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Mechanical Properties of Al-Mg-Si/Groundnut Shell Particulate Composite Produced By Stir Casting Method

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ABSTRACT : *In this paper, some mechanical properties of a particulate strengthened Al-Mg-Si composite using groundnut shell particles in powdered and ash forms were investigated. Stir casting method was used to produce the alloy of Al-Mg-Si with 2, 4, 6, 8 and 10 % weight groundnut shell particulates. The miscrostructure of the various alloy particulate composites produced were examined while tensile, hardness and impact properties determined. The result obtained shows that hardness values increased with increase in the amount of groundnut shell particles with the best result of 44.5 HRB at 8 % weight groundnut shell ash particulates. The yield strength and ultimate tensile strength increased with increasing particulate addition with 47 kN/mm^2 at 10 % and 110 kN/mm^2 at 4 % ash particulates respectively while the impact strength also showed similar trend. It was then concluded that hardness, tensile strength and impact strength of Al-Mg-Si alloy were enhanced by the addition of groundnut shell particulate using stir-casting method and thus can be used in automobile components such as wheels and engine cylinder blocks.*

KEYWORDS *- Groundnut shell, hardness, impact strength, microstructure, stir casting.*

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I INTRODUCTION

There has been great interest in recent times in the creation of wealth from waste with increased research in agricultural wastes. Several researchers have investigated the possibility of using agricultural wastes as reinforcement in composite production. Among the most investigated industrial and agro wastes that have been used as reinforcing materials in aluminum matrix composites (AMCs) include coal fly ash (FA), red-mud, rice husk ash (RHA) and bagasse ash [1-4].

Materials with good strength to weight ratio are becoming very essential in modern engineering designs especially for automotive and aerospace applications where improved machine efficiency and reduced fuel consumption are critical requirements to be satisfied. Also, modern infrastructure, equipment and machineries that are currently developed require materials that have good combination of properties to match service demands. Aluminium matrix composites (AMCs) represent a class of materials that offer wide range of properties that can measure up with the design requirements of some of the aforementioned applications [5]. AMCs are primarily reinforced with fibres or particulates which are usually ceramic materials (SiC, Al_2O_3, WC, B_4C, TiO_2, BN). They can be produced via solid route processing (such as powder metallurgy) and liquid metallurgy processing routes (rheocasting, compocasting, liquid infiltration, stir casting are a few examples) [6, 7]. Without disregard to the technical competence of other processing routes available, stir-casting remains the most utilised technique due to its simplicity, flexibility, low cost and commercial viability [7].

Nigeria is one of the largest producers of groundnut in the world producing, 3,028,571 tons per annum after China (16,685,915 tons) and India (6,857,000 tons) in 2016 [8]. There is current effort to increase production capacity by additional 120,000 metric tons in the next few years. This implies that groundnut shells will continue to contribute significantly to the solid waste in the country due to limited secondary applications of the groundnut shell. Efforts have been made to recycle groundnut shell by processing it into ash for use as cement replacement in concrete mixtures due to their pozzolanic characteristics (attributable to their high silica and alumina content) [9, 10].

Particulate reinforced metal matrix composites (PMMCs) are currently being used as structural components in aerospace, automotive and industrial applications. Discontinuously reinforced metal matrix composites have received much attention because of their improved specific strength, good wear resistance and modified thermal properties unattainable in either of the starting (monolithic) materials [11]. These materials have emerged as the important class of advanced materials giving engineers the opportunity to tailor material properties according to their needs. Essentially these materials differ from the conventional engineering materials from the view point of homogeneity. PMMCs combine the ductility and toughness of the metal matrices with the high strength and stiffness of the ceramic reinforcement to achieve properties unattainable in either of the starting materials. PMMCs often have high strength to weight ratios, which is an important consideration in weight sensitive applications. Other distinctive properties of PMMCs include good thermal stability and excellent wear resistance [12]. Dispersing small particulates (less than 1µm) in a metal increases its strength, typically by Orowan type strengthening mechanisms. Traditionally high modulus ceramic particulates such as silicon carbide (SiC) and alumina (Al_2O_3) have been used as reinforcements purposely for stiffness enhancement, plus strengthening. It is however, known that other property benefits can be achieved by carefully controlling the matrix properties, the reinforcement properties, and the interface formed between them.

This study aims to use groundnut shell to produce particle reinforcement for AMCs thereby further adding value to efforts in groundnut shell waste management thus contributing to reduction in current environmental waste management challenges.

TABLE 1: Composition of Groundnut Shell Ash

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	P_2O_3	MnO	SO_3	*LOI
41.42	11.75	12.60	11.23	3.51	0.63	1.02	11.89	1.71	0.23	0.44	3.57

*LOI = loss on ignition

Sourse: (Alaneme *et al*, 2015) [13].

II MATERIALS AND METHODS

2.1 Materials and Equipment

The materials utilized in this research work include high purity (99.95 %) aluminum electrical wires obtained from Northern cable company NOCACO, Kaduna, silicon powder obtained from a chemical shop in Zaria, Mg obtained from a chemical store in Jos and groundnut shell waste obtained from a farm at Bukan Ari village in Lafia, Nasarawa State, alumina polishing powder, etchant, cylindrical tube and emery paper of grits 320, 400, 600, 800, 1000.

Electric Furnace, Crucible, Stirrer, Hounsfield balanced Impact testing machine, Indentec universal hardness testing machine, grinding and polishing machine**,** Metallurgical Microscope, Digital weighing balance, Sensitive electronic weighing machine.

2.2. Experimental Procedure

2.2.1 Preparation of the groundnut shell waste

The groundnut shell waste was collected from Bukan Ari Village in Lafia, Nasarawa State and dried in the sun after sorting. After drying, the groundnut shell waste was pounded in a mortar to powdered form. After the pounding, it was sieved to fine particle size. Some of the powder was taken for conversion to ash by heating to temperature of 750 ^{0}C in a charcoal fired crucible furnace and allowed at this temperature for about 40 minutes for complete conversion.

2.2.2 Samples production

The samples were produced by keeping the percentage of magnesium and silicon constant at 0.8 and 1.2 % respectively while varying the percentage weight of groundnut shell particles in both ash and powdered forms from 0-10 wt %.

A split mould with diameter 20 mm and 300 mm length was used to produce the cylindrical rods. High purity aluminum electrical wires were charged in a graphite crucible onto a gas fired furnace and the temperature of the furnace raised to 680 ^{0}C for purpose of super-heating the molten aluminum. The required 0.8 % magnesium and 1.2 % silicon were then added to the molten aluminum in the furnace.

The molten metal was continuously stirred in order to ensure homogenization. The melt was brought out from the furnace for the temperature to reduce before the introduction of the groundnut shell particles. The particles were preheated to 150 ^{0}C to make their surface oxidized and boil off volatile matter. The preheated groundnut shell particles were then added and mixed manually for about 5 minutes. In the final mixing process, the furnace temperature was controlled between 670 ^{0}C and 680 ^{0}C and the pouring temperature were controlled to about 660 ^{0}C. A total of 10 heats were carried out to produce the composites with various compositions (0, 2, 4, 6, 8, and 10 %) of the particulates in both powdered and ash forms.

2.2.3 Heat treatment of the samples

The test samples were solution heat –treated at temperature of 500 ^{0}C in heat treatment furnace, soaked for 30 minutes at this temperature and then rapidly quenched in warm water at 60 ^{0}C. Age hardening of the samples was carried out at 170 ^{0}C and soaked for 30 minutes then cooled in air.

2.2.4 Determination of the tensile properties.

The tensile properties of the as –cast and age hardened samples were conducted using Hounsfield tensometer. The test pieces were machined to the standard shape and dimension as specified by the machine state. The samples were locked securely in the grips of the upper and lower cross beams of the testing machine. A small load was initially applied to seat the sample in the grips and then the load was increased gradually until failure occurred.

2.2.5 Hardness test

The hardness values of both as–cast and age hardened samples were determined using Indentec Vickers hardness tester with 1.56 mm steel ball indender, minor load of 10 kgf, major load of 60 kgf and hardness value of 101.2 HRB as the standard block. Calibration of testing machine using the standard block the samples were placed on anvils, which act as a support for the test samples, a minor load of 10 kgf was applied in the samples in a controlled manner without including impact or vibration and zero datum position was established, and then the major load of 60 kgf was then applied, 1.59 mm indenter was used. The reading was taken when the large pointer came to rest or had showed appreciably and dwelled for up to 2 seconds. Three readings were observed and the average value taken.

2.2.6 Impact strength

The Impact Strength test of the as-cast and age hardened samples was conducted using Izod Impact Testing Machine. The impact test was conducted on the notched samples with standard cylindrical impact test samples measuring 60 mmx12 mm with notch depth of 2 mm and a notch tip of 0.2 mm at angle of 45^o. Before the test samples were mounted on the machine, the pendulum was released to calibrate the machine. A test sample was then gripped vertically in a vise and the force required to break the bar was released from the freely swinging pendulum. The value of the angle through which the pendulum had swung before the test sample was broken corresponded with the energy absorbed in breaking the sample and this was read from the calibrated scale on the machine.

2.2.7 Microstructural examination

Metallographic specimens were cut to dimensions 15 mm length by 10 mm diameter from the as–cast and age hardened samples of the Al–Mg–Si/groundnut shell particulates composite. The samples were mechanically ground using grit papers of 320, 400, 600, 800 and 1000 microns after which they were polished and the mirror-like specimens etched in Kellers reagent for 15 seconds. Microstructures of the specimens were obtained using an optical metallurgical microscope- NJP-120A at x200 magnification and uploaded.

III RESULTS AND DISCUSSION

3.1 Effect of particulate on tensile strength

The results of yield strength for both the as-cast and age-hardened composites are shown in Figure 1. It can be observed from the results for both the ash and powdered particulate samples as well as the as-cast and age hardened samples that the yield strength increased progressively up to the 10 wt% reinforcement used. The heat treated samples in both ash and powdered particulate samples gave better yield strengths compared to the as cast with the ash particulate having the highest value of 47 kN/mm^2 at 10 wt% reinforcement.

The tensile strength showed an increase in values for the age hardened samples, with the best result of 110 kN/mm^2 for 4 wt % age hardened groundnut shell ash in Figure 2. The age hardened samples in both ash and powdered particulate samples gave higher tensile strength compared to the as cast.

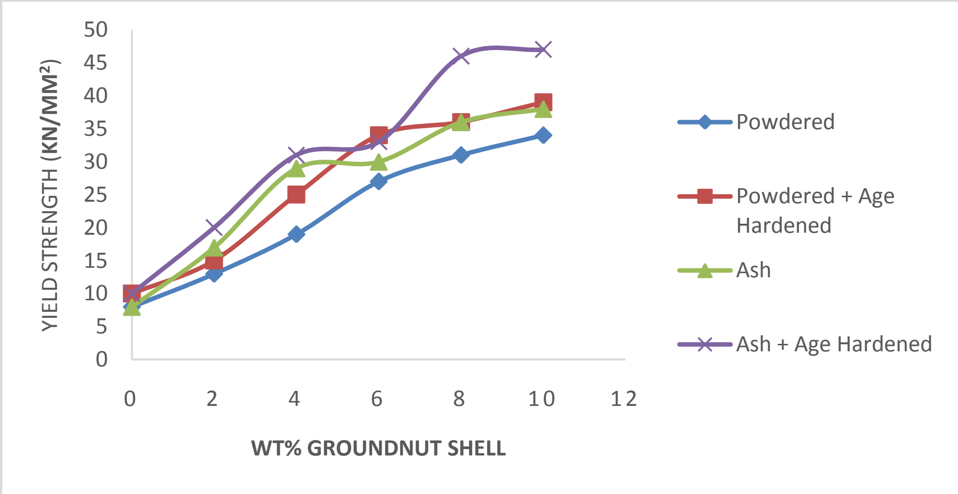


Figure 1: Yield Strength vs wt. % Groundnut Shell Particles

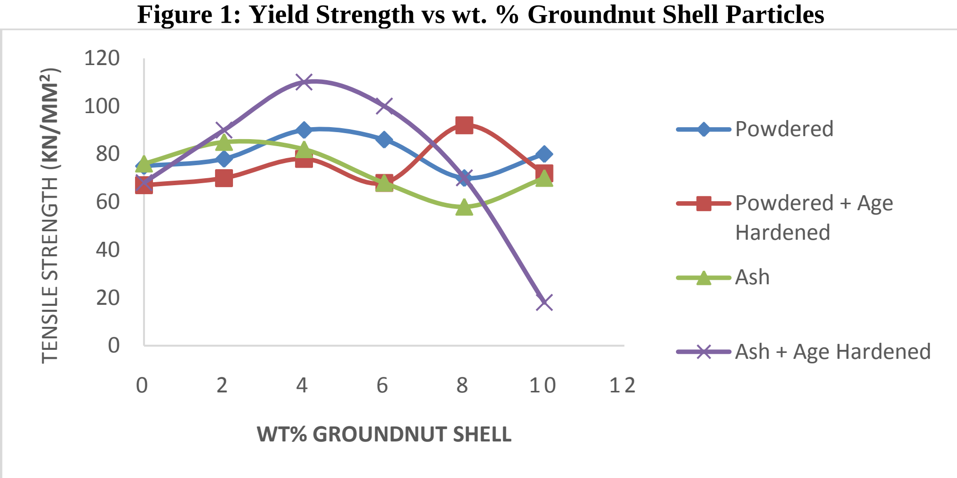


Figure 2: Tensile Strength vs wt. % Groundnut Shell Particles

3.2 Effect of particulate on hardness

The hardness values of Al-Mg-Si/groundnut shell composites are shown in Figure 3. It can be observed from the results that the hardness values increase progressively up to 44.5HRB (age hardened) and 23 HRB (as-cast) for 8 % addition of reinforcement of the ash particulate and then decreased thereafter while for the powdered, the hardness values increase to 31.3 HRB (age hardened) and 18.1 HRB (as-cast) at 8 % addition of the reinforcement and then decreased thereafter due to overcrowding of the reinforcement within the matrix. The results showed that the age hardened samples had better hardness values than the as-cast samples.

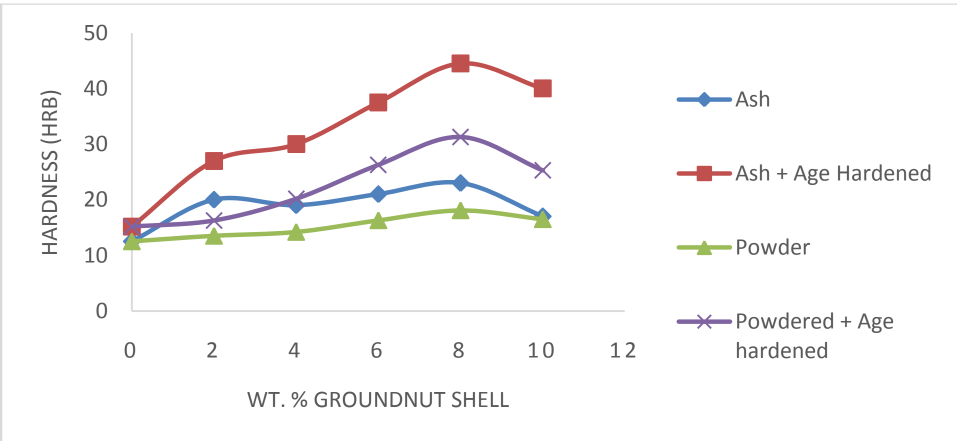


Figure 3: Hardness (HRB) vs. wt. % Groundnut Shell Particles

3.2 Effect of particulate on impact toughness

The results of the impact energy is shown in Figure 4. It can be observed from the figure that the impact strength increases for both as-cast and age hardened samples of powdered particulate with increased weight per cent of the particulate reaching a maximum of 42.90 J and 46.55 J at 8 wt% particulates addition for the as-cast and age hardened samples respectively and decrease thereafter. While for the ash particulates, the impact energy also showed a similar trend with an increase in impact energy up to 48.95 J for age hardened and 24.4 J for as-cast at 8 wt % particulates addition and then decrease at 4 % particulates addition. Generally, the impact for the age hardened samples is higher than that of the as-cast samples.

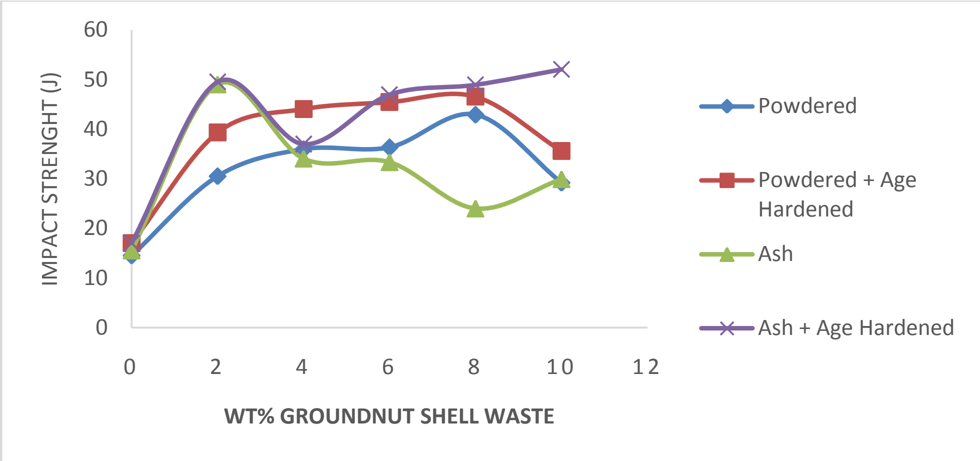
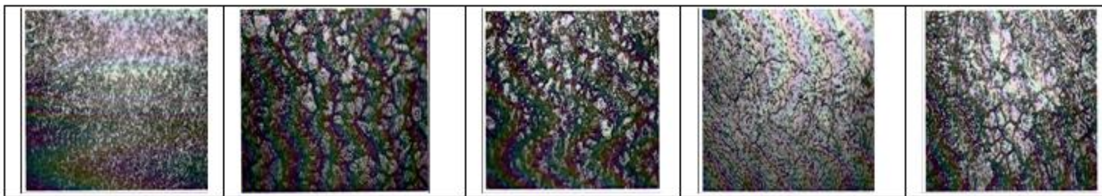


Figure 4: Impact Strength vs. wt. % Groundnut Shell Particles

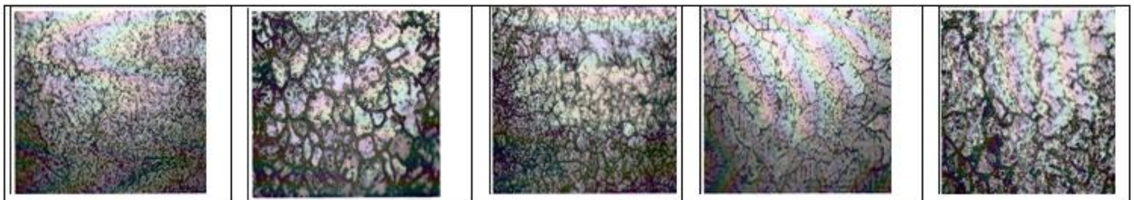
3.4 Effect of particulates on microstructures

Microstructural studies of the cast composites before and after age hardening revealed a reasonable uniform distribution of groundnut shell particles for both powdered and ash, with a slight segregation of particles in some of the samples. The distribution of the groundnut shell particles was influenced by good wettability of the groundnut shell particles by the molten metal and good interfacial bonding between the groundnut shell particles and the matrix. The structures consisted essentially of α-Al, Mg_2S, intermetallic compounds as well as the groundnut shell particulates distributed within the grains for the powdered and ash in both the as-cast and age-hardened conditions.



a) As cast	b) 2 %	c) 4 %	d) 6%	e) 8 %

Plate I: Microstructures of Al-Si-Mg Alloy Reinforced with Groundnut Shell Powder at various Weight %.



2 %	4 %	6 %	8 %	10 %

Plate II: Microstructures of Al-Si-Mg Alloy Reinforced with Groundnut Shell Ash at various Weight %.

IV CONCLUSION

The result of this investigation leads to the following conclusions:

i. The hardness values of both the as cast and age hardened samples increase with increase in the wt % of groundnut shell particles with the age hardened giving highest value at 8 wt % particulate. .
ii. The yield strength and ultimate tensile strength increased with increasing particulate addition with heat treated samples giving highest values at 10 wt% and 4 wt% respectively.
iii. The impact strength improved as particulate addition increased with heat treated samples having higher values.

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