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Production of Motorcycle Piston with Improved Mechanical Properties and Wear Resistance using Scrap Aluminium Alloys

[1]Abdul Audu, [1]Abdussalam Mamoon, [1]Nazir N. Yunusa
[1]Department of Mechanical Engineering, Kaduna Polytechnic, Kaduna, Nigeria
Corresponding Author: Abdul Audu

ABSTRACT : *This research work is aimed at improving the wear resistance and mechanical properties of a cast motorcycle piston from recycled aluminium pistons. Locally sourced recycled aluminium piston was used as the matrix whereas a charcoal ash content of constant percentage was used as the reinforcement material. The compositions of the recycled piston scrap and charcoal ash were acquired. The matrix material was kept at its slurry state under heat and preheated volume fractions of 0% and 10% charcoal ash particles were added by stir casting. The molten mixture was then poured into a mould having prepared piston sand core in place to obtain a piston. Careful examination was done on the piston after fettling and cleaning, where the piston was found to be good. The cast piston was machined to standard piston size and dimension. The microstructural and mechanical properties of the composites were studied. The result indicated that there was increase in the melting temperature, solidification temperature, hardness and wear resistance of the reinforced composite, which may be due to the hindrance in dislocation movement of the aluminium particles as a result of the introduction of the charcoal particles. The microstructural test reveals that the particles became closely packed together which prevented excessive wear loss. However, the ultimate tensile strength was found to reduce slightly.*
KEYWORDS: *Aluminium, Composite, Mechanical Properties, Piston, Stir Casting.*

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I. INTRODUCTION

Increased public awareness on global environmental issues and depletion of natural resources makes sustainability and recycling of non-renewable natural resources very vital. Among all materials, recycled aluminium accounts for one-third of global aluminium consumption and has been recycled since its first commercial production. Global environmental policies and regulations have prompted the search for materials that are environmentally friendly as well as decrease the rate of consumption of fossil fuel [1]. This can be achieved if the efficiency of the automobile is improved by reducing the weight of the automobile whose main components are the engine and the frame. Engine piston is an element of the crankshaft assembly, which take part in the conversion of thermal energy into mechanical work [2]. The piston is one of the most stressed components of an entire vehicle. Engine piston failures occur at various mileages and are due to different causes. These failures are caused by material defects and engineering and operational errors. Materials that are most commonly used for manufacturing pistons include: cast iron, alloy steel and aluminium alloys, aluminium-silicon (Al-Si) alloys and aluminium-copper (Al-Cu) alloys.

Aluminium alloys are distinguished by good formability during casting and good machinability (machine cutting). These alloys are characterised by their low hardness & strength indices at elevated temperature (low mechanical properties), low wear resistance and large thermal expansion coefficient [3]. To overcome these shortcomings, these alloys are reinforced with ceramic materials to develop new composite materials.

Composites are emerging engineered materials as a result of a combination of two or more materials in which tailored properties can be achieved. The term composite broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix) and which derive its distinguishing characteristics from the constituents and from the properties of the boundaries (interfaces) between the different constituents [4]. Composites materials offer high strength to weight ratio, corrosion resistance, and good fatigue resistance which makes them highly competitive against conventional materials.

Recently, an extensive variety of research interest has been on-going by attempting to add reinforcement materials into aluminium matrix with the aim of improving and enhancing the properties of the composite. The most frequently used reinforcement in developing pistons of combustions engine are alumina (Al_2O_3), Silicon Carbide (SiC), graphite and fly ash [5]. The addition of these hard ceramic materials into the aluminium alloy makes it possible to increase the specific elastic modulus of aluminium, improve its thermal properties etc. as well as help in developing new materials with better mechanical properties than the matrix [6] [7]. Walczak *et* al [8] reported that pistons made of composites and characterized by limited specific weight make it possible to increase their fatigue strength and the resistance to thermal shocks in the piston bottom and jacket area operating in extreme temperature environment.

Some of the techniques used by researchers are casting, powder metallurgy, friction stir processing, ball milling and hot rolling. However, casting process is largely used as a result of its low cost, capability of producing large complex shapes and high production rate [9]. In order to produce high-quality castings from composites, studies have shown that several modifications must be made to the normal melting and casting practice. The most obvious modification involves the continuous stirring of the molten composite in order to keep the reinforcement particles in suspension. The alloy should be melted at a controlled temperature and the desired quantity of reinforcement added to the molten aluminium alloy [10].

This research was motivated by the limited number of findings reported on the effect of locally sourced ash reinforced aluminium alloy metal matrix composites. Non uniformity in the particle size and composition of charcoal ash is another major problem in ash reinforced aluminium MMCs. Therefore, the aim of this paper is to study the effect of a locally sourced charcoal ash addition on the microstructure and mechanical properties of a recycled scrap aluminium alloy.

II. MATERIALS AND METHOD

2.1 Materials

The matrix and reinforcing materials used in the research work include recycled aluminium motorcycle piston and ash powder, both sourced locally at Kaduna, Nigeria. The chemical compositions of the matrix and the reinforcement were investigated at Solid Mineral Research Centre (Step-B), Kaduna Polytechnic, and are shown in the table 1& 2 below.

Table 1: Chemical composition of aluminium scrap

% Al	% Si	% Fe	% Mn	% Mg	% Cr	% Zn	% Cu	% Ti	Total
85.20	13.0	0.6	0.5	0.1	0.2	0.1	0.1	0.2	100

Table 2: Chemical composition of ash particles obtained using XRF

Compound	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	TiO_2	K_2O	Na_2O	SO_3
Weight %	40.3	24.5	26.2	1.2	2.2	0.6	1.7	1.4	0.3

2.2 Method

2.2.1 Production of Piston Core

Pure silica sand was used in the production of the piston core. A binder (sodium silicate) and sugar were added and mixed thoroughly with the silica sand. The addition of sugar is to improve the collapsibility and ease of knockout of the core. A split core box was rammed full with the mixed core sand; it is then baked to reduce the moisture content of the mixture as well as making it more compact. This method was adopted by Ozioko (2012) [11].

2.2.2 Production of Casting

This method was adopted by Datau et al (2017) [12]. Recycled motorcycle aluminium piston, free from dust and contamination, were charged in a crucible and kept in a charcoal furnace. A blower was used to superheat the temperature. At the start of melting of recycled aluminium, the temperature of the furnace was raised to about 660°C and at this temperature the pure aluminium was melted. After a time interval of 9 minutes, the aluminium melt was stirred thoroughly for proper mixing. With steady melting, the furnace temperature was raised to 720°C and the melt was held at this temperature for few minutes.

The composite materials were prepared by dispersing the reinforcing 10% volume weight ash particles in the recycled piston scrap melt using stir-casting technique. The steps involved in preparing the composite were: stirring the melt using a mechanical stirrer, dispersing the preheated ash particles of size less than 40g in the vortex of the melt with stirring speed of 600 rpm for 3 minutes and pouring the melt in the sand mould. The mould, having predefined cavity of required piston dimensions was allowed to cool to room temperature. The reinforced cast piston was then removed from the sand mould and was machined to the required piston dimension. The same procedures were followed for preparing separate composite material containing 0% volume weight ash in recycled piston melt.

2.2.3 Machining of Cast Piston

The reinforced and unreinforced cast pistons were fettled, placed on a lathe and machined to standard specification of Jincheng motorcycle piston. The pistons after machining were subjected to surface finish and dimensional accuracy by touch, visual inspection, and vernier calliper. The pictorial view of the cast machined piston is shown in figure 1 below.

Figure 1: (a) imported and machined cast piston (b) inverted Cast piston (c) upright cast piston

2.2.4 Mechanical Testing of Composites

Two (2) samples each of reinforced and unreinforced composites were made for tensile, hardness and wear resistance tests. The samples were in accordance with ASTM standard method of testing of materials. For the tensile test, the grip end of the test samples were attached to the grip holder of the tensile machine (i.e. Mosanto Tensometer) and a gradual application of tensile load through a wheel were applied on the steel specimen until fracture.

For hardness test, it was carried out to measure the capacity or ability of a material to withstand or resist indentation, with the aid of Avery visual hardness testing machine. An indenter of 2mm (0.002m) was firmly fixed in the machine's chuck and hence, locked via the lock knob. The test specimen was then securely placed on the anvil (work table), in an approximate centre to the indenter. The test specimen was elevated, such that it is in contact with the indenter. Hence, the test specimen was put under preliminary (minor) load without shock, by moving the hand wheel. Thus, the test specimen was put under major load of 120kg via the loading lever. The pointer was then observed, until it comes to rest. After, a period of 15sec. approximately, the major load was then unloaded. Hence, the test specimen was disengaged and observed under microscope. The schematic diagram of the specimen for tensile and hardness tests are shown in the figure 4 below:

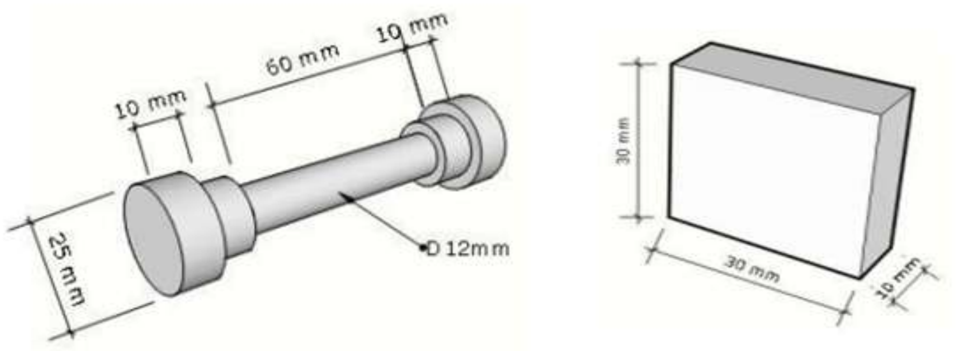

Figure 2: schematic diagram of the tensile and hardness specimens [12]

2.2.5 Tribological Testing of Composites

In this test, the wear test specimen in the shape of a cylinder was pressed under load onto a rotating disc made of hardened steel. The distance of the pin from the centre of the disc and the rotating speed was controlled to obtain a constant sliding velocity. The constant sliding distance was achieved by calculating the number of disc revolutions and wear. Tests were carried out for constant load i.e., 453g for the cast materials. The sliding velocity and the sliding distance were fixed at 0.15m/s and 9 and 18 metres for a sliding time of 60 and 120 seconds.

2.2.6 Microstructural Analysis of Composite

The specimens were ground, polished and etched and then observed under optical microscope in sequences. Wet grinding operation with water was done by using emery paper of SiC with the different grits size of (320, 400, 600, and 800). The samples were polished by using diamond paste with special polishing cloth and lubricant. The samples were etched by using etching solution which was composed of 10ml of nitric acid, 4ml of hydrofluoric acid and 200ml of distilled water. Then the samples were washed with water and alcohol and dried. Optical examination of samples was performed using optical microscope (photographic visual metallurgical microscope) equipped with camera and connected to a computer.

III. RESULTS AND DISCUSSION

3.1 Chemical Composition Analysis

The chemical composition of the reinforced, unreinforced and imported composites were conducted and presented in table below. This is done in other to investigate as well as ascertain if there was substantial variation and possible reasons.

Table 3: Chemical composition analysis of reinforced and unreinforced cast

Material		Chemical composition (%)							
	Fe	Cu	Si	Zn	Mg	Mn	Cr	Ti	Al
Unreinforced	0.6	0.1	9.5	0.1	0.5	0.1	0.2	0.2	Balance
Reinforced	2.4	0.8	14.3	0.1	0.2	0.6	Nil	0.1	Balance
Imported	0.4	0.8	22	0.1	0.5	0.1	0.1	0.2	Balance

From the result of the chemical composition analysis, it can be seen that there is decrease in the percentage amount of iron, magnesium. This could be due to the excessive melting temperature and volatility of magnesium in molten form as well as reaction between the metal alloy and the preheated ash particles. Additionally, it can be seen that the percentage amount of silicon and iron has greatly increased. This could be due to the fact that the content of the elements in the ash reinforcement is high.

3.2 Mechanical Properties Test Result

The result obtained from the tensile and hardness tests are presented in the table 4 below. The table gives the tensile strength and hardness values for the reinforced, unreinforced and imported cast samples.

Table 4: Mechanical Properties Test Result.

Materials	Tensile (N/mm^2)	Hardness (BHN)
Unreinforced	112	60
Ash Reinforced	108	81
Imported	117	67

From the result, it can be seen that the hardness value of the reinforced composites is higher than that of the unreinforced composite. The increase in hardness could be explained by diffusion assisted mechanism, and also by hindrance of dislocation by reinforcing atoms, i.e. foreign particle of second phase. However, it can be seen that the hardness value of the imported piston material is lesser than the hardness value of the reinforced, but greater than the hardness value of the unreinforced cast. The addition of the ash particles may be the reason why the hardness value of the reinforced is higher than the hardness value of the imported piston whereas the greater loss of particles (alloying elements) may have resulted in the reduction of the hardness value of the unreinforced recycled cast.

The result of the tensile test shows that there is a slight decrease in the tensile strength after reinforcement. However, it can be seen that the tensile strength of the imported piston material is higher than both the reinforced and unreinforced cast piston.

3.3 Tribological Test Result

From the result obtained in table 5, it was found out that wear rate of the unreinforced casting is higher than that of the reinforced one. The lower wear rates in composites with charcoal ash particles were attributed to good interfacial bonding in the composites. This means that the reinforcement of charcoal ash particles protected the aluminium alloy matrix effectively when subjected to load. Additionally, the wear loss of the imported piston was similarly found to be lesser than the reinforced piston. This indicates that there was improvement of wear resistance of the alloy as a result of the addition of the charcoal ash.

Table 5: Wear resistance results

Material	Load (g)	Velocity(m/s)	Sliding distance (m)	Time (s)	Wear loss (gm)
Unreinforced	453	0.15	9	60	0.38
Reinforced	453	0.15	9	60	0.29
Imported	453	0.15	9	60	0.35

3.4 Microstructural Analysis Result

The microstructure of the composites used is an important indicator of the quality of the composites and a measure of the effectiveness of the technique adopted for the production. The micrographs from figures 2 below revealed that there was fairly uniform distribution and proper bonding of ash particulates throughout the matrix alloy. For the unreinforced composites, the dark portions on the images show the alloying materials of the recycled aluminium alloy while the white portions represent the aluminium particles. Similarly, the dark portion of the reinforced composites shows the reinforcing materials (ash and other allying materials) whereas the white portions represent the aluminium particles.

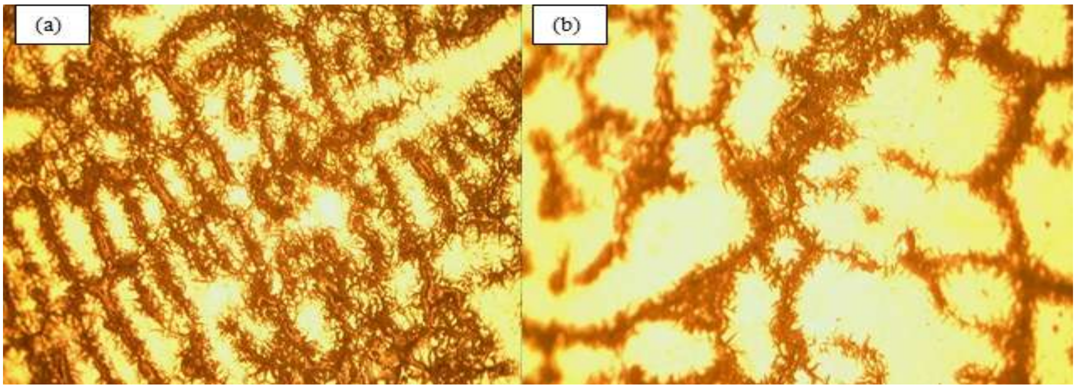

Figure 2: Micrograph of composites (a) 0% ash reinforced (b) 10% ash reinforced

3.5 Physical Inspection of Cast Piston

Upon inspection of the cast piston, it was observed to have a relatively rough surface. This may be due to the improper impurity control during casting or due to loss of most alloying elements due to oxidation when melted. Some minor defects found on the surface of the casting clearly indicate the inclusion of impurity was unavoidable. However, the external surface roughness and defects were removed after the successful machining operation of the piston to standard piston size and dimension.

The weight of the cast piston was found to be slightly heavier than the imported piston when weighed on a digital weighing machine. This may be due to the effect of the addition of ash and the possible agglomeration of the reinforcement particles.

IV. CONCLUSION

From the result of the research, the following conclusions were drawn:

i. Charcoal ash particles are successfully used to fabricate the aluminium matrix composite via stir casting technique.
ii. Variations were observed between the composition of the unreinforced, reinforced and imported composites. This is an indication that the introduction of the reinforcement into the matrix and the process significantly changes the composition of the recycled aluminium alloy.
iii. Reinforcing aluminium piston scrap with charcoal ash affects the mechanical properties. The hardness value of the reinforced composites was found to be higher than that of the unreinforced and imported composite whereas there was slight decrease in the ultimate tensile strength of the composite.
iv. The wear resistance of the charcoal ash reinforced composite was found to be better than bothe unreinforced and imported piston. This may be due to lack of dislocation movement of the particles due to hindrance from reinforcing materials.
v. The micrographs revealed that there was fairly uniform distribution and proper bonding of ash particulates throughout the matrix alloy.
vi. The cast piston was mounted on a Jincheng motorcycle for engine performance test. However, all attempts made to start the engine prove abortive. This may be due to the slight increase in the weight of the cast piston compared to the imported piston.

V. RECOMMENDATION

At the end of the research, the following are recommendations are proposed:

1. The percentage and size of the charcoal reinforcement should be varied, so that researchers can properly understand and find the best percentage where the effect of charcoal ash on the mechanical properties of recycled aluminium piston.
2. Microstructural analysis of the unreinforced, imported and varied volume concentrationof ash reinforced composites should be done to fully understand the microstructural changes that occur after reinforcement.
3. It is recommended that the casting parameters should be varied, so as to produce a cast piston which is slightly lesser in weight.

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