Determination of Braking Speed of Developed Hybrid Particle Reinforced Aluminium Alloy Composite

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Abstract- This paper is aimed at comparing the braking speed of the developed Composite Brake Disc (CBD) with that of a nodular cast iron Honda Accord (2000) Model Brake Disc (HABD). The test samples were produced from Aluminium alloy (Al6061), Coconut Shell Ash (CSA) and Silicon Carbide (SiC) by Stir casting and machined into standard specimens for microstructure analysis, density test, mechanical tests (hardness, tensile and impact), wear test and thermal test. The characterization of coconut shell ash particle was carried out using X-ray Fluorescent equipment. Six samples were produced, four composite samples; C1 (70% Al, 5% SiC, 20% CSA), C2 (70% Al, 10% SiC, 15% CSA), C3 (70% Al, 15% SiC, 10% CSA) and C4 (70% Al, 20% SiC, 5% CSA), aluminium alloy sample (A1) and as-cast nodular cast iron sample (N1) obtained from HABD. Sample 'C4' had the best physical, mechanical, wear and thermal properties (Density: 3.15 g/cm³, Hardness: 68 kg/mm², Tensile Strength: 196.12 N/mm², Impact Energy: 8.05 J, Wear rate: 0.0002328 g/m, Thermal Conductivity: 72.57 W/m-K) and was used to produce the CBD. From the values of coefficient of frictions obtained for CBD and HABD, the braking speeds were calculated and HABD was seen to have a lower braking speed (56.65 m/s) than the CBD (94.42 m/s) because of its higher coefficient of friction. The higher braking speed of the composite brake disc (CBD) as compared to the Honda Accord Brake Disc (HABD) could be as a result of inadequate reinforcements in the aluminium alloy matrix. Hence, the produced CBD cannot be used as an alternative for the nodular cast iron Honda accord brake disc (HABD) even as problems of heavy weight and breakage that may occur due to heavy impact associated with cast iron brake disc have been addressed using the developed composite.

Keywords- Aluminium Alloy, Braking Speed, Coconut Shell, Composite, Silicon Carbide

1 INTRODUCTION

Metal composites have found applications in many areas of daily life for quite some time. For many researchers, the term 'composite' is often equated with light metal matrix composites (Karl, 2006). In recent times, the use of coconut shell ash reinforcements has increased due to their low cost, density and, increase in fatigue strength especially at higher temperatures, improvement in thermal shock resistance, improvement in corrosion resistance, availability as agricultural waste (Apasi, 2016). The presence of particles like SiO₂, MgO, MnO, Al₂O₃ etc in coconut shell ash are clearly oxide based or ceramic based (Pournesh, 2017).

Silicon carbide (SiC) is an abundant non-oxide ceramic which has diverse industrial applications that is suitable for abrasion and cutting application due to its high hardness, strength, chemical and thermal stability, high melting point, oxidization resistance etc (Houyen et al., 2011). Aluminium alloys are broadly used as main matrix element in composite material (Bucham, 2019). A brake disc is a wheel brake which slows down rotation of the wheel caused by pushing brake pads against the disc with a set of calipers. The brake disc is usually made from cast iron and it is fixed between the wheel rim and the wheel hub (Ukessay, 2016; Simon et al., 2013).

This paper is aimed at comparing the braking speed of the developed MMC brake disc with that of a nodular cast iron Honda accord 2000 model brake disc. The details of experimentation and results are discussed in subsequent sections below.

2 BRIEF REVIEW OF RELATED LITERATURE

Chennakesava (2010) studied mechanical properties for different metal matrix composites produced from Al 6061, Al 6063 and Al 7072 matrix alloys reinforced with silicon carbide particulates. The ductility of Al/SiC metal matrix composites are in the descending order of Al 6061, Al 6063 and Al 7072 matrix alloys. Mg improved the wettability between Al and SiC particles by reducing the SiO₂ layer on the surface of the SiC. The fracture mode is ductile in nature. Himansu (2017) studied the mechanical and machinability properties of aluminium coconut shell ash composite by Taguchi approach and concluded that the mechanical properties (Hardness and Tensile strength) increase with increasing coconut shell ash.

3 MATERIALS, EQUIPMENT AND METHODS

3.1 MATERIALS

Aluminium alloy (Al6061) was used as the matrix material while coconut shell, silicon carbide and graphite were used as the particulate reinforcements. Sodium hydroxide was used for degassing and magnesium powder was used for wetting.

3.2 EQUIPMENT

The equipment used in this research are; Optical Microscope (OM), X-ray Fluorescent (XRF), Searle's Apparatus, Grinding and Polishing Machine, Mould, Table Lathe Machine, Centre Lathe Machine, Crucible

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furnace, Universal thermocouple, Graphite crucible, Mechanical stirrer, Avery Hardness Testing Machine, W-type Monsanto Tensometer, Avery Denison Impact Testing Machine, Pin-on-Disc Machine

3.3 METHODS

3.3.1 Processing of Coconut Shell Ash

Coconut shells were ground to produce coconut shell powder. The powder was packed in a graphite crucible and preheated for about 40 minutes to produce coconut shell ash particle (CSAp). The coconut shell ash particles were sieved to obtain fine and uniform particle size as shown in Fig. 1. The chemical analysis of the coconut shell ash was carried out using X-ray Fluorescent (XRF) equipment.

Fig. 1: Coconut Shell Ash

3.3.2 Preparation of Samples

The Stir casting method as shown in Fig. 2 which is a type of liquid state method of composite fabrication was used. In this study, aluminium alloy scraps were cleaned and preheated to a temperature (120°C) below the melting temperature of aluminium for 30 minutes to remove any moisture before being charged into the furnace. Silicon carbide and magnesium powder were also preheated for 40 minutes to remove moisture and gases from the surfaces of the particles.

The coconut shell ash particles (CSAp) were preheated for about 45 minutes to eliminate impurities and moisture content. The coconut shell ash was sieved to give uniform particle size. The preheated aluminium was charged into the furnace and heated to a temperature of 740°C to form molten aluminium before the addition of sodium hydroxide to degas the melt. The melt was stirred with a steel shaft stirrer having 3 blades at the bottom made at an angle of 120° from each other. The stirring was done at a speed of 220 rpm and 680°C. Coconut shell ash, graphite and silicon carbide particles were added to the molten

metal while the stirring was on-going. The speed was thereafter reduced and maintained to 75 rpm due to increase in viscosity of the mixture. At the maintained speed of 80 rpm, magnesium powder was added to reduce the surface tension of the mixture so as to enhance wettability between the particles (reinforcements) and the molten aluminium. The stirring was maintained for another 20 minutes for homogeneous mixing before pouring the mixture into moulds to form cast composite rods (Fig. 3) which were used as samples. The process was repeatedly done by varying the percentage by weight of coconut shell ash and silicon carbide while graphite and magnesium remain the same for all samples as shown in Table 1.

Fig. 2: Stir Casting Set-Up

Fig. 3: Cast Rods

3.4 EXPERIMENTATION

The following tests and examinations were conducted on the specimens using various international standard procedures; Density Test (ASTM D792), Hardness Test (ASTM E10), Impact Test (ASTM E23), Tensile Test (ASTM E8), Wear Test (ASTM G99), Thermal Test (ASTM C518), Microstructure Examination (ASTM E3)

Table 1. Weight Composition of the Samples

Samples	Aluminium Alloy (g)	Silicon Carbide (g)	Coconut Shell Ash (g)	Graphite (g)	Magnesium (g)	Total (g)
A1 (Aluminium Alloy)	1000	0	0	0	0	1000
C1 (Composite)	700	50	200	30	20	1000
C2 (Composite)	700	100	150	30	20	1000
C3 (Composite)	700	150	100	30	20	1000
C4 (Composite)	700	200	50	30	20	1000

3.5 PRODUCTION OF PROTOTYPE COMPOSITE BRAKE DISC

The steps used in the production of the composite brake disc (Fig. 6) are itemized as follows:

- A wooden pattern (Fig. 4) was produced using the standard dimension of the conventional cast iron brake disc as shown in Table 2 and divided into two halves along the parting line, one for the drag and the other for the cope. The pattern was used to form the mould cavity. The pattern was made oversize to account for shrinkage in cooling and solidification, and to provide enough metal for subsequent machining operation.
- Core was made from foundry sand with the addition of resin for strength by means of core boxes and was used to produce internal surface in the casting.
- The sand for the mould was prepared and was used to make the mould (Fig. 5) with the help of the pattern and the core. A sprue was made to pour the melt into the mould cavity and a riser was also made to feed the casting as it shrinks and solidifies.
- The optimized formulation of the composite in molten form was poured into the prepared mould through the sprue which then solidifies after some time to form the composite brake disc.
- The mould was removed and the brake disc was cleaned and then inspected.
- Surface finishing such as polishing was done on the brake disc for better appearance.

Table 2. Pattern Design Parameter

Parameter	Size (mm)
Outer (Rotor) diameter	256
Centre (hub) hole diameter	64.2
Bolt size	12.6
Bolt circle	4 x 14.3
Height	47

(1) Top Half of the Mould (2) Bottom Half of the Pattern
Fig. 4: Pattern of the Composite Brake Disc

(1) flask (2) sprue (3) Cope (4) parting line (5) Drag (6) Riser
(7) Mould cavity (8) Core
Fig. 5: Section of the Mould

Fig. 6: Prototype of Composite Brake Disc Produced

3.6 LIVE PERFORMANCE TEST (BRAKING SPEED)

The prototype brake disc and the Honda accord 2000 model brake disc were tested and their stopping distances (S_d) calculated using the formula (Softschools, 2020);

$$S_d = \frac{v^2}{2\mu g} \quad (1)$$

Where; ' v ' is the velocity of the car, ' μ ' is the coefficient of friction between the tyres and the road and ' g ' is the acceleration due to gravity.

From the live performance test conducted, the velocity of the car was kept constant and uniform at 16.67 m/s for both the standard Honda accord brake disc (HABD) and the composite brake disc (CBD). At the uniform speed, coefficient of frictions of 0.25 and 0.15 were obtained for the HABD and the CBD respectively.

From the values of coefficient of frictions obtained, the braking speeds were calculated using the expression;

$$(B_d) = \frac{S_d}{t} \quad (2)$$

The stopping time (t) was calculated using a digital stop clock.

4. RESULTS AND DISCUSSION

4.1 RESULTS OF EXPERIMENTS

The various results obtained during the experimental work are shown in Tables 3-5.

Table 3. Chemical Compositions of Honda accord 2000 model brake disc

Element	C	Si	Mn	P	S	Fe
Weight Percentage	3.4	2.6	0.8	0.15	0.1	92.95

Table 4. Chemical Composition of Al6061

Element	Mg	Si	Cu	Cr	Al
Weight Percentage	0.01	0.60	0.28	0.20	98.91

Table 5. Chemical Compositions of Coconut Shell Ash

Constituents	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	N ₂ O	SiO ₂	ZnO	MnO	Residue
Weight Percentage	15.4	0.59	12.3	0.62	16.2	0.45	45.01	0.33	0.26	8.84

4.2 DISCUSSION OF RESULTS

4.2.1 Chemical and Characterization Analyses

The chemical compositions of Honda Accord (2000) model and Aluminium Alloy (Al6061) and the characterization of Coconut Shell Ash are as follows:

(i) Chemical Compositions of Honda Accord (2000) Model Brake Disc: Honda accord 2000 model brake disc contains iron as its major constituent which is about 93% by weight. It contains five other elements which are carbon, silicon, manganese, phosphorus and sulphur as shown in Table 3. The large portion of carbon in it is in the form of rounded particles or nodules.

(ii) Chemical Composition of Aluminium Alloy (Al6061): From the chemical composition of aluminium alloy (Al6061) as shown in Table 4, it can be seen that the main alloying elements are silicon and copper with 0.60 and 0.28 weight percentage respectively. Magnesium and Silicon combines as magnesium silicide (Mg₂Si) in the alloy thereby increasing the strength of the alloy. Al6061 is heat treatable, has high corrosion resistance, excellent extrudability and moderate strength. Because of the magnesium silicide which adds to the strength of the alloy, the alloy was adopted as matrix for the composites.

(iii) Characterization of Coconut Shell Ash Particle (CSAp): From Table 5, CSAp contains nine metallic oxides which include Al₂O₃, CaO, Fe₂O₃, K₂O, MgO, N₂O, SiO₂, MnO, ZnO. The result showed that SiO₂ has the highest percentage (45.01%) by weight of all the oxides present in CSAp, followed by Al₂O₃ (15.4%) and Fe₂O₃ (12.3%). The presence of particles like SiO₂, MgO, MnO, Al₂O₃ etc in coconut shell ash are clearly oxide based or ceramic based (Pournesh, 2017). Because of the ceramic nature (i.e., hard, strong and dense) of the oxides, CSAp were used as particulate reinforcement in this work.

4.2.2 Microstructure Analyses of Samples

From the micrograph (Fig. 7), it can be seen that the microstructures of the composite C4 shows small

discontinuities and a reasonable uniform distribution of the reinforcement particles. The dark phase is the reinforcement phase, the white phase is the aluminium alloy phase and the thin black lines are the interfaces. The addition of a considerable amount of magnesium powder into aluminium alloy as a wetting agent, made the CSA, SiC and graphite particles to bond properly with the aluminium alloy. The microstructure of sample N1 (nodular cast iron) in Fig. 8 shows the presence of graphite which is in the form of tiny black balls or nodules. The nodules are responsible for the strength and ductile nature of the nodular cast iron (Bucham, 2019)

Fig. 7: Micrograph of C4

Fig. 8: Micrograph of N1

4.3 OPTIMIZATION AND DISCUSSION OF RESULTS

The summary of the results from the tests are as shown in Table 6.

Table 6. Summary of Test Results

Samples/Tests	Density (g/cm ³)	Hardness (kg/mm ²)	Tensile Strength (N/mm ²)	Impact Energy (J)	Wear Rate (g/m)	Thermal Conductivity (W/m-K)
A1	2.75	35	110.18	15.00	0.0007928	129.58
C1	2.81	53	159.66	13.90	0.0006720	106.71
C2	2.90	59	186.22	12.55	0.0005865	100.78
C3	2.96	62	195.77	11.00	0.0005069	82.46
C4	2.15	68	196.12	8.05	0.0002328	72.57
N1	5.81	88	221.16	6.00	0.0001208	64.79

From the results (Table 6), it can be seen that the developed composite 'C4' has the lowest value of density, wear rate, impact energy and thermal conductivity compared with other composites. It can also be seen that 'C4' has the highest value of hardness and tensile strength compared with other composites. C4 also gives a relatively better microstructure than the other cast composites (C1, C2 and C3).

From the results obtained, it is therefore evident that composite sample 'C4' gives the best result amongst the composites which can be relatively compared with the N1 (Honda accord 200 model brake disc). The lowest value of density (2.15 g/cm^3) for 'C4' makes it a better material than 'N1' with density of 5.81 g/cm^3 in terms of weight reduction. The higher impact energy (8.05 J) of 'C4' makes it a better shock absorption material than 'N1' with impact energy of 6.00 J . C4 has lower hardness value of 68 kg/mm^2 and a higher wear rate of 0.0002328 g/m when compared with 'N1' thereby making 'N1' a better material for indentation/scratch and wear resistance. The results also show that 'C4' has a good thermal property than 'N1' because of its higher thermal conductivity of value (0.0002328 W/m-K). Fig. 9 is a graph showing the braking speeds of HABD and CBD.

Fig. 9: Graph of Braking Speed against Brake Disc Type

From the graph (Fig. 9), the braking speed of CBD is higher than that of HABD because of its lower coefficient of friction. The lower coefficient of friction of CBD could be as a result of inadequate reinforcements in the aluminium alloy. This is because the reinforcing materials are responsible for the hardness of the CBD. The harder a material, the higher its coefficient of friction (Mahdi et al, 2015).

5 CONCLUSIONS

From the discussion, it can be concluded that the addition of CSA, SiC and graphite particles increases the hardness of the developed composite (CBD). The coefficient of friction increases with increase in hardness and the problems of heavy weight associated with the cast iron brake disc (HABD) and breakage due to heavy impact that may occur with cast iron brake disc (HABD) have been addressed using the developed composite (CBD) because of its lower density (2.15 g/cm^3) and higher impact energy (8.05 J) when compared to (CBD) with density of 5.81 g/cm^3 and impact energy of 6.00 J .

The developed composite (CBD) is not a better braking material than the Honda Accord Brake Disc (HABD) because of its higher braking speed. Hence, the produced (CBD) cannot be used as an alternative for the nodular cast iron Honda accord brake disc (HABD) even as problems of heavy weight and breakage due to heavy impact associated with cast iron brake disc have been addressed using the developed composite.

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