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Mechanical And Microstructural Properties Of Al-Sic Auto Brake Disc Rotor Composite

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Abstract
Aluminium Matrix Composites (AMC) are combinations of aluminium alloy and other components usually non-metal and commonly ceramic such as silicon carbide (SiC) and aluminium oxides (Al_2O_3) in order to improve the engineering properties of the aluminium alloy. This research work examined the mechanical and microstructural properties of Al-SiC auto brake disc rotor composite. Aluminium ingots were first heated in the furnace at a temperature of 720°C to molten state and SiC particles having average size of 25 μm preheated to 840°C for about two hours were added as reinforcement (5%, 10%, 15%, and 20% of SiC). The mixture was then stirred for 10 minutes at 850 rpm to ensure homogenous distribution of Composite Metal Particles (CMP) prior to pouring into the preheated metallic mould at 940°C. A control sample without SiC additions was also produced. The produced samples were shaped into standard samples for the purpose of hardness, impact, tensile, compression properties determination and wear. The morphology examination and elemental composition analysis of phases present in the produced composite samples were carried out using scanning electron microscope, with the attached energy dispersive X-ray spectroscopy. Auto brake disc rotor was produced with standard dimension. The mechanical properties showed improvement in terms of hardness, impact toughness, compressive stress, decrease in yield stress and wear rate, it was observed that there is an increase in the Charpy impact strength of the reinforced AMC when compared with unreinforced Al. The highest impact strength was recorded at 15 wt. % reinforcement. This obviously translate that, with the presence of SiC the impact strength of the composite was improved. The Scanning Electron Microscope (SEM) results revealed the phases present in the composite while the Energy Dispersive X-ray indicated the elemental composition of the composite.

Keyword: Aluminium matrix composite; Mechanical property; SEM, EDX, Silicon Carbide

1. INTRODUCTION

AMC material systems offer superior combination of properties in such a manner that today no existing monolithic material can rival. Over the years, AMC have been tried and used in numerous structural, non-structural, and functional applications in different engineering sectors (Clyne, 2001). Aluminium based composite materials are leading in this area, they are fabricated using many methods, including powder metallurgy processes, and then formed, e.g., by hot extrusion (Dobrzanski *et al.,* 2005).

Current engineering applications require materials that are stronger, lighter, and less expensive. A good example is the current interest in the development of materials that have good strength to weight ratio suitable for automobile applications where fuel economy with improved engine performance is becoming more critical (Alaneme *et al.,* 2013). In-service performance demands for many modern engineering systems require materials with broad spectrum of properties, which are quite difficult to meet using monolithic material systems (Bhushan and Kumar, 2011). Some of these property combinations include high specific strength, low coefficient of thermal expansion and high thermal resistance, good damping capacities, superior wear resistance, high specific stiffness, and satisfactory levels of corrosion resistance (Boopathi *et al*., 2013).

The common metallic alloys utilized are alloys of light metals (Al, Mg and Ti). However, other metallic alloys like zinc (Zn), copper (Cu) and stainless steel have been used. Aluminium remains the most utilized metallic alloy as matrix material in the development of MMCs and the reasons for this has been reported (Wang and Wang, 1992). However, high cost and limited supply of conventional ceramic reinforcing materials especially in developing countries has remained a major problem associated with the development of Discontinuously Reinforced Aluminium Matrix Composites (DRAMCs) as reported by Deshmanya and Purohit (2012). Other challenges facing DRAMCs that are reported to be of interest to researchers are inferior ductility, low fracture toughness and inability to predict the corrosion behavior of AMCs.

The failure of conventional cast iron brake disc rotor because of wear due to heat generated around the rotor is of great concern. Such failures often resulted to economic losses and reliability problem. Therefore, the present work investigated the effect of SiC addition on aluminium matrix for the purpose of brake disc rotor production.

2. MATERIALS AND METHODS

The materials used are Aluminium ingots and silicon carbide particles while equipment employed for stir casting comprises Pit furnace, Crucible, Tong, Cope and drag die cavity mold, and Pin on disc. Mechanical properties were determined using Universal tensile testing machine, Vickers's hardness testing machine and Universal Impact tester. Microstructural analysis was carried out using Scanning Electron Microscope (SEM/EDS) of ASPEX 3020 model.

2.1 Methodology

The samples were produced using stir casting technique. Aluminium ingots were first melted in the furnace at a temperature of 720^{o}C to molten state before SiC articles were added to the melt. The metal matrix was reinforced with SiC particle having average particle size (APS) of 25 µm similar to the report of Houyen *et al.* (2011). Silicon carbide was preheated at 840^{o}C for about two hours (2 h) before adding it to the melt. Furnace with a temperature range of 3000^{o}C was used to melt the matrix material. The furnace has a temperature controller with thermocouple to control and measure the temperature. An electric motor was fixed to the furnace to provide stirring motion to the stirrer. The furnace was assembled with titanium impeller as stirrer and speed of the stirrer was varied with a speed controller attached to it. The samples were produced by varying reinforcement of 5%, 10%, 15%, and 20% of SiC to the melt of Al and then stirred for 10 minutes at 850 rpm to ensure homogenous distribution of CMPs prior to pouring into the preheated metallic mould at 940^{o}C. A control sample without SiC addition was also produced, molten composite was then allowed to solidify in the mould. The produced samples were shaped into standard samples for the purpose of hardness, impact, tensile, compression properties determination and wear.

2.1.1 Hardness Test

The Vickers hardness test method was used for our produced samples, it consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136^{o} between opposite faces subjected to a load of 50 kgf. The full load was applied for 12 sec. The two diagonals of the indentation left in the surface of the material after removal of the load were measured using a microscope and their average calculated. The area of the sloping surface of the indentation was calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

2.1.2. Impact Test

A Charpy V-notch specimen was machined from the produce composite to sizes of 10 mm x 10 mm x 55 mm with a 2 mm deep V-shaped notch, placed across parallel jaws in the impact-testing machine. The pointer is set up to its maximum value (300 J). The hammer was released from the initial height downward towards the sample. Observations and the energy absorbed are recorded and tabulated. This process was repeated for another specimen while observations are recorded and tabulated.

2.1.3 Tensile Test

The produced composite castings were machined to standard shape and gripped at both ends by the test apparatus, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, the force on the specimen and its displacement was continuously monitored and plotted on a stress-strain curve until failure. The load was converted to a stress value and the displacement was converted to a strain value.

Figure 1: Silicon carbide particles of 25 µm size

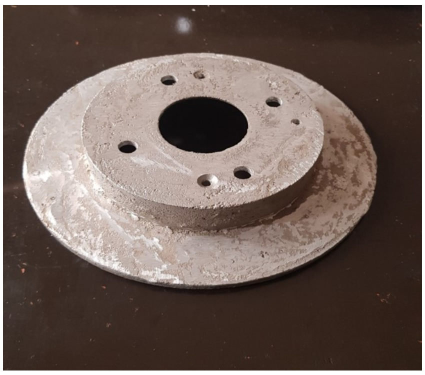

Figure 2: Developed brake disc rotor

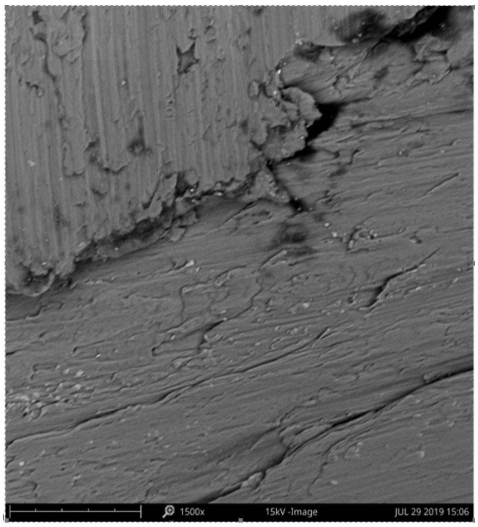

Figure 3: SEM for 0% Wt. reinforcement

2.1.4 Compression Test

A fixture was used to align the machined specimen of a uniform rectangular cross section, 140 mm x 155 mm x 12 mm in the wedge grips and the grips are therefore tightened. The wedges were inserted into the compression fixture, and an extensometer was used to measure strain, which was attached to the specimen. The specimen was compressed to failure.

2.1.5 Wear Test

A pin-on-disc wear tester was used to carry out the tests. The pin was loaded against a flat rotating disc such that a circular wear path was described by the machine. The machine was then used to evaluate wear properties of the composite materials under pure sliding conditions. The test sample is loaded with mass of 1.65 Kg (16.18 N) at a revolution speed of 250rev/sec for 60 seconds. This process was repeated for all wt. % reinforced sample.

2.2 Scanning Electron Microscopy Test (SEM)

The scanning electron microscope (SEM) was employed to produce images by scanning the sample with a high-energy beam of electrons. These electrons interact with the sample, produce secondary electrons, backscattered electrons, and characteristic X-rays. These signals were collected by one or more detectors to form images which are then displayed on the computer screen. When the electron beam hits the surface of the sample, it penetrates the sample to a depth of a few microns, depending on the accelerating voltage and the density of the sample. Many signals, like secondary electrons and X-rays, are produced because of this interaction inside the sample.

3. RESULTS AND DISCUSSION

The brake disc rotor produced from the composite is as shown in Figure 2.

3.1 Scanning Electron Microscopy and EDX

Figures 3, 5, 6, 7 and 8 give the SEM images while Figure 4 and Tables 1 to 6 showcase the EDX results of the composites.

Table 1-5 show the chemical elements composition of the produced Al-SiC composite. The major elemental component is Al with a significant weight concentration, while carbon has the second highest weight concentration. The other elements present in the composite are Mg, Si, Fe and Na with their various weight concentrations. Magnesium and Silicon combined as magnesium silicide (Mg_2Si) in the alloy thereby increasing the strength of the alloy.

3.2 Hardness Results

Table 6 shows the Vickers hardness values of reinforced Aluminium matrix composites (AMCs) containing varying wt. % of silicon carbide (SiC) reinforcements. It can be observed that addition of silicon carbide (SiC) particles

Table 1: EDX Micrograph element analysis table for 0% Wt. reinforcement

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
13	Al	Aluminium	83.50	91.65
6	C	Carbon	15.75	6.86
12	Mg	Magnesium	0.42	0.60
26	Fe	Iron	0.23	0.76
11	Na	Sodium	0.10	0.13

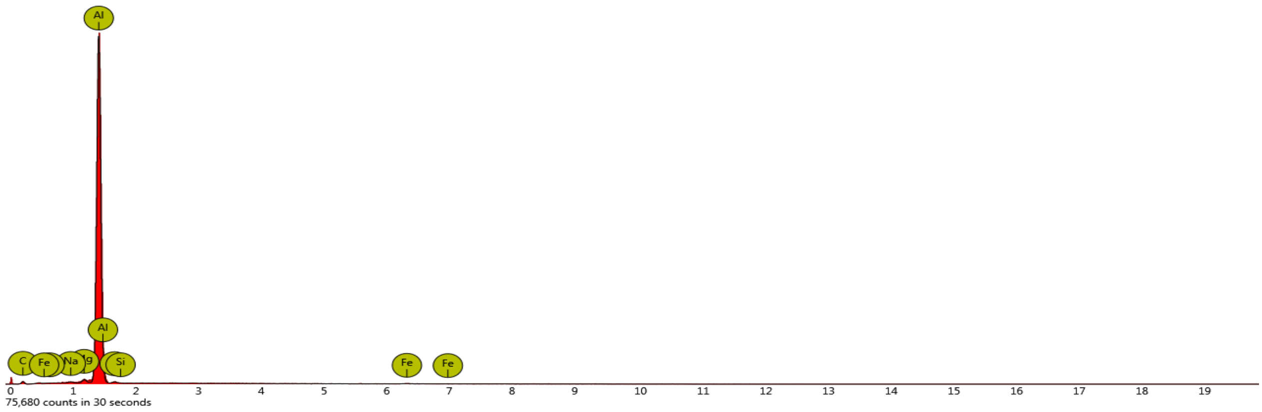

Figure 4: EDX micrograph of reinforced aluminium matrix composites (AMCs) with 15 % silicon carbide (SiC) particles.

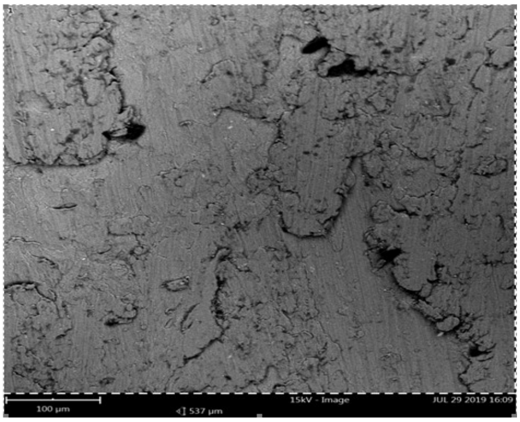

Figure 5: SEM for 5% Wt. reinforcement

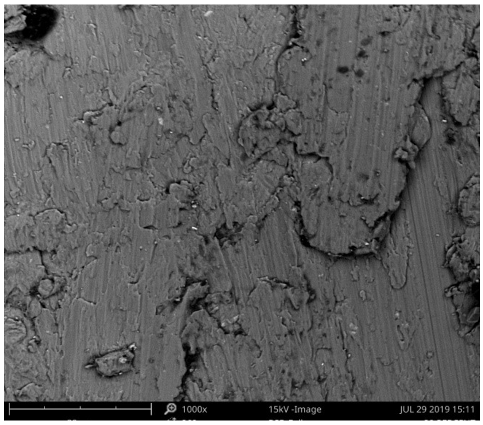

Figure 6: SEM for 10% Wt. reinforcement

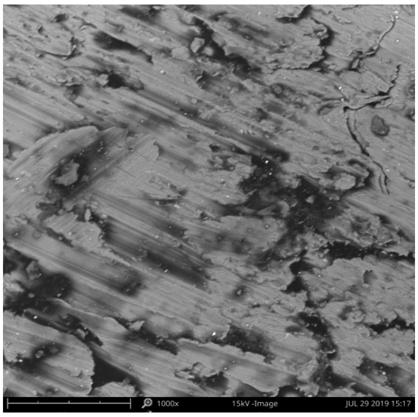

Figure 7: SEM for 15% Wt. reinforcement

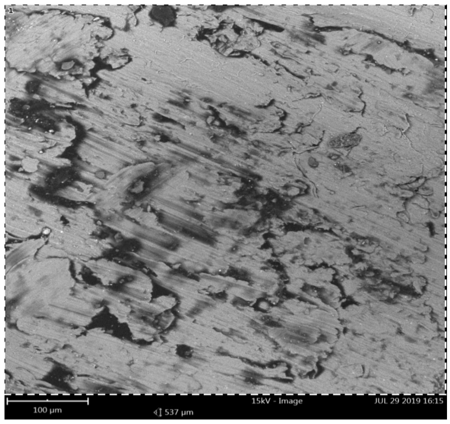

Figure 8: SEM for 20% Wt. reinforcement

Table 2: EDX Micrograph element analysis table for 5% Wt. reinforcement

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
13	Al	Aluminium	80.46	89.63
6	C	Carbon	18.37	8.34
12	Mg	Magnesium	0.48	0.58
14	Si	Silicon	0.32	0.44
26	Fe	Iron	0.25	0.85
11	Na	Sodium	0.12	0.16

Table 3: EDX Micrograph element analysis table for 10% Wt. reinforcement

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
13	Al	Aluminium	78.31	87.62
6	C	Carbon	20.30	10.40
12	Mg	Magnesium	0.55	0.63
14	Si	Silicon	0.42	0.49
26	Fe	Iron	0.25	0.66
11	Na	Sodium	0.17	0.20

Table 4: EDX Micrograph element analysis table for 15% Wt. reinforcement

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
13	Al	Aluminium	73.57	85.06
6	C	Carbon	24.66	12.69
12	Mg	Magnesium	0.68	0.71
14	Si	Silicon	0.54	0.65
26	Fe	Iron	0.25	0.60
11	Na	Sodium	0.29	0.29

Table 5: EDX Micrograph element analysis table for 20% Wt. reinforcement

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
13	Al	Aluminium	66.94	80.08
6	C	Carbon	31.06	17.01
12	Mg	Magnesium	0.66	0.72
14	Si	Silicon	0.60	0.70
26	Fe	Iron	0.50	1.25
11	Na	Sodium	0.24	0.24

Table 6: Vickers hardness values for different wt. % reinforced samples

SiC Content (%)	Hardness values 1 (Vickers)	Hardness Values 2 (Vickers)	Average Hardness Values (Vickers)
0	179.30	174.20	176.75
5	187.10	186.40	186.75
10	190.90	189.60	190.25
15	195.70	192.30	194.00
20	200.80	197.90	199.35

Table 7: Values for impact test of different wt. % reinforced samples.

SiC Content	Impact Energy (Joules)
0%	45.2
5%	52.3
10%	60.3
15%	67.9
20%	65.2

Table 8: Tensile Stress at yield test for different wt. % reinforced samples

SiC Content	Tensile stress at Yield (MPa)
0%	98.714
5%	91.686
10%	80.067
15%	72.836
20%	43.609

Table 9: Values of maximum Compressive stress test for different wt. % reinforced samples.

SiC Content	Max Compressive stress (MPa)
0%	111.0884
5%	152.82694
10%	164.60385
15%	198.18771
20%	212.36219

in Al matrix composites enhanced the hardness of the reinforced Aluminium matrix composites (AMCs) when compared with unreinforced Al. The hardness values can be seen to increase with SiC content. The presence of harder and well bonded silicon carbide (SiC) particles in Al matrix that impede the movement of dislocations has helped to increase the hardness of the reinforced Aluminium matrix composites (AMCs). Similar result was reported by Adebisi *et al*. (2016).

3.3 Impact Results

Table 7 above shows that the impact energy increased with SiC content. It was observed that there was an increase in the Charpy impact strength of the reinforced Aluminium matrix composites (AMCs) when compared with unreinforced Al. The highest impact strength was recorded at 15 wt. % reinforcement. This obviously translates that, with the presence of SiC the impact strength of the composite is improved.

3.4 Tensile Test

The relationships between tensile strength and wt. % of silicon carbide (SiC) reinforcements of fabricated composites are shown in Table 8 above. Tensile strength was inversely proportional to the SiC content. The highest tensile strength was recorded for the sample without SiC content. From the tensile test results, it was observed that the tensile strength of the reinforced aluminium matrix composites (AMCs) is lower than unreinforced Al. Decrease in tensile strength of aluminium matrix composites (AMCs) can be attributed to the applied tensile load transfer to the strongly bonded silicon carbide (SiC) reinforcements in Al matrix, grain refining strengthening effect, making it brittle and increasing its dislocation density near matrix-reinforcement interface. Similar result was reported by Adetunji *et al.* (2021).

3.5 Compressive Stress

The relation between compressive strength and wt. % of silicon carbide (SiC) reinforcements of fabricated composites are shown in Table 9 above. Compressive strength increased with increase in SiC content. It can be observed that the compressive strength of the reinforced aluminium matrix composites (AMCs) is greater than unreinforced Al. Increase of compressive strength may be attributed to the stronger bonding in the reinforced aluminium matrix composites. This is similar to the report of Saravanan and Kumar (2014) on aluminium (AlSi10Mg) with reinforcement material at 9 and 12 wt.% considering different weights of microns, it was observed that the compressive strength increased with wt. reinforcement.

3.6 Wear Rate Test

It is observed from Table 10 above that wear rate for unreinforced Al is greater than that of the silicon carbide (SiC) reinforced aluminium matrix composites (AMCs). This is because the softer Al matrix was worn away from the surface during wear test in unreinforced sample compared with reinforced samples. The Al matrix would generally wear off from the surface leaving the hard silicon carbide (SiC) particles behind. These exposed silicon carbide (SiC) particles would protect the Al matrix from further wear. The resistance to wear at contacting surface increased as the %wt. of silicon carbide (SiC) in the aluminium matrix composites (AMCs) increased. This is evident as 20% wt. silicon carbide (SiC) reinforced aluminium matrix composites (AMCs) gave the lowest amount of wear rate and hence poses the maximum wear resistance of all the test samples. All of which showed that the toughness of composite is improved with increasing %wt. of SiC reinforcement. This agreed with the report of Rehman and Al-Rashad (2013) where the results of the experiments concluded that by adding silicon carbide and Al matrix at 20%wt of silicon carbide contents, AMC gave maximum wear resistance. Hence silicon carbide reinforced AMCs provided better wear resistance when compared with unreinforced aluminium.

4. CONCLUSIONS

The mechanical and microstructural properties of Al-SiC auto brake disc rotor composite were investigated in this work. For this experimental study, aluminium matrix composites (AMCs) of varying silicon carbide (SiC) content (0, 5, 10, 15, and 20 wt. %) were prepared using stir casting fabrication technique. Hardness, impact, tensile strength, compressive, wear, and microstructural characteristics of the prepared composites were studied. Based on experimental evaluation, following conclusions were reached.

1 The brake disc rotor presented here was developed with Aluminium matrix composites (AMCs) reinforced with silicon carbide (SiC) particles using stir casting technique. Different wt.% fractions were produced and the wt. % with optimal values was selected as 15% SiC.

2 The Mechanical properties (Hardness, impact, tensile strength, compressive, and wear) of the produced Aluminium matrix composites (AMCs) reinforced with silicon carbide (SiC) particles showed remarkable improvement over that of the control samples. The Vickers hardness strength value of 176.75 for the control sample, increased with increasing silicon carbide (SiC) content and maximum obtained hardness value is 199.35 for 20 wt. % silicon carbide (SiC) reinforced Aluminium matrix composites (AMCs). There was an increase in the Charpy impact strength of the reinforced Aluminium matrix composites (AMCs) when compared with unreinforced Al. The highest impact strength was recorded at 15 wt. % reinforcement. The tensile strength showed little decrease with increase in SiC addition while compressive strength increased. The wear rate of samples decreased as SiC addition increased. It was established that the particulate silicon carbide (SiC) reinforcements have direct influence on the above outlined mechanical properties, hence helped in selecting sample wt. % with the optimal ratio of 15% SiC.

3 The surface morphology of the produced Aluminium matrix composites (AMCs) reinforced with silicon carbide (SiC) particles characterized using the scanning electron microscopy (SEM) showed homogeneous sample distribution which became denser as SiC addition increased in percentage.

The Energy Dispersive X-ray (EDX) indicated the composition of the composite where Al, C, Si, Mg and Fe were prominent.

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