}Mg\text{-}Si}$ = Density of Al-Mg-Si alloy, $wt._{RHA}$ = Weight fraction RHA, $\rho_{RHA}$ = Density of RHA, $wt._{SiC}$ = Weight fraction SiC, and $\rho_{SiC}$ = Density of SiC.

The experimental densities were compared with the theoretical densities for each composition of the RHA-SiC reinforced composites produced; and it served as basis for evaluation of the percent porosity of the composites using the relations [20]:

$$\%\ porosity = \{(\rho_T - \rho_{EX}) \div \rho_T\} \times 100\ \% \qquad (2.2)$$

where, $\rho_T$ = Theoretical Density (g/cm³), $\rho_{EX}$ = Experimental Density (g/cm³).

## 2.5 Tensile Properties

The tensile properties of the composites was evaluated with the aid of tensile tests performed following the specifications of ASTM 8M-91 standards [21]. The samples for the test were machined to round specimen configuration with 6 mm diameter and 30 mm gauge length. The test was carried out at room temperature using an Instron universal testing machine operated at a strain rate of $10^{-3}$/s. Three repeat tests were performed for each grade of composite produced to guarantee repeatability and reliability of the data generated. The tensile properties evaluated from the stress-strain curves developed from the tension test are - the ultimate tensile strength ($\sigma_u$), the 0.2 % offset yield strength ($\sigma_y$), and the strain to fracture ($\varepsilon_f$).

## 2.6 Fracture Toughness Evaluation

The fracture toughness of the composites was evaluated using circumferential notch tensile (CNT) specimens [22]. Samples for the CNT testing were machined having gauge length, specimen diameter (D), notch diameter (d), and notch angle of 30, 6, 4.5 mm, and 60 °C respectively. The specimens were then subjected to tensile loading to fracture using an Instron universal testing machine. The fracture load ($P_f$) obtained from the load – extension plots generated from the CNT testing were used to evaluate the fracture toughness using the empirical relations by Dieter [23]:

$$K_{1C}=P_f/(D)^{3/2}[1.72(D/d)-1.27] \qquad (2.3)$$

where, D and d are respectively the specimen diameter and the diameter of the notched section. The validity of the fracture toughness values obtained was determined using the relations in accordance with Nath and Das [24]:

$$D \geq (K_{1C}/\sigma_y)^2 \qquad (2.4)$$

Three repeat tests were performed for each composite composition and the results obtained were taken to be highly consistent if the difference between measured values for a given composite composition is not more than 2 %.

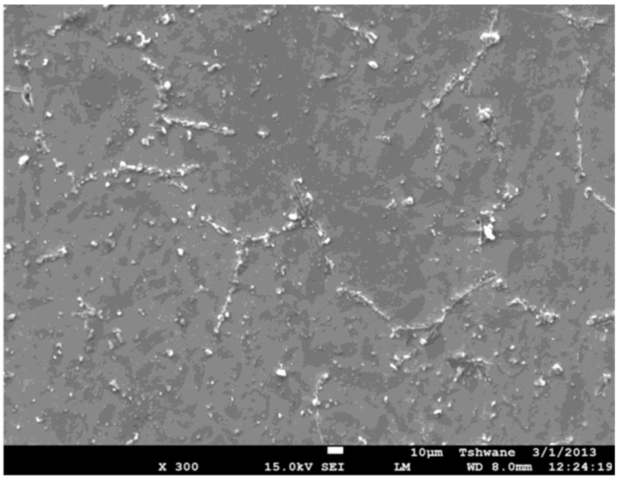
## 2.7 Microstructural Examination

A JSM 7600F Jeol ultra-high resolution field emission gun scanning electron microscope (FEG-SEM) equipped with an EDS was used for detailed microstructural study and for determination of the elemental compositions of the composites.

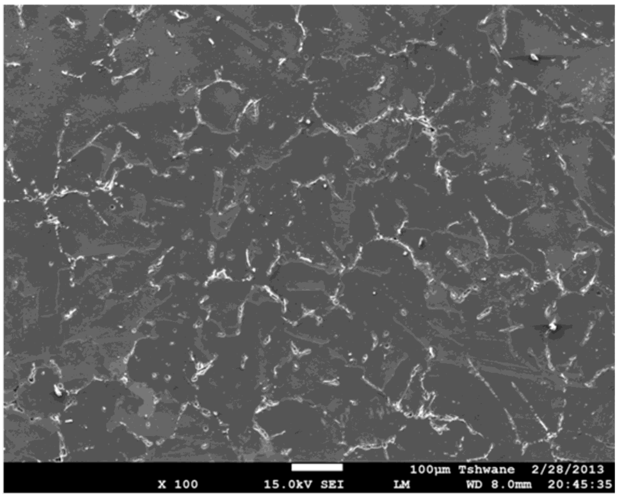
## 3. RESULTS AND DISCUSSION

## 3.1 Microstructure

Figure 1 shows some representative SEM micrographs of the RHA - SiC reinforced AMCs produced. It is observed that there is a good dispersion of the RHA and SiC particulates in the Al alloy matrix and little particle clusters are observed. Thus there is no significant problem of segregation or sedimentation which often occurs during solidification of MMCs having components with different densities and wettability characteristics [25]. This shows that the two step stir casting process adopted for the production of the composites is reliable judging from the microstructures examined in Fig. 1.



(a)



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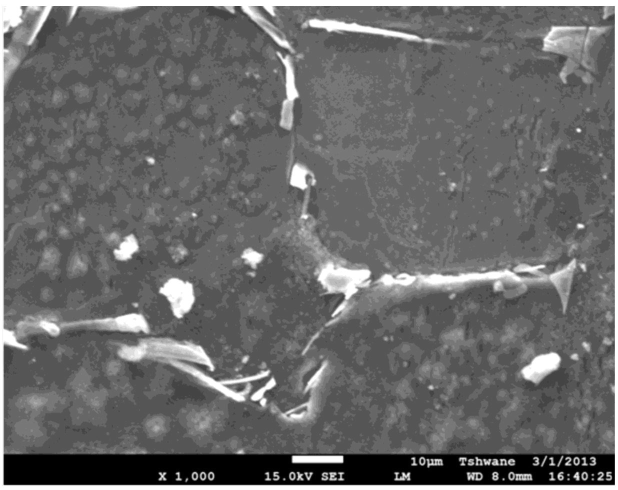

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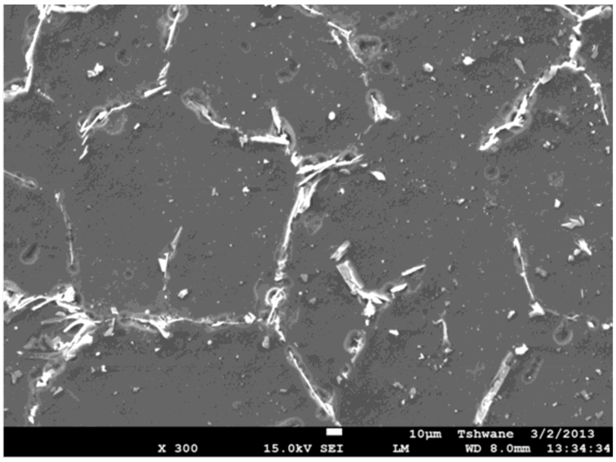


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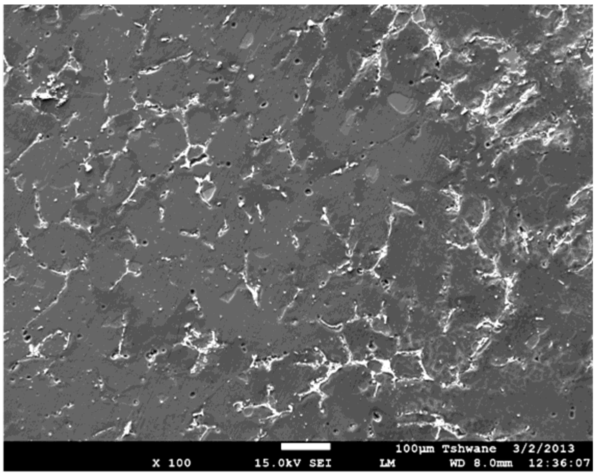
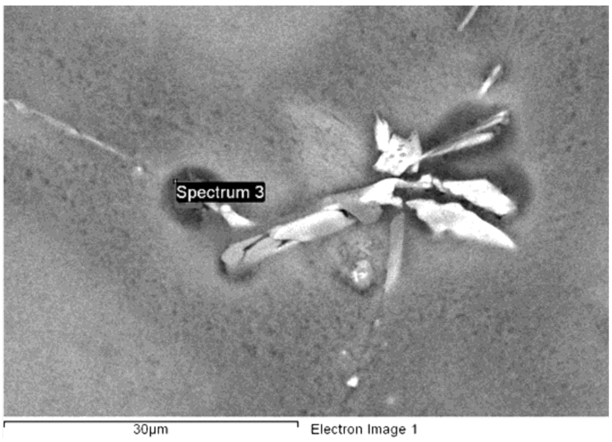



(e)

**Fig. 1.** (a) SE image of the Al-Mg-Si/5 wt% SiC composite showing the SiC particles dispersed in the Al-Mg-Si matrix; (b) SE image of the 5 wt% hybrid reinforced Al-Mg-Si/RHA-SiC composite having RHA: SiC weight ratio of 1:3; (c) SE image of the 7.5 wt% hybrid reinforced Al-Mg-Si/RHA-SiC composite having RHA: SiC weight ratio of 1:3; (d) SE image of the 10 wt% hybrid reinforced Al-Mg-Si/RHA-SiC composite having RHA: SiC weight ratio of 1:3; (e) SE image of the Al-Mg-Si/10 wt% RHA composite showing the RHA particles dispersed in the Al-Mg-Si matrix.

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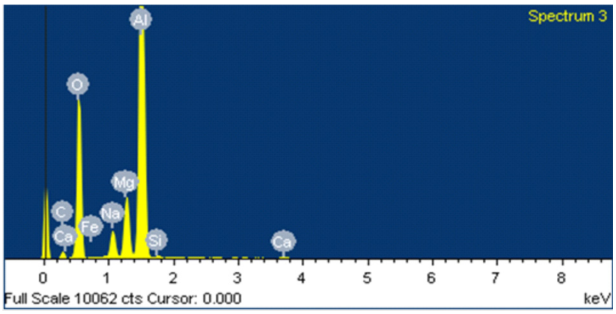
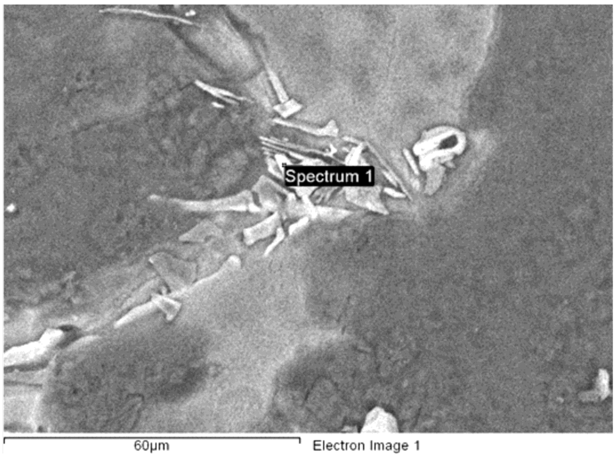
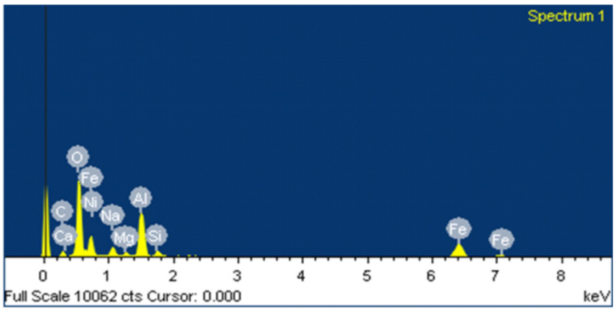



(b)

**Fig. 2.** (a) Representative SE Photomicrograph showing the reinforcing particles dispersed in the Al-Mg-Si matrix; (b) EDS profile of the particle in 2(a) confirming the presence of $Al_2O_3$, $SiO_2$, $Fe_2O_3$, $K_2O$, CaO, SiC and Na.




(a)




(b)

**Fig. 3.** (a) Representative SE Photomicrograph of some clustered particles dispersed in the Al-Mg-Si matrix; (b) EDS profile the particles identified in 3(a) confirming the presence of $Al_2O_3$, $SiO_2$, $Fe_2O_3$, SiC, Cao, and Na which are constituents from the RHA-SiC hybrid reinforcement.

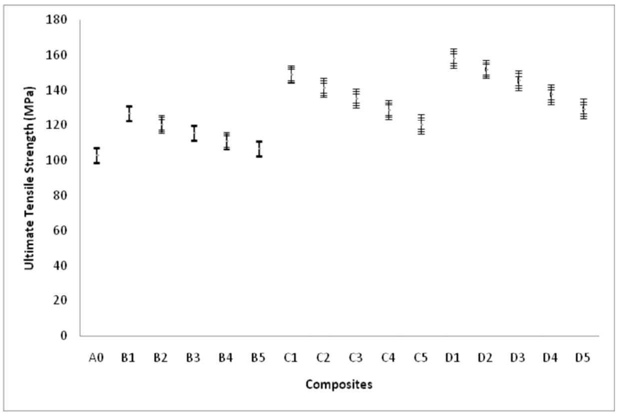
The EDS profiles of the particulates in the composites produced, some of which are presented in Figs. 2 and 3, show peaks of aluminium (Al), oxygen (O), carbon (C), iron (Fe), silicon (Si), calcium (Ca), sodium (Na) and magnesium (Mg). The presence of these elements confirm the presence of SiC; as well as silica ($SiO_2$), alumina ($Al_2O_3$), Potassium oxide ($K_2O$), ferric oxide ($Fe_2O_3$), and Magnesium oxide (MgO) which are constituents derived from the rice husk ash (Table 2).

### 3.2 Composite Density and Estimated Percent Porosity

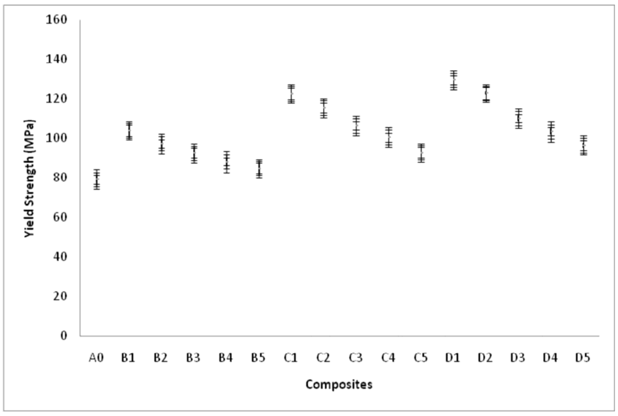
The results of the composite densities and estimated percent porosity are presented in Table 3. It is observed from the results that the estimated porosity values are not dependent on the weight percent of the reinforcement phase or the weight ratio of RHA to SiC. It is however noted that the estimated porosity levels are less than 4 % which has been reported to be the maximum permissible in cast AMCs [26]. The low porosity levels of the composites supports our submission that the two step stir casting method adopted for producing the composites is reliable. As a result of the lower density of RHA (0.31 g/cm$^3$) in comparison to SiC (3.6 g/cm$^3$), it is expected that the density of the composites will reduce with increase in the RHA content in the composite as observed from Table 3.

### 3.3 Mechanical Behaviour

The variation of tensile strength and yield strength of the composites produced is presented in Figure 4. It is observed that there is a general increase in tensile strength (Fig. 4a) and yield strength (Fig. 4b) with increase in weight percent of the RHA-SiC hybrid reinforcement. However, for specific weight percents of the hybrid composites (that is B, C, and D series), it is noted that the tensile and yield strength decreases with increase in the weight proportion of RHA in the RHA-SiC reinforcement. For the composites containing 5 wt% of the reinforcing phase, it is observed that 4.9, 8.9, 12.5, and 15.8 % reduction in tensile strength was obtained from the composites with weight ratio RHA: SiC of 1:3, 1:1, 3:1, and 1:0 (that is containing 25, 50, 75, and 100 % RHA) in comparison to the 5 wt% SiC single reinforced Al matrix composite. For the composites containing 7.5 wt% of the reinforcing phase, reductions of 5, 9, 13.4, and 19 % were observed for the compositions of 1:3, 1:1, 3:1, 1:0 RHA: SiC weight ratios respectively (in comparison with the 7.5 wt% SiC single reinforced composite). In the case of the composites containing 10 wt% reinforcements, reductions of 4, 8.1, 13.2, and 18.3 % was observed in comparison to the 10 wt % SiC single reinforced Al matrix composite.




(a)




(b)

**Fig. 4.** (a) Variation of tensile strength for the monolithic Al-Mg-Si alloy, single reinforced and hybrid reinforced Al-Mg-Si/RHA-SiC composites; (b) variation of yield strength for the monolithic Al-Mg-Si alloy, single reinforced and hybrid reinforced Al-Mg-Si/RHA-SiC composites.

It has been well reported that particle reinforced AMCs achieve improved strength due to load transfer from the matrix to the particles (direct strengthening) and creation of more dislocations which serve as constraints to plastic deformation by thermal mismatch between the particles and the Aluminium matrix arising from their differences in coefficient of thermal expansion (indirect strengthening) [27-28]. Thus even in a scenario where the particles are not sufficiently strong to induce strengthening via the 'direct route' of load transfer from matrix to particles, the indirect strengthening it could offer is adequate to induce some strength improvements well and above that of the monolithic alloy. In the present case under investigation, the reduction in strength observed with increase in the RHA content of the composites is as a result of the decrease of the direct strengthening capacity of RHA which contains predominantly silica. Silica is noted to be a softer ceramic with elastic modulus of 60-70 GPa, which is within the range of Aluminium unlike SiC which has an elastic modulus of 400GPa. Thus the efficiency of load transfer from the Al matrix to the particles (load carrying capacity) of the hybrid particulates will be dependent on the amount of SiC than RHA. However, it should be noted that samples B5, C5, and D5 which contain only RHA, show a progressive increase in tensile strength and yield strength with the increased weight percent of RHA supporting our hypothesis that the indirect strengthening mechanism (which entails dislocation generation results in higher dislocation densities with increased weight percent of the particles) can result in modest improvement in strength with increase in the weight percent of the reinforcing particles.

The variation of the specific strength of the composites produced with weight ratio of RHA/SiC is presented in Fig. 5. It is observed that the specific strengths of the composites generally increased with increase in the weight percent of the reinforcing phase (that is RHA-SiC weight percent). Also the specific strength values decreases with increase in the RHA content in the hybrid reinforcement.

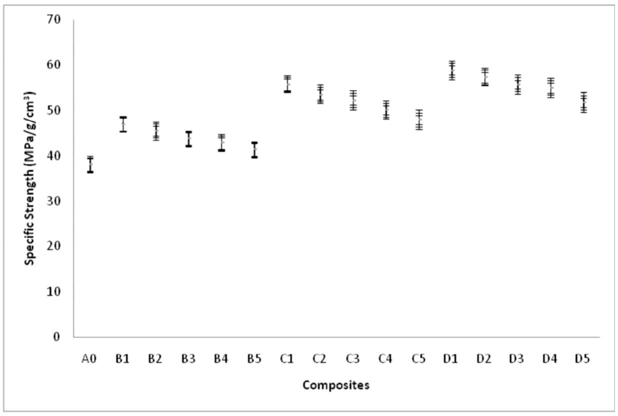



**Fig. 5.** Variation of specific strength for the monolithic Al-Mg-Si alloy, single reinforced and hybrid reinforced Al-Mg-Si/RHA-SiC composites.

However, the % decrease in specific strength of the composites is generally lower in comparison with that of the ultimate tensile strength analyzed earlier. For the 5 wt% compositions, it is observed that 3.1, 6.8, 8.75, and 11.9 % reduction in specific strength is obtained. For the 7.5 wt % compositions (grades) 3.93, 6.2, 10 and 13.9 % reductions were obtained. In the case of the 10 wt% grade, 2.6, 5.3, 6.54, and 11.9 % reductions were obtained. The results show that the composites with composition of 1:3 weight ratio RHA: SiC (25 % RHA: 75 % SiC) can offer comparable specific strength values at reduced cost of production of the composite since its difference is less than 4 % for the three weight percents of reinforcement worked on.

The results of the variation of strain to fracture of the composites with weight percent reinforcement and weight ratio RHA/SiC is presented in Fig. 6. It is observed that there is a general decrease in ductility of the composites with increase in the weight percent of reinforcing phase in the composites. Closer observation show that for each weight percent of hybrid composites produced, the strain to fracture was invariant to the weight ratio of RHA/SiC. It can be inferred from the results that the ductility levels of the hybrid composites is not compromised by the addition of RHA in the hybrid compositions. Thus its capacity to sustain plastic strain without fracture is not impelled by the addition of RHA.

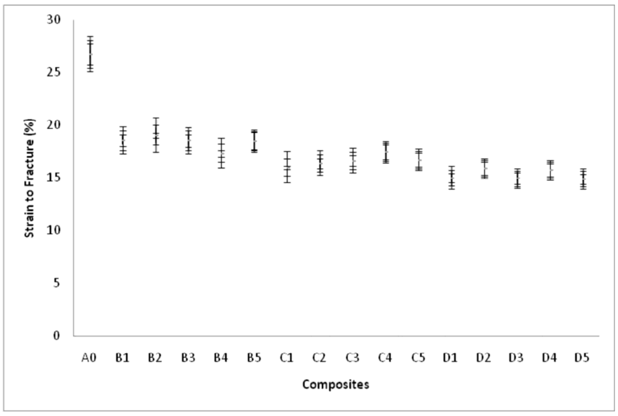



**Fig. 6.** Variation of strain to fracture for the monolithic Al-Mg-Si alloy, single reinforced and hybrid reinforced Al-Mg-Si/RHA-SiC composites.

The fracture toughness values determined by the use of circumferential notched tensile (CNT) specimens are presented in Fig. 7. The values obtained were reported as plain strain fracture toughness because the conditions for valid $K_{1C}$ (plain strain condition) was met with the specimen diameter of 6mm when the relation D ≥ $(K_{1C}/\sigma_y)^2$ [24] was utilised to validate the results obtained from the CNT testing. It is observed that the fracture toughness decreases with increase in the weight percent of the composites. But for specific weight percents of the composites (that is B, C, and D series) it is observed that the composite compositions containing RHA had improved fracture toughness results compared with the single SiC reinforced grades of the composites. Thus the addition of RHA appears to be beneficial in terms of improving the resistance to crack propagation of the composites making them slightly less susceptible to sudden crack failure in comparison with the single reinforced SiC composite grades. The mechanism of fracture in particle reinforced Al matrix composites have been reported by several authors [29-30]. The primary mechanisms of fracture have been reported to be facilitated by one or a combination of particle cracking, interfacial cracking or particle debonding [31]. In the present case, the improved fracture toughness of the composites containing RHA, is most likely due to the reduced amount of relatively harder and brittle SiC particles in the composites [19]. The SiC particles like most hard and brittle ceramic particles have a higher tendency to undergo rapid crack propagation [32].

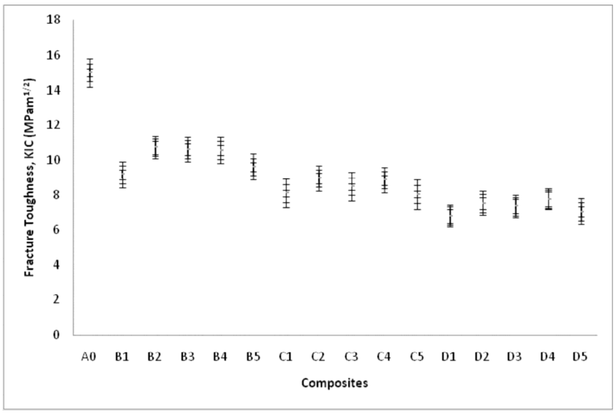



**Fig. 7.** Variation of Fracture Toughness for the monolithic Al-Mg-Si alloy, single reinforced and hybrid reinforced Al-Mg-Si/RHA-SiC composites.

## 4. CONCLUSIONS

The mechanical behaviour of Al-Mg-Si alloy matrix composites containing 5, 7.5, and 10 weight percent of RHA and SiC reinforcements prepared in weight ratios 0:1, 1:3, 1:1, 3:1, and 1:0 respectively was investigated. The results show that:

1. The estimated porosity values are not dependent on the weight percent of the reinforcement phase or the weight ratio of RHA to SiC. They were however less than 2.5 % in all grades produced.
2. There is a general increase in tensile strength, and yield strength with increase in weight percent of the RHA-SiC hybrid reinforcement. However, the tensile and yield strength decreases with increase in the weight proportion of RHA in the RHA-SiC reinforcement.
3. The specific strength followed the same trend as the tensile and yield strengths; however, the % decrease in specific strength of the composites is generally lower in comparison with that of the ultimate tensile strength. The composites with composition of 1:3 weight ratio RHA to SiC (25% RHA: 75% SiC) offers comparable specific strength values with the SiC single reinforced grades of the composite.
4. There is a general decrease in ductility of the composites with increase in the weight percent of reinforcing phase in the composites. However, the strain to fracture was invariant to the weight ratio of RHA/SiC.
5. The fracture toughness decreases with increase in the weight percent of the composites. But the composite compositions containing RHA had improved fracture toughness compared with the single SiC reinforced grades.

## Acknowledgement

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