

RESEARCH PAPER

## IMPROVING MECHANICAL PROPERTIES OF ALUMINIUM ALLOY THROUGH ADDITION OF COCONUT SHELL-ASH

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### ABSTRACT

*This paper investigates the microstructure and mechanical properties of aluminum alloy (Al-Si-Fe) reinforced with coconut shell-ash particulate. The aluminium (Al-Si-Fe) alloy composite was produced by a double-stir casting process at a speed of 700 rpm for 10 and 5 minutes at first and second stirring respectively. The samples produced from addition of 0-15 wt% coconut shell-ash particles (CSAp) were prepared and subjected to microstructural and mechanical properties testing. The results of the microstructural analysis of the composite reveal a fairly uniform distribution of the coconut shell-ash particles in the matrix with increase in volume fraction of CSAp. The mechanical property test results revealed that, hardness of the developed composite increased with increasing percentage weight of CSAp. Also the tensile and yield strength at 0.2% offset values of Al-Si-Fe/CSAp composite increased with percentage increase in CSAp up to 9% addition above which a little decrease in both tensile and yield strength was observed.*

**Keywords:** Matrix, coconut shell, mechanical properties, stir- casting, particulate, reinforcements

### INTRODUCTION

Particulate reinforced Metal Matrix Composites (PMMCs) are currently being used as structural components in aerospace, automotive and industrial applications (AlAdemilua, *et al.*, 2013; Prasad and Ramachandra, 2013; Vannan and Paul, 2014). Discontinuously reinforced metal matrix composites have received much attention because of their high specific strength and stiffness, good wear resistance and modified

thermal properties, which are difficult to achieve in a monolithic metal alloy or conventional material (Wahab, *et al.*, 2009; Naher, *et al.*, 2003). These materials have emerged as an important class of advanced materials giving engineers the opportunity to tailor material properties to various engineering applications (Naher, *et al.*, 2003). PMMCs combine the ductility and toughness of the metal matrix with the high strength and stiffness of the ceramic rein-

forcement (SiC, Al<sub>2</sub>O<sub>3</sub>) to achieve better properties (Vannan and Paul, 2014). The outstanding properties of PMMCs include high strength to weight ratio, excellent mechanical properties coupled with wear resistance and thermal stability, which makes them desirable as engineering material for various structural, automotive, aerospace, sports and tribological applications (Vannan and Paul, 2014; 2007). Small particulate (less than 1 μm) dispersion into metals induces an Orowan strengthening mechanism, which in turn improves the strength of the material (Minlin *et al.*, 2014). Traditionally, high modulus ceramic particulates such as silicon carbide (SiC) and alumina (Al<sub>2</sub>O<sub>3</sub>) have been used for reinforcements purposely for stiffness and strength enhancement. It is however known that, additional and tailored properties can still be achieved by carefully controlling the properties of the matrix, the reinforcement and the interface formed between them (Ademilua, *et al.*, 2013; Prasad and Ramachandra, 2013; Dobrzanski, *et al.*, 2010).

Particle reinforced MMCs are produced through various routes such as powder metallurgy, liquid metallurgy, squeeze casting rolling and extrusion techniques (Deuis, *et al.*, 1997). However, liquid metallurgy technique (stir casting) is chosen as a promising route due to its versatility, low cost, and its efficiency to homogeneously distribute the reinforcement in the metal matrix for mass production (Kevin and Sijo, 2015).

Various works have been done on stir casting of aluminium alloy composites using different kinds of reinforcements such as synthetic ceramic particulates (SiC, Al<sub>2</sub>O<sub>3</sub>), industrial wastes (flyash, red mud), and agro-waste (rice husk, bamboo leaf ash) derivatives with outstanding results.

Prasad and Ramachandra evaluated factors affecting sliding wear behaviour of Al-flyash metal matrix composites using stir and squeeze casting techniques. It was reported that the addition of the flyash by weight percentage and

the applied squeeze pressure caused the improvement in hardness and wear resistance of the composite (Prasad and Ramachandra, 2013). Similarly, an increasing trend of hardness and impact strength with increase in weight percentage of SiC was observed by Deepak *et al* (2009). They submitted that the optimum hardness and impact strength of 45.5 BHN and 36 N-m were achieved at 25 %wt fraction of SiC.

Similar results were reported with several other agro-waste (palm oil clinkers, rice husk, and coconut shell), where enhanced mechanical properties of the composites were achieved at low cost (Lancaster, *et al.*, 2013).

A published study on the mechanical properties and corrosion behaviour of aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash (BLA) showed that the hardness, ultimate tensile strength and percentage elongation of the hybrid composite decrease with increase in BLA. However, the result of Al-10 wt% of SiC single reinforcement of the same study, presented superior mechanical properties. Moreover, in separate studies investigating the tribological properties of reinforced aluminium alloy basalt and beryl particulate composites (Vannan and Paul, 2014; Abdul and Bhaskar, 2012), both basalt and beryl particulates are reported to significantly improve the hardness and sliding wear resistance of the aluminium alloy due to the hardness of the particles and the formation of tribo-induced rich basalt short fibre film on the mating surfaces. Coconut shells (agro-waste material) as aforementioned have suitable particulate reinforcement properties. These materials are readily available in Nigeria but they are considered to be of little or no economic importance. The realization of these materials through continuous research is pertinent to achieving a low cost metal matrix composite production technique with uncompromised strength for various engineering applications. Very few studies have been focused on coconut shells in metal matrix composite. In the works

of Apasi *et al.*, (2012) and Madakson *et al.*, (2012), they both separately concluded that CSAp could be used in the production of light weight metal matrix composite with good thermal and wear resistance.

Daramola *et al.*, (2015) evaluated the mechanical and corrosion properties of Al 6063 alloy/coconut shell composites. They noticed increase in hardness, tensile strength with increase in percentage weight of coconut shell with decrease in corrosion resistance. Agunsoye *et al* (2014) obtained similar result that the mechanical and wear properties of recycled waste aluminium can be reinforced with coconut shell. Conversely, the effects of CSAp on mechanical properties of aluminium silicon iron alloy have not been reported to the best of authors' knowledge. Thus, the objective of this work is to improve the mechanical properties of Al-Si-Fe alloys by CSAp addition and investigate its effects on other properties of the resulting composite.

#### **MATERIALS AND METHOD**

The materials used in this work include coconut shells obtained from a coconut seller, 99.70% purity aluminium cables of 2.5 mm diameter

from Northern Cable Company (NOCACO), Kaduna, Nigeria as the matrix, silicon Tokuyama Corporation Chemical industry) and iron powder of 50  $\mu\text{m}$  grain size (Xi' AnLanzhiguang Fine Material Co., Ltd China).

#### **Preparation of coconut ash particulates**

The coconut shells were first ground to form powder (Fig. 1a) and fired at a temperature of 1300  $^{\circ}\text{C}$  for 3 hours in a graphite crucible using an electric resistance furnace, to form the coconut shell ash powder (CSAp) as shown in Fig. 1b. The particle size analysis of the coconut shell ash was carried out in accordance with BS1377:1990 (Prasad and Ramachandra, 2013; Aigbodion, 2007; Bienia, *et al.*, 2003). About 100g of CSAp was put in a set of sieves arranged in descending order of fineness and shaken for 15 minutes in accordance with the recommended time for achieving complete classification. Particles of size 100 $\mu\text{m}$  of the reinforcement were used in this investigation due to its fine nature.

#### **Composite production**

The metal matrix composite was produced using the double stir-casting technique. The specimens were produced by keeping the per-



**(a)**



**(b)**

**Fig.1: Photograph showing coconut (a) shell powder and (b) shell ash**

centage of iron powder (2% wt) and silicon (7 % wt) in the matrix constant and varying the reinforcing material (coconut shell ash) particles in the range of 0,3,6,9, 12, and 15 wt%. The chemical compositions of the matrix and coconut shell ash were shown in Fig. 2 and table 1 respectively. The aluminium and 7 %wt Si were then charged in a graphite crucible kept in an electric resistance furnace and heated to 750 °C till the entire alloy in the crucible completely melted. Then, 2 wt% iron powder was added to the melt. Degassing tablets hexachloroethane) and 1wt% magnesium were simultaneously added to reduce hydrogen entrapment and enhance wettability of the reinforcement (CSAp) and the Al-Si-Fe alloy melt respectively. A stainless steel stirrer with rotational speed of 700 rpm (Fig. 3) was gradually lowered into the melt. The 3wt% CSA particles preheated to 800 °C for one hour to promote wettability and homogenization of the composite slurry melt was added into the melt at a constant rate. The stirring of the slurry was then continued for another five minutes after the completion of CSA feeding. The mixture was poured into the steel cylindrical mould of 20 mm diameter by 200 mm long, which has also been preheated to 50°C for 30 minutes by a

long tong for safety purpose to obtain uniform solidification in open air. The same approach was used in the production of the composites containing 6, 9, 12 and 15 wt% CSA particle reinforcement.

#### Determination of the hardness value

The hardness values of the samples were carried out in accordance with ASTM E18-79, standard, using the Rockwell hardness tester on 'B' scale with 1.56 mm steel ball indenter. It has a minor load of 10 kg and major load of 100 kg with hardness value of 101.2 BHN on the standard block. Calibration of the hardness tester was carried out while all the mating surfaces were thoroughly polished and cleaned with fine grain emery paper of 320 grit size before the test. The test was carried out at three different spots on the testing surfaces to avoid the possible effect of indenter resting on the harder particles and the average of all the three readings was taken. The Brinell hardness value (BHN) was obtained using the relationship below;

$$BHN = \frac{F}{A_c} \quad (1)$$

Where F is the load (kilograms) and  $A_c$  is the

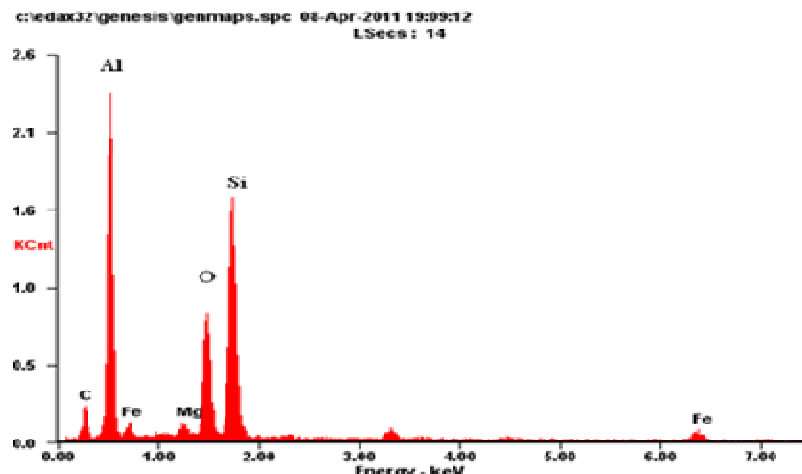
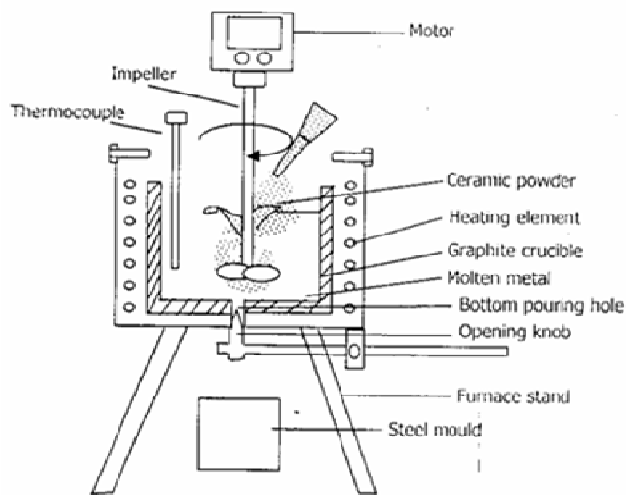


Fig 2: SEM analysis of elemental composition of aluminum alloy (matrix)

**Table 1: XRF analysis of elemental composition of coconut shell-ash particles**

Element	% Composition
Al <sub>2</sub> O <sub>3</sub>	15.6
CaO	0.57
Fe <sub>2</sub> O <sub>3</sub>	12.4
K <sub>2</sub> O	0.52
MgO	16.2
Na <sub>2</sub> O	0.45
SiO <sub>2</sub>	45.05
MnO	0.22
ZnO	0.3



**Fig. 3: Schematic diagram of stir casting technique**

is the actual surface area of the indentation in square millimetres.

**Tensile testing**

The tensile test of the composite samples was conducted on the Tinius-Olsen tensile testing machine at a strain rate of  $2 \times 10^{-3} \text{ S}^{-1}$ . The test pieces were machined to the standard shape and dimensions as specified by the American Society for Testing and Materials (ASTM –E8M). The sample was locked securely in the grips of the upper and lower jaws of the testing machine. A small load was initially applied to seat the

sample in the jaws and then gradually increased until failure occurred. The value of the load and extension were recorded and used in obtaining the strength of the composite as a function of the CSAp.

**Microstructural examination**

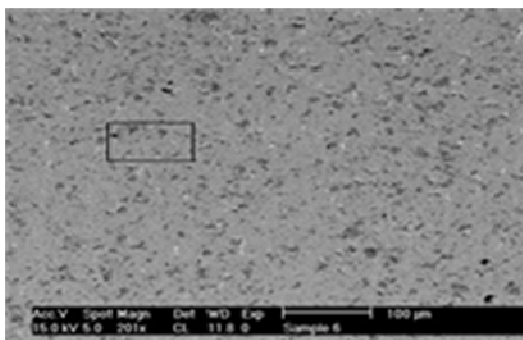
Metallographic specimens were cut transversely from the unreinforced and reinforced samples of Al-Si-Fe/CSAp particulate composites (Fig. 4). The sectioned specimens were then mounted on Bakelite and mechanically ground progressively on grades of SiC impregnated emery paper of 80

-600 grits sizes using water as the coolant. The ground specimens were then polished using 1- $\mu$ m alumina polishing powder suspended in distilled water. The final polishing was done using 0.5- $\mu$ m alumina polishing powder suspended in

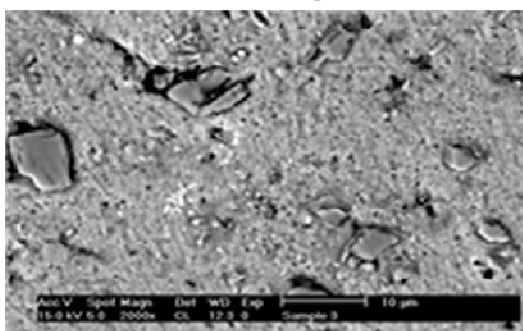
distilled water. The etching of the polished specimen was done using Keller's reagent. The structure obtained for various additions of CSAp were observed using scanning electron microscope (SEM) with inbuilt camera and presented in Fig. 5.



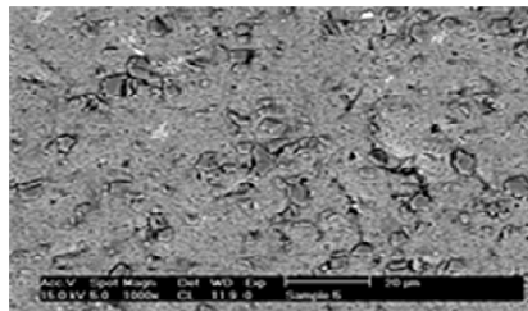
**Fig. 4: Photograph of samples of the Al-Si-Fe/CSAp composite produced**



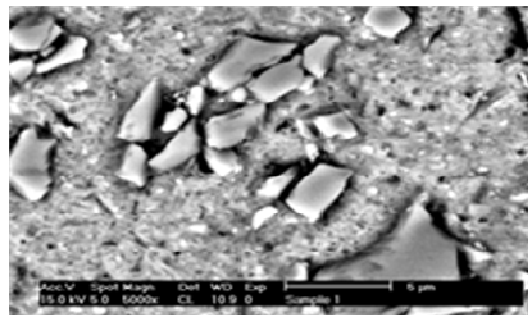
3% wtCSAp



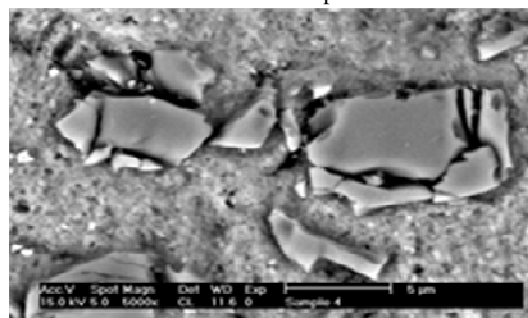
6% wtCSAp



9% wtCSAp



12% wtCSAp



15% wtCSAp

**Fig. 5: Microstructure analysis of Al-Si-Fe/CSAp Composites at varying CSAp weight percentage**

**RESULTS AND DISCUSSION**

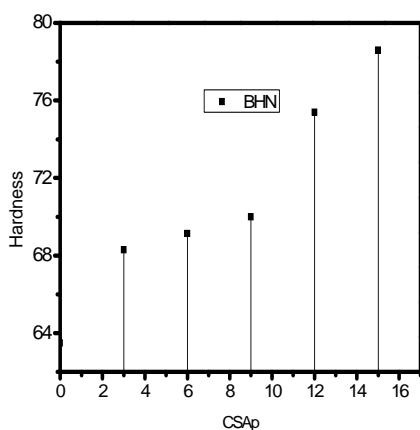
**Evaluation of the hardness behaviour**

Hardness of the developed composites increased with increase in CSAp additions. It is noteworthy that the hardness value of coconut shell ash according to Apasi *et al.*, (2012) is 95.05HB and the presence of the hard ceramic phase in the ductile matrix has resulted in the increase in hardness of the composite (Fig. 6). The hardness values increased from 63.50 HRB at 0wt% to 78.60 HRB at 15wt% coconut shell ash particles. These increments are attributed to the increase in the weight percentage of the hard and brittle phase of CSAp in the aluminium alloy matrix. This hardness of the coconut shell ash particles is obtained from the SiC, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> in the chemical makeup of the particles as revealed by the CSAp XRF analysis presented in Table 1. Additionally, the presence of CSAp in the alloy increase the dislocation density at the particle-matrix interfaces as a result of differences in coefficient of thermal expansion (CTE) between the hard and brittle reinforced particles and soft and ductile metal matrix resulting in elastic and plastic incompatibility between the

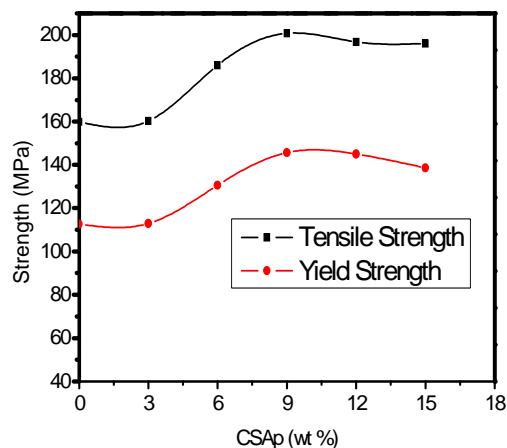
matrix and the reinforcement (Mahmoud, 2008).

**Tensile properties of the composite**

The result of ultimate tensile strength (UTS) and 0.2 % offset yield stress (YS) of the composite at various volume fractions of CSAs is as shown in Fig. 7. The result indicates a higher value of both YS and UTS for all volume fractions of CSAp in the composite compared to aluminium alloy matrix. Both the yield and tensile strength follow the same trend and increases with increase in volume fraction of CSAp in the matrix. The maximum value of both tensile and yield strength was obtained at 9 wt% volume fraction of CSAp addition after which further addition resulted in gradual decrease in both the tensile and yield strengths. This increase behaviour in the tensile properties of the composites may be attributed to good particle-matrix interfacial bonding, wettability, the fine reinforcement particle size and the strengthening effect of the coconut shell ash particles in the aluminium alloy matrix. However the behaviour of the composite with CSAp volume fraction beyond 9 wt% weight fraction



**Fig. 6:** Variation of hardness with %wt of CSAp



**Fig. 7:** Variation of strength with wt% coconut shell ash particle

is presumed to have been as a result of mismatch along the grain boundaries of matrix-reinforcement composition. Consequently this resulted in weakening the load carrying capacity of the composite above 9 wt % volume fraction to reduce the strength of the composite. This result is in agreement with the work of other researchers (Aigbondon and Hassan, 2013).

#### Macrostructural and microstructural analysis

Macrostructural observation of the specimens at 50x revealed a significant uniform distribution of coconut shell ash particles (CSAp) with micro traces of some particles segregation. This is presumed to be as a result of the imbalance in density of both the matrix and the reinforcement during solidification. Notably, the result of SEM for microstructural examination of the specimens shown in Fig. 5, reveals a fairly uniform distribution of CSAp in the matrix in all %wt addition of the reinforcements. The uniform distribution of CSAp in the matrix, can be attributed to a number of factors which includes, effective stirring of the slurry, degassing tablet used and good wettability that resulted in improved interfacial bonding between the matrix and the coconut shell ash particles (Agunsoye *et al.*, 2014). However, micro traces of segregation/agglomeration of the reinforcement particles rarely seen at lower magnification were clearly observed at higher magnification. The maximum clustering of CSAp in the matrix was observed at 15% weight as shown in Fig. 5. This was because addition of CSAp in the matrix beyond 15 wt% made the composites slurry too thick with reduced fluidity and homogeneity of the molten composites. Micrographs of the microstructures of composite specimens at various fraction of CSAp are shown in Fig. 5.

#### CONCLUSIONS

In this work, Al-Si-Fe/CSAp composite has been successfully developed using double stir casting technique. Microstructure examination and mechanical properties (hardness, tensile and yield strength) evaluation on the developed composite samples were carried out. The fol-

lowing specific conclusions can be drawn so far with the result and discussion above.

1. The hardness values of the developed composites increased with increasing percentage weight of coconut shell ash additions due to its hard ceramic phase in the matrix.
2. The addition of CSAp to Al-Si-Fe alloy matrix increased the tensile and the yield strength of the composite developed.
3. For optimum strength application, 9 wt% CSAp is recommended while in the case of hardness and wear resistance application, 15 wt% Al-Si-Fe/CSAp is recommended.
4. The economic value of waste coconut shell can be increased through the conversion of waste to wealth.

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