Usak University Journal of Material Sciences

journal homepage: http://uujms.usak.edu.tr

Research article

Development of Al-Si-Fe/Rice husk ash particulate composites synthesis by double stir casting method

Victor Sunday Aigbodion

Department of Metallurgical and Materials Engineering, University of Nigeria, Nsukka, Nigeria

Received 17 September 2012   Revised 06 November 2012   Accepted 14 November 2012

Abstract

The dispersion strengthened of Al-2.8%Si-0.8%Fe alloy reinforced with rice husk ash was produced by double stir-casting method. Properties namely: density, hardness, impact energy, tensile strength and microstructure were analyzed. The result of the tests and analysis carried out, revealed that addition of rice husk ash as reinforcement increases hardness values with a decrease in density and impact energy, as the weight fraction of rice husk ash increased in the alloy. The strength increased up to a maximum of 15 wt% addition of the reinforcement. The microstructure revealed the distribution of the rice husk ash particle in the ductile metal matrix. However, an increase in strength and hardness values occurs because the highly dispersed phase severely restricts the movement of dislocation through the metal lattice. This study has showed that abundant rice husk can be used in the production of metal matrix composites for engineering applications.

Keywords: *Metal matrix composites, rice husk ash, microstructure and mechanical properties*

1. Introduction

In the last two decades, most research and development efforts have aimed at reinforcing monolithic metals and alloys with a ceramic phase with the primary purpose of enhancing their properties, spanning the domains of physical, mechanical and fracture behavior[1-2]. Also strong interest has been shown in the application of metal matrix composites (MMCs) in the design of many engineering and non-engineering components [3-4].

Thus researchers have worked out separately to reinforce SiC, Al_2O_3 (i.e. carbides, Nitrides and oxides) TiB_2, Boron and Graphite into the Aluminium matrix to achieve different properties and they are expensive [5].

The ever-increasing demand for low cost reinforcement stimulated the interest towards production and utilization of using by-product from industry as reinforcement since they are readily available or are naturally renewable at affordable cost.

Corresponding author: Tel: +23 – 480 – 28433576
e-mail: aigbodionv@yahoo.com

Aigbodion [6] have used Kankara clay(aluminosilicate) in reinforcing Al-Si alloy; Bienia et al. [7] used fly ash in reinforcement of aluminium matrix; Naresh [8] worked on the development and characterization of metal matrix composite using red mud an industrial waste for wear resistant applications. Fly ashes from coal combustion have been successfully combined with aluminium alloys using the foundry process to produce a class of MMCs called Ashalloys [9-14]. It was demonstrated by Rohatgi et al. [13-14] 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 research that investigation on the possibility of using rice husk ash in Al-Si-Fe alloy particulate composite for engineering applications was motivated. The results that will be obtained in this research can act as a starting point for both industrial designers and researchers to design and develop MMCs components using this Agro-industrial waste for engineering applications which will be a great benefit to Nigeria and the world at large.

2. Experiment Procedure

2.1. Materials

High purity aluminium electrical wires obtained from Northern Cable Company NOCACO (Kaduna), ferrosilicon, rice husk ash particle, moulding box, silica sand, bentonite and Etchants.

2.2. Equipment

Pyrometer, mechanical stirrer, crucible, electrical resistance furnace, Avery Denison impact tester, Rockwell hardness, Tinus – Olsen tensile test machine, grinding and polishing machine, and Scanning electron microscope.

2.3. Method

Mini Pal compact energy dispersive X-ray spectrometer (XRF) was used for the elemental analysis of the rice husk ash. The system is controlled by a PC running the dedicated Mini Pal analytical software [3].

The synthesis of the metal matrix composite that was used in this study was produced using double stir-casting method at the Foundry Shop of the National Metallurgical Development Centre, Jos, Nigeria. The specimens were produced by keeping the percentage of iron and silicon constant and varying the reinforcing material (rice husk particle) particles in the range 5-20%. All the melting was carried out in a clay-graphite crucible in a resistance furnace. Al-2.8%Si-0.8%Fe alloy was preheated at 450^{o}C for 2 hours before melting, and before mixing the rice husk ash particles, was preheated at 1000^{o}C for 1 hour to make their surfaces oxidized[1-2].

The furnace temperature was first raised above the liquidus 720^{o}C to melt the alloy completely and then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated rice husk ash particles was added and mixed manually. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state.

After sufficient manual mixing was done, the composite slurry was re-heated to a fully liquid state and then automatic mechanical mixing was carried out for about 20 minutes at an average stirring rate of 150 rpm. In the final mixing processes, the furnace temperature was controlled between 730 and 740^{o}C and 0.01%NaCl-KCl was added as a covering flux. The pouring temperature was controlled to be about 720^{o}C [2].

A preheated sand mould with diameter 18 mm and 30 mm length was used to prepare cast bars. After casting, the density and porosity of the varying composition produced was determined and the specimens were machined into tensile, impact and hardness test specimen for the purpose of determining the mechanical properties.

The basic method of determining the density of a specimen by measuring the mass and volume of the specimen was used. The density of the specimen was then estimated from the formula given below [9-14]:

$$\text{Density}=\text{mass}/\text{volume}\ (g/cm^3) \tag{1}$$

The specimens for apparent porosity (P_a) were kept in the oven at 110^{o}C for 3 hours to obtain constant weight D. The specimen was then suspended in distilled water and boiled on a hot plate for 30 minutes. After boiling, while still in hot water, the water was displaced with cold water and the weight S was measured on a digital balance hinged on the tripod stand. The test specimen was removed from the water, and extra water was wiped off from the surface by lightly blotting the specimen with wet towel and the weight W of the soaked specimen suspended in air was measured. The apparent porosity of the specimen were determined from the relationship below [3-4]:

$$P_a = W\text{-}D/W\text{-}S \times 100(\%) \tag{2}$$

The microstructure and the chemical compositions of the phases present in the composites test samples were studied using a JOEL JSM 5900LV Scanning Electron Microscope equipped with an Oxford INCA™ Energy Dispersive Spectroscopy system at the department of Chemical and Metallurgical Engineering, University of Witwatersrand, Johannesburg South Africa. The samples were firmly held on the sample holder using a double-sided carbon tape before putting them inside the sample chamber. The SEM was operated at an accelerating voltage of 5 to 20 Kv [3,14].

Hardness was determined using the Rockwell hardness test machine. The indenter used was a 1.56 mm steel ball and minor load of 10 kg and major load of 100 kg was applied. Rockwell B scale and Hardness of 101.2 HRB standard block were used [1-2].

Impact tests were conducted using a fully instrumented Avery Denison test machine and striking velocity 3.5 m/sec. Charpy impact tests were conducted on notched specimens. Test specimens measured 75 mm length with diameter of 10 mm. The notch had a depth of 2 mm and a notch tip radius of 0. 02 mm at an angle of 45^{o} [5-7].

The tensile properties were conducted on Tinus– Olsen test machine, the original diameter of the specimens were 12.5 mm and gauge length of 50 mm. The yield strength, ultimate tensile strength and percentage elongation of the specimens were determined [2].

3. Results and Discussion

The XRF chemical composition of the rice husk ash is represented in Table 1. XRF analysis confirmed that SiO_2, Al_2O_3 and Fe_2O_3 were found to be the major constituents of the ash. The presence of silicon dioxide, iron oxide and alumina in the ash shows that the ash contains hard substances [2-3,9-14]. Some other oxides viz. K_2O, Na_2O and MnO were also found to be present in traces. The presence of hard elements like SiO_2, Al_2O_3 and Fe_2O_3 suggests that the rice husk ash can be used as particulate material for reinforcement.

Table 1

XRF analysis of rice husk ash

Element	Al_2O_3	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	25.34	4.67	18.54	0.62	1.30	0.25	38.80	0.11	0.04

Macro structural studies of the developed composites revealed a reasonably uniform distribution of rice husk ash particles and a slight macro-segregation of particles in some places. The distribution of rice husk ash particles is influenced by good wettability of the rice husk ash by the molten metal and good interfacial bonding between rice husk ash particles and matrix material. The good wettability obtained in this study was a result of the double stirring method used during casting which helped to avoid gravity segregation [2-3].

The XRD pattern of the aluminium alloy and the alloy reinforced with coconut shell ash composites manufactured by stir casting method are shown in Figs. 1-2. From the Figs. 1-2, it was observed that the major phases of the aluminium alloy are Fe_3Si, Al_6Fe, Al and SiO_2(see Fig. 1). The composite shows smaller inter-planar distance, and the Phases are SiC, Fe_3C FeSi SiO_2 and C(see Fig. 2). In these diffractograms, one can evidently deduce the crystalline phases of the aluminium alloy from that of the composites material. The X-ray patterns show Fe_3Si, Al_6Fe, Al presence in the matrix Aluminium alloy and evident of the coconut shell ash particles in the composite.

The microstructure of the unreinforced alloy is shown in Fig. 3. The structure reveals the eutectic silicon containing $FeSiAl_5$ phase in aluminium matrix. Figs. 4-5 show the microstructure of the reinforced alloy with rice husk ash particle. The microstructure reveals that there are small discontinuities and a reasonably uniform distribution of rice husk ash particulates. The ceramic phase is shown as dark phase, while the metal phase is white. However, there is an agglomeration and segregation of rice husk ash particles in the microscale with alloy reinforced with 20 wt% rice husk ash particle (see Fig. 5). These structures are in line with the co-continuous interlaced phases of aluminium-alumina needles as found by Aigbodion[2]. These structures are in agreement with phases studied by other researchers [8-12].

Finally, as mentioned above, no particle fragmentation occurs in the aluminium alloy melt, giving rise to a clean surface, which can form an intimate contact with the aluminium alloy melt and obtain a perfect metallurgical bonding after solidification without impurities or gas presenting at particle-matrix interface.

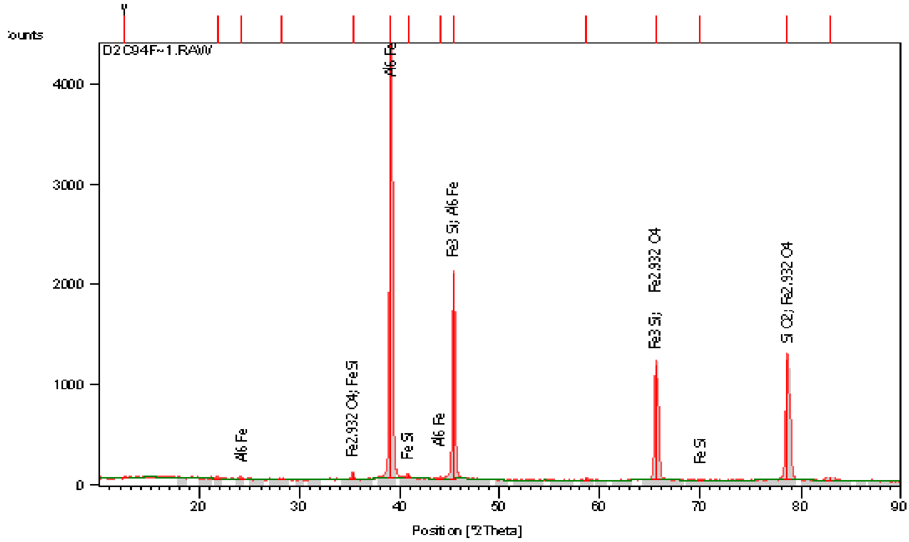

Fig. 1 XRD pattern of the aluminium alloy

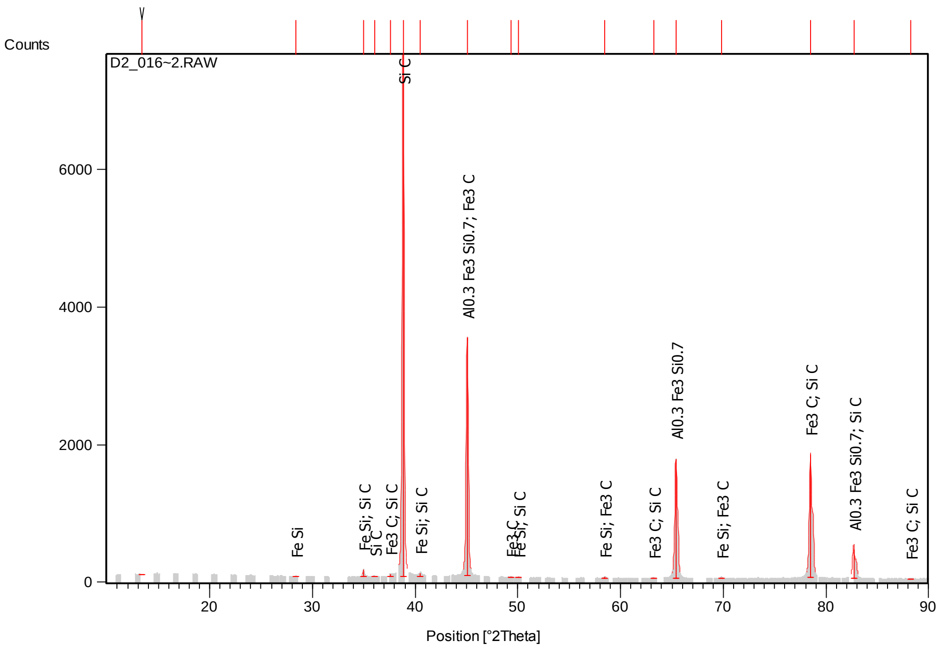

Fig. 2 XRD pattern of the composite with 10 wt% rice husk ash

The diversified chemical composition of rice husk ash particles and its high reactivity can form compounds by chemical reactions between rice husk ash particles and liquid aluminium during the synthesis of the composites. The reaction between rice husk ash-reinforcement containing silica and liquid aluminium can lead to the formation of alumina and silicon [3]

$$4Al + 3SiO_2 = 2Al_2O_3 + 3Si$$

The development of some primary silicon single crystals in the vicinity of rice husk ash is seen in Fig. 3.

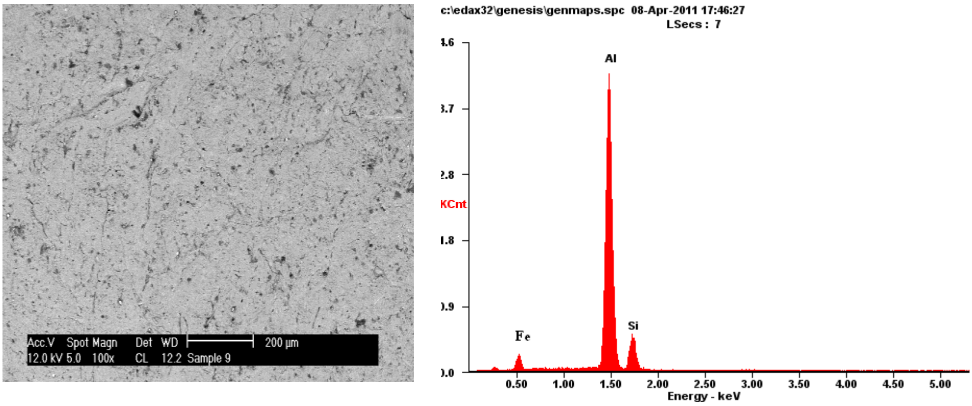

Fig. 3 SEM/EDS of the aluminium alloy

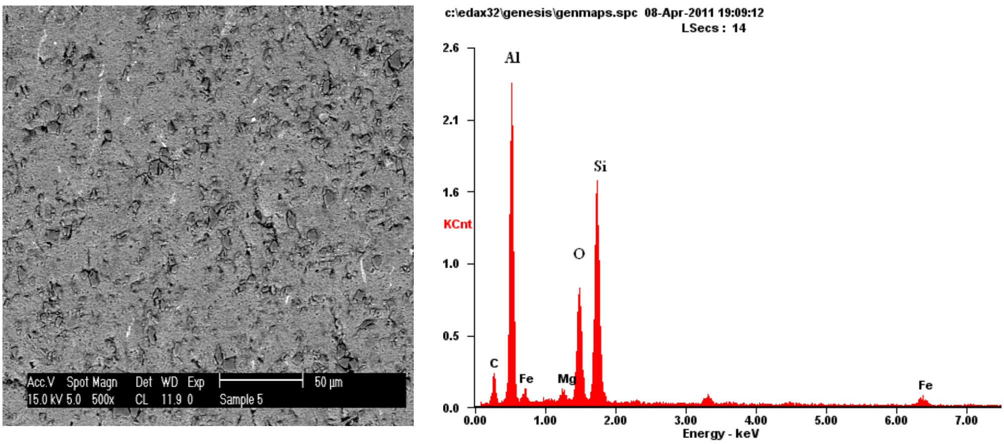

Fig. 4 SEM/EDS of the aluminium alloy reinforced with 10 wt% rice husk ash

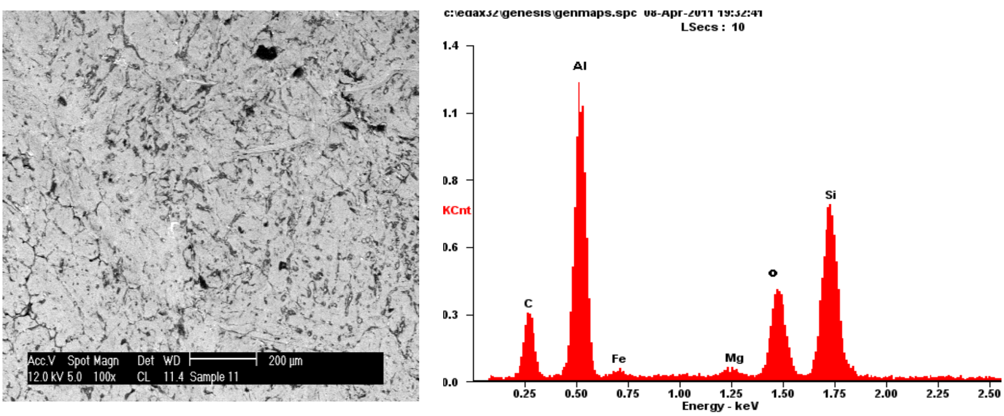

Fig. 5 SEM/EDS of the aluminium alloy reinforced with 20 wt% rice husk ash

The results of density measurements on the base alloy and reinforced materials are shown in Fig. 6.

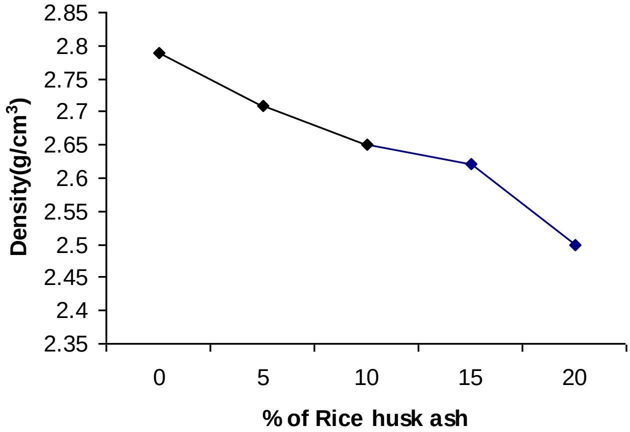

Fig. 6 Variation of density with weight percentage of rice husk ash addition

The results reveal that the presence of rice husk ash particulates has little effect on the density of the MMCs. Since the density of the reinforced rice husk particles composites decreased from 2.79 g/ cm^3 at 0% rice husk addition to 2.50 g/ cm^3 at 20%rice husk ash addition. Hence, not much change in the MMCs density was observed.

The apparent porosity values of the reinforced MMCS with rice husk ash particles slightly increased with percentage rice husk ash addition (see Fig. 7).

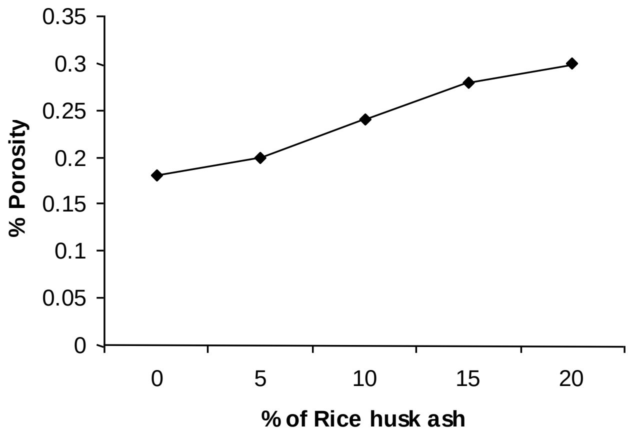

Fig. 7 Variation of percentage of porosity with weight percentage of rice husk ash addition

The obtained values were lower than that obtained by Zhou et al. [15]. The lower values of apparent porosity obtained in this study was a result of the use of a covering fluxes combine with double stirring method during casting. The yield strength and ultimate tensile strength increased with increasing percentage rice husk ash addition up to maximum values of 100.56 and 125 N/mm^2 at 15% rice husk addition and then decreased to 100.12 and 123 N/mm^2 at 20% rice husk ash addition respectively (see Figs. 8-9).

The decrease in the strengths at 20% rice husk ash addition is attributed to the agglomeration and segregation of rice husk ash particles in the microstructure (see Fig. 5). With increasing weight fraction of rice husk ash, more loads are transferred to the reinforcement which also resulted in a higher tensile strength. This behavior is in agreement with the work carried out by Aigbodion and Hassan [1]. This result may be attributed to several factors including the good particle-matrix interfacial bonding, the fine reinforcement particle size, the strengthening effect of the rice husk ash on the aluminium alloy matrix [14-15].

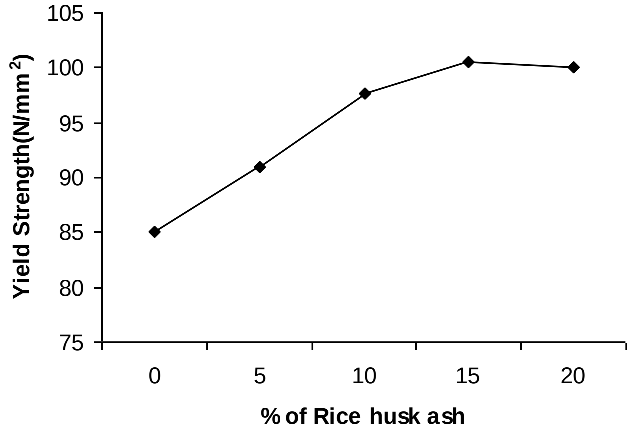

Fig. 8 Variation of Yield Strength with weight percentage of rice husk ash addition

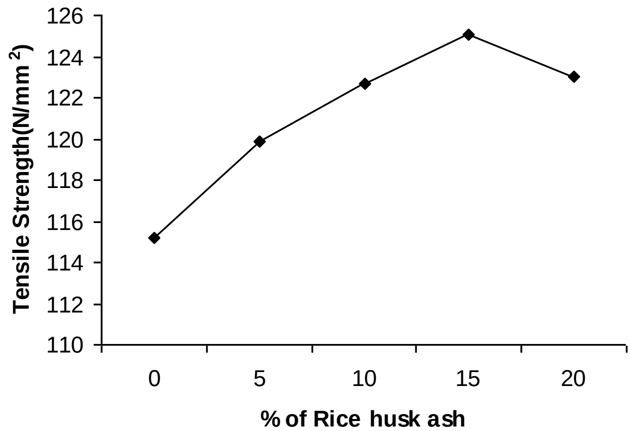

Fig. 9 Variation of Tensile Strength with weight percentage of rice husk ash addition

In general, when ceramic particles are introduced to a metal matrix by casting method, particle-porosity clusters tend to occur due to the poor wettability and gas entrapment during mixing [1-5]. However, the defect has not been found in the present study, which can be attributed to the good wettability of the rice husk ash particles with aluminium alloy melt which helped the dispersion process of the particles in the aluminium alloy melt [15]. The hardness values increases as the percentage rice husk ash addition increases in the alloy (see Fig. 10).

This is due to increase in the percentage of the hard and brittle phase of the ceramics body in the alloy. The rice husk ash addition reinforcement to the alloy increases the dislocation density at the particles-matrix interfaces. This is in agreement with the result obtained by Rohatgi et al. [13-14]. This is because the differences in coefficient of thermal expansion (CTE) between the hard and brittle reinforcing particles and soft and ductile metal matrix result to elastic and plastic incompatibility between the matrix and the reinforcement. Hence, there is an improvement in the hardness values.

The strengthening effect of rice husk ash particles is noticeable, with the hardness values and tensile strength values of the composites. To understand the above improvement, it is desirable to discuss the strengthening mechanism in details. Generally, the mechanical properties of metallic materials are significantly affected by various factors, such as grain-boundaries, sub-structures, solid solutions, second phases, and so on. For the present materials, contributions from sub-structures and solid solutions effects can be ignorable. Based on the structural information obtained above (Figs. 3-4), the grain refinement of the matrix and the reinforcement contributed by breadfruit seed hull ash particles are the main reasons for the improvement of the hardness and tensile strength illustrated above.

The impact energy (see Fig. 11) decreased as the percent rice husk ash addition increased in the alloy. The brittle nature of the reinforcing materials rice husk ash plays a significant role in degrading the impact energy of the composite, since the unreinforced alloy and the alloy with 5% rice husk ash particles have the highest impact energy which means they are the toughest of them all.

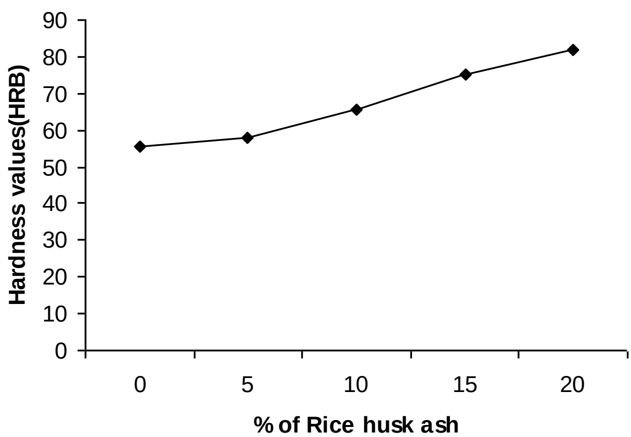

Fig. 10 Variation of hardness values with weight percentage of rice husk ash addition

The increase in strength with percent rice husk ash addition may be due to the formation of nearly uniform distribution of rice husk ash particles of the soft alloy (see Figs. 2-3) which acts as a key and thereby building up resistances to slip; hence, increasing the strength of the reinforced alloy.

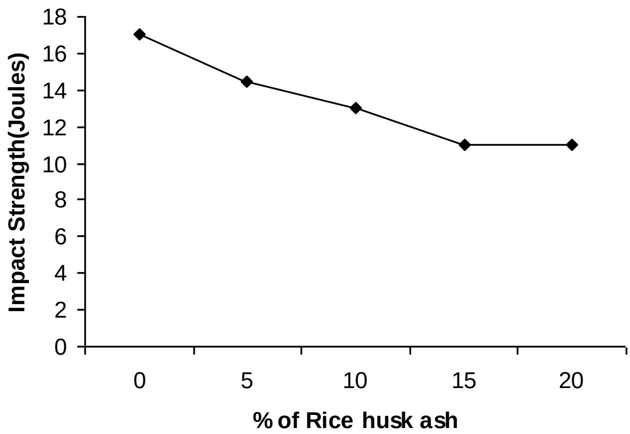

Fig. 11 Variation of Impact energy with weight percentage of rice husk ash addition

4. Conclusions

Considerable success was recorded in the synthesis of Al-Si-Fe alloy with rice husk ash addition. From the results obtained in this research, it can be concluded that addition of rice husk ash particles using double stir casting method to Al-Si-Fe alloy increases both the yield strength, ultimate tensile strength and hardness values up to a maximum values of 79.98, 106.12 Nmm^2 and 67 HRB respectively at 15% rice husk ash addition. However, it is accompanied by a general reduction in impact energy and density. There is general slight increase in the apparent porosity of the composites with percentage rice husk ash addition which is still lower than the recommended values. For optimum service performances of this alloy, rice husk ash addition should be between 10-15% and not exceed 15% in order to develop better necessary properties.

References

1. Aigbodion VS and Hassan SB. Effects of silicon carbide reinforcement on microstructure and properties of cast Al-Si-Fe/SiC particulate composites. Journal of Materials Science and Engineering A, 2007; 447: 355 – 360.
2. Aigbodion VS. Potential of using bagasse ash particle in metal matrix composite, PhD Dissertation, Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Samaru, Zaria, Nigeria, 34 – 50, 2010.
3. Siva Prasad D and Rama Krishna A. Production and mechanical properties of A356.2 /RHA composites. International Journal of Advanced Science and Technology, 2011; 33: 51 – 58.
4. Arun Kumar MB and Swamy RP. Evaluation of mechanical properties of Al6061, flyash and e-glass fiber reinforced hybrid metal matrix composites. ARPN Journal of Engineering and Applied Sciences, 2011; 6(5): 40 – 44.
5. Rohatgi PK, Rajan TPD, Pillai RM, Pai BC and Satyanarayana KG. Fabrication and characterization Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes. Composites Science and Technology, 2007; 67, 3369 – 3377.
6. Aigbodion VS. Particulate-strengthened of Al-Si alloy/alumino-silicate composite materials science and Engineering A, 2007: 460 – 461, 574 – 578.

7. Bienia J, Walczak M, Surowska B and Sobczaka J. Microstructure and corrosion behaviour of aluminium fly ash composites. Journal of Optoelectronics and Advanced Materials, 2003; 5(2), 493 – 502.
8. Naresh P. 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, India, 23 – 34, 2006.
9. Guo RQ, Rohatgi PK and Nath D. Compacting characteristics of aluminium-fly ash powder mixtures. Journal of Materials Science, 1996; 31, 5513 – 5519.
10. Guo RQ, Rohatgi PK and Ray S. Casting characteristics of aluminium alloy, fly ash composites. Transactions of the American Foundrymen's Society, 1996; 104: 1097 – 1102.
11. Rohatgi PK and Guo RQ. Low Cost Cast Aluminium – fly ash composites for ultralight automotive application. TMS Annual Meeting, Automotive Alloys, 157-168, 1997.
12. Rohatgi PK. Low-cost, fly ash containing aluminium matrix composites. JOM, 1994; 29: 55 – 59.
13. Rohatgi PK, Guo RQ and Keshavaram BN. Cast aluminium alloy – fly ash composites. Key Engineering Materials, 1995; 104-107: 283 – 292.
14. Rohatgi PK, Guo RQ, Iksan. H, Borchelt EJ and Asthana R. Pressure infiltration technique for synthesis of aluminium-fly ash particulate composite. Metallurgical & Materials Transaction A, 1997; 244: 22 – 30.
15. Zhou W and Xu ZM. Casting of SiC reinforced metal matrix composites. J. Materials Proc. Technol., 1997; 63: 358-363.