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Effect of Varying Silicon Carbide Particulate On The Mechanical Properties Of Aluminium Based Alloy Automobile Brake Disc Component

Victor E. Ogbonna[1], Patrick S. Olayiwola[2*], H.E Mgbemere[1]

[1]Department of Materials & Metallurgical Engineering, Faculty of Engineering, University of Lagos, Akoka-Yaba, Lagos 23401, Nigeria

[2]Department of Mechanical & Biomedical Engineering, College of Engineering, Bells University of Technology, Ota, Ogun State 234037, Nigeria

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ABSTRACT

In the current study, effect of varying Silicon Carbide particulate on the mechanical properties of Aluminium based alloy automobile brake disc component was investigated. The result of experimental investigation on mechanical properties of Silicon Carbide particle reinforced Aluminium Matrix was achieved for composite brake disc using universal tensile test machine, Rockwell hardness testing machine and numerical/theoretical model. The influence of reinforced ratio of 5, 10, 15 20, and 25 weight percentage of Silicon Carbide particles on mechanical properties was examined. Aluminium Metal Matrix Composites containing, 5, 10, 15, 20, and 25 weight percentages of reinforcement Particles was obtained using Stir-Casting method. The result obtained showed that highest Yield Strength (350.64MPa), Modulus of Rigidity (6137.4MPa), and Hardness (76.5Kg/mm^2) was obtained on 25wt%SiC (190µm) particle reinforcements.

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*Dr. Patrick S. Olayiwola
Email Address:olayiwola_patrickshola@yahoo.com
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1. Introduction

Metal-Matrix Composites (MMCs) are relatively new class of Engineering Materials that exhibits high stiffness-to-weight ratio, significant weight reduction, wear resistance and thermal stability when compared with unreinforced matrix alloy[1], although aluminium has high strength, ductility, thermal and electrical conductivity [2]. However, Aluminium silicon carbide metal matrix composites are used in various fields like aerospace, aircrafts, underwater, automobile, substrate in electronics, and turbine blade [3].

In addition, a brake disc is a device by means of which artificial frictional resistance is applied to a moving machine member, in order to retard or stop the motion of a machine while it runs at certain speed [4]. In automobile industries, reducing fuel consumption and house gas emissions are achievable through the brake disc application using light weight materials. However, it has been found that the mechanical behaviour of brake disc is improved with application of the Metal-Matrix Composite.

These materials having a lower density and higher thermal conductivity as compared to the conventionally used grey cast iron have been used for many applications like automobile brake disc. Metal-Matrix Composite, as a relatively new class of engineering materials, has received attention over the past decades as one of the substitutes for iron and steel. They have great potentials as new engineering materials in aerospace, nuclear, and defense industries. Moreover, these advanced materials have the potential to perform better under severe service conditions like higher speed, higher load etc. which are increasingly being encountered in modern automobiles. Metal-matrix composites are attracting the attention of manufacturers and users because of their exceptional mechanical properties and growing availability due to continued research to develop better and cheaper composite materials [5].

Particle-reinforced Metal-Matrix Composite (MMC) is one class of composite that is easy and cheap to manufacture. One prospective process of producing Metal-Matrix Particulate Composites (MMPC) has long been identified as Stir-Casting technique [6]. Stir-Casting method of producing composite is particularly attractive to the developing nations venturing into Metal-Matrix Particulate reinforce Composite MMPC development because of the reduced sophistication, possibility of using conventional foundry equipment and relatively low cost of the process. Since brake disc rotor is a crucial component from safety point of view, materials used for brake systems should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature and environment, and high durability. Therefore these factors such as load, velocity, temperature and environment, and high durability and reactivity, volume fraction of the reinforcing material, type of the reinforcing material and distribution of the reinforcing material are reviewed using the existing literature.

Using the information available, the need for consideration and the ability of brake disc to withstand high friction and less abrasion wear becomes imperative in brake disc application [7, 8]. According to Corke [9], the most commonly used criterion whilst deciding on a material is the weight. Therefore the present investigation was performed to ascertain effect of varying Silicon Carbide as a reinforcement particulate on mechanical behavior of aluminium based alloy automobile brake disc component.

Table 1: Spectra-analysis of the chemical composition of aluminium alloy

Si	Cu	Mn	Mg	Zn	Ti	Cr	Ni	V	Pb	Al	Fe
0.38	0.05	0.12	0.02	0.07	0.01	0.007	0.005	0.006	0.02	98.62	0.25

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2. ESSENTIAL MECHANICS

The generalized Hook's law equations for the general case of cylindrical anisotropy using the strain coefficients a_{ij} is given by,

$$\left.\begin{aligned} \varepsilon_r &= a_{11}\sigma_r + a_{12}\sigma_\theta + \ldots + a_{16}\tau_{r\theta} \\ \varepsilon_\theta &= a_{12}\sigma_r + a_{22}\sigma_\theta + \ldots + a_{26}\tau_{r\theta} \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \gamma_{r\theta} &= a_{16}\sigma_r + a_{26}\sigma_\theta + \ldots + a_{66}\tau_{r\theta} \end{aligned}\right\} \quad (1)$$

However, to simplify the system for the situation where the plane of the cross-section is a plane of elastic symmetry, some strain coefficients are set to zero, viz-a-viz.,

$$\begin{aligned} a_{14} &= a_{24} = a_{34} = a_{46} = a_{15} \\ &= a_{25} = a_{35} = a_{56} = 0 \end{aligned} \quad (2)$$

Also, the state of stress and strain in the brake disc plate can be obtained from the average values of the stress components $\bar{\sigma}_r, \bar{\sigma}_\theta, \bar{\tau}_{r\theta}$ and projections of displacement across the thickness [10], namely;

$$\bar{\sigma}_r = \frac{1}{b}\int_{-b/2}^{b/2} \sigma_r dx \quad (2)$$

$$\bar{\sigma}_\theta = \frac{1}{b}\int_{-b/2}^{b/2} \sigma_\theta dx \quad (3)$$

$$\bar{\tau}_{r\theta} = \frac{1}{b}\int_{-b/2}^{b/2} \tau_{r\theta} dx \quad (4)$$

$$\bar{u}_r = \frac{1}{b}\int_{-b/2}^{b/2} \bar{u}_r dx \quad (5)$$

$$\bar{u}_\theta = \frac{1}{b}\int_{-b/2}^{b/2} \bar{u}_\theta dx \quad (6)$$

On the basis of generalized Hook's law equations, the average strains and displacements are determined from the following equations

$$\bar{\varepsilon}_r = a_{11}\bar{\sigma}_r + a_{12}\bar{\sigma}_\theta + a_{13}\bar{\tau}_{r\theta} \quad (7)$$

$$\bar{\varepsilon}_\theta = a_{12}\bar{\sigma}_r + a_{22}\bar{\sigma}_\theta + a_{26}\bar{\tau}_{r\theta} \quad (8)$$

$$\bar{\gamma}_{r\theta} = a_{16}\bar{\sigma}_r + a_{26}\bar{\sigma}_\theta + a_{66}\bar{\tau}_{r\theta} \quad (9)$$

with

$$\left.\begin{aligned} \varepsilon_r &= \frac{\partial \bar{u}_r}{\partial r} \\ \varepsilon_\theta &= \frac{1}{r}\frac{\partial \bar{u}_r}{\partial \theta} + \frac{\bar{u}_r}{r} \\ \gamma_{r\theta} &= \frac{1}{r}\frac{\partial \bar{u}_r}{\partial \theta} + \frac{\partial \bar{u}_\theta}{\partial r} - \frac{u_\theta}{r} \end{aligned}\right\} \quad (10)$$

On writing Eqns. (7-9) in matrix form gives,

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & a_{16} \\ a_{12} & a_{22} & a_{23} & 0 & 0 & a_{26} \\ 0 & 0 & a_{33} & a_{34} & 0 & 0 \\ 0 & 0 & a_{34} & a_{44} & a_{45} & 0 \\ 0 & 0 & a_{35} & a_{45} & a_{55} & 0 \\ a_{16} & a_{26} & a_{36} & 0 & 0 & a_{66} \end{pmatrix} \begin{pmatrix} \bar{\sigma}_r \\ \bar{\sigma}_\theta \\ 0 \\ 0 \\ 0 \\ \bar{\tau}_{r\theta} \end{pmatrix} = \begin{pmatrix} \bar{\varepsilon}_r \\ \bar{\varepsilon}_\theta \\ 0 \\ 0 \\ 0 \\ \bar{\gamma}_{r\theta} \end{pmatrix} \quad (11)$$

$$\bar{\sigma} = \mathbf{a}_{ij}^{-1}\bar{\varepsilon} \quad (12)$$

That is,

$$\bar{\sigma} = \mathbf{E}\bar{\varepsilon} \quad (13)$$

where $\mathbf{a}_{ij}^{-1}$ is the elastic constants matrix and $\mathbf{E}$ is elastic modulus matrix.

3. EXPERIMENTAL PROCEDURE

3.1 Material and Methods

A composite brake disc system was produced using SiC particles with 190µm as reinforcement and aluminium alloy as the base matrix using stir casting method in an improvised furnace (black smith hearth furnace), where preheated reinforcement (SiC) particles at a temperature of 900^0C was added and stirred slowly and poured into sand mould. The relative volume of the metal matrix (aluminium) and reinforcement (SiC) particles were determined using the mass volume relationship.

Hardness test was carried out by the Rockwell hardness test Machine. For this hardness test on the MMC samples, the scale HRB was used. Based on the HRB scale, a load 100kgf was applied on each MMC samples through a 1/16 inch diameter spherical shaped

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steel indenter. The load was applied to the sample and the hardness values were obtained immediately from the Machine. Tensile test was carried out by the Extensometer test Machine. The test pieces of gauge length of 28mm and diameter of 5mm were placed in a test piece holder and secured in position. Load was applied until the test piece fracture and the results were obtained immediately from the machine.

For metallographic examination of the cast samples, the test pieces were cut from the bulk of the cast samples and mounted in a thermosetting Phenolic powder using the mount press. The mounted test pieces were ground with abrasive papers following the orders of 150, 220, 400, 600, 800 and 1000 grit sizes after which they were polished and etched. They were washed and dried. Their micrographs were taken using optical microscope at a magnification of X400

4. RESULTS AND DISCUSSION

Aluminium Metal Matrix Composites containing, 5, 10, 15, 20, and 25 weight percentages of reinforcement particles was obtained using Stir-Casting method. The result obtained showed that highest Strength (350.64MPa), Modulus of Rigidity (6137.4MPa), and Hardness (76.5Kg/mm^2) was obtained on 25wt%SiC (190μm) particle reinforcements.

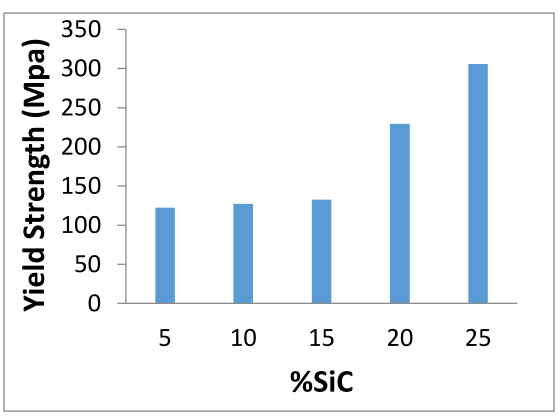

Figure 1: Yield Strength versus varying %wtSiC.

From the result obtained in the tensile test of the specimen bar, it was observed that the more the weight percentage reinforcement, the greater the yield strength and more decreased in ductility occurs. However, result showed that 25% SiC reinforcement has greater yield strength compared to other varying % Sic reinforcement, (see Table 2 and Figure 1 and 2). In analysing the properties as stated above, the reactions at the interface of Metal Matrix Composite (MMC) where considered and the primary reaction for Al-SiC was in accordance to [10 - 13] as shown below:

$$4Al + 3SiC \rightarrow AL_4C_3 + 3Si$$

Table 2: Yield strength with varying %SiC

%SiC	Yield strength (MPa)
0	116.50
5	122.26
10	127.36
15	132.45
20	229.24
25	350.64

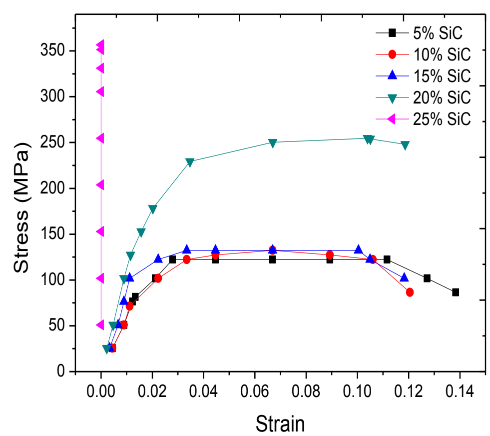

Figure 2: Stress – Strain Curve for varying %wt Silicon-Carbide

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Furthermore, the Aluminum carbide layer contributed to the increase of Yield Strength, Hardness, Modulus of rigidity and reduction in Ductility of the reinforced Metal Matrix compared to unreinforced MMC. In addition, result showed that there is more elongation at 0 %wtSiC sample as such the ductility was high thereby leading to the decreased in Yield Strength and Hardness (See Figure 3).

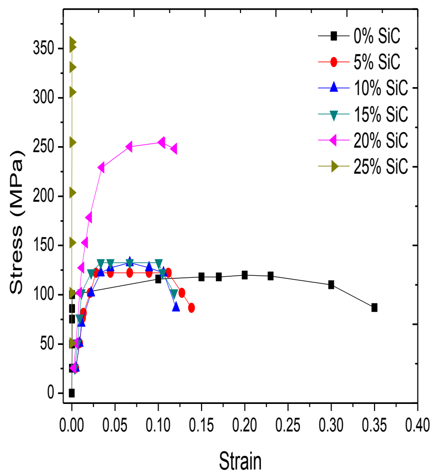

Figure 3: Stress – Strain Curve for both reinforced and unreinforced Metal Matrix Composite

Table 3: Modulus of Rigidity of varying fraction of SiC

Varying fraction of SiC (%)	Modulus of Rigidity (E), *MPa*
5 %	3345.67
10 %	4817.8
15 %	5102.3
20 %	5560.1
25 %	6137.4

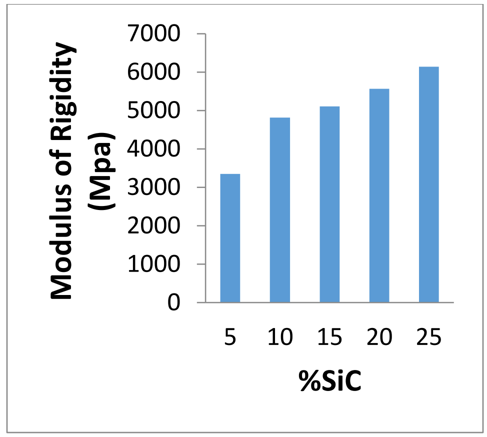

Figure 4: Modulus of Rigidity of varying %SiC

The modulus of rigidity increases with increasing weight percentage reinforcement as shown in Figure 4. Furthermore, it was observed that 25%SiC reinforcement shows more modulus of rigidity as a result of low ductility and high yield strength, see Figure 4 for 25%SiC particulate reinforcement compare to other %SiC Particulate reinforcement. However this aforementioned observation above will make Aluminum based alloy automobile brake disc of 25%SiC reinforcement a better chance of having good wear resistance and stable/reliable frictional property under the condition of load, high speed and more durable.

Table 4: Hardness (HRB) for varying %SiC

Varying % SiC	Rockwell Hardness number in HRB –scale (kg/mm^2)
5% SiC	37
10% SiC	61
15% SiC	73.5
20% SiC	74.9
25% SiC	76.5

For hardness test result, using rock well hardness tester, result showed that there is an increase in hardness with increasing weight percentage reinforcement of 5%wt SiC, 10%wt SiC, and 15%wt SiC but become minimal

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between 15%wt SiC, 20%wt SiC, and 25%wt SiC as shown in Table 3 and Figure 5. However this minimal increased in the hardness of the volume fraction 15, 20, and 25 %wt SiC samples is as a result of less penetration of the indenter when the load was applied and this revealed that the higher the volume fraction, the greater the density [14],

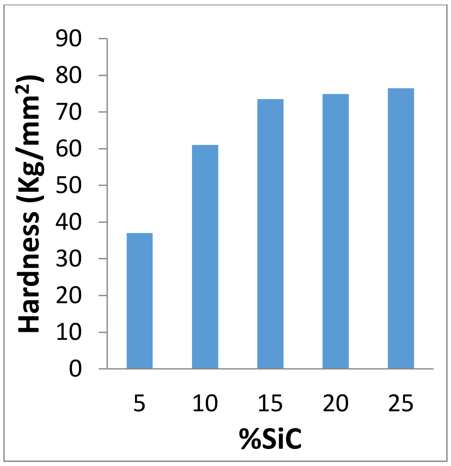
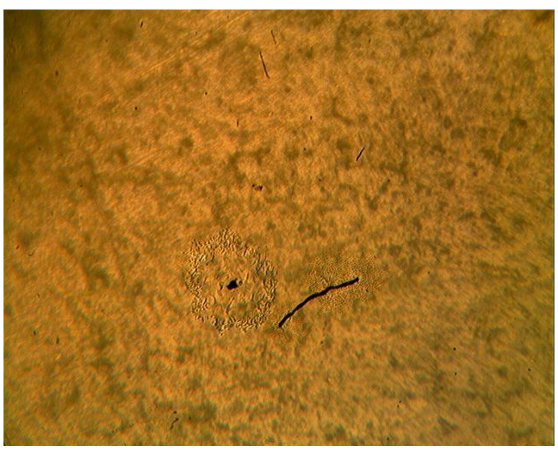
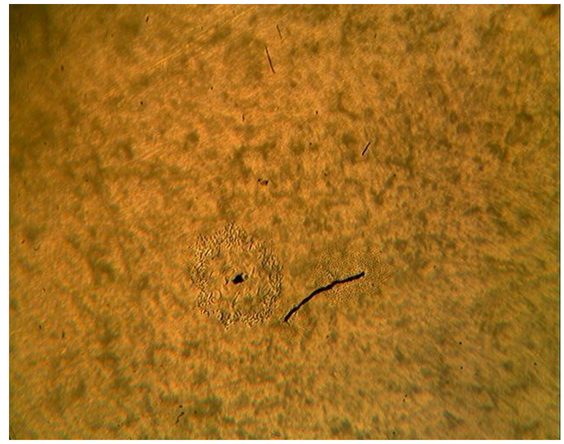


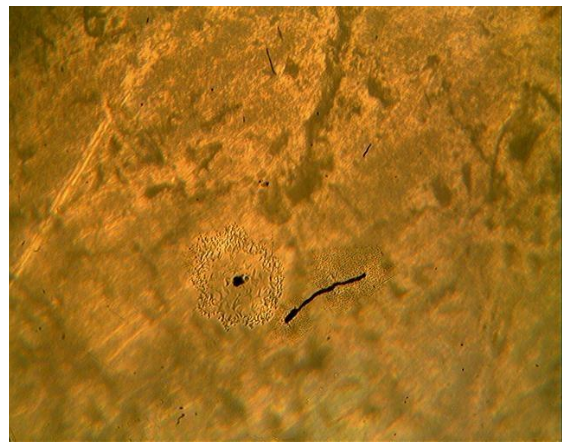
Figure 5: Rockwell Hardness of varying %SiC



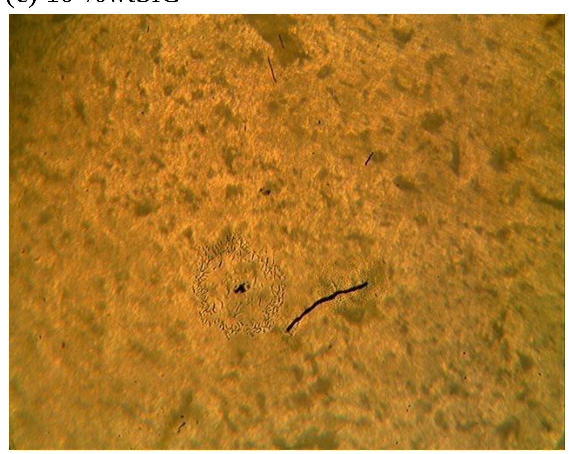
(a) 0 %wtSiC



(b) 5%wt SiC



(c) 10 %wtSiC



(d) 25 %wtSiC

Figure 6: Optical Micrograph of Aluminium Based alloy with varying volume fraction of %SiC reinforcement particles (x400)

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Although in the present work result showed a slight increase in density and more wear resistance observed. In addition MMCs with aluminium as the matrix benefit from good wear resistance, high specific modulus and specific strength [15, 16].

Figure 6(a – d), shows the microstructure of the Al-SiC composite at different volume fraction that is obtained from cast component (in-gate).

Figure 6(a) shows the microstructure of unreinforced aluminium alloy. However there is a change in microstructure of the 10%wt SiC where there is whitish colour indicating the aluminium matrix and blackish part indicate Silicon carbide particulate but not reasonable distributed. Although, other sample shows the same result in 25%wt sample but the micrograph depict a better

microstructure showing that the SiC is uniformly distributed in the Al matrix. Figure 7 illustrates the sample brake disc made with the aluminium based alloy for the various experiments carried-out.

Figure 7: Aluminium Based alloy automobile brake disc with 25%SiC reinforcement particles after casting

5. CONCLUSION

Considerable success was recorded in the experiment of Aluminium base Metal-Matrix particulate reinforcement composite brake disc

(1) A high degree of hardness, modulus of rigidity, strength, and weight reduction was achieved using 190μm SiC reinforcement particle in producing composite brake disc by Stir Casting method.

(2) The use of 25%SiC reinforcement particle improves the modulus of rigidity of the Al base Metal-Matrix composite.

(4) The more the weight percentage reinforcement the more the hardness in the Al base Metal-Matrix composite

(5) A composite brake disc system was produced using SiC particles with 190μm as reinforcement and aluminium as the base matrix using stir casting method. Still, electronic stability control system is being incorporated into the braking systems so as to improve the maneuvrability of vehicles [17].

Nomenclature

MMC Metal Matrix Composite

MMPC Metal matrix particulate composite

SiC Silicon Carbide

HRB Rockwell hardness on scale B

σ_r Radial normal stress, ($\overline{\sigma}_r$ - average value)

σ_θ Circumferential normal stress ($\overline{\sigma}_\theta$ - average value)

$\tau_{r\theta}$ Shear stress ($\overline{\tau}_{r\theta}$ - average value)

ε_r Radial normal strain ($\overline{\varepsilon}_r$ - average value)

ε_θ Circumferential normal strain ($\overline{\varepsilon}_\theta$ - average value)

$\gamma_{r\theta}$ Shear strain ($\overline{\gamma}_{r\theta}$ - average value)

a_{ij} Elastic constants

$\mathbf{a}_{ij}$ Elastic constants matrix

$\mathbf{E}$ Modulus of rigidity matrix

u_r - Average value of radial displacements

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u_θ - Average value of displacements along the circumference

r Radius of disc

b Disc thickness

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