Gazi University Journal of Science
GU J Sci
26(3):449-457 (2013)

Evaluation of Cast Al-Si-Fe alloy/Coconut Shell Ash Particulate Composites

S.Y. AKU[1], D.S. YAWAS[1], A. APASI[1,♠]

[1]Ahmadu Bello University, Department of Mechanical Engineering, Samaru, Zaria, Nigeria.

Received: 06.02.2012 Resubmitted: 09.03.2013 Accepted:03.05.2013

ABSTRACT

Al-7wt%Si-2wt%Fe alloy/Coconut shell ash(CSAp) composites having 3-15wt%coconut shell ash were fabricated by double stir-casting method. The microstructure, hardness values and density of the composites were evaluated. The density of the composites decreased as the percentage of coconut shell ash increases in the aluminum alloy. This means that composites of lower weight component can be produced by adding CSAp. Microstructural analysis showed fairy distribution of coconut shell ash particles in the aluminum alloy. The presence of the coconut shell ash particles in the matrix alloy resulted in a much smaller grain size in the cast composites compared to the matrix alloy as confirmed from X-ray diffractometer analysis. Significant improvement in hardness values is noticeable as the wt% of the coconut shell ash increased in the alloy. Hence, this work has established that incorporation of coconut shell particles in aluminum matrix can lead to the production of low cost aluminum composites with improved hardness values.

Key words: Aluminum alloy, Coconut shell ash, Density, Microstructure and Hardness values

♠Corresponding author, e-mail: okomasi@yahoo.com

1. INTRODUCTION

Metal Matrix Composites (MMCs) reinforced with ceramic particulates offer significant performance advantages over pure metals and alloys. MMCs tailor the best properties of the two components, such as ductility and toughness of the matrix and high modulus and strength of the reinforcements [1-2]. These prominent properties of these materials enable them to be potential for numerous applications such as automotive, aerospace and military industries [3].

MMCs can be divided into three categories: particle reinforced MMCs, short fiber reinforced MMCs and continuous fiber reinforced MMCs. Of these three categories, the fabrication cost of particulate reinforced MMCs is low [3-4], which makes it attractive and commercially viable to consider for industrial applications [4].

The high cost of current metal matrix composites(MMCs), interfacial reaction and high density of most common ceramic reinforcement compared to aluminum alloys has inhibited production on a large industrial scale, for example in the automotive industry [2-3]. In attempts to overcome this limitation, several research and development (R&D) programme were focused on the reinforcement of aluminum-based MMCs using low cost industrial waste byproducts as the reinforcement particulate. This could reduce the cost and the weight of energy intensive metals for potential applications in engineering components for a new generation of vehicles. However, the future commercialization of these materials in automotive industry will be also influenced by the ability to recycle the scrap and the final components when its useful life is over. 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 [1, 4].

The ever-increasing demand for low cost reinforcements stimulated the interest toward production and utilization of by-products from industries as reinforcements since they are readily available or are naturally renewable at affordable cost. Hassan and Aigbodion [5] has used bagasse ash(sugar cane waste) in development of metal matrix composites, Aigbodion [3] has used Kankara clay (alumino-silicate) in reinforcing Al–Si alloy, Bienia et al.[4] used fly ash as a reinforcement in aluminium matrix, Prasad [6] worked on the development and characterization of metal matrix composite using red mud, an industrial waste for wear resistant applications. They all reported good dispersion and recovery of the particles in the composites 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 [7-8]. It was demonstrated by Rohatgi et al [9] 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. Hence, composites with coconut shell ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. It is therefore expected that the incorporation of coconut shell ash particles in aluminium alloy will promote yet another use of this low-cost waste by-product and thereby, reducing the cost of aluminium products. Based on the forgoing, the present investigation has been focused on the utilization of abundantly available coconut shell in useful manner by dispersing it into aluminium to produce composites by stir casting method.

2. MATERIALS AND METHOD

2.1. Materials

The coconut shell used in this work was obtained from a coconut seller in Kaduna, Kaduna state of Nigeria.

2.2. Equipment

Equipment used in this research are- electrical resistance furnace, X-ray diffractometer (XRD), Scanning electron microscope with energy dispersive spectrometer (SEM/EDS) Machine, X-ray fluorescent XRF, Brinell hardness machine.

2.3. Method

The coconut shell was grinded to form coconut shell powder; the powder was packed in a graphite crucible and fired in muffle electric heat treatment furnace at temperature of 1300^{o}C to form coconut shell ash (CSAp).

The particle size analysis of the coconut shell ash particles was carried out in accordance with BS1377:1990 [5]. About 100g of the coconut shell ash particles was placed unto a set of sieves arranged in descending order of fineness and shaken for 15minutes which is the recommended time to achieve complete classification. The weight retained on 100µm was used in this research [6].

Mini Pal compact energy dispersive X-ray spectrometer (XRF) was used for the elemental analysis of the coconut shell ash. The system is controlled by a PC running the dedicated Mini Pal analytical software [6].

The metal matrix composite that was used in this study was produced at the Foundry shop of the National Metallurgical Development Centre, NMDC, and Jos Nigeria by double stir casting method. The specimen were produced by keeping the percentage of iron and silicon constant, while the coconut shell ash particles (CSAp) were varied from 3-15wt%CSAp with interval of 3wt%. High purity aluminum cable wire free from dust and contamination with 7wt%Si was charged into a graphite crucible. The crucible furnace was heated to about 750^{o}C till the entire alloy in the crucible melted and then 2wt % iron powder was then added. The reinforcement particles (CSAp) were preheated to 950^{o}C for 2 hrs before incorporation into the melt in order to improve wettability and harmonize the temperature [5]. After the molten metal was fully melted, degassing tablets (hexachloroethane) were added to reduce porosity. A stirrer made of stainless steel with graphite coating was lowered into the melt slowly to stir the molten metal at the speed of 450–500 rpm. Before adding the (CSAp), 1wt%Mg was added to the melted. The preheated CSAp were then added into the molten metal by vortex method. The stirring was continued for another 5 min after the completion of feeding of the CSAp. A preheated sand mould with diameter 15 mm and 300mm length was used to produce cast bars. Using these processes, 3–15wt%CSAp composites were produced. After casting, the density, hardness test and the microstructure examination were conducted for the various grades of composite produced.

The basic method of determining the density of a sample by measuring the mass and volume of the sample was used. The density of the sample was then estimated from the formula given below [1, 5]:

$$\text{Density} = \frac{Mass}{Volume} \quad \text{-----------------------------}(1)$$

The composite samples were investigated to identify and quantify the phases using X-ray diffraction technique at the department of chemical and metallurgical engineering, University of Witwatersrand, Johannesburg South Africa. The same sample preparation, method were used for all the composite samples. Bruker D8 θ-θ X-ray diffractometer equipped with CoK_{α} monochromating multilayered mirrors was used for the analysis. Rietveld refinement software, TOPAS^{TM}, was used for quantitative analysis [5].

The microstructure and the chemical compositions of the phases present in the coconut shell ash and test samples were studied using a JOEL JSM 5900LV Scanning Electron Microscope equipped with an Oxford INCA^{TM} 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 [1, 8].

The hardness values of the samples were determined (ASTM E18-79) using the Rockwell hardness tester on "B" scale (Frank Well test Rockwell Hardness Tester, model 38506) with 1.56mm steel ball indenter, minor load of 10kg, and major load of 100kg and hardness value of 101.2HRB as the standard block [3, 5].

3. RESULTS AND DISCUSSION

The XRF chemical composition of the coconut shell ash is represented in Table 1. XRF analysis confirmed SiO_2, Al_2O_3, MgO and Fe_2O_3 were found to be major constituents of the ash. Silicon dioxide, iron oxide and alumina are known to be among the hardest substances [5, 10]. Some other oxides viz. CaO, 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 suggested that, the coconut shell ash can be use as particulate reinforcement in metal matrix since the chemical composition has similarity with the XRF analysis of rick husk ash, bagasse ash and fly ash currently used in metal matrix composites [2, 5, 8].

Table 1. XRF analysis of Coconut shell ash.

Element	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	15.6	0.57	12.4	0.52	16.2	0.45	45.05	0.22	0.3

Morphology of the coconut shell ash by SEM with EDS is showed in Figure 1.

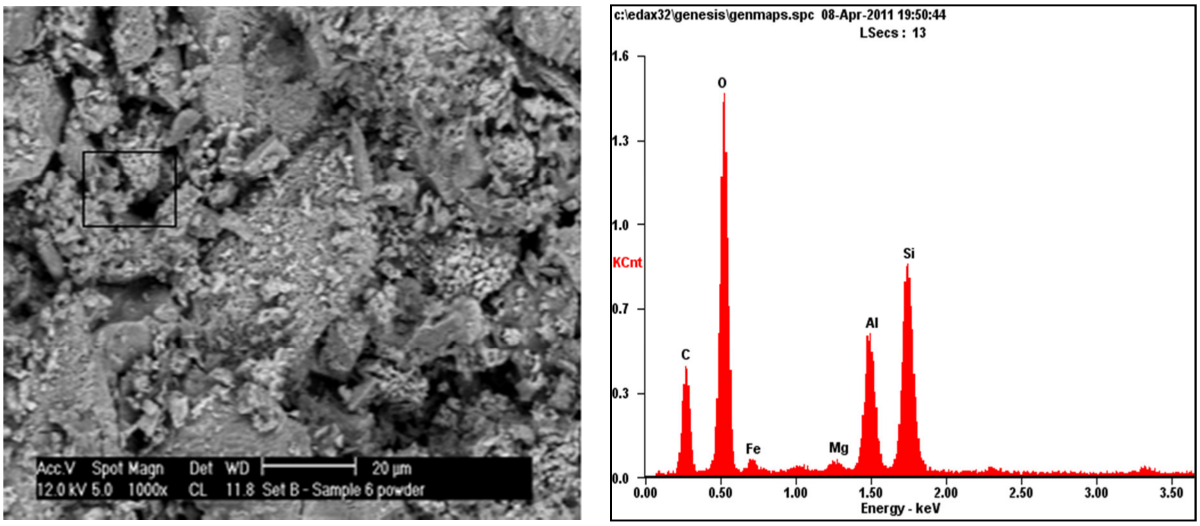

Figure 1. SEM/EDS spectrum of Coconut shell ash.

CSAp were observed to be solid in nature, but irregular in size. Some spherical shape particles can also be seen in the Figure 1. The chemical analysis of CSAp morphology consists mainly of Si, C, O, Mg, and Fe as shown in the EDS scan (see Figure 1). The results are consistent with XRD analysis of other biomass by [2, 5].

Macrostructural observations revealed a reasonably fairy distribution of coconut shell ash particles in the aluminium alloy. The distribution of coconut shell ash particles is influenced by fair wettability of the coconut shell ash by the molten metal and fair interfacial bonding between coconut shell particles and matrix material. The wettability obtained in this study was as a result of the used of the degassing tablets combined with double stirring method during casting which help to avoid gravity segregation. This prevented the composite slurries from oxidation and breakdown of the gas layer. It was observed that during the casting of the composites, increasing the weight percentage coconut shell ash particles beyond 15wt% made the composites slurry too thick and the fluidity of the molten composites was reduced.

The density decreased with increasing percentage additions of coconut shell ash particles in the aluminium alloy (see Figure 2). The density of coconut shell ash was 2.05g/cm^3 which were less dense than aluminium alloy. Hence, the overall density of the composites decreased with wt% additions of coconut shell ash. e.g the density of the composites decreased from 2.85g/cm^3 at 0wt% to 2.68g/cm^3 at 15wt% coconut shell ash. This showed that composites with light weight auto-components can be made with coconut shell ash. This is in agreement with the earlier work of Hassan and Aigbodion [5] and Rajan et a l[9].

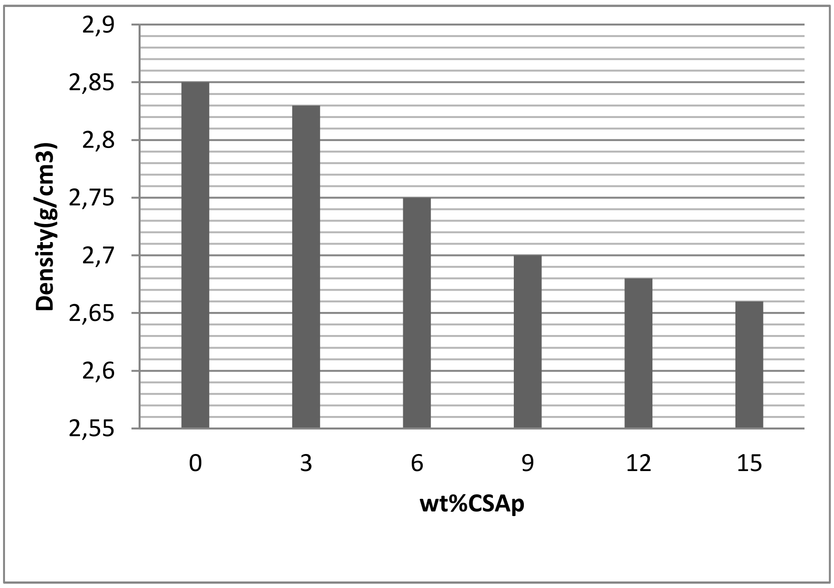

Figure 2. Variation of Density with wt% of Coconut shell ash.

The XRD pattern of the aluminium alloy and the alloy reinforced with 9wt% coconut shell ash composite manufactured by double stir casting method were showed in Figures 3-4. From Figures 3-4, it was observed that, the major phases in the aluminum alloy were Fe3Si, Al_6Fe, α-Al(see Figure 3). The composite showed smaller inter-planar distance and the Phases are SiC, Fe_3C, FeSi, SiO_2 and C (see Figure 4). In these diffractograms, one can evidently deduce the crystalline phases of the aluminium alloy from that of the composites material. The X-ray patterns showed Fe_3Si, Al_6Fe, α-Al presence in the matrix aluminium alloy and evident of the coconut shell ash particles in the composite.

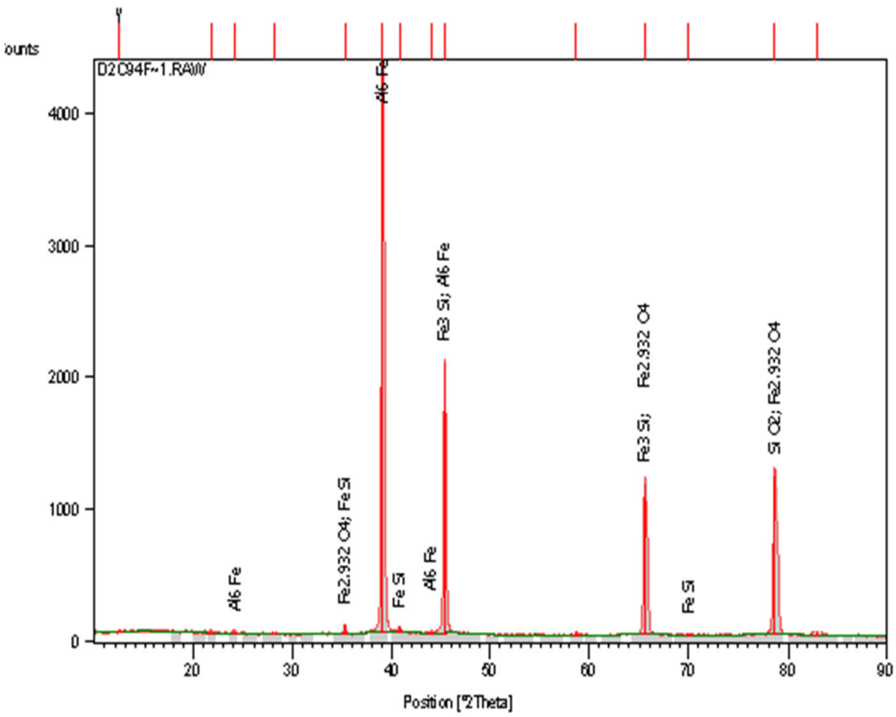

Figure 3. XRD pattern of the Aluminium alloy.

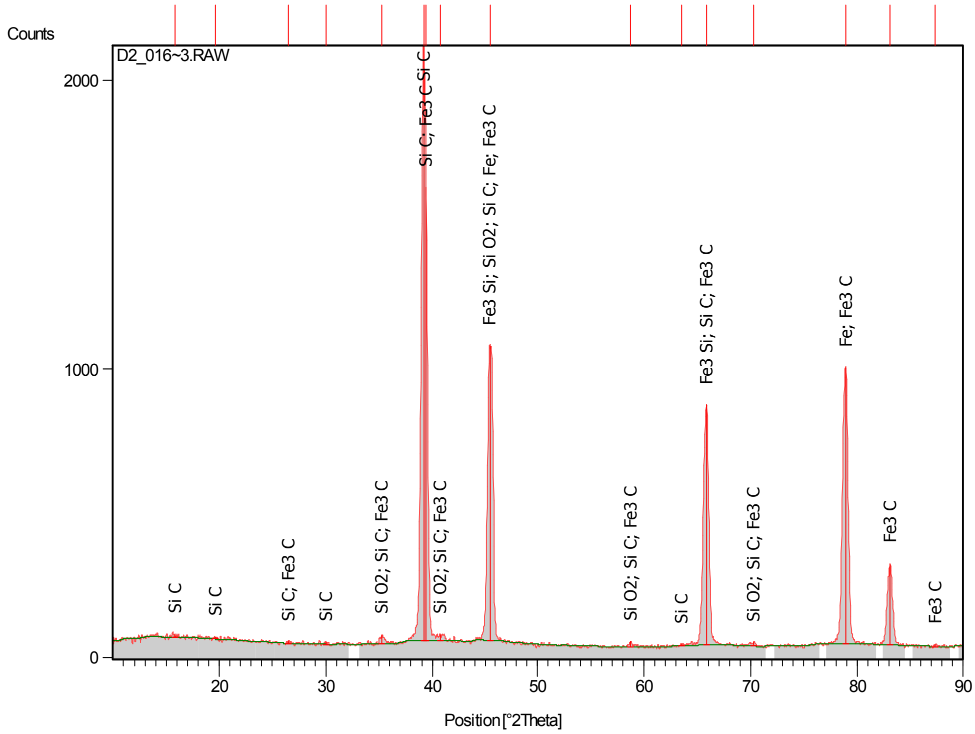

Figure 4. XRD pattern of the composite with 9wt%CSAp.

The microstructure of the aluminum alloy and that of the aluminum alloy with 9wt% coconut shell ash were analyzed using Scanning Electron Microscopy/Energy Dispersive Spectrometer. The microstructure of the aluminum alloy is showed in Figure 5. The structure reveals the eutectic phase containing Fe_3Si, Al_6Fe, in α-aluminum matrix.

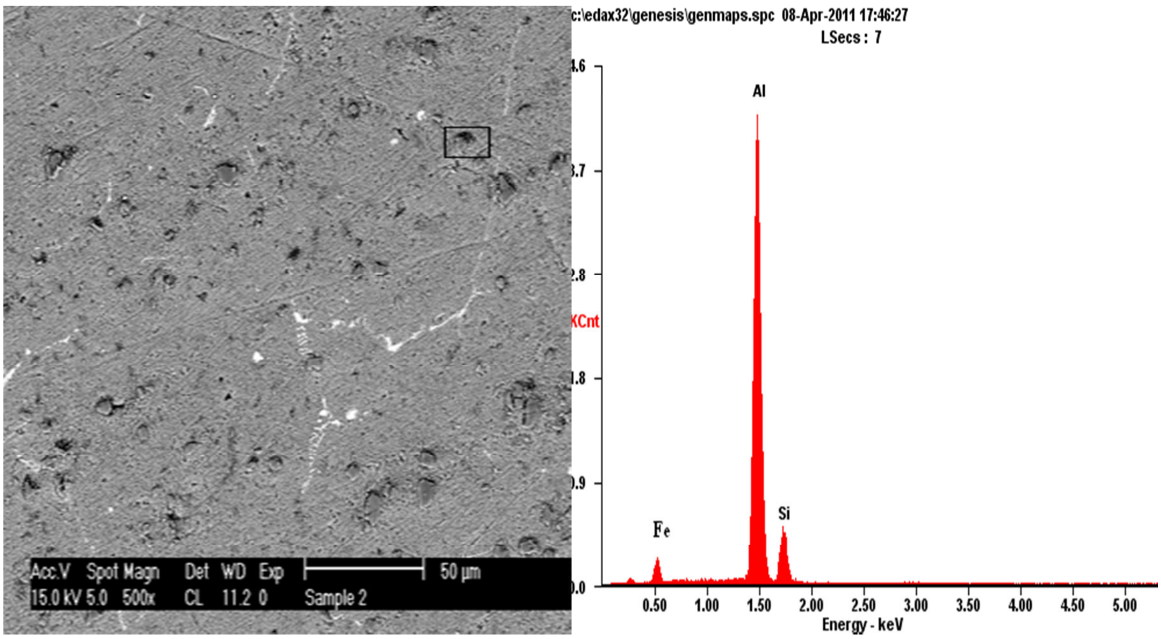

Figure 5. SEM/EDS spectrum of the aluminum alloy.

The microstructure of the composites reveals small discontinuities and a reasonably distribution of coconut shell ash particles in the aluminum matrix. The ceramic phase is showed as dark phase, while the metal phase is white (see Figure 6). Good retention of coconut shell ash particles was clearly seen in the microstructures of the composites. Fairy good interfacial bonding were obtained by heating of coconut shell ash particulates prior to dispersion and addition of magnesium in small quantities during stirring improved wettability of coconut shell ash particles. These structures are in agreement with phases studied by other researchers [8-9].

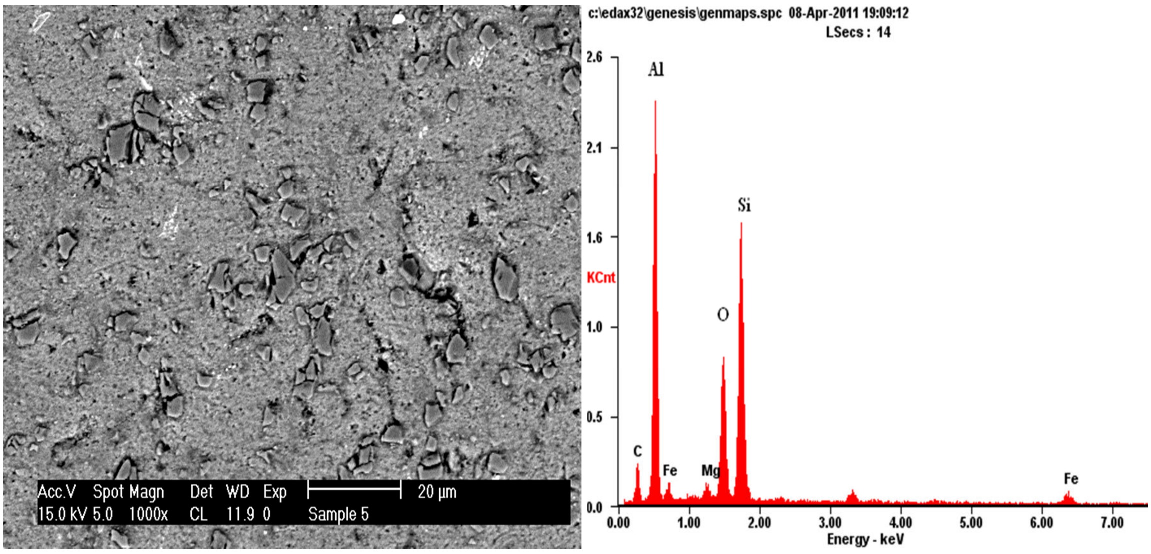

Figure 6. SEM/EDS spectrum of the aluminum alloy with 9wt%CSAp.

The diversified chemical composition of coconut shell ash particles and its high reactivity can form compounds by chemical reactions between coconut shell ash particles and liquid aluminium during the synthesis of the composites. The reaction between CSAp-reinforcement containing silica and liquid aluminium can lead to the formation of alumina and silicon. This accounted for the large peak of Si in the EDS of the composite then the EDS of the matrix (see Figures 5-6).

$4Al + 3SiO2 = 2Al_2O_3 + 3Si$-------------------------- (2)

The development of some primary silicon single crystals in the vicinity of coconut shell ash is seen in Figure 6. The microstructure of the composite clearly shows a uniform distribution of coconut shell ash in the aluminium alloy matrix. In the composites examined, some effects of unfavourable phenomena were observed, which frequently form in the structures of cast composites, such as formation of particle agglomerates.

In all the samples, polygonal morphology particles and aluminium alloy matrix with a eutectic structure formed in the interdendritic region can be seen. The particles were mostly embedded in the aluminium alloy grains, while others were along the grain boundaries with eutectic phases. The particle distribution is relatively uniform, though particle rich and particle-free regions can be seen due to the effect of solidification.

The hardness values of the developed composites increased with an increasing percentage of coconut shell ash particle additions. This is noteworthy that the hard value of coconut shell ash is 95.05HB and the presence of the hard ceramic phase in the ductile matrix has resulted into the increase in the hardness of the composite (see Figure 7). For example the hardness values increased from 63.50HRB at 0wt% to 78.60HRB at 15wt%coconut shell ash particles. These increments were attributed to increases in weight percentage of hard and brittle phase of the coconut shell ash particles in the aluminium alloy. This hardness values of the coconut shell ash particles are obtained from the SiC, Al_2O_3, Fe_2O_3 and SiO_2 of the chemical made up of the particles. Also the presence of coconut shell ash particles in the alloy increases the dislocation density at the particles-matrix interfaces. This is as a results of differences in coefficient of thermal expansion (CTE) between the hard and brittle reinforced particles and soft and ductile metal matrix which results to elastic and plastic incompatibility between the matrix and the reinforcement [1, 6-8].

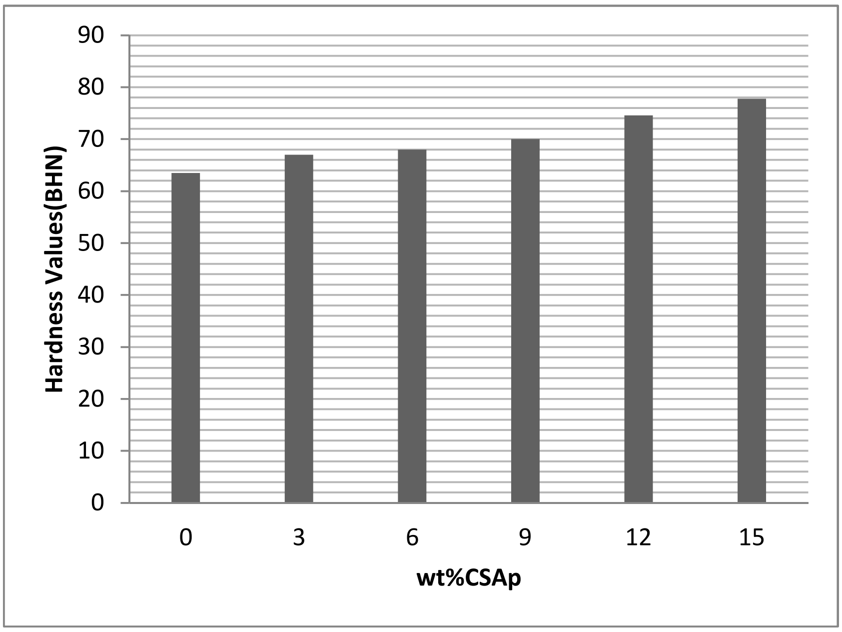

Figure 7. Variation of Hardness values with wt% coconut shell ash.

4. CONCLUSIONS

From the results and discussion above the following conclusions can be made:

1. Aluminum alloy/coconut shell ash composites were synthesized successfully by using double stir casting technique.
2. The density decreased as the percentage of coconut shell increases in the alloy. This means that composites of lower weight component can be produced.
3. Microstructural analysis shows the fairy distribution of coconut shell ash particles in the aluminum alloy.
4. The fairy interfacial bonding between the alloy and the coconut shell ash particles resulted in the lower values of pore in the casted composites.
5. Incorporation of coconut shell particles in aluminum matrix can lead to the production of low cost aluminum composites with improved hardness values.

REFERENCES

[1] Aigbodion, V.S., Hassan, S.B., "Effects of silicon carbide reinforcement on microstructure and properties of cast AI-Si-Fe/SiC particulate composites", ***Journal of Materials Science and Engineering A***, 447355-360 (2007).

[2] Prasad, D., Krishna, A., "Fabrication and Characterization of A356.2-Rice Husk Ash Composite using Stir casting technique", ***International Journal Of Science Eng.ring And Technology***, 2(12):7603-7608(2010).

[3] Aigbodion, V.S., "Particulate-strengthened of Al-Si alloy/alumino-silicate", ***Composite Materials Science and Engineering A***, 460-461: 574-578(2007).

[4] Bienia, J., Walczak, M., Surowska, B., Sobezaka, J., "Microstructure and corrosion behaviour of aluminum fly ash composites", ***Journal of Optoelectronics and Advanced Materials***, 5(2): 1-93 - 502 (2003).

[5] Hassan, S.B., Aigbodion,V.S., "The study of the Microstructure and Interfacial Reaction of Al-Cu-Mg/Bagasse Ash Particulate Composite", ***Journal of Alloy & Compounds***, 491: 571–574(2010).

[6] Prasad, N., "Development and characterization or metal matrix composite using red Mud an industrial waste for wear resistant applications", PhD thesis Department of Mechanical Engineering, ***National Institute of Technology Rourkcla*** -769 008 (India) January, 23-34 (2006).

[7] Harun, M.B., Shamsudin, S.R., Yazid, H., Selemat, Z., Jalil, M., "Effects of Fly Ash particle Reinforcement on Microstructure, Porosity and Hardness in Al-(Si-Mg) Cast composite", ***Malaysian Institute for Nuclear Technology***, AJSTD,23(1&2):113-122(2006).

[8] Rajan, T.P.D., Pillai, R.M., Pai, B.C., Satyanarayana, K.G., Rohatgi, P.K., "Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes", ***Composites Science and Technology***, 67: 3369–3377(2007).

[9] Rohatgi, P.K., Guo, R. Q., Keshavara, B.N., "Cast aluminium alloy–fly ash composites",***Key Engineering Materials***, 104–107:283–92(1995).

[10] Ejiofor, J.U., Reddy, R.G., "Developments in the processing and properties of particulate Al-Si composites", ***JOM Publication Of Minerals, Metals And Materials Society***, 49(11): 31-37 (1997).