SAJSET
ISSN: 2992-3581

Savannah Journal of Science and Engineering Technology
Volume: 01; Issue: 05; Pages: 244-250; 2023.
www.sajsetjournal.com.ng

DOI: xx.xxxx.x/sajset-01-2023-0049

SAJSET
ISSN: 2992-3581

Production and characterization of aluminium matrix composite with mixture of silicon carbide and groundnut shell ash as reinforcement for automotive application

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Paper History
Received: 01st June, 2023
Accepted: 27th August, 2023
Published: Sept, 2023

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Abstract:
The mechanical behaviour of Al6063 alloy reinforced with a hybrid of silicon carbide (SiC) and groundnut shell ash (GSA) was investigated to establish the possibility of developing low-cost, high-performance material for automotive application. SiC and GSA particles were utilized to prepare 3g, 6g, 9g and 12g of the reinforcing phase, Al 6063 alloy was employed as the matrix using a double stir casting technique. To characterize the composites, Vickers hardness, compressive strength and microstructure examination were conducted. The results show that the composite with 12g reinforcement has Vickers Hardness value of 67.69 for SiC reinforced and 63.31 for SiC+ GSA reinforced composite indicating a 6.91% reduction in hardness compared to the SiC reinforced composite. The compressive Strength of the composite increased with increase in SiC and decreased with increase in GSA for 6g reinforcement, the compressive strength decreased by 3.15% in the SiC+GSA reinforced composite as compare to SiC reinforced composite. The reduction in hardness value and compressive strength can be attributed to the presence of refractory oxides which is the dominant constituent in GSA and are noted to have lower hardness and compressive strength in comparison to SiC particles. The microstructure reveals that the reinforcing particles (SiC, GSA) were visible and fairly well distributed in the Al 6063 alloy matrix. From the results obtained, GSA has shown a great potential to serve as a partial replacement for SiC in the development of low cost - high performance aluminium hybrid composite for automobile components application.

Keywords: *Al6063 alloy, Automotive, Composite, Groundnut shell ash, Stir casting, Silicon carbide*

1. Introduction

Metal matrix hybrid composites [MMHCs] consist of a metal matrix and two or more reinforcements. They are formed by reinforcing two or more materials of varying properties with a matrix phase. There is a growing interest in developing MMHC in the aircraft and automobile industry because they possess combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties [1]. Aluminium Matrix hybrid Composites (AMHCs) has received increasing attention as engineering materials in recent years. The use of single reinforcement in aluminium matrix may sometimes lead to deterioration in its physical properties. However, to overcome the setback of single reinforced composites, the technology of the use of two different types of reinforcements is being explored in AMHC [2]. Hard reinforcements such as SiC, TiO2, Al2O3, TiB2 etc. will improve the mechanical properties AMHC [1, 3]. The introduction of a ceramic material into aluminium matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys [4].

Aluminium alloy-based matrix composites with ceramic particulate reinforcement have shown great promise in automobile automotive applications [5]. AMC brake rotors and drums are typically produced by casting processes [6, 7]. A number of automobiles now use AMC brake components, these materials have a lower density and higher thermal conductivity as compared to the conventionally used grey cast iron, and in addition, they are expected to result in weight reductions of up to 50 – 60 % in brake systems [8]. Brake disc is a crucial component from safety point of view, material properties of brake disc should be such that they provide homogenous friction coefficient, low density, high corrosion resistance, high modulus of elasticity, high wear resistance, high heat conductivity, low thermal expansion coefficient and high specific strength [9]. Presently, there is increasing interest in developing low cost - high performance AMHC using ashes processed from Agricultural wastes as partial replacement for conventional synthetic reinforcements like SiC and alumina. Very encouraging results have been observed from Aluminium matrix composites reinforced with hybrid mix of the agricultural waste ashes (e.g., rice husk ash, bamboo leaf ash, cocoanut shell ash) and the synthetic reinforcements (e.g., SiC and alumina) [9,10].

2. Materials and method

2.1 Materials

The matrix material used is aluminium alloy Al6063, GSA of SAMUT 21 groundnut specie and SiC of particles size 320 grit served as the reinforcement. Table 1 shows the chemical composition of Al 6063 alloy.

2.2 Methods

2.2.1 Production of GSA

The Groundnut Shell was washed to remove impurities. It was first put in a plastic container and water was poured over it, the soil falls to the bottom after agitation. When the shells are cleaned, it was removed and Sun-dried for 48 hours. Subsequently, the groundnut shell was burnt in open air in a perforated metallic drum which serves as a burner, to obtain the ash.

Table 1: Chemical composition of Al 6063 alloy [11, 12].

Element	Al	Si	Fe	Cu	Mn	Mg	Ni	Zn	V
% composition	98.76	0.47	0.32	0.22	0.012	0.39	0.001	0.01	0.01

The ash from the burning process was allowed to cool and was collected after 12 hours. Thereafter, the ash was heated in a furnace at a temperature of 650˚C for 120 minutes in order to reduce the volatile constituents of the ash [10]. The groundnut shell ash was sieved using a sieve with 425 mesh size and stored in polythene bags.

2.2.2 Production of hybrid aluminium composite.

The aluminium alloy matrix reinforced with GSA and SiC aluminium hybrid composite was produced using double stir casting process [13]. In order to eliminate the dampness in the reinforcements and improve wet ability with the molten aluminium alloy, the GSA and SiC particles were pre-heated in an oven at a temperature of 250˚C. A furnace was used to melt the aluminium alloy billet at a temperature of 700˚C in order to ensure that the alloy melt completely. The liquid alloy was then cooled in the furnace to a semi – solid state at a temperature of 600˚C. Then the pre-heated GSA and SiC particles were added to the molten aluminium alloy. Manual stirring of the slurry was performed from this temperature for 3 minutes. The composite slurry was then heated to 750˚C and a second stirring was performed mechanically using a three bladed steel stirrer at a stirring speed of 350 rpm for 2 minutes for different samples of 3g, 6g, 9g and 12g reinforcements before casting in a prepared mould of 100 x 50 x 15 mm dimensions. After Solidification, the castings were removed from the mould, then cut using power saw and machined to the required shape and size using a milling machine for different tests.

2.3 Hardness Test

Vickers hardness tester model MV1-PC was used to perform the Vickers hardness test. Prior to testing, the surface of the hybrid composite test sample of size 25x15x10 mm was subjected to grinding and polishing operations to obtain a flat and smooth surface finish according to ASTM E-18 Standard [14]. The test sample was indented with a pyramid shaped diamond indenter subjected to a direct load of 0.98N applied for 10 seconds. The indentation left in the test sample is measured with low powered microscope. The indentation is the average of three readings and the Vickers hardness was determined using Vickers hardness number table.

2.4 Compressive test

The test was carried out on a machined sample of length 25x10mm diameter according to ASTM E9 Standard [15]. Compressive test was conducted by gradually applying load hydraulically using a digital universal material testing machine model Cat. Nr.261 with maximum load of 100kN. The load was applied to the sample continuously, the sample tends to buckle and reduce in length with increase in diameter until it reaches the yield point. The reading was obtained from the digital readout.

2.5 Microstructural examination.

The microstructure studies were used to investigate the grain size, shape, and the distribution of the reinforcement within the matrix. The samples were belt grinded with different grade of 80, 120, 360, 600, 800 grits emery paper, followed by polishing using polishing cloth and polishing paste with Al_2O_3 particles. The polished samples were etched with mixture of equal volume of HNO_3 (0.1%) and HCl (37%) solution [16]. The examination was performed on the samples using a JSM-6480 Model (JOEL) X200.

3. Results and discussion

3.1 Hardness Value

The results of micro-hardness test conducted on the SiC and SiC+GSA reinforced composite containing different weight percentage of SiC and GSA particles for 3g, 6g, 9g and 12g reinforcement is presented in Figure 1.

As observed from the Figure 1, composite samples containing 3% reinforcement has a Vickers hardness number 48.25 for SiC reinforcement A1, 45.83 and 41.67 for SiC+GSA reinforcement A2 and A3 respectively. This indicates a reduction in hardness of about 5.28% and 15.7% compare to SiC reinforced composite. Samples B with 6g reinforcement has hardness value of 52.57 for SiC reinforced composite B1, 49.38 and 48.13 for SiC+GSA reinforced composites B2 and B3 respectively indicating 6.46% and 9.22% reduction in hardness. Sample C with 9g follows similar trend with sample A and B for both SiC and SiC+GSA reinforced composite.

Sample D with 12g reinforcement has the highest value of hardness 67.69 for the SiC reinforcement D1, 63.31 and 60.59 for the SiC+GSA reinforcement D2 and D3 respectively, indicating 6.91% and 11.86% reduction in hardness compared to the SiC reinforced composite.

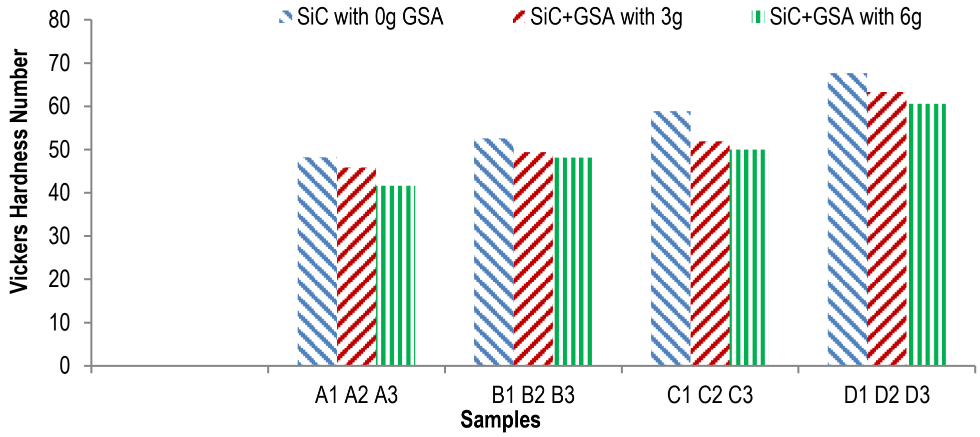

Figure 1. Variation of Hardness for SiC and SiC+GSA reinforced composites

This is an indication that the addition of GSA particles as partial reinforcement to SiC only result in slight decrease in hardness of the selected weights of the reinforcement utilised in this research. The slight reduction in hardness is attributed to the presence of refractory oxides (SiO_2, Al_2O_3 and Fe_2O_3) [17] which is the dominant constituent in GSA particles. Similar hardness behaviour was observed in Alamene, *et al*. [18]. The refractory oxides are noted to have lower hardness level and lower load bearing capacity in comparison to SiC. Hence the slight decrease in the hardness of the SiC+GSA composite.

Subsequently, it is noted generally that hardness of SiC reinforced composite increase linearly with increase in reinforcement and decrease slightly with increase in weight of GSA particles in SiC+GSA composite. The increases in the SiC reinforced composite may be due to the presence of hard SiC particles which offers more resistance to plastic deformation which leads to increase in hardness of the composites [19].

3.2 Compressive Strength

The results of compressive strength for SiC and SiC+GSA reinforced composite samples with different weight of SiC and GSA for 3g, 6g, 9g and 12g reinforcement is presented in Figure 2.

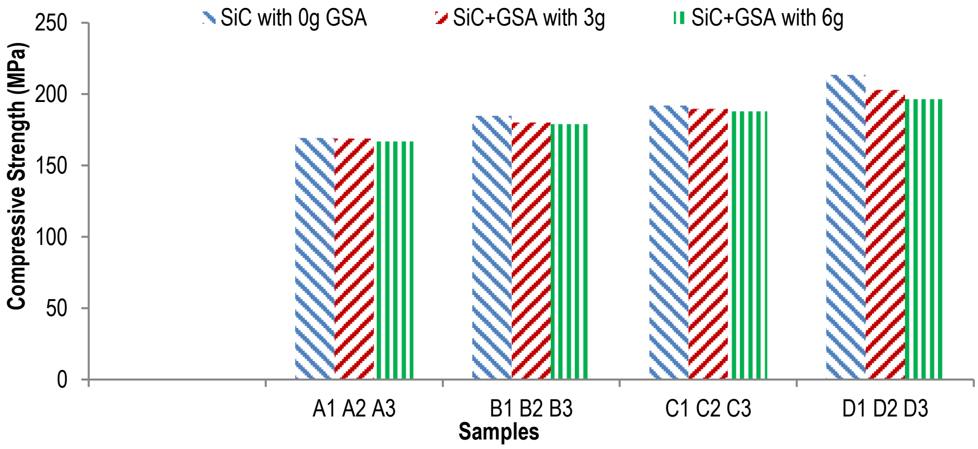

Figure 2. Variation in compressive strength for SiC and SiC+GSA reinforced composites.

It is observed in Figure 2 that there is an increase in compressive strength for the SiC reinforced composite and slight decrease for the SiC+GSA reinforced composite for each group of reinforcement. Composite sample A1 with 3gSiC reinforcement has an average compressive strength of 169.38 MPa, the SiC+GSA reinforcements A2 and A3 have compressive strength of 168.94 MPa and 166.78 MPa respectively, this indicates a reduction of 0.26% and 1.55% compare to the SiC reinforced composite. In the case of 6g, the variation in compressive strength decreases by 2.67% and 3.26% for SiC+GSA reinforcement B2 and B3 respectively. Similar trend is observed for values of compressive strength for sample C with 9g reinforcement and sample D with12g reinforcement. The slight decrease in compressive strength of the SiC+GSA composite may be attributed to the presence of silica and alumina which are the dominant constituent in GSA and are less abrasive than SiC. While the increase in compressive strength for the SiC reinforced composites may be due to hardening of the matrix by SiC particles which also acts as barriers while taking load [19, 20]. Composite sample D1 has the highest compressive strength of 213.43 MPa for SiC reinforced composite and D2 has the highest compressive strength of 202.94 MPa for SiC+GSA reinforced composite.

3.3 Thermal conductivity

The result of thermal conductivity test conducted on the SiC and SiC+GSA reinforced composite containing different weight of SiC and GSA particles for 3g, 6g, 9g and 12g reinforcement are presented in Figure 3.

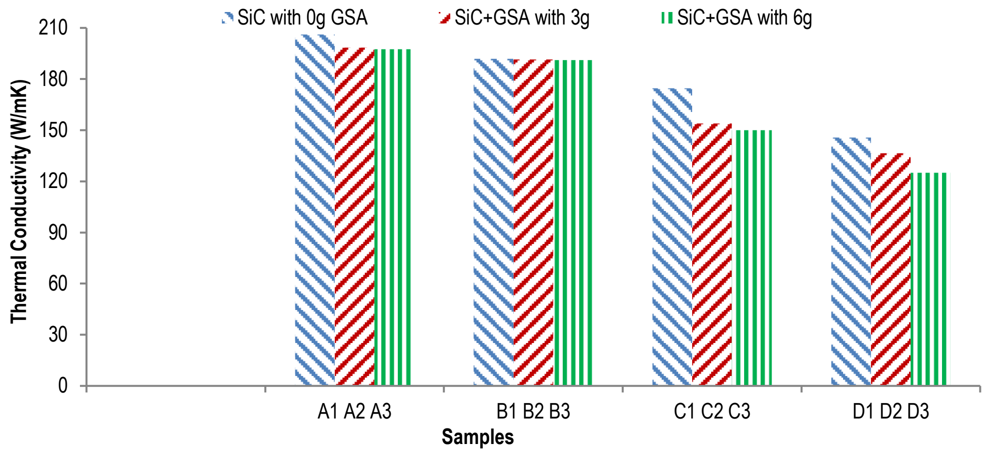

Figure 3. Thermal conductivity for SiC and SiC+GSA reinforced composites.

The thermal conductivity of the SiC reinforced composite A1 with 3g reinforcement is 206.21 W/mK while that of the SiC+GSA reinforced composites A2 and A3 is 198.42 and 197.59 W/mK, respectively. These results show a decrease in thermal conductivity of about 3.92% for A2 and 4.36% for A3. The decrease in thermal conductivity of the composite is due to the interfacial reaction between the SiC and the Al6063 matrix. Ren, et al. [21] stated that the interfacial reaction between SiC particles and Al matrix can reduce the thermal conductivity of the composites. The thermal conductivity for SiC reinforced composite B1 is 191.89 W/mK and for the SiC+GSA reinforced composites B2, B3 is 191.56 and 191.02 W/mK, respectively when the reinforcement is varied within 6g. The composite shows a slight decreased in thermal conductivity of 0.17% and 0.45% for the SiC+GSA composite. Composites B2 and B3 have comparable thermal conductivity compared to that of SiC reinforced composite B1. This is a clear indication that the addition of low cost agro-waste, GSA as a partial reinforcement to SiC in aluminium 6063 does not degrade the thermal conductivity characteristics of the hybrid composite.

The variation of thermal conductivity of composite sample C decrease to 13.5% as the reinforcement increases. Sample D composites have lower thermal conductivity compared to all the composites produced. There is a decrease in thermal conductivity of 6.8% for the SiC+GSA composites compared to the SiC reinforced composite. D3 has the lowest thermal conductivity of about 125.06 W/mK. The decrease in thermal conductivity is as a result of lower thermal conductivity of GSA and SiC (120 W/mK) compared to that of Al 6063 (200 W/mK) [22]. The thermal conductivity of the composite decreased with increase in reinforcement. This is in line with Okumus, *et al.* [23], in which the thermal conductivity decreased with increase in graphite reinforcement.

3.4 Wear rate

The average wear rate for both SiC and SiC+GSA reinforced composites with different weights of SiC and GSA for 3g, 6g, 9g and 12g reinforcement is presented in Figure 4.

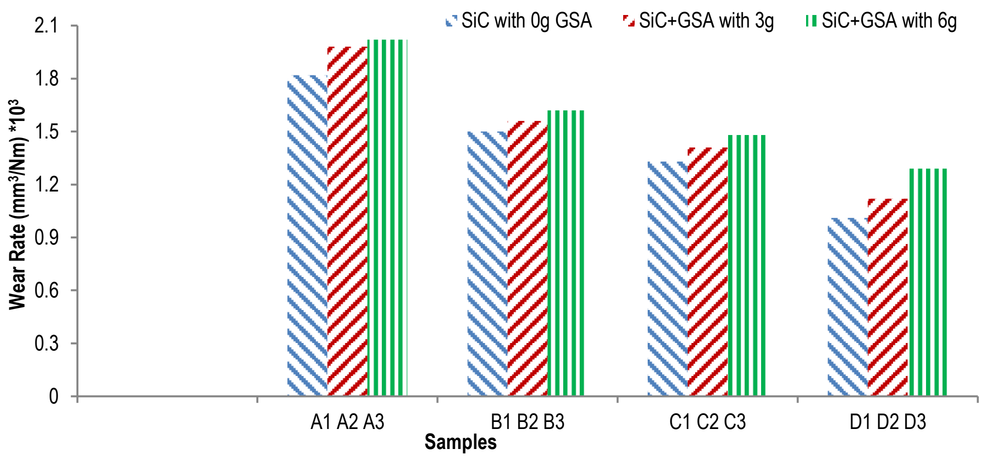

Figure 4. Wear rates for SiC and SiC+GSA reinforced composites

For composites sample A with 3g reinforcement, it is observed that the SiC reinforced composites A1 has wear rate of 1.82 x 10^{-3} mm^3/Nm. The wear rate of SiC+GSA reinforced composites A2 and A3 increases by 8% and 9.9%, respectively. The increase in wear rate may be attributed to the comparatively poor bonding between SiC+GSA and the matrix material. Hence, there may be particles pull out during wear test. For sample B with 6g reinforcement, it is observed that the wear rate of the SiC+GSA composites B2 and B3 had comparable wear rate to that of SiC reinforced composite B1. This is another clear indication that the addition of low cost agro-waste, GSA as a partial reinforcement to SiC in aluminium 6063 does not degrade the wear resistance characteristics of the composite. Similar observation was revealed when Navin, *et al.* [24] investigated the material characterization of aluminium (Al 360) reinforced with SiC and CSA hybrid composite in weight ratio of 1:3, 1:1 and 3:1 fabricated by stir casting for clutch plate application.

Sample C1 with 9g SiC reinforcement has wear rate of 1.33 x 10^{-3} mm^3/Nm, it is observed that there is 5.67% and 10.13% decrease in wear rate for the SiC+GSA reinforced composite C2 and C3 respectively. For the 12g reinforcement D3, it is observed from Figure 4 that the SiC reinforced composite D1 has the lowest wear rate in all the composites produced. The hybrid composites D2 and D3 have lower wear rates compare to all the SiC+GSA composites produced. These lower wear rates may be attributed to good wet ability and less porosity which has been reported to improve the mechanical and tribological properties of aluminium matrix composite Suryanarayanna et al. [25]. This is a further indication that adding GSA particles can improve the wear resistance of aluminium based matrix composite and are comparable to SiC reinforced composites. Samples after wear test are shown in plate VIII. Alaneme et al. [18] came to a similar conclusion when they studied the wear behaviour of Al-Mg-Si alloy matrix hybrid composites reinforced with Rice Husk Ash (RHA) and SiC.

3.5 Microstructural Examination

The microstructure of the SiC and SiC+GSA reinforced composite produced are represented in Figure 5 (a, b, c, and d).

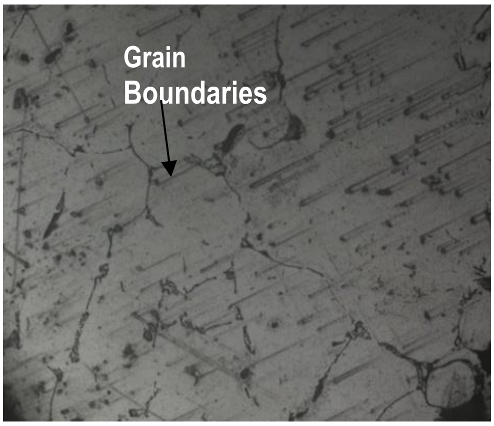

Figure 5(a). Microstructure of composites 3g SiC+GSA reinforcement

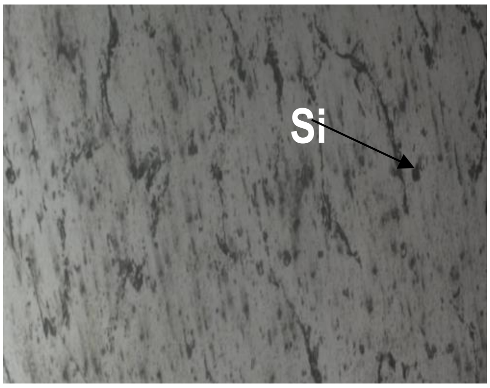

Figure 5(b). Microstructure of composites 6g SiC+GSA reinforcement

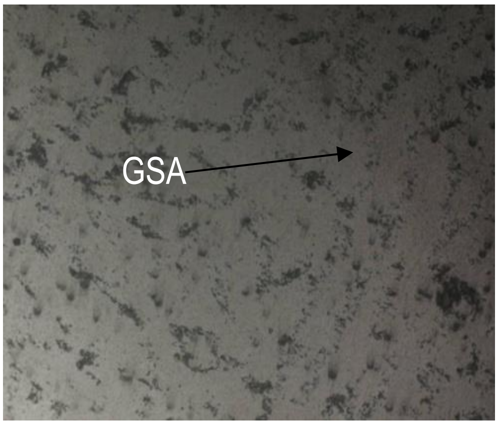

Figure 5(c). Microstructure of composites 9g SiC+GSA reinforcement

Figure 5(d). Microstructure of composites 12g SiC+GSA reinforcement

It is observed that the reinforcing particles (SiC, GSA) were visible and fairly well distributed in the Al 6063 alloy matrix. This is an indication that the double stir casting process adopted for the composite production is reliable. Similar feature and observation have been reported by Alaneme and Sanusi [13]. The SiC particles dispersed in the Al 6063 alloy matrix for SiC reinforced composite with 3g were revealed in fig4a. Fig4c shows the dense distribution of particles in the SiC+GSA composite containing 12g reinforcement, this is due to the higher volume of the GSA particles which have very low density (0.45g/cm^3) in comparison to SiC (3.18g/cm^3) [26]. The uniform distribution and good bonding of SiC/GSA particles in the Al matrix hybrid composites have greater tribological and mechanical properties such as good compressive strength, low wear rate, high damping capacity, and their outstanding properties. Strong homogeneous microstructure between the reinforcement and the matrix helps in the load exchange from the reinforcement to the matrix. Thus, enhance the crack resistance of the composites [27, 28]. However, formation of clusters of reinforcement particles can be seen at some places in the microstructure, the characterization of the composites at these areas would provide different result [29]. Researchers such as [23, 30] reported that clustering phenomenon decreases the mechanical, tribological and physical properties of composites.

4. Conclusion

Hybrid aluminium alloy matrix composite containing 3g, 6g, 9g and 12g GSA and SiC particles as reinforcement was produced using double stir casting technique. The hardness, compressive strength and microstructure were investigated. The results show that hybrid aluminium matrix composites with up to 12gSiC and GSA particles as reinforcement could be easily produced using double stir casting technique. The hardness and compressive strength of the SiC reinforced composite increases with increase in SiC particles and the hardness and compressive strength of the SiC+GSA composites decreases slightly with increase in GSA particles in comparison to SiC reinforced composite. The microstructure revealed that the SiC and GSA particles were fairly distributed in the aluminium matrix. GSA particles can be used as partial reinforcement material in the production of high performance, low-cost hybrid aluminium composite in sectors where light weight and enhance mechanical properties is necessary.

The Vickers hardness value and compressive strength of the produced composites are lower than the generic properties of brake disc. Thermal conductivity are within the range of generic property of aluminium brake disc.

Acknowledgement

The authors wish to sincerely thank the authorities of Modibbo Adama University of Technology Yola, Ahmadu Bello University Zaria, Technical Skill Acquisition Center Yola and Technical Skill Acquisition Center Mayo-Belwa for allowing access to their equipment during this research work.

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