# Microstructure and Mechanical Behaviour of Stir-Cast Al-Mg-Sl Alloy Matrix Hybrid Composite Reinforced with Corn Cob Ash and Silicon Carbide

Oluwagbenga Babajide Fatile[1, *], Joshua Ifedayo Akinruli[1] and Anthony Akpofure Amori[2]

[1]Glass and Ceramic Technology Department, School of Science and Computer Studies, Federal Polytechnic Ado-Ekiti, Ekiti State, Nigeria.

[2]Mechanical Engineering Department, School of Engineering, Federal Polytechnic Ilaro, Ogun State, Nigeria.

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## Abstract

In this present study, the microstructural and mechanical behaviour of Al-Mg-Si alloy matrix composites reinforced with silicon carbide (SiC) and Corn cob ash (An agro-waste) was investigated. This research work was aimed at assessing the suitability of developing low cost- high performance Al-Mg-Si hybrid composite. Silicon carbide (SiC) particulates added with 0,1,2,3 and 4 wt% Corn cob ash (CCA) were utilized to prepare 10 wt% of the reinforcing phase with Al-Mg-Si alloy as matrix using two-step stir casting method. Microstructural characterization, density measurement, estimated percent porosity, tensile testing, and micro-hardness measurement were used to characterize the composites produced. From the results obtained, CCA has great potential to serve as a complementing reinforcement for the development of low cost-high performance aluminum hybrid composites.



**Keywords:** mechanical behaviour, microstructure, corn cob ash, hybrid composite, stir-cast

## 1. Introduction

The development of low cost and high performance advance engineering materials for various engineering applications has continued to draw the attention of researchers in material engineering field, several authors have reported about the design of metal matrix composites [1]. Metal matrix composites (MMCs) possess improved properties such as high specific strength; specific modulus, damping capacity and better wear resistance compared to unreinforced alloys. One of the emerging metal matrix composites with wide range of applications is aluminium matrix composites (AMCs). Aluminium matrix composite possess some unique properties such as high specific strength, good wear resistance, elevated temperature toughness, low density, high stiffness, low coefficient of thermal expansion, corrosion and high temperature resistance among others when compared with its monolithic counterpart [2-4]. These unique properties are very useful for the fabrication of a wide range of components and parts utilized in engineering and other industrial applications [5] Several authors have centered their research work on aluminium matrix composite materials because of its' wide range of applications especially in the design of components for automobiles, aircrafts, marine structures and facilities, sports and recreation, defense assemblies among many other areas of applications [4, 6]. The application areas of Al based composites is expected to continue growing, this is possible by virtue of the attractive property spectrum possessed by AMCs and the

* Corresponding author. E-mail address: gbengacharles@yahoo.com

Tel.: +2348038479608

relative low cost of production in comparison with other competing MMCs (such as Magnesium ,Copper ,Titanium and Zinc) for similar applications [7-9]. Proper selection of reinforcing material for Al matrix composite material and techniques process are very important factors in ensuring that desired property combinations are achieved [10].

Recently, the design of low density and high performance aluminium based composites at relatively reduced cost has received much attention from materials researchers [11]. Different authors have reported about the use of Particulate ceramic materials such as alumina (3.9 g/cm$^3$) and silicon carbide (3.18 g/cm$^3$) for reinforcing AMCs [12]. The densities of these reinforcements are higher than that of Aluminum (2.7 g/cm$^3$) thereby resulting the increase in the weight of aluminum matrix based composites produce depending on the fraction of the reinforcement utilized [13]. Synthetic reinforcement such as silicon carbide (SiC) is not produced in most developing countries despite their wide range of application in these countries. The importation of these materials from developed countries are at high cost due to high tariff and high foreign currency and this has led to the increase in the cost of producing aluminium based composite in developing countries. For this reason, it is necessary to source for these reinforcements locally so as to reduce the cost of production of (AMCs).

Lately, researchers from developing countries have been working on low cost options of producing aluminium based composite material. One of the options which being considered by these local researchers currently is the utilization of ashes that obtained from the burning and conditioning of agro‐wastes such as coconut shell, ground nut shell and bamboo leaf as particulates reinforcement for the development of MMCs [14-15]. Several authors have reported that the chemical analysis of these agro‐waste showed that they often contain an appreciable percentage of silica and other refractory oxides such as Alumina and hematite [15-16]. It was further discovered that these agro‐wastes have density which are considerably lower than that of the widely used synthetic reinforcements such as SiC and $Al_2O_3$. The only major limitation reported by several authors about the use of these agro-waste ashes for reinforcing Aluminium based composite material is that the strength levels achieved in the AMCs is marginal even when high volume percents of these reinforcements were utilized [17]. This trend was attributed to high percentage of Silica which is the major constituent present in these agro‐waste ashes. $SiO_2$ has elastic modulus ranges between 60‐70 GPa which falls within the same range as that of Aluminum which is 60 GPa, when compared to the elastic modulus of $Al_2O_3$ which ranges between 300‐375 GPa and that of SiC which ranges between 410‐450 GPa [18-19].

However, very few researchers from developing countries have harnessed the superior strength, lower cost and density advantages of these agro wastes. This research work is aimed to the possibility of developing high-performance low-cost Aluminium hybrid composite reinforced with Corn cob ash and silicon carbide. The use of CCA in this study is as a result of its very low density(1.96 g/cm$^3$) in comparison to SiC (3.18 g/cm$^3$) and $Al_2O_3$ (3.9 g/cm$^3$), it is availability in large quantity and distribution in most part of the developing countries, and it is cheaper processing cost [18, 20].

Management of agro wastes in most developing countries is by burning in open air which often causes environmental pollution, and the best approach to avert this menace is to explore more recycling techniques; applications where recycled wastes can be productively utilized. This work is part of current efforts which has being initiated in order to harness the potentials of different agro waste ashes for the development of low-cost high-performance Aluminium based hybrid composites. Alaneme *et al.* [21] reported that low cost hybrid composites could have potentials for use in stress bearing and wear resistance applications among others. In this paper, the processing, microstructural features, and mechanical behavior of an Al-si-mg matrix composite which are reinforced with varied weight ratios of Corn cob ash and silicon carbide are reported.

## 2. Materials and Method

### *2.1. Materials*

Al-Mg-Si alloy was selected as Al matrix for the investigation. Spark spectrometric analyzer was used to determine the chemical composition of the Aluminium alloy and the result is presented in Table 1. Chemically pure silicon carbide (SiC) with average particle size of 50 μm and processed ash (<60 μm) derived from controlled.

Burning and sieving of dry corn cob were used as reinforcement for the Al matrix.

Table 1 Elemental composition of Al-Mg-Si alloy

| | |
|---|---|
| Si | 0.4002 |
| Fe | 0.2201 |
| Cu | 0.0080 |
| 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 |
| Li | 0.0000 |
| Na | 0.0009 |
| V | 0.0027 |
| Al | 98.88 |

### *2.2. Processing of corn cob ash*

Corn cobs were gathered in large quantities at Ado-Ekiti, a town in south western part of Nigeria. The corn cobs were dried in the sun for three days so as to remove the water content from it and then to aid the burning process. A metallic drum with perforated holes on its body was used to burn the corn cobs. The dried corn cobs were placed in the metallic drum and burnt in open air in order to enhance the combustion. The ash obtained in the drum was allowed to cool in the drum before removal. The ash obtained was then conditioned in a furnace at the temperature of $650^0$C for 180 minutes so as to reduce the carbonaceous and volatile constituents of the ash in accordance with [21]. After conditioning, sieve shaker was used to carry out particle size analysis of the corn cob ash. The chemical analysis of the corn cob ash was determined using X-ray fluorescence spectroscopy. The result of the chemical composition is as presented in table 2.

Table 2 Chemical composition of corn cob ash (CCA)

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $TiO_2$ | $Na_2O$ | $K_2O$ | $P_2O_3$ | MnO |
|---|---|---|---|---|---|---|---|---|---|
| 77.05 | 5.64 | 2.97 | 2.45 | 1.71 | 0.25 | 0.49 | 3.81 | 0.71 | 0.23 |

### *2.3. Composite production*

The composites were produced by adopting two steps stir casting process in accordance with Alaneme and Aluko [22]. Charge calculation was utilized to determine the amount of corn cob ash (CCA) and silicon carbide (SiC) required to prepare 10 wt% reinforcements (in the Al matrix) consisting of 0:10, 1:9, 2:8, 3:7, and 4:6 corn cob ash and silicon carbide weight percent respectively. The CCA and SiC particles were initially preheated at a temperature of 250℃ to remove moisture and to help the improvement of wettability with the Al‑Mg‑Si alloy melt. The Al‑Mg‑Si alloy ingots were charged into a gas‑fired crucible furnace and heated to a temperature of 750℃ ± 30℃ (above the liquidus temperature of the alloy) to ensure the alloy melts completely. The liquid alloy was then allowed to cool in the furnace to a semi solid state at a temperature of about 600℃. The preheated corn cub ash and Sic particles along with 0.1 wt% magnesium were then charged into the melt at this temperature and stirring of the slurry was performed manually for 10 minutes. The composite slurry was superheated to 800℃ ± 50℃ 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.

### *2.4. Density measurement*

The density of the composite production was determined in order to study the effect of the CCA‑SiC wt% proportions on the densities of the composites produced. The experimental density was also used to determine the porosity levels in the composites produced. This was carried out by comparing the measured and theoretical densities of each weight ratio of CCA‑SiC reinforced composite produced using established procedure [23]. The density for each composite sample was determined by accurately weighing the sample using a high precision electronic weighing balance. The measured weight of each sample was divided by their respective volume. The theoretical density was determined by using the rule of mixtures given by:

$$dc = dm*Vm + df*Vf \tag{1}$$

where

dc,dm,df – densities of the composite, matrix and dispersed phase respectively;

Vm,Vf – volume fraction of the matrix and dispersed phase respectively.

The percent porosity of the composites was evaluated in accordance with [5] using the relations:

$$\% \text{ porosity} = \{(\rho T - \rho EX) \div \rho T\} \times 100\% \tag{2}$$

Where, $\rho T$ = Theoretical Density (g/cm3), $\rho EX$ = Experimental Density (g/cm3).

### *2.5. Tensile test*

Tensile tests were performed on the composites produced in accordance with the specifications of ASTM 8M-91 standards [24]. The samples for the test were machined to cylindrical 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. 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 determined using circumferential notch tensile (CNT) specimens in accordance with [5]. The composites were machined for the CNT testing, the corresponding gauge length, specimen diameter (D), notch diameter (d), and notch angle of 30mm, 6mm, 4mm and $60^0$. The specimens were then subjected to tensile loading to fracture using an instron universal testing machine. The fracture load (*P*f) obtained from the CNT specimens' load – extension plots were used to evaluate the fracture toughness which used the empirical relations in accordance with [25]:

$$K_{1C} = Pf/(D)3/2[1.72(D/d)–1.27] \tag{3}$$

Where, D and d are respectively the specimen diameter and the diameter of the notched section. The validity of the fracture toughness values was evaluated using the relations in accordance with [26]:

$$D \geq (K_{1C}/\sigma y)^2 \quad (4)$$

Using the above relation, the value of fracture toughness for each samples were determined.

*2.7. Hardness test*

The hardness of the composites was used to determine using an Emco TEST DURASCAN Microhardness Tester equipped with eCos workflow ultra-modern software. Before the test was carried out, the specimens to be used were cut out from each composite sample and they were well polished so as to obtain a smooth and flat surface finish. Load of 100 g was applied on each of the specimens and the hardness profile was determined in accordance with standard procedures. Multiple hardness tests were performed on each sample and the average value taken as a measure of the hardness of the specimen.

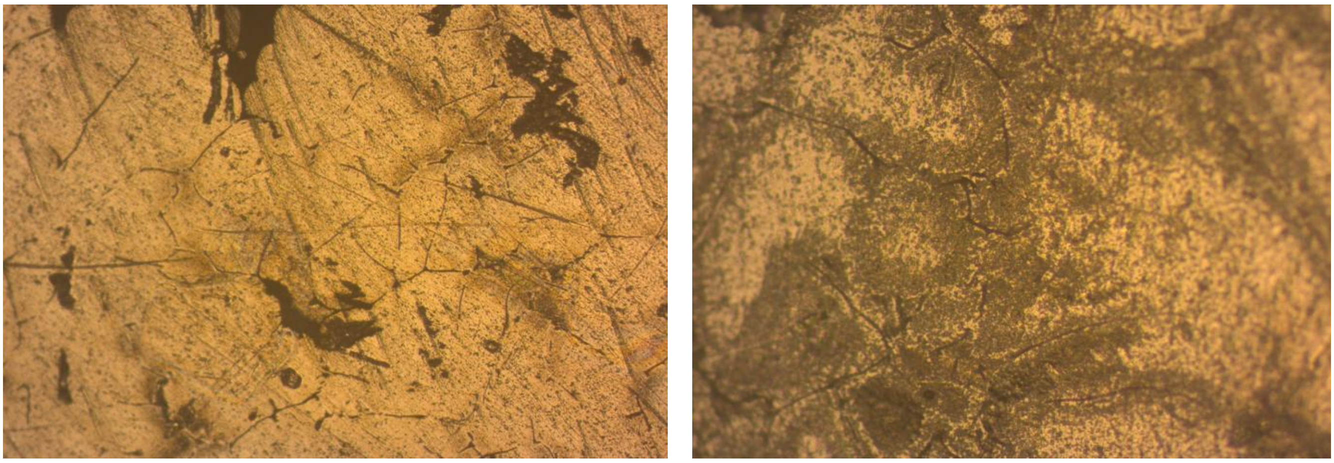
*2.8. Microstructural examination*

A Zeiss Metallurgical Microscope with accessories for image analysis was used for optical microscope investigation of the composites produced. The specimens for the test were metallographically polished and etched before microscopic examination was performed. The specimens for the test were machine-cut from rods and then ground and polished. Grinding was performed with 80, 120, 360, 600 and 800 grits emery paper, while polishing was done using polishing cloth and polishing paste with $Al_2O_3$ particles. The Polished samples were etched with mixture of equal volume of HNO3 and HCl solution before they were viewed under microscope.

## 3. Results and Discussion

*3.1. Microstructure*

Fig.1 shows the representative optical micrographs for Aluminum hybrid composites reinforced with CCA and SiC. It is observed that the reinforcing particles (CCA and SiC) are visible and a uniformly dispersed of the particulates in the Aluminum matrix is evident. It is also observed from Fig. 1b that there is high volume of particulate dispersed in the aluminum matrix for 4wt% CCA reinforced composite in comparison to the single reinforced Al-Mg-Si/10 wt% SiC composite.



(a) Photomicrograph of the Al-Mg-Si/10 wt% SiC composite shows the SiC particles dispersed in the Al-Mg-Si matrix

(b) Photomicrograph of the Al-Mg-Si/4wt% corn cob ash-6 wt% SiC hybrid composite showing a high density of particles dispersed in the Al-Mg-Si matrix

Fig. 1 Microstructural characteristics of the composite samples showing corn cob ash and SiC particles dispersed in Al-Si-Mg matrix

### 3.2. Composite density and estimated percentage porosity

The results of the estimated percent porosity of the composites are presented in Table 3. It is observed from comparison of the experimental and theoretical densities of the composites that slight porosity (maximum of 2.332%) exists in the produced composites. This implies that the use of CCA and SiC as complimenting reinforcements in the aluminum matrix composite did not bring about any significant rise in porosity level of the hybrid composites when compared with the sample without CCA. The result also indicated that the stir casting method employed for the production of the composite material was effective in minimizing the porosity of the composite produced. This is in agreement with porosity less than 4% reported to be acceptable in cast Aluminium matrix composites [23].

Table 3 Composites density and estimated percentage porosity

| Samples | Weight ratio of CCA and SiC | Theoretical density | Experimental density | Percentage porosity |
|---|---|---|---|---|
| A | 0:10 | 2.753 | 2.728 | 0.908 |
| B | 1:9 | 2.722 | 2.680 | 1.543 |
| C | 2:8 | 2.702 | 2.639 | 2.332 |
| D | 3:7 | 2.675 | 2.620 | 2.056 |
| E | 4:6 | 2.650 | 2.598 | 1.962 |

### 3.3. Mechanical behaviour

The mechanical properties of the composites are presented in Figs. 2-7. The hardness (Fig. 2), ultimate tensile strength (Fig. 3) and yield strength (Fig. 4) of the composites are observed to decrease gradually in the value of CCA content in the composites. 2.15%, 3.23%, 7.53% and 12.90% reduction in hardness and 2.16%, 5.95%, 8.11% and 12.43% reduction in ultimate tensile strength were observed for hybrid composite containing 1, 2, 3, and 4 wt% CCA respectively in comparison to composite without CCA. This trend can be attributed to the composition of CCA which is dominated by silica ($SiO_2$) which has been reported to be of lower hardness and strength in comparison with SiC [27]. Hence the slight decrease in mechanical properties of the composite is justified. Reference [22] has reported that when hard particulates are used as reinforcement in metal matrix composites (MMCs), there is room for improvement in the strength due to the synergy of direct and indirect strengthening mechanism usually arise in metal matrix composites as a result of the transfer of load from the weaker matrix to the harder and stiffer particulates through the matrix particulate interface, this will result in increased resistance to plastic deformation and a higher work hardening capacity in MMCs [28-29].

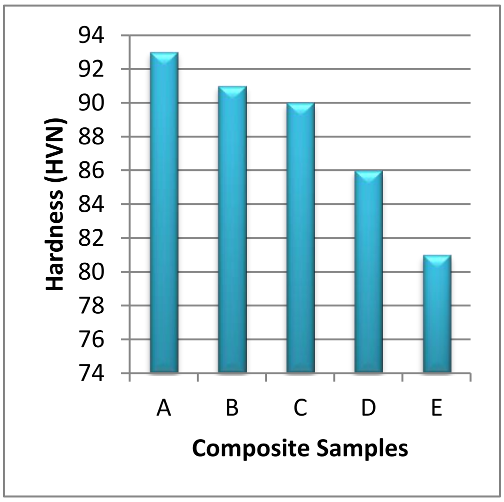



Fig. 2 Variation of Hardness for the single reinforced Al-Mg-Si/10 wt% SiC and hybrid reinforced Al-Mg- Si/CCA-SiC composites

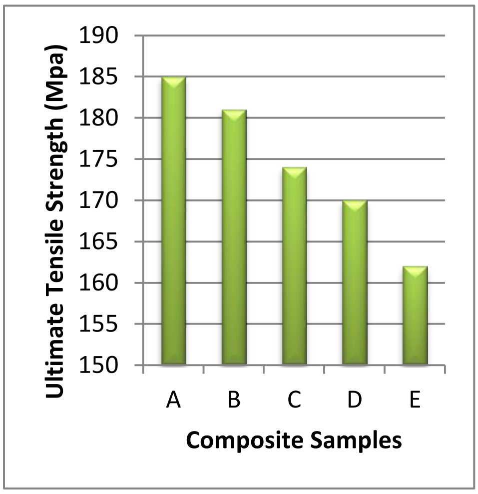



Fig. 3 Variation in ultimate tensile strength for single reinforced Al-Mg-Si/10 wt% SiC and hybrid reinforced Al-Mg- Si/CCA-SiC composites

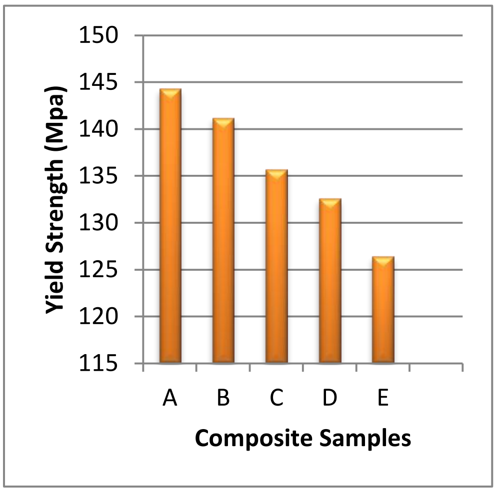



Fig. 4. Variation of Yield Strength for the single Reinforced Al-Mg-Si/10 wt% SiC and hybrid Reinforced Al-Mg-Si/CCA-SiC composites

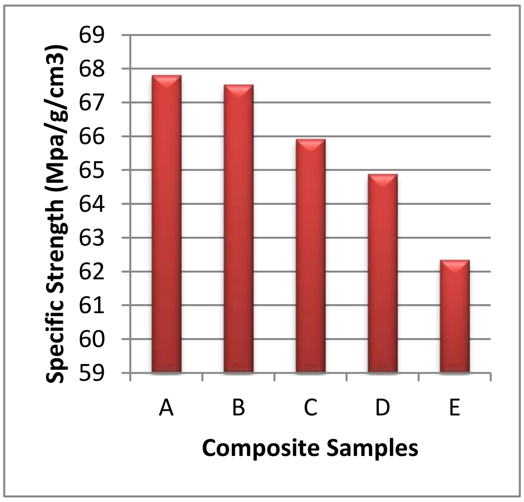



Fig. 5. Variation of Specific strength for single Reinforced Al-Mg-Si/10 wt% SiC and hybrid Reinforced Al-Mg-Si/CCA-SiC composite

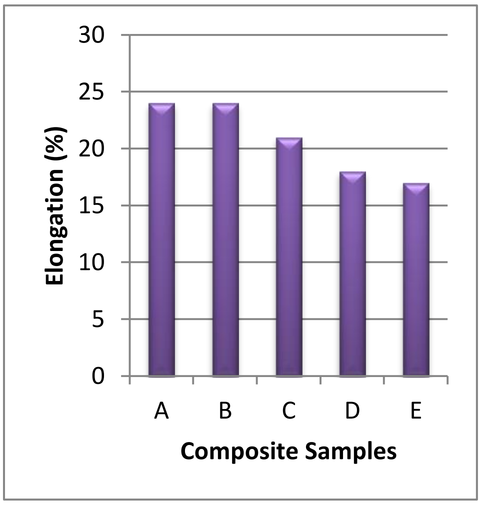



Fig. 6. Variation of (%) Elongation for the single reinforced Al-Mg-Si/10 wt% SiC and hybrid Al-Mg-Si/CCA-SiC composites

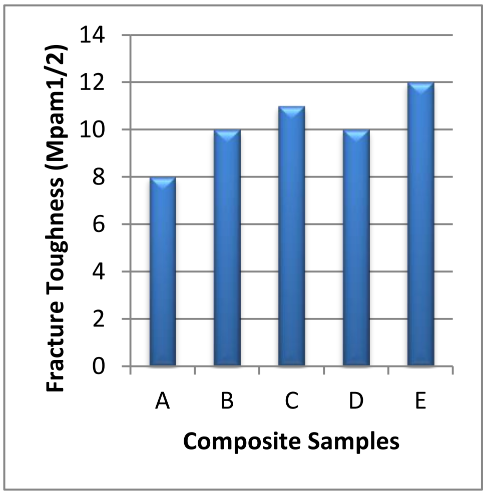



Fig.7. Variation of Fracture toughness for single reinforced Al-Mg-Si/10 wt% SiC and hybrid Al-Mg-Si/CCA-SiC composites

The specific strength (Fig. 5) and percentage elongation (Fig. 6) of the composites were equally observed to decrease slightly with increase in CCA contents. The decrease in specific strength of 0.41%, 2.77%, 4.52% and 8.05% were observed in composites containing 1, 2, 3, and 4 wt% of CCA respectively in comparison with the sample without CCA. The specific strength of 1 wt% CCA containing composite is comparable to that of the sample without CCA which shows that comparable strength to weight ratios can be achieved using cheap CCA as complementing reinforcement in the production of SiC reinforced Al matrix composite thereby reducing cost. Fig. 6 which is the plot of strain to fracture shows that there was no difference between the ductility of 1 wt% CCA containing composite and composite grade without CCA. This shows that good ductility can still be achieved by making use of CCA as complimenting reinforcement in SiC reinforced Al matrix composite.

The fracture toughness values obtained were reported as plain strain fracture toughness because it meets the conditions specified by reference [26] and [22]. The fracture toughness of the composite produced followed reverse trend that is there was a slight increase in fracture toughness with increase in the CCA content with 4 wt% CCA containing composite exhibiting the highest fracture toughness. This behaviour may be attributed to the presence of silica which is a softer ceramic in comparison with SiC. This is in agreement with previous work reported by reference [30] where it was noted that for most engineering materials fracture toughness scales inversely with yield strength. The mechanism of fracture in Al matrix composites has been reported by several authors [29, 30].

During the course of this research work, silicon carbide was purchased at the cost of ~56.25 US dollars/Kg while corn cob ash was processed at ~5.37 US dollars/Kg. This implies that about 50.88 US dollars can be saved by using less expensive CCA as reinforcement in aluminum matrix composites. This analysis shows that depending on the weight percent of CCA in the hybrid reinforcements, lightweight aluminum composites can be produced at reduced cost. From the results of this research work, the maximum decrease in Hardness and UTS of 12.90% and 12.43% respective were observed in 4 wt% CCA containing composites in comparison to composites without CCA. Depending on area of applications, low cost 4 wt% CCA containing composites can still compete favourably with samples reinforced with more expensive silicon carbide. The result of this research work is in agreement with previous works reported by other authors [3, 19, 21].

## 4. Conclusions

The microstructural studies and mechanical behaviour of Al-Mg-Si matrix composites containing 0:10, 1:9, 2:8, 3:7, and 4:6 wt % corn cob ash and silicon carbide as reinforcement were investigated. The results show that:

(1) The less dense Al-Mg-Si/CCA/SiC hybrid composites have estimated percent porosity levels as composite grade without GSA (maximum of 2.332% porosity). This indicated that the use of CCA did not arise in any significant rise in porosity level.

(2) The hardness, ultimate tensile strength, and percent elongation of the hybrid composites decreased gradually in CCA content of the composites.

(3) The fracture toughness of the hybrid composites was observed to be superior to that of the composite sample without GSA.

(4) There is no significant difference between the percentage elongation of 1wt% CCA containing composite and the composite grade without CCA.

(5) CCA has great promise to serve as a complementing reinforcement for the development of low-cost high-performance aluminum hybrid composites.

## References

[1] H. K. Muhammad, I. P. Muhammad , A. U. Mukhtiar, "Manufacturing of aluminum composite material using stir casting process," Mehran University Research Journal of Engineering & Technology, vol. 30, no. 1, pp. 53-64, 2011.

[2] K. K. Alaneme, "Corrosion behaviour of heat treated Al-6063/ SiCp composites immersed in 5wt% NaCl solution," Leonardo Journal of Science, vol. 18, pp. 55- 64, 2011.

[3] K. K. Alaneme, B. O. Ademilua, and M. O. Bodunrin, "Mechanical properties and corrosion behaviour of aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash," Tribology in Industry, vol. 35, no. 1, pp. 25-35, 2013.

[4] A. Macke, B. F. Schultz, and P. Rohatgi, "Metal matrix offer the automotive industry an opportunity to reduce vehicle weight, improve performance," Adv. Materials and Processes, vol. 170, no. 30, pp. 19-23, 2012.

[5] K. K. Alaneme, "Influence of thermo-mechanical treatment on the tensile behaviour and CNT evaluated fracture toughness of borax premixed SiCp reinforced aluminum (6063) composites," International Journal of Mechanical and Materials Engineering, vol. 7, pp. 96-100, 2012.

[6] K. K. Alaneme and O. A. Aluko, "Fracture toughness (K1C) and tensile properties of as-cast and age-hardened aluminium (6063)—silicon carbide particulate composites," Scientia Iranica, vol. 19, no. 4, pp. 992-996, 2012.

[7] T. V. Christy, N. Murugan, and S. Kumar, "A comparative study on the microstructures and mechanical properties of Al 6061 alloy and the MMC Al 6061/TiB2/12p," Journal of Minerals and Materials Characterization and Engineering, vol. 9, no. 1, pp. 57-65, 2010.

[8] S. Mitrović, M. Babić, B. Stojanović, N. Miloradović, M. Pantić and D. Džunić, "Tribological potentials of hybrid composites based on Zinc and Aluminium alloys reinforced with SiC and graphite particles," Tribology in Industry, vol. 34, no. 4, pp. 177-185, 2012.
[9] M. K. Surappa, "Aluminum matrix composites: challenges and opportunities," Sadhana, vol. 28, no. 1&2, pp. 319-334, 2003.
[10] S. Valdez, B. Campillo, R. Perez, L. Martine and H. Garcia, "Synthesis and microstructural characterization of Al−Mg alloy−SiC particulate composite," Materials Letters, vol. 62, no. 17&18, pp. 2623-2625, 2008.
[11] M. A. Maleque, A. Atiqah, R. J. Talib, and H. Zahurin, "New natural fibre reinforced aluminium composite for automotive brake pad," International Journal of Mechanical and Materials Engineering, vol. 7, pp. 166-170, 2012.
[12] D. B. Miracle "Metal matrix composites – from science to technological significance," Composites Science and Technology, vol. 65, no. 15&16, pp. 2526- 2540, 2005.
[13] S. B. Prabu, L. Karanamoorty, S. Kathiresan, and B. Mohan, "Influence of stirring speed and stirring time on distribution of particulates in cast metal matrix composite," Journal of Materials Process Technology, vol. 171, pp. 268-273, 2006.
[14] P. B. Madakson, D. S. Yawas, and A. Apasi, "Characterization of coconut shell ash for potential utilization in metal matrix composites for automotive applications," International Journal of Engineering Science and Technology, vol. 4, no. 3, pp. 1190-1198, 2012.
[15] V. S. Aigbodion, S. B. Hassan, E. T. Dauda and R. A. Mohammed, "Experimental study of ageing behaviour of Al-Cu-Mg/bagasse ash particulate composites," Tribology in Industry, vol. 33, pp. 28-35, 2011.
[16] O. A. Olugbenga and A. A. Akinwole, "Characteristics of bamboo leaf ash stabilization on lateritic soil in highway construction," International Journal of Engineering and Technology Innovation, vol. 2, no. 4, pp. 212-219, 2010.
[17] S.D. Prasad and R. A. Krishna, "Production and mechanical properties of A356.2 /RHA composite," International Journal of Advance Science and Technology, vol. 33, pp. 51-58, 2011.
[18] S. D. Prasad and R. A. Krishna, "Tribological properties of A356.2/RHA composites," Journal of Material Science and Technology, vol. 28, no. 4, pp. 367-372, 2012.
[19] H. Zuhailawati, P. Samayamutthirian and C. H. Mohd Haizu, "Fabrication of low cost Aluminium matrix composite reinforced with silica sand," Journal of Physical Science, vol. 18, no. 1, pp. 47-55, 2007.
[20] E. A. Okoronkwo, P. E. Imoisili and S. O. Olusunle, "Extraction and characterization of amorphous silica from corn cob ash by sol-gel method," Journal of Chemistry and Material Research, vol. 3, no. 4, pp. 68-72, 2013.
[21] K. K. Alaneme, I. B. Akintunde, P. A. Olubambi, and T. M. Adewale, "Fabrication characteristics and mechanical behaviour of rice husk ash – Alumina reinforced Al-Mg-Si alloy matrix hybrid composites," Journal of Material Research and Technology, vol. 2, no. 1, pp. 60-67, 2013.
[22] K. K. Alaneme and A. O. Aluko, "Production and age hardening behaviour of borax pre-mixed SiC reinforced Al - Mg - Si alloy composites developed by double stir casting technique," The West Indian Journal of Engineering, vol. 34, no. 1&2, pp. 80-85, 2012.
[23] K. K. Alaneme, "Mechanical behaviour of cold deformed and solution heat-treated alumina reinforced AA 6063 composites," Journal of European Ceramic. Society, vol. 35, no. 2, pp. 31-35, 2013.
[24] ASTM E 8M, Standard test method for tension testing of metallic materials (Metric). Annual Book of ASTM Standards, Philadelphia, 1991.
[25] G. E. Dieter, Mechanical metallurgy. Singapore: McGraw-Hill, 1988.
[26] S. K. Nath and U. K. Das, "Effect of microstructure and notches on the fracture toughness of medium carbon steel," Journal of Naval Architecture and Marine Engineering, vol. 3, pp. 15-22, 2006.
[27] T. W. Courtney, Mechanical behaviour of materials, 2nd ed. India: Overseas Press, 2006.
[28] N. Chawla and Y. Shen, "Mechanical behaviour of particle reinforced metal matrix composites," Advance Engineering Material, vol. 3, pp. 357-370, 2001.
[29] M. T. Milan and P. Bowen, "Tensile and fracture toughness properties of SiCp reinforced Al alloys: Effects of particle size, particle volume fraction and matrix strength," Journal of Material Engineering Performance, vol. 13, pp. 775- 783, 2004.
[30] K. K. Alaneme, S. M. Hong, I. Sen, E. Fleury and U. Ramamurty, "Effect of copper addition on the fracture and fatigue crack growth behaviour of solution heat - treated SUS 304H Austenitic Steel," Material Science and Engineering, vol. 527, no. 18 &19, pp. 4600-4604, 2010.