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Original Research Article

Wear Rate Characteristics of Basalt-Based Composites as Material for Brake Pad

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Abstract

The production of the basalt-based composite material was carried out using compression moulding. The selected materials basalt rock, bronze chips, cast-iron chips, glass fibre and phenolic resin were crushed into powder and sieved with a sieve size of 150microns. An optimization model based on the rule of mixture was developed to obtain the volume fractions of the constituent materials and a factorial Design of three levels and three factors was applied to obtained different sets of manufacturing parameters for the production of the samples using MINITAB 18 software. Twenty-seven samples with dimension of 20mm diameter and 8mm height were produced based on the formulation obtained from the optimization model and factorial design, this samples were subjected to tests. The test result shown that the basalt-based wear rate ranges from $9.0X10^{-5}$ to $1.52x10^{-4}$g/m and by volume is from $4.04x10^{-12}$ to $7.97x10^{-12}m^3/Nm$. The density of the composites ranges from 2382.76 to $2781.33kg/m^3$. The Thermogravimetric Analysis (TGA) result shown that the basalt-based composites is thermally stable up to a temperature of 530^0C before thermal degradation started setting in and Differential Thermal Analysis (DTA) result shown that the highest mass degradation occurred at a temperature of 600^0C. Hence the basalt rock is a good material that can withstand high temperature.

Keywords: Wear, Rate, Characteristics, Basalt, Composite, Brake, Pad.

INTRODUCTION

Brake system is the vital mechanism which play a critical role in the safety of automotive, imagine a vehicle or motor circle without a brake system, danger can only be imagined.

Brake pad is an essential and critical component of the brake system because it provides the friction surface, in each wheel there are two brake pads with their friction surface facing the rotating disc of the wheel. When the brake is applied fluid from brake master cylinder under pressure pushes the pistons in the wheel brake pot outwards, this in turn forces the brake pad friction surface against the rotating disc and retard the speed of the moving vehicle until the vehicle come to rest.

Basically, the brake system converts the kinetic energy of the moving car into heat energy and dissipate the heat at the wheels. This has made a brake pad to be a complex component which cannot be made from a single material; hence brake pad is a composites material made from two or more materials in macroscopic scale.

These constituent materials combine in macroscopic to form the composite of brake pad play different roles in influencing the properties of brake pad no matter how small the quantity of the material maybe it will still influence the properties of the composite material.

Other factors that influence the properties of composite material are the manufacturing parameters (Taiwo *et al.*, 2019).

History records the use of many kinds of materials for brakes ('friction materials'). For example, wagon brakes used wood and leather. In fact, many current brake materials still contain organic-based materials, like polymers and plant fibers. Emerging railroad technology in the1800's required brake materials to perform under high loads and speeds.

Friction experiments were conducted with iron brake shoes in the 1870's (Blau, 2001).

Brake pad and shoe additives serve a variety of functions. Even a difference of a percent or two of additive concentration can affect performance, so composition control is important (Blau, 2001).

The gradual phasing-out of asbestos in automotive brake friction materials in many parts of the world because of its health challenge has sparked the onset of extensive research and development into safer alternatives materials. As a result, the brake friction industry has seen the birth of different brake pads and shoes in the past decade, each with their own unique composition, yet performing the very same task. These materials are categorized in organic, semi-metallic and ceramics.

Among the three categories of brake pad materials that is organic, semi-metallic and ceramics. Ceramics is adjudged to be the best material for brake pad, but it is expensive because of highly specialized equipment require in processing (Krenkel and Langhaf 2014).

The work is to explore the possibility of using basalt as substitute for ceramic material in brake pad with consideration on the wear rate and thermal degradation.

Wear as a property of brake pad define the life span of brake because the more the material during brake application the less the life span and vice versa. Other factors that affect wear are the nature of road and driver's behaviour.

Therefore, it is important that the wear rate is low so that the brake pad last longer in service, however, there should be a balance so that it doesn't become too hard that brake disc get wear off.

Basalt originates from volcanic magma and flood volcanoes, a very hot fluid or semifluid material under the earth's crust, solidified in the open air. Basalt is a common term used for a variety of volcanic rocks, which are gray, dark in colour, formed from the molten lava after solidification (Artemenko and Kadykova, 2008)

Basalt is well known as rock found in virtually every country around the world. Its main use is as a crushed rock used in construction, industrial and highway engineering. However, it is not commonly known that basalt can be used in manufacturing and made into fine, superfine and ultra-fine fibres. Basalt rock is available in Plateau State and in large quantity.

A typical photograph of basalt rock is shown in plate 1 and the chemical composition as determined at Nigeria Institute Mining and Geoscience Tudun Jos Plateau Nigeria is shown in table 1.

Plate 1: Basalt rock in Bachit, Riyom LGA Plateau State Nigeria.

Table 1: Chemical Composition Basalt Rock

Chemical Composition of Basalt	**%**
SiO_2	52.8
Al_2O_3	17.5
Fe_2O_3	10.3
TiO_2	1.38
CaO	8.59
MgO	4.63
Na_2O	3.34
K_2O	1.46
LOI	8.52

Basalt Rock fibres have no toxic reaction with air or water, are non-combustible and explosion proof. When in contact with other chemicals they produce no chemical reactions that may damage health or the environment. It has good hardness and thermal properties, can have various application as construction materials. Basalt is a major replacement to the asbestos, which poses health hazards by damaging respiratory systems. Basalt base composites can replace steel (1 kg of basalt reinforces equals 9.6 kg of steel) as light weight concrete can be get from basalt fiber. (Kunal, 2012, http://basaltfm.com/eng/index/html; dt 12/10/2010).

As it is made of basalt rock is cheap and has several excellent properties (good mechanical strength, excellent sound and thermal insulator, non-flammable, biologically stable, etc. (Saravanan, 2006).

Nicholson G. (1995), avers that volume percent is the correct unit of measure for friction material composition. While the exact compositions of commercial friction materials are almost never published in the open literature, the constituent of the brake pad material are normally made known. One of the most used constituents over the years is asbestos.

Nicholson G. (1995), the positive attribute of asbestos is that asbestos is thermally stable up to 500^{0}C above which it produces silicates, asbestos helps regenerate the friction surface during use, silicates produced by asbestos are harder and more abrasive than asbestos, asbestos insulates thermally, it processes well, it is strong yet flexible, and is processed as available at a reasonable cost.

Piyush *et al*., (2016), in their study for effective brake performance it was concluded that the exploit in brake is a function of the wear mechanism and friction properties of contacting materials

Madhusudhan and Kumar (2017), analyzed the wear behaviour of the SiC reinforced epoxy polymer composites using Taguchi methods and the result showed that load predominantly influencing the wear characteristics beside material factor.

Liew and Nirmal (2013) States that despite the fast progress of manufacturing technologies, wear has always been a great challenge for brake pad materials. The generated heat during friction process under diverse conditions which results to wear of materials.

Kahraman and Sugozu, (2019), investigated NOA brake friction materials using Taguchi and Response Surface Methodology and stated that the percentage contribution for braking pressure is 99.28%.

Yusubov (2021), stated that the changes in the microstructure due to increased temperature causes the generation of surface cracks and damage. Thus, formation of micro-cracks ultimately contributes to increased wear rate. When applied load increases the contact pressure between pin and disc surface temperature increases and because of frictional temperature rise material removal also begins to increase.

Xingming *et al*., (2016), in their review stated that worn surface usually characterized by material surface deformation, removal and friction layer formation. This results to intensive wear and changes on contact surface morphology can reduce friction coefficient. In the nineteenth century asbestos was used as the best material for brake pad because of its heat resistant and good mechanical properties asbestos has used as major constituent for friction materials, nonetheless, due environmental and health concerns, the use of asbestos has banned in many countries.

Eriksson and Jacobson (2000), suggested that contact plateaus are formed mainly by phenolic resin binder, which have been compacted during friction. If the sliding continues, the debris is reduced in size by fragmentation and worn debris particles begin to participate in the formation a of secondary plateaus or leave the friction surface.

(Krishnan *et al*., 2020), Frictional and wear resistances are the important parameters of the brake pad for better operation.

Cueva *et al*., (2003), Investigated the wear resistance of three different kinds of grey cast iron (grey iron grade 250, high carbon grey iron and titanium alloyed grey iron) used for the brake rotors and equated them with the data obtained with a compact graphite iron (CGI). Friction coefficients for brake material pairs vary from 0.07 to 0.7.

Anderson (1987), but generally most automobiles work in a smaller range. Typical friction coefficient values vary from approximately 0.3 to 0.6

(Xiao *et al*., (2016), stated that disc brakes are mostly used these days in the vehicles because of its faster heat dissipation characteristics. Braking pads are the backing sheets of steel, having friction content which is attached to the surface facing the rotor of the disk brake. Brake pads convert the kinetic energy of car through friction into thermal energy.

Hatam and Khalkhali (2018), stated that friction causes the release of energy with material wearing out which led to heating of brake parts and releases wear particles. Therefore, wear of brake pads results to the decrease in performance of the brakes which generates the need to replacement of brake pads.

Shravan and Konkala (2020), Studied the wear behaviour of three composite materials with the objective of getting a substitute for asbestos, these materials are Asbestos, Asbestos free and Cl3003 material. It was observed that the wear rate of all materials depends on the applied load with Cl3003 composite having the least wear rate followed by asbestos and asbestos-free has the highest. They concluded that Cl3003 is the best substitute to asbestos.

MATERIALS AND METHODS

The materials were carefully selected to give the desire service requirement of the composite material. These materials are basalt rock obtained from Bachit District in Riyom Local Government Area of Plateau State, glass fibre, bronze and cast-iron chips gotten as a waste from machine shop. Table 2 shows the functions of the selected materials in the composite.

Table 2: Materials Selected and Their Functions

S/N	Material	Function
1	Basalt powder	Filler & friction dust
2	Bronze chips	Improve thermal conductivity
3	Cast iron chip	Service as lubricate because of graphite
4	Fibre glass	Improve mechanical strength
5	Phenolic resin	Binder (matrix)

Materials Preparation

In order to have homogeneous mixture the materials were grinded to fine particle and 150micro was used in sieving the materials. Grinding material to a finer powder enables it to be homogeneously mixed and when it is properly bonded the material behave isotropically. Photographs of selected materials plate 2.

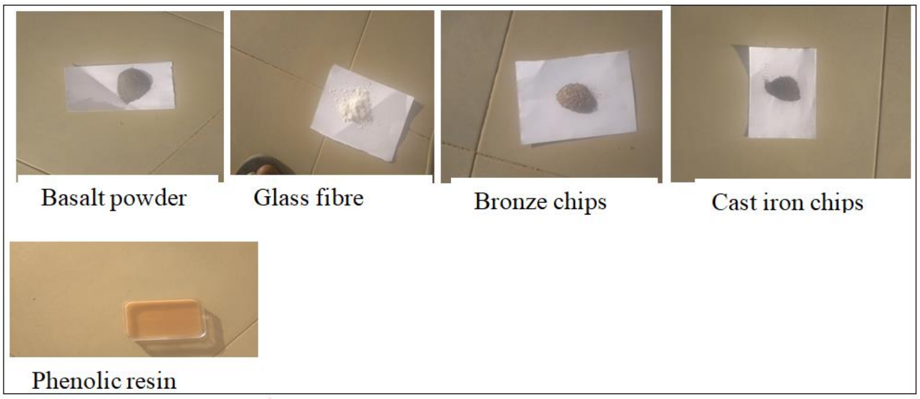

Plate 2: Photographs of Selected Materials

METHODS

Optimization model was developed based on the rule of mixture and the following assumptions were made:

1. There is a perfect binder between the particulates
2. The void content is less than 1%
3. The particulates are equidistance hence the material is isotropy (Matthew and Rawlings, 2005).

Thus, the model is:

$$\max f(\mu) = \sum_{j=1}^{5} c_j \nu_j$$

Subject to:

$$\sum_{j=1}^{5} a_{ij}\nu_j \geq b_i \ \forall_i \ 1 \ldots 5$$

This is express as:

Maximize $f(\mu) = \mu_{ba}\nu_{ba} + \mu_{gf}\nu_{gf} + \mu_{br}\nu_{br} + \mu_{ci}\nu_{ci} + \mu_p\nu_p$ …. objective function

Objective is to maximize coefficient of friction

Subject to:

$$\sigma_{ba}\nu_{ba} + \sigma_{gf}\nu_{gf} + \sigma_{br}\nu_{br} + \sigma_{ci}\nu_{ci} + \sigma_p\nu_p \geq 110 \quad \ldots (1)$$
$$\tau_{ba}\nu_{ba} + \tau_{gf}\nu_{gf} + \tau_{br}\nu_{br} + \tau_{ci}\nu_{ci} + \tau_p\nu_p \geq 6 \quad \ldots (2)$$
$$H_{ba}\nu_{ba} + H_{gf}\nu_{gf} + H_{br}\nu_{br} + H_{ci}\nu_{ci} + H_p\nu_p \geq 65 \quad \ldots (3)$$
$$Q_{ba}\nu_{ba} + Q_{gf}\nu_{gf} + Q_{br}\nu_{br} + Q_{ci}\nu_{ci} + Q_p\nu_p \geq 20 \quad \ldots (4)$$
$$E_{ba}\nu_{ba} + E_{gf}\nu_{gf} + E_{br}\nu_{br} + E_{ci}\nu_{ci} + E_p\nu_p \geq 76 \quad \ldots (5)$$
$$\nu_{ba} + \nu_{gf} + \nu_{br} + \nu_{ci} + \nu_p \leq 1 \quad \ldots (6)$$
$$\nu_{ba}, \nu_{gf}, \nu_{br}, \nu_{ci}, \nu_p \geq 0.12$$

Constraint

Where:
The subscripts
ba = Basalt
gf = glass fibre
br = bronze
ci = cast iron chips
p = phenolic
ν = Volume fraction
σ = compressive strength of material
E = Young modulus
H= Hardness of material
Q = Thermal conductivity of material
μ = Friction coefficient of material
τ = Shear strength of material
Constraint 1 = compressive strength
Constraint 2 = Shear strength
Constraint 3 = Hardness
Constraint 4 = Thermal conductivity

Constraint 5 = Modulus of elasticity
Constraint 6 = sum of the volume fraction

The coefficients of the volume fractions as obtained from the table of properties of the selected materials were substituted in the equations and the equation below was formed
Maximize $f(v) = 0.7v_B + 0.5v_g + 0.22v_b + 0.4v_c + 0.15v_p$

Subject to:
$226v_B + 1080v_g + 315v_b + 340v_c + 45v_p \geq 110$
$66v_B + 1722v_g + 303v_b + 570v_c + 48v_p \geq 6$
$74v_B + 74v_g + 65v_b + 65v_c + 48v_p \geq 65$
$1.5v_B + 0.005v_g + 63v_b + 46v_c + 0.25v_p \geq 20$
$78v_B + 73v_g + 100v_b + 180v_c + 3.8v_p \geq 76$
$v_{ba} + v_{gf} + v_{br} + v_{ci} + v_p \leq = 1$
$v_{ba}, v_{gf}, v_{br}, v_{ci}, v_p \geq 0.12$.

After developing the optimization model, an excel solver optimization tool was used to obtain the optimum composition of the selected constituents' materials that will gives the optimum desire properties of brake pad. The compositions in volume fractions are basalt 38%, glass fibre 12%, bronze chips 12%, cast iron chips 26% and phenolic resin 12%.

The result of the optimization obtained from the excel solver is shown in tables 3 and 4.

Table 3: Solution of Objection Function and Volume Fractions

Cell	Name	Original Value	Friction coefficient
$D$6	max(fμ) υba	0	0.476196494
Cell	Name	Original Value	Volume Fracrion
$D$5	solution υba	0	0.382788315
$E$5	solution υgf	0	0.12
$F$5	solution υbr	0	0.12
$G$5	solution υci	0	0.257211685
$H$5	solution υp	0	0.12

Table 4: Solutions of Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$17	Constraint 1 LHS	421.2323524	$D$17>=$E$17	Not Binding	311.2323524
$D$18	Constraint 2 LHS	318.0254022	$D$18>=$E$18	Not Binding	312.0254022
$D$19	Constraint 3 LHS	67.48509483	$D$19>=$E$19	Not Binding	2.485094831
$D$20	Constraint 4 LHS	20	$D$20>=$E$20	Binding	0
$D$21	Constraint 5 LHS	97.37159191	$D$21>=$E$21	Not Binding	21.37159191
$D$22	Constraint 6 LHS	1	$D$22=$E$22	Not Binding	0
$D$5	solution υba	0.382788315	$D$5>=0.12	Not Binding	0.262788315
$E$5	solution υgf	0.12	$E$5>=0.12	Binding	0
$F$5	solution υbr	0.12	$F$5>=0.12	Binding	0
$G$5	solution υci	0.257211685	$G$5>=0.12	Not Binding	0.137211685
$H$5	solution υp	0.12	$H$5>=0.12	Binding	0

Optimization of Manufacturing Parameters Using Design of Experiment

Apart from the volume fraction influence on the properties of brake pad, manufacturing parameters also have significant control on the properties of brake pad.

It is on this premise, the work looked at the under listed manufacturing parameters which have influence on the properties of brake pad, these parameters are:

1. Moulding pressure.
2. Heat treatment temperature.
3. Heat treatment time.

Design of Experiment (DOE) was used to generate different set of manufacturing parameters. Full factorial design was run on MINITAB 18 software which generates these set of manufacturing parameters.

These sets of different conditions generated as shown in table 2 were used to produced twenty-seven samples.

These three manufacturing parameters are (moulding pressure, heat treatment temperature and heat treatment time) which are the factors have minimum, medium, and high levels.

In this case the factorial design will take the form $(L)^N$.

Where L = level and N= factors

For this design N represents the manufacturing parameters which are three (3)

Therefore, the number of runs = 3x3x3 =27

Kim and Jang (2003) used the Taguchi's method to optimize the manufacturing parameters of brake pad and it was found that the best parameters are moulding pressure 27MPa, heat treatment temperature 200^{0}C and heat treatment time six hours.

Based on this the research assumed the following levels in table 5 to produce the brake pad.

Table 5: Manufacturing parameters level

S/N	Level	Moulding Pressure (MPa)	Heat Treatment Temperature (^{0}C)	Heat Treatment time (mins)
1	low	24	180	5
2	Medium	27	200	10
3	High	30	220	15

These low, medium and high levels are input in the DOE design which uses the Minitab software to give the factorial design as shown in Table 6.

Table 6: Factorial Design Manufacturing Parameters Using Design of Experiment Minitab 18

Std Order	Run Order	Pt Type	Blocks	Mp	Cte	Cti
8	1	1	1	24	220	10
6	2	1	1	24	200	15
25	3	1	1	30	220	5
7	4	1	1	24	220	5
1	5	1	1	24	180	5
11	6	1	1	27	180	10
24	7	1	1	30	200	15
12	8	1	1	27	180	15
16	9	1	1	27	220	5
4	10	1	1	24	200	5
26	11	1	1	30	220	10
20	12	1	1	30	180	10
21	13	1	1	30	180	15
15	14	1	1	27	200	15
27	15	1	1	30	220	15
3	16	1	1	24	180	15
2	17	1	1	24	180	10
9	18	1	1	24	220	15
13	19	1	1	27	200	5
10	20	1	1	27	180	5
22	21	1	1	30	200	5
23	22	1	1	30	200	10
19	23	1	1	30	180	5
5	24	1	1	24	200	10
17	25	1	1	27	220	10
18	26	1	1	27	220	15
14	27	1	1	27	200	10

Production of Samples

A cylindrical mould of diameter 20mm and 8mm height was constructed for the production of the samples. The mould was properly cleaned and constitutes materials that form the samples were weighed/ measured based on the volume fraction of each constituent as obtained from the optimization model. The mixture of these materials was properly mixed using a two arm-stirrer at a speed of 250rev/min for 20 minutes to form homogeneous mixture before pouring the mixture into the mould after the mould was waxed with Vaseline, this is to enable easy removal of the samples from the mould.

The mixture poured into the mould is compressed at different pressure of 24MPa, 27MPa and 30MPa using hydraulic press.

After compressing the mixture, the samples were ejected from the mould and cured in an oven at different curing temperatures and curing time based on the design parameters obtained from the Design of Experiment (DoE) as shown in DoE table 5. Some samples produced are shown in plate 3.

Plate 3

Wear

Twenty-seven samples were produced and subjected to wear test using Aston Paar tribometer and ran at a velocity of 10cm/s under a load of 8N for a sliding distance of 50m. Before running the test on the tribometer the initial weight (m_1) of the samples was recorded in (g) and after running test the final weight (m_2) of the samples were recorded using an electronic digital weigh balance M311L.

The samples are shown in plate 2.

Weight lost = Initial weight – Final weight = m_1-m_2.

Wear rate = $\frac{\Delta W}{Sliding\ distance}$

Where:

ΔW weight loss

Volume wear = $\frac{Loss\ Volume}{Force\ x\ Sliding\ Distance}$ …. (Oluwaseyi, 2021)

The result obtained is shown in table 6.

Density of Samples

Density expressed the mass of body per volume, in determining the density of the basalt brake pad portion of friction part of the brake pad was cut off and the weight weighed on an electronic digital weigh balance M311L the weight was recorded. Applying the Archimedes principle, the was piece cut and dropped in volume measuring cylinder containing water initially at 58.00ml, when the piece was dropped into the volume measuring cylinder the volume of water rises to 65.5ml. It therefore means that the volume of the piece is 7.5ml. These records are tabulated in table 7. Three samples were taken since most properties of the basalt-based composite are influenced by mould pressure, for this reason high, medium and low moulding pressure samples were picked, and their density determined. These pressures are 30, 27 and 24MPa.

Density (ρ) = $\frac{Mass\ of\ sample}{Volume\ of\ sample}$

Table 7: Experimental Density of Basalt Brake Pad at different Manufacturing Parameters

sample	weight of sample(g)	volume of water(ml)	volume of water + sample (ml)	volume of sample (ml)	Density (kg/m^3)
15	20.86	58.00	65.50	7.50	2,781.33
18	20.74	58.00	66.00	8.00	2,592.50
26	20.73	58.00	66.60	8.70	2,382.76

The result of the wear is showed in Table 8.

Table 8: Results of wear rate

Sample	Moulding pressure (MPa)	Curing temperature (^{0}C)	Curing time (min)	weight loss (g)	Volume loss (m^3)	Volume loss (m^3/Nm)	Wear Rate g/m
1	24	220	10	0.0075	3.15E-09	7.87E-12	0.00015
2	24	200	15	0.0074	3.11E-09	7.76E-12	0.000148
3	30	220	5	0.0045	1.62E-09	4.04E-12	0.00009
4	24	220	5	0.0075	3.15E-09	7.87E-12	0.00015
5	24	180	5	0.0075	3.15E-09	7.87E-12	0.00015
6	27	180	10	0.0056	2.16E-09	5.40E-12	0.000112
7	30	200	15	0.0045	1.62E-09	4.04E-12	0.00009
8	27	180	15	0.0057	2.20E-09	5.50E-12	0.000114
9	27	220	5	0.0057	2.20E-09	5.50E-12	0.000114
10	24	200	5	0.0076	3.19E-09	7.97E-12	0.000152
11	30	220	10	0.0046	1.65E-09	4.13E-12	0.000092
12	30	180	10	0.0045	1.62E-09	4.04E-12	0.00009
13	30	180	15	0.0047	1.69E-09	4.22E-12	0.000094
14	27	200	15	0.0054	2.08E-09	5.21E-12	0.000108
15	30	220	15	0.0045	1.62E-09	4.04E-12	0.00009
16	24	180	15	0.0075	3.15E-09	7.87E-12	0.00015
17	24	180	10	0.0076	3.19E-09	7.97E-12	0.000152
18	24	220	15	0.0074	3.11E-09	7.76E-12	0.000148
19	27	200	5	0.0055	2.12E-09	5.30E-12	0.00011
20	27	180	5	0.0056	2.16E-09	5.40E-12	0.000112

21	30	200	5	0.0045	1.62E-09	4.04E-12	0.00009
22	30	200	10	0.0046	1.65E-09	4.13E-12	0.000092
23	30	180	5	0.0047	1.69E-09	4.22E-12	0.000094
24	24	200	10	0.0076	3.19E-09	7.97E-12	0.000152
25	27	220	10	0.0055	2.12E-09	5.30E-12	0.00011
26	27	220	15	0.0054	2.08E-09	5.21E-12	0.000108
27	27	200	10	0.0055	2.12E-09	5.30E-12	0.00011

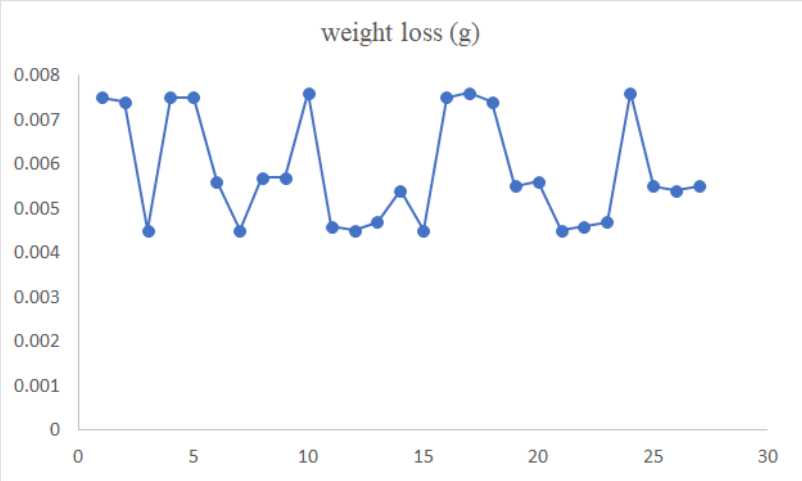

Fig 1: Weight loss of Basalt-based Composite

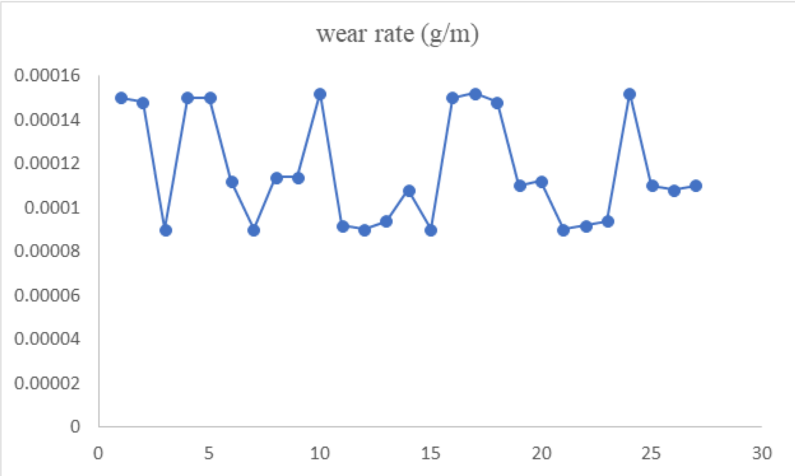

Fig 2: Wear rate of Basalt-based Composite

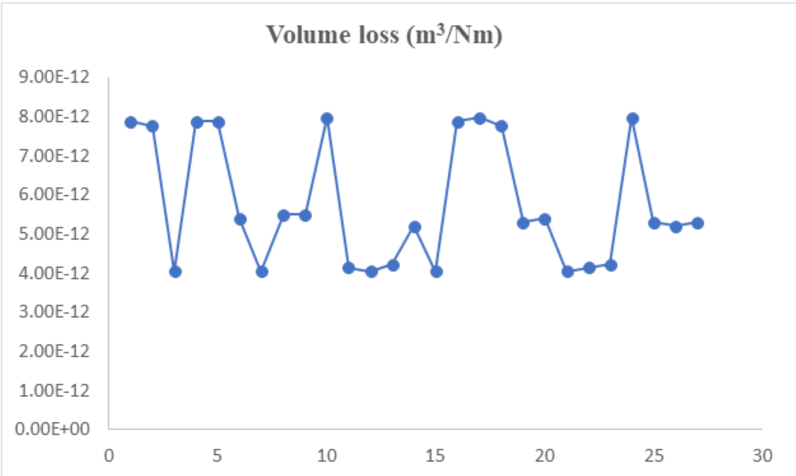

Fig 3: Volume loss of Basalt-based Composite

Thermogravimetric Analysis (TGA)

The thermal analysis was conducted to know the thermal stability of the basalt brake pad, the TGA was conducted in Federal University Minna using PerkinElmer TGA 4000. The sample of the basalt-based composite with weight 14.933 grams was placed on a pan inside the furnace of the TGA analyzer which is supported by a stem connected to a balance which weigh the material as heating is progressing. The heating temperature was set from 30^0C to 900^0C at 10^0C/min. in a nitrogen atmosphere with a purge rate of 20ml/min. this was done so that the sample only reacts to temperature.

The change in mass of the sample over temperature was recorded and displayed on the screen.

DISCUSSION OF RESULT

The wear rate indicates the amount of material removed under application of load over a sliding surface of the material. The result in Table 7 shown that increasing the moulding pressure decreases the wear rate because the higher the moulding pressure the more materials particles are highly packed and the bonding of the material become better and wear rate is less. The wear rate at 30MPa ranges between $9.0x10^{-5}$g/m and $9.4x10^{-5}$g/m this value is slightly higher than that and ceramics matrix brake pad which is $1.9x10^{-6}$g/m (Stephen *et al.*, 2020). However, the wear rate of the basalt-based composites can be improved on if the particle sizes are further reduced (Amaren *et al*., 2013).

Curing temperature has less influence on the wear rate of the basalt-based composite samples while curing time has insignificant influence.

The regression equation expressed the relationship of the influential manufacturing parameters. It is obvious from the expression that only moulding pressure and curing time has influence on the wear characteristics of the basalt-based composite and the is no interaction between the manufacturing parameters.

The Pareto chart and Factorial plot as obtained from the Minitab 18 software showed that the curing time does not have influence on the wear rate, curing temperature has little influence while moulding has the highest influence.

The manufacturing parameters of 30mPa moulding pressure gives a better weight loss ranging from 0.0045- 0.0047g followed by 27MPa moulding and the 24MPa gives more weight loss as shown in Figure 1. The same pattern is shown in figures 2and 3 for wear rate and volume loss respectively.

Regression Equation

The regression equation of the wear rate as expressed below shows that the only moulding pressure and curing temperature has influence on the wear rate.

Wl= 0.005874 + 0.001637 Mp_24 - 0.000330 Mp_27 - 0.001307 Mp_30 + 0.000059 Cte_180- 0.000030 Cte_200 - 0.000030 Cte_220

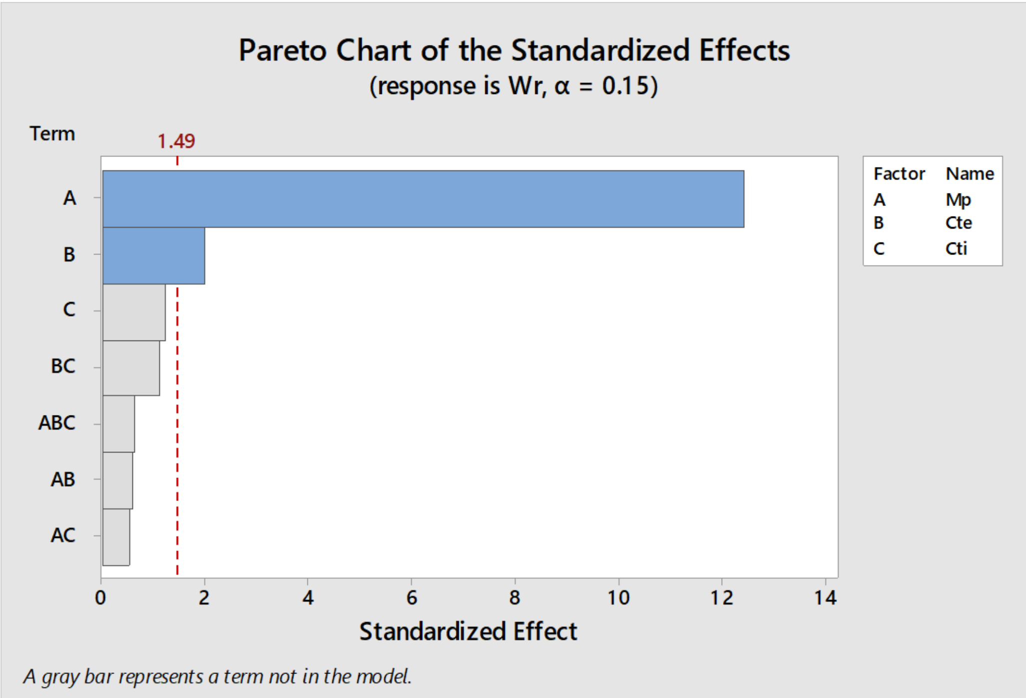

Fig-4: Pareto chart of wear rate

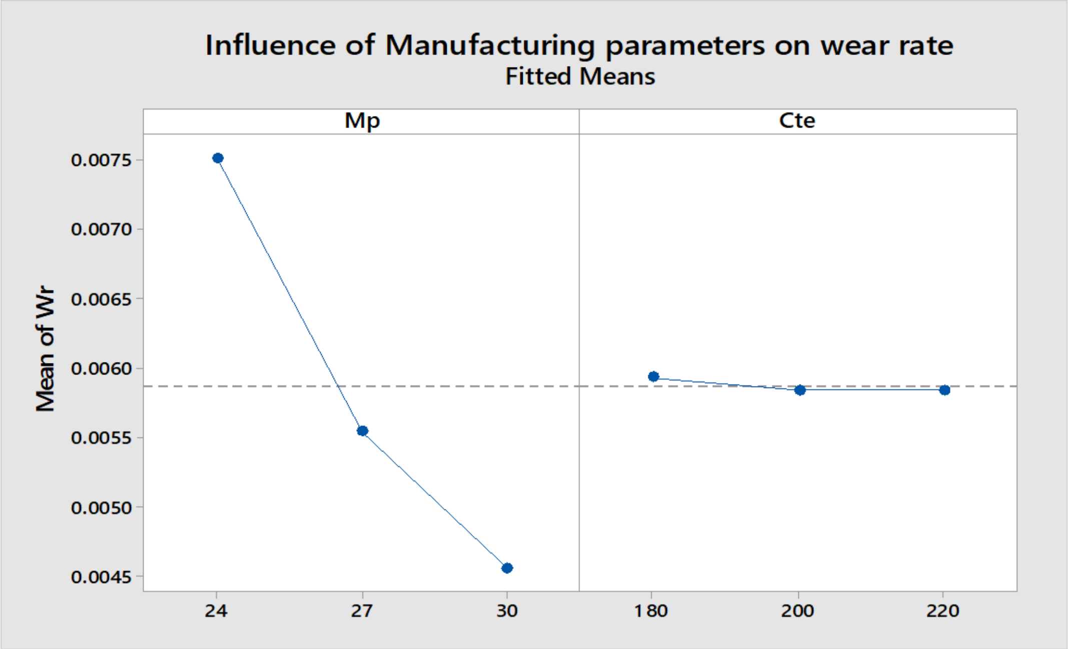

Fig 5: Factorial plot of Wear rate

Density

It is observed that the density of the basalt-based composite increased with increased in moulding pressure. The reason being that as the moulding pressure increased the particles of the constituent materials are packed more closely thereby reducing the volume of the composite by eliminating the pores in between the particles but the mass remained unchanged.

Since density is a function of mass divided by volume and mass remained unchanged while the volume of the composite decreases, the density increases.

This finding confirmed the work of (Taiwo *et al*., 2019) on the effect of moulding pressure on brake lining produced from industrial waste. The curing temperature and time does not have much influence on the density.

TGA/DTA

In Figure 6 the TGA curve shows three steps of weight loss; the first is from 30^0C to 300^0C which is weight lost as a result of moisture, from 300^0C to 530^0C is as a result of further removal of moisture and volatile materials and from 530^0C to 828^0C as a result of pyrolysis. From the graph it is obvious the basalt-based composite is thermally stable up to temperature above 500^0C which meets the positive attribute of asbestos (Nicholas G, 1995).

The Differential Thermal Analysis (DTA) curve in blue colour shows that the highest mass decomposition of the sample occurs at 600^0C.

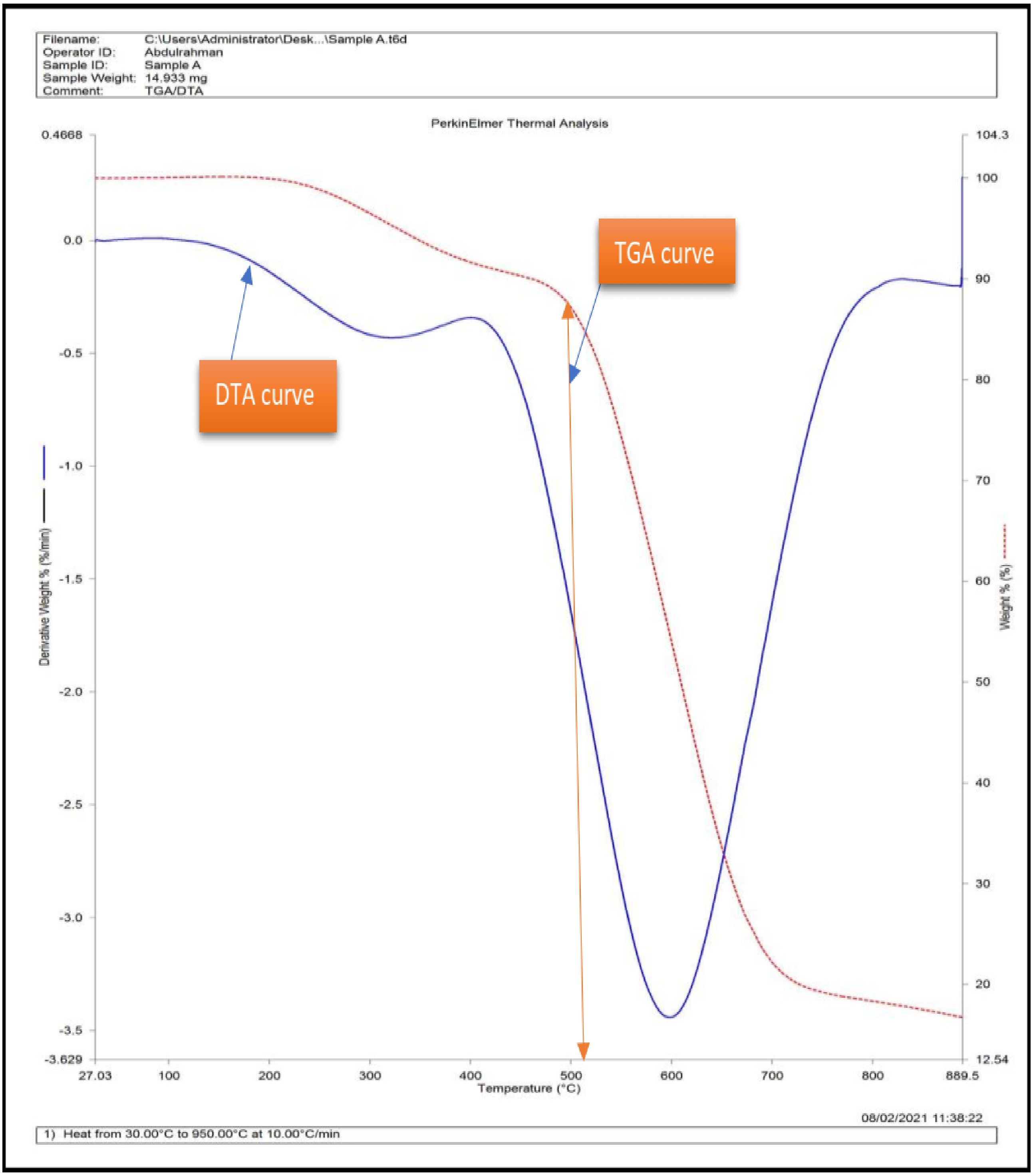

Fig 6: TGA/DTA of Basalt-based composite

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CONCLUSION

The wear characteristics of basalt-based composite exhibited good level of low wear rate, although it is slightly higher than that of ceramics but with further reduction in particle size there will be significant improvement on the wear resistance. According to work onon the effect of particle size of periwinkle shell as a material for brake pad (Amaren *et al*., 2013). The thermal stability is very good which explain the possibility of maintaining good coefficient of friction at high temperature.

RECOMMENDATION

It is recommended that further research on the reduction of particle size to study the wear behaviour of the material it is important.

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