Journal of King Saud University – Engineering Sciences (2016) 28, 222–229

King Saud University

Journal of King Saud University – Engineering Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Mechanical properties and microstructural analysis of Al–Si–Mg/carbonized maize stalk waste particulate composites

J.E. Oghenevweta [a], V.S. Aigbodion [b,*], G.B. Nyior [a], F. Asuke [a]

[a] Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria
[b] Department of Metallurgical and Materials Engineering, University of Nigeria, Nsukka, Nigeria

Received 30 July 2013; accepted 26 March 2014
Available online 3 April 2014

KEYWORDS

Al–Si–Mg alloy;
Carbonized maize stalk particulates;
Mechanical properties and microstructures

Abstract The mechanical properties and morphological analysis of Al–Si–Mg/carbonized maize stalk particulate composites was investigated. The compositions of the composite include a matrix of Al–Si–Mg and the carbonized maize stalk particulates as reinforcement ranging from 2% to 10% at an interval of 2%. Properties such as mechanical behaviour of the composites were examined and these include tensile strength, tensile modulus, hardness value, impact energy, percentage elongation and percentage reduction in area. Besides, the microstructures of the developed Al–Si–Mg/carbonized maize stalk particulate composites were investigated. The results of the microstructures of the composite show a uniform dispersion of the reinforcement along the grain boundaries of the alloy. The tensile strength and hardness values increase to 85.60 N/mm^2 and 24HRB at 8 and 10 wt% of carbonized maize stalk respectively, but there is a slight decrease in the impact energy values, values of percentage elongation and percentage reduction in area as the reinforcement increases. From these results of investigation, we concluded that the carbonized reinforcing maize particulates can be used to enhance the properties of Al–Si–Mg alloy for engineering applications.

1. Introduction

Metal matrix composites, as we know them today, have evolved significantly during the past 20 years. The primary support for these composites has come from the aerospace industry for airframe and spacecraft structures. More recently the automotive, electronic and recreation industries have been working diligently with these composites. The driving force behind the development of most of the existing composites has been their capability to be designed to provide needed types of material behaviour. Discontinuously reinforced metal matrix composites have virtually isotropic properties and lend themselves to metallic design methodologies (Aigbodion and Hassan, 2007). The particle and whisker reinforced composites have the advantage of being formable by standard metalworking practices. Classically, stiffness and strength have received

* Corresponding author. Tel.: +234 8028433576.
E-mail address: aigbodionv@yahoo.com (V.S. Aigbodion).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2014.03.009
1018-3639

the most attention as tailorable properties (Kakani and Kakani, 2009).

Discontinuously reinforced aluminium composites are being recognized as an important class of engineering materials that are making significant progress. The reasons for their success are related to their desirable properties including low density, high hardness, high compressive strength, wear resistance, etc. (Aigbodion and Hassan, 2007).

The high cost of current MMCs compared to aluminium alloys has inhibited production on a large industrial scale, for example, in the automotive industry. In the attempt to overcome this limitation, several research and development (R&D) programmes (Aigbodion, 2010) were focused on the refinement of aluminium-based MMCs using low cost industrial waste by-products as the reinforcement particulate. Reinforcing an aluminium alloy with particles of a second phase can improve the physical, mechanical and tribological properties of the material, or it may result in material savings at little detriment to the properties desired. This could reduce the cost and the weight of energy intensive metals for potential applications in engineering components for a new generation of vehicles (Arun Kumar and Swamy, 2011).

The ever-increasing demand for low cost reinforcements stimulated the interest towards production and utilization of by-products from industries as reinforcements since they are readily available or are naturally renewable at affordable cost. Aigbodion (2007) has used Kankara clay (alumino-silicate) in reinforcing Al–Si alloy, Naresh (2006) worked on the development and characterization of metal matrix composite using red mud, an industrial waste for wear resistant applications. Bienia et al. (2003) used fly ash in reinforcement of aluminium matrix. They all reported good dispersion and recovery of the particles in the composite castings. Fly ashes from coal combustion have been successfully combined with aluminium alloys using the foundry process to produce a class of MMCs called Ashalloys. It was demonstrated by Rohatgi et al. (2007) that Ashalloys offer the advantages of reducing the disposal volumes of electric utility industries, providing a high value-added use of fly ash, and at the same time introduced a class of new materials with improved properties at reduced cost. It is in the light of the foregoing researches that investigation into the possibility of using maize stalk ash in metal matrix particulate composite for engineering applications was motivated.

Research has showed that Al–Si–Mg alloys were reinforced with ceramic materials such as SiC, Al_2O_3, and Ti_3. But recent research has showed that biodegradable agricultural wastes can be used to reinforce the alloy. Locust bean shell waste particulates were used as reinforcement on Al–Si–Mg alloy and it was observed that the tensile strength and hardness values increase as the reinforcement increases (Sidi, 2011). Moreover, orange peel ash particulates were used to reinforce Al–Si–Mg alloy and the results showed that there is a slight decrease in the mechanical properties due to poor adhesion of the reinforcement to that of the alloy (Shehu, 2011). Carbonized maize stalk particulates have been used to reinforce polyester and the results showed an enhancement in the mechanical properties of the developed composites (Hassan et al., 2012).

Therefore, this present study is aimed to see the feasibility of using carbonized waste maize stalk particulate as reinforcement of the Al–Si–Mg alloy and to investigate the influence of carbonized maize stalk particulate addition on the mechanical properties and microstructures of the developed composites taking into consideration the interfacial adhesion of the reinforcement in the alloy. The significance of this research is to determine the variation in the mechanical properties and microstructures of Al–Si–Mg alloy by exploiting the influence of the carbonized maize reinforcement in the Al–Si–Mg alloy.

2. Materials/equipment

The materials used in this research are high pure aluminium cables which were sourced from Northern Cable Company (NOCACO), Kaduna, Nigeria while pure silicon and magnesium powders were obtained from National Metallurgical Development Centre (NMDC), Jos. Maize stalk teguments were obtained from agricultural farm in Sabon Gari, Zaria, Nigeria. Other materials such as polishing cloths, Alumina polishing powder, etchant, cylindrical tube and grit papers of various sizes 120, 240, 320, 400 and 600 were obtained from the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria.

The equipment used for this research work includes: metal stirrer, crucible and charcoal furnace, Hounsfield tensometer with serial No. W3179, Indenter universal hardness testing machine Type 8187.5LKV model B, Hounsfield impact energy testing machine Type 6701, Metallurgical microscope connected to a computer system, lathe machine, Setra weighing balance model BL-4105.

2.1. Methods

2.1.1. Carbonization of the reinforcement

The maize stalk wastes were washed in a bowl full of distilled water. After washing, the maize stalk was dried and then cut to pieces and thereafter, it was heated in the absence of air at a temperature of 1200 °C in a coke fired crucible furnace. It was allowed at this temperature for about 1 h for complete conversion into particulates. The product was grounded into fine particles and screened (see Fig. 1).

2.1.2. Sieved analysis

100 g of the reinforcing particulate samples was charged into a set of sieve mesh arranged in descending order of fineness. The samples were shaken for 15 min which is the recommended time to achieve complete classification in accordance with BS 1377:1990. The weight that was retained on each set of sieve mesh was taken and expressed as percentages of the total sample weight. From the weight retained, the grain fineness number (GFN) was computed from the expression;

$$\text{Grain fineness number (GFN)} = \frac{\text{Total product}}{\text{Total sum of percentages collected in each sieve}} \quad (1)$$

2.1.3. Production of the developed composites

The developed composites that are used in this research were produced in the Department of Metallurgical and Materials Engineering workshop, Ahmadu Bello University, Zaria. The composites were produced by keeping the weight percentage of magnesium and silicon constant at 1% Mg and 7% Si according to standard for the preparation of the alloy of this type and varying the amount of carbonized maize stalk particle addition.

Figure 1 Photograph of the sieved carbonized maize stalk particles.

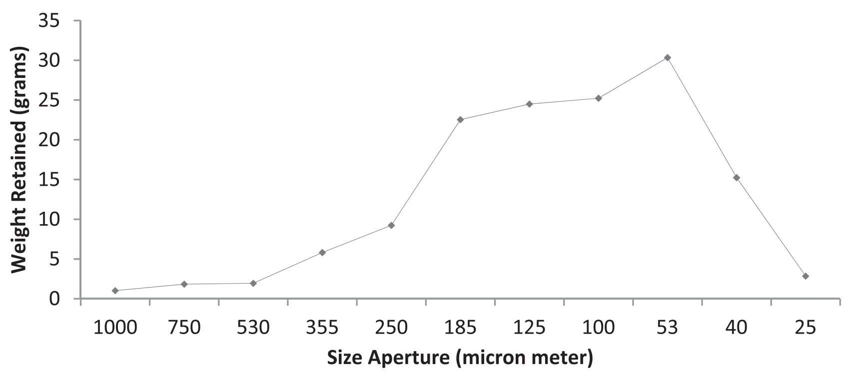

Figure 2 Sieved size analysis of the carbonized maize stalk particles.

The aluminium electrical wires were charged in a graphite crucible and allowing it to melt. After the melting, aluminium was inoculated with the required 1% Mg and 7% Si and thereafter the carbonized maize stalk particulates were added to the melt in the furnace and then stirred thoroughly before pouring.

The molten mixtures were stirred continuously in order to ensure the alloy and the carbonized reinforcing particulates' homogeneity. The melt was brought out from the furnace and poured into a mould having a dimension of 300 mm in length and a diameter of 20 mm. A total of 6 heats were carried out to produce the composites with varying composition of carbonized maize stalk particulate of 0, 2, 4, 6, 8, and 10 respectively. Thereafter, the samples were prepared into standardized test samples in order to determine the mechanical properties of the developed Al–Si–Mg/carbonized maize stalk particulate composites.

2.1.4. Microstructural examination

Optical microscopic analyses were carried out to study the various microstructures of the developed composites. The samples were sectioned and cut out from the unreinforced and reinforced samples. Mounting of the specimens with fused Bakelite was carried out and thereafter, mechanically ground on grades of emery paper (60–800 grits) size using water as the coolant. The ground specimens were polished using a suspension of one-micron size alumina polishing powder in distilled water. Final polishing was done using 0.5 micron alumina polishing powder. After the polishing operation, etching of the specimens was carried out using Keller's regent. The microstructures of the specimens were recorded photographically using an optical microscope with an in-built camera.

3. Results and discussion

Fig. 2 shows the particle size distribution of the maize stalk ash sample. The grain fineness number (GFN) of sample was computed to 92.12. Based on this value, the sample is considered to be fine since GFN of 100 is ranked the most fine. Besides, four mesh sieve sizes contained the bulk of the retained sample on four consecutive sieves corresponding to 185, 125, 100 and 53 μm size fractions therefore, the sample has met the America Foundrymen's Society (AFS) specification. Particles that were retained in 53 μm mesh size were selected for this research because it contained high volume of sieved MSA particles (see Fig. 2).

Macrostructures of the samples revealed a reasonably uniform distribution of the reinforcement (carbonized maize stalk particles) and a slight clustering of particles in some places. The dispersion of these reinforcing particles is influenced by reasonable wettability of the maize stalk particles by the molten metal and probable reasonable interfacial bonding between these particles and Al–Si–Mg alloy. It was also observed that on increasing the percentage weight of the reinforcement beyond 10 wt%, the composite slurry became very thick and the fluidity of the molten metal reduced drastically.

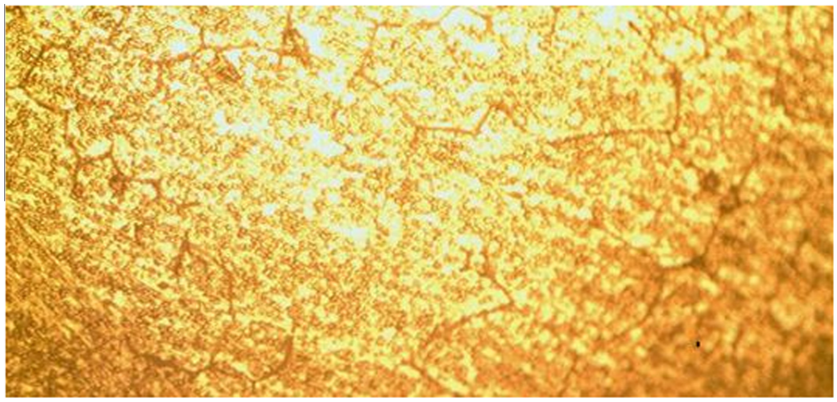

Figure 3 Photomicrograph of unreinforced as-cast Al–Si–Mg alloy, showing magnesium silicide, (Mg_2Si) (black) and α-Al matrix (white). ×100.

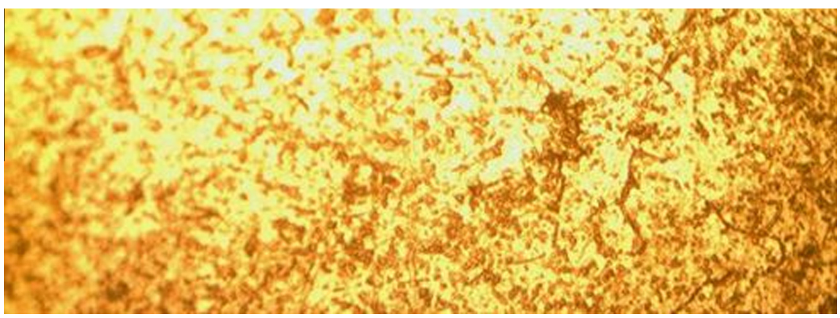

Figure 4 Photomicrograph of Al–Si–Mg/2 wt% carbonized maize stalk particulate composite showing Mg_2Si (black) and uniform dispersion of the maize stalk particulate along the grain boundaries (black) and in the grains of the α-Al matrix (white). ×100.

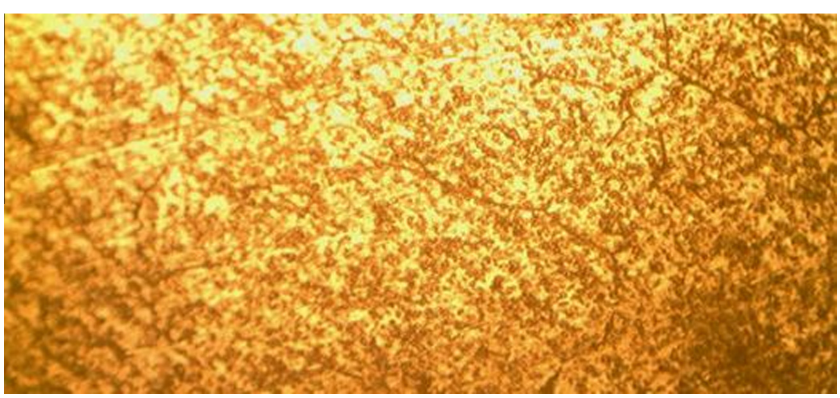

Figure 5 Photomicrograph of Al–Si–Mg/4 wt% maize stalk particulate composite shows a wide distribution of the maize stalk particulates (black) both along the grain boundaries and on the grain of the α-Al matrix (white). ×100.

The microstructure of the unreinforced Al–Si–Mg alloy is shown in Fig. 3. The structure consists of essentially α-Al matrix and Mg_2Si and Al_6SiMg_4 intermetallic compounds distributed within the grains (Shehu, 2011).

Figs. 4–8 show the microstructures of the developed composites. The microstructures consist of small phase discontinuities (phase heterogeneity) and a reasonably uniform distribution of carbonized maize stalk particles in the matrix (phase homogeneity).

It was also observed that the reinforcing phase is shown as dark, while some of the metal phases are either shown as black or white (see Figs. 4–8). Besides, the microstructures also show a tangible agglomeration and segregation of the carbonized reinforcing particles in the Al–Si–Mg/10 wt% carbonized maize stalk particle (see Fig. 8). But other developed composites (Figs. 4–7) show reasonably good distribution of the carbonized maize stalk particles in the Al–Si–Mg alloy. Because of the wettability of magnesium in the matrix excluding the

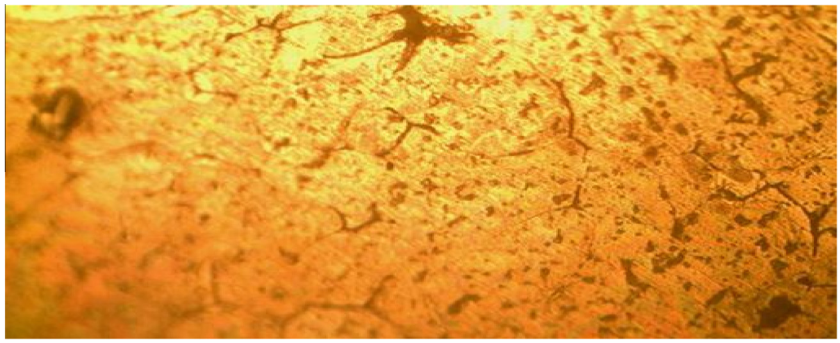

Figure 6 Photomicrograph of Al–Si–Mg/6 wt% maize stalk particulate composites shows a wider distribution of the maize stalk particulates (black) both along the grain boundaries and on the grain of the α-Al matrix (white). ×100.

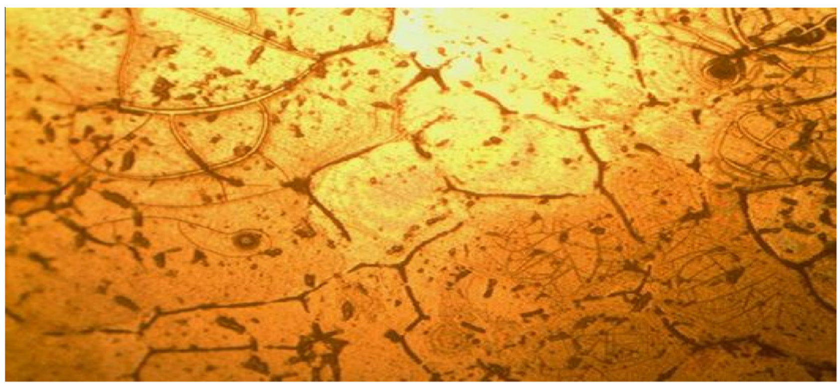

Figure 7 Photomicrograph of Al–Si–Mg/8 wt% maize stalk particulate composites shows a more dispersion of the maize stalk particulates (black) both along the grain boundaries and on the grain of the α-Al matrix (white). ×100.

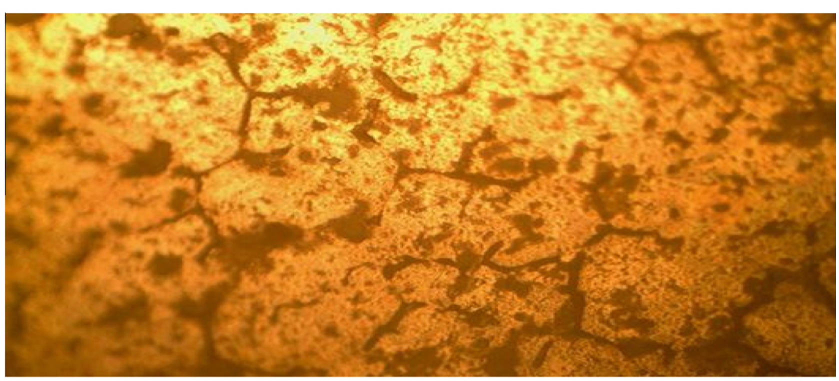

Figure 8 Photomicrograph of Al–Si–Mg/10 wt% maize stalk particulate composites shows a densely segregation and clustering of the maize stalk particulates (black) both along the grain boundaries and on the grain of the α-Al matrix (white). ×100.

double mechanical stirring, there is a tendency of the Al–Si–Mg alloy with the reinforcing particles to experience interfacial bonding. These research findings are in agreement with studies carried out by AnsaryYar et al. (2009) and Aigbodion et al. (2010).

The tensile strength increased with an increasing percentage of carbonized maize stalk particle additions up to maximum values of 85.60 N/mm^2 at 8 wt% of carbonized maize stalk particle addition and then decreased to 65.52 at 10 wt% of carbonized maize stalk particle addition while the tensile modulus which is the ratio of stress to strain increases continuously as the maize stalk particles are added (see Figs. 9 and 10 respectively). The maximum values obtained for both ultimate tensile in this composites at 8 wt% carbonized maize stalk particles as compared with reduced values of this property at 10 wt% carbonized maize stalk particles addition is attributed to the uniform distribution of the carbonized maize stalk particles in the microstructure of the 8 wt% carbonized maize stalk particles (see Fig. 7) as compared with the microstructure of composite with 10 wt% of carbonized maize stalk particles addition (see

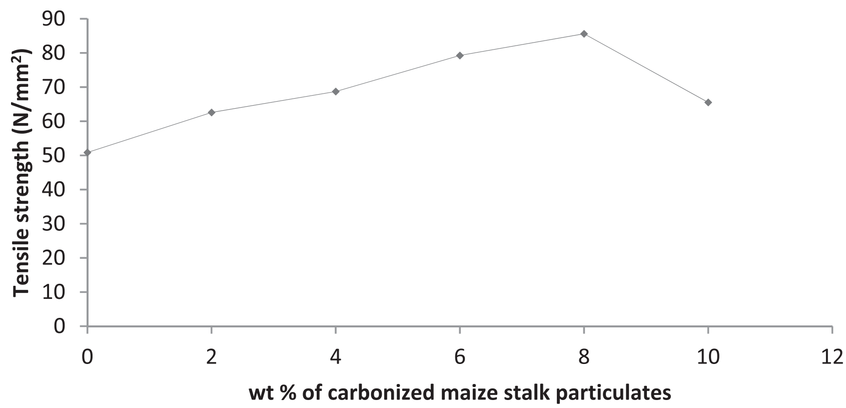

Figure 9 Variation of tensile strength with wt% of carbonized maize stalk particles.

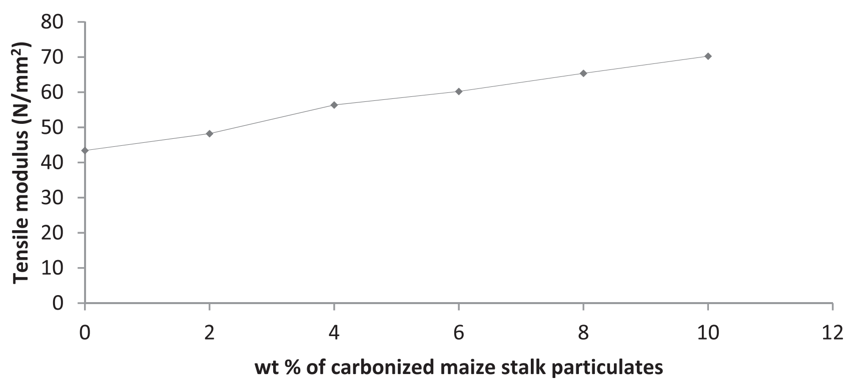

Figure 10 Variation of tensile modulus with wt% of carbonized maize stalk particles.

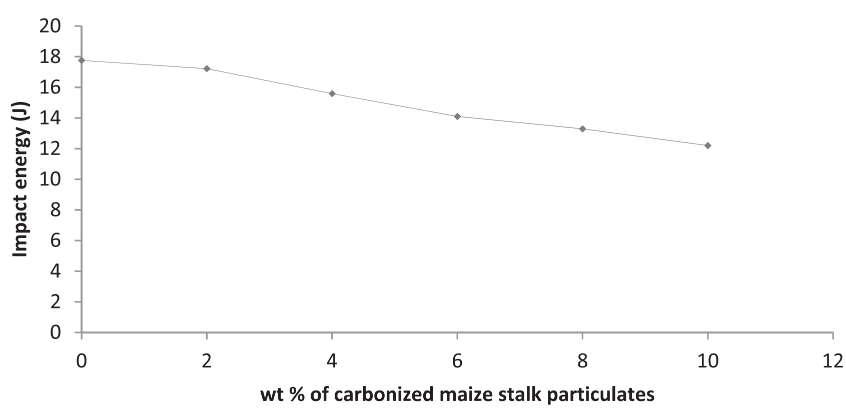

Figure 11 Variation of impact energy with wt% of carbonized maize stalk particles.

Fig. 8). It was verified by Aigbodion et al. (2010) that the contribution of inter-particle distance to strain hardening arises from the fact that the space permitted a dislocation to manoeuvre round obstacles limits the tensile stress. This means that the smaller the interparticle spacing, the higher the strength. This is in agreement with earlier research by Aigbodion et al. (2010).

The impact energy of the developed composites shows decreasing trend as the weight percent of carbonized maize stalk particle addition increases in the Al–Si–Mg alloy (see Fig. 11). The brittle nature of the reinforcing carbonized maize stalk particle plays a vital role in reducing the impact energy of the developed composite. This is in agreement with the earlier observation of Aigbodion et al. (2010).

The percent elongation and percent reduction in area show a continuous decrease as the carbonized maize stalk particles are added (see Fig. 12). The continuous reduction in these properties of these composites could be attributed to the presence of the reinforcing particles clustering in the Al–Si–Mg alloy. Besides, plastic deformation of the mixed metal matrix and the non-deformable reinforcement is more difficult than the metal matrix.

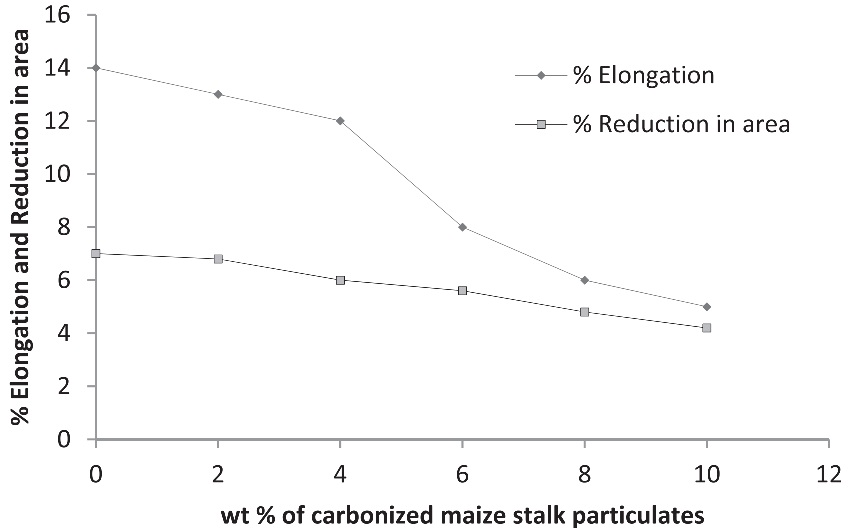

Figure 12 Variation of percent elongation and reduction in area with wt% of carbonized maize stalk particles.

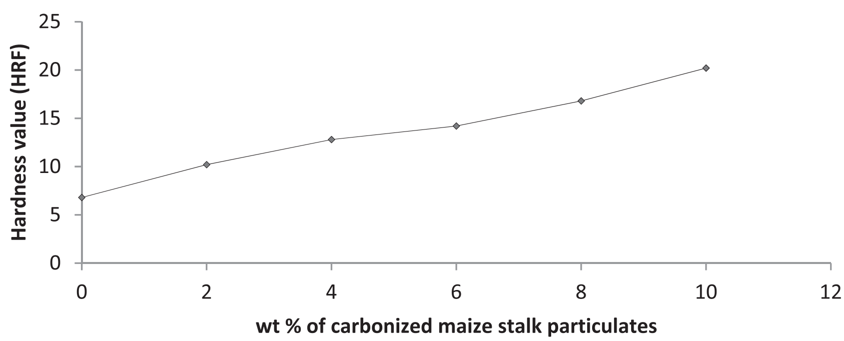

Figure 13 Variation of hardness value with wt% of carbonized maize stalk particles.

The hardness values of the composites increased with an increasing percentage of carbonized maize stalk particle additions. This is probably due to the presence of hard reinforcing carbonized maize stalk particles in the ductile Al–Si–Mg matrix (see Fig. 13).

The 10 wt% of the reinforcement addition to the alloy yielded the highest hardness value. Particle addition may probably increase the strain energy in the periphery of the particles in the matrix and these tendencies may be due to the formation of dislocation at the boundary of these particles (Bedir, 2006). Thus, dislocation motion in the developed composites may probably cause an increase in the residual stress of the composites leading to increased hardness. Theoretically, we know that the higher the amount of the hard particles in the ductile matrix, the higher the density of the dislocation, and as a result, the higher the hardness of the composite as verified by Aigbodion 2007; Sudarshan and Surappa, 2008.

5. Conclusions

The development of Al–Si–Mg/carbonized maize stalk particulate composite has been investigated and the following conclusions are made:

1. The addition of the carbonized maize stalk particulate in Al–Si–Mg alloy affects the microstructures and mechanical properties of Al–Si–Mg/carbonized maize stalk particle composites.
2. The hardness values of Al–Si–Mg/carbonized maize stalk composites increase from 6.80HRF to 20.20HRF as the wt% carbonized maize stalk particulate addition increases.
3. The tensile strength of the developed Al–Si–Mg/carbonized maize stalk particle composite increases from 50.86 to 85.60 N/mm^2 as the carbonized maize stalk addition increases while the tensile modulus also increases from 43.42 to 70.25 N/mm^2 as the carbonized maize stalk particles increases.

References

Aigbodion, V.S., Hassan, S.B., 2007. Effects of silicon carbide reinforcement on microstructure and properties of cast Al–Si–Fe/SiC particulate composites. J. Mater. Sci. Eng. A 447, 355–360.

Aigbodion, V.S., Hassan, S.B., Oghenevweta, J.E., 2010. Microstructural analysis and properties of Al–Cu–Mg/bagasse ash particulate composites. J. Alloys Compd. 497, 188–194.

Aigbodion, V.S., 2007. Particulate-strengthened of Al–Si alloy/alumino-silicate composite. Mater. Sci. Eng. A 460–461, 574–578.

Aigbodion, V.S., 2010. Potential of using Bagasse ash particle in Metal Matrix Composite, PhD Dissertation, Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Samaru, Zaria, Nigeria, pp 34–50.

AnsaryYar, A., Montazerian, M., Abdizadeh, H., Baharvandi, H.R., 2009. Microstructure and mechanical properties of aluminum alloy matrix composite reinforced with nano-particle MgO. J. Alloys Compd. 484, 400–404.

Arun Kumar, M.B., Swamy, R.P., 2011. Evaluation of mechanical properties of Al6061, Flyash and E-glass fiber reinforced hybrid metal matrix composites. ARPN J. Eng. Appl. Sci. 6 (5), 40–44.

Bedir, F., 2006. Fabrication of two-layered Al-B_4C composites by conventional hot pressing under nitrogen atmosphere and their characterization. J. Mech. Sci. Technol. KSME 20, 1002–1011.

Bienia, J., Walczak, M., Surowska, B., Sobczaka, J., 2003. Microstructure and corrosion behaviour of aluminum fly ash composites. J. Optoelectron. Adv. Mater. 5 (2), 493–502.

Hassan S.B., Oghenevweta, J.E., Aigbodion, V.S., 2012. Morphological and mechanical properties of carbonized waste maize stalk as reinforcement for eco-composites. J. Compos. Part B: Eng. Elsevier, 43B(5), 2230–2236.

Kakani, S.L., Kakani, A., 2009. Material Science, New Age International (P) Ltd, pp. 593–609.

Naresh, P. 2006. Development and characterization of metal matrix composite using red Mud an industrial waste for wear resistant applications, PHD thesis Department of Mechanical Engineering, National Institute of Technology Rourkela 769 008 (India), January, pp. 23–34.

Rohatgi, P.K., Rajan, T.P.D., Pillai, R.M., Pai, B.C., Satyanarayana, K.G., 2007. Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes. Compos. Sci. Technol. 67, 3369–3377.

Shehu Umar, 2011. Development of Al–Si–Mg/orange peels ash particulates eco-composites for engineering applications. Undergraduate research thesis submitted to the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria.

Sidi, M.S. 2011. Development of Al–Si–Mg/bean shell waste particulate. Undergraduate research thesis submitted to the Department of Metallurgical and Materials Engineering, Ahmadu Bello University.

Sudarshan, M., Surappa, K., 2008. Synthesis of fly ash particle reinforced A356 Al composites and their characterization. Mater. Sci. Eng. A 480, 117–124.