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The Tribological Behaviour of Silumin Reinforced with Carbonized Plantain Fibre Ash Particulate for Possible Motorbike Parts Fabrication

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Abstract: *The management of waste products may reduce pollution and dumping sites. Therefore, one of the main goals of contemporary research is to recover these wastes through conversion into a more environmentally acceptable material that applies to fabrication engineering. This study demonstrated that waste products such as plantain waste are good reinforcement in the development of composite materials because it was found to be environmentally responsible and economically inventive. Materials made from agricultural waste appear amazing, showing immense potential and boosting green engineering. This research investigates the mechanical behaviours of silumin alloy reinforced with carbonized plantain fibre (CPF) for developing motorbike clutch lever. The ISO standards sieve series specifications of 565 and 3310/1 were employed under the requirements of the American Society for Testing and Materials (ASTM). The different weight percentages of 2.5-10% of CPF were used to advance the investigated matrix composites. The morphology of the surface damage behaviour of the composites was investigated via scanning electron microscopy (SEM)***.** *The results of the mechanical property showed an increase in wear behaviour. The best signal-to-noise (SN) ratio, a criterion for evaluating the superiority features, was attained through Taguchi's robust design process and was validated using Minitab18 software. The optimal wear value of 50.20g/min and the control factors are established for the composite.*

KEYWORDS*:* Silumin, Carbonized Plantain fibre, mechanical properties, Matrix, Wear rate, particulate, reinforcements.

INTRODUCTION

The degradation of the environment by man as a result of higher population enhanced living standards attributable to technology development has a damaging effect on the environment and agriculture activities. Industrialized undertakings are synonymous with generating a large number of waste materials. The major innovation, therefore, is to pursue developmental projects in the field of engineering and materials development with positive effects on both humans and their environments. (Alaneme, et al, 2014; Suleiman, et al, 2018).

Research has shown that agro-waste materials are good reinforcement in composite materials development as they are found to be environmentally friendly with such materials formed exhibiting the great potential to create opportunities and promote green engineering. The interest received by Aluminum Metal Matrix Composites (Al-MMCs) as engineering materials is on the increase; ceramic materials on the other hand are introduced to produce composite materials with a blend of aesthetics and robustness in both physical, and chemical. The mechanical properties are hardly achievable with aluminium alloy alone. (Maurya, et al, 2019; Abdulwahab, et al , 2017)

Al-MMCs are typically enhanced through reinforcement integration as such both mechanical, as well as tribological properties, are improved. Researchers have shown the prospect of replacing conventional metals with composites materials in aerospace and other fabricating industries because of better behaviour, weight reduction and economic connivance of composite materials. (Zamri, et al, 2011; Maleque, et al, 2012; Rajesh and Santosh, 2017)

MATERIALS AND METHODS

The Aluminum scraps in this work were gotten from dumpsites while Silicon was bought from Dopemu Industrial and Allied products market, Lagos state, Nigeria. The pseudo-stem used in this research was acquired from a local plantain farm at Isiala Ngwa South, Abia State-Nigeria. The chemicals (Acetic Anhydride, Acetic Acid and Sodium Hydroxide) used for the fibre treatment were procured from Ogbete Main Market in Enugu State, Nigeria.

Preparation of Carbonated Plantain Fibre

After decomposition, fibre was separated from impurities like hemicelluloses and pectin, and afterwards washed and sun-dried. 13,500 grams of plantain fibre by weight was obtained. The chemical treatment followed an established natural fibre treatment procedure with sodium hydroxide has been proven to boost fibre to matrix interfacial interaction with better bonding characteristics of composite strength(). Sodium hydroxide- an inorganic compound for its effectiveness- was employed at 97% pure concentration. To further remove impurities from the fibre and increase fibre strength 6750 grams of fibre was soaked in a NaOH solution of 1:3 to H_2O. To deactivate the sodium hydroxide effect, 10% acetic acid was applied to 6750grams of fibre, which was then thoroughly washed to neutrality utilizing immersion in water, followed by running water, finally filtered and sun-dried to a fibre weight of 13,250 grams from the 13,500 grams obtained after decomposition.

Further treatment was carried out on the dried fibre to stabilize its cell walls from moisture and avoid degradation environmentally. Ethanoic anhydride- the simplest isolable anhydride of carboxylic acid was applied at 10% concentration to 6750grams of fibre which as well improved the fibre dimensional stability. The neutral stance of the fibre was achieved through thorough water washing. Litmus testing was employed to make sure of the fibre's neutrality or otherwise.

Equipment and mineralogical characterization of the carbonated plantain fibre
Energy Dispersive X-ray Spectrometer was employed for the mineralogical Characterization; a basic investigation of the carbonized plantain fibre, with the help of a Mini pal 4 ED-X machines from Panalytical of Netherlands. To make pellets, the specimen after being weighed was mashed in a mortar, and thereafter compacted in a hydraulic press.
The spectral data of the specimen was then evaluated to ascertain the level of concentration of the basic elements in the sample, which was formulated as a result of the percentage weight fraction. The specimen compartment of the spectrometer was filled with the pellets. 30kv of voltage and 1 mA of electric current were applied to the X-rays after 10 minutes.

Preparation of silumin (2.5-10 wt %) CPF particulate composites
According to Massalski, Okamoto, Subramanian, and Kacprzak, 1990, Silumin is a binary eutectic alloy with a weight composition of between 3 - 25% Si. The Silicon- brittle nonmetallic element in the silumin compound increases its wear resistance and decreases the thermal expansion coefficient, the machining characteristics, as well as casting, are improving, and at the lowest freezing point, the eutectic Al-Si phases come together and develop until hardening is completed. At 20^{OC}, a hypoeutectic alloy comprises a ductile basic aluminium phase and a coarse solid yet fragile eutectic silicon phase. Silumin apart from aluminium and silicon which are the main elements, consists of other elements like copper, magnesium, manganese, zinc, iron etc the capacity of these elements to dissolve in aluminium is dependent on temperature increase. The concentration of Silumin used in this work is presented in Table 1. The balancing weight per cent is aluminium used to prepare Silumin. The gravity die stir casting procedure was used in fabricating the composite used in this investigation. A 30mmX100 mm mould was used to cast the composite. Oil-fired graphite was used to carry out the melting process. At 200°C, the Silumin compound was preheated for 30 minutes and a constant temperature of 720˚C pouring was done, degassing - the process of unwanted or excess gas was done by adding sodium carbonate to drive out hydrogen, the temperature was increased to 800˚C and the carbonated plantain 4fibre particulate of 50μm was launched into the

silumin compound. To reduce slag formation, proper mixing is required, an economic mechanical stirrer AML-P series appropriate for mixing liquid of high viscosity and density was employed to improve mixing and guarantee homogeneous mixing of the reinforcement and Silumin compound.

Table 1: Chemical analysis of silumin used for this research

Constituents	Wt %
Manganese (Mn)	0.010
Magnesium (Mg)	0.011
Iron (Fe)	0.020
Copper (Cu)	0.006
Silicon (Si)	12.00
Aluminum (Al)	Balance

Experimental procedure

The reinforcement material was a combination of carbonated plantain fibre particulates. To increase the fluidity of melted composites, five different weight percentages of CPF (0 %, 2.5 %, 5%, 7.5% and 10 %) and 1 wt.% of magnesium powder—were utilized as wetting agents (Barah, 2021).The mechanical and tribological properties of silumin/carbonated plantain fibre composites were investigated in this research. The produced composites were microstructurally investigated to determine the crystallographic structure of samples using X-ray diffraction (XRD), and Energy dispersive spectroscopy (EDS) employed to determine the relative abundance of chemical components in the silumin carbonized plantain fibre particles as well as elemental mapping. Scanning electron microscopy (SEM) was employed for failure analysis and quality control as well as for investigating the morphologies of worn surfaces to better understand the wear mechanism. (Barah, 2021).

The following composite combinations were fabricated for this study.

i. Control (Silumin 100%)
ii. 97.5% Silumin + 2.5% CPF.
iii. 95% Silumin + 5% CPF.
iv. 92.5% Silumin + 7.5% CPF.
v. 90% Silumin + 10% CPF.

Wear test

According to ASTM G99 test method standard, a specific set of test parameters (load, sliding speed, materials, etc) were used, and the wear experiments were conducted at 30°C of temperature and between 60–65 per cent of relative humidity, after each trial, the sample and counter disc are

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thoroughly wiped, and any clinging wear residue was removed using acetone. A digital scale with a minimum count of 0.1 mg was used to weigh the specimen to uncover the losses incurred

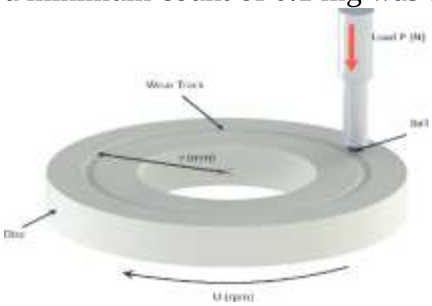

Fig 1: Schematically Pin-on-Disk test to ASTM G 99 (Salguero, et al, 2018).

Evaluating the sample Weight

To determine the appropriate weight of the sample needed, the help of an accurate and extremely sensitive electronic weighing balance was required. It was fitted with cambers to reduce the effect of airflow which might negatively affect the readings (Muralikrishna, et al, 2020).

The composition of the sample is shown in table 2 below. The following straightforward formula as expressed below can be used to obtain the minimum mass of the gross sample:

$$M_s = \frac{1}{2}\left({}^{\rho}/_{{\sigma_1}^2}\right)\left(\frac{1}{W_1} - 2\right){d_1}^3 \times 10^3 \qquad (1)$$

where M_s is the maximal mass in grams and ρ is the density of powder in grams per cubic meter, ${\sigma_1}^2$ is the allowed sample error of variance, W_1 is the fraction mass of the irregular size as sampled and ${d_1}^3$ is the arithmetic means, in cubic centimetres, of the cubes with the largest diameters in the size category. This formula can be used if the largest class has a scope array of merely 1.41:1 and W_1 is below half of the overall sample in percentage dependent on the determined particle size in millimetres, with the least incremental mass as prescribed by ISO 3081 (Ravikumar, et al, 2021). Under this standard, the least mass of an increase with the highest constituent part of 10-0 mm equals 0.3 kg by this specification.

Table 2 Composition of a sample.

Silumin %wt	100	97.5	95	92.5	90
CPF % wt	0	2.5	5	7.5	10

A classification technique was used to calculate the size of particle distribution or remove several particles from the spread, (particle size distribution analysis). The measurement of the deferred particles in a liquid beneath the impact of energy produced through different forces such as the force of gravity, centrifugal force, or force of inertia is often the basis for powder classification. Usually, the fluid is always air or water. The direction of the stream helped to distinguish the classifiers (Xiaoyan, et al, 2018). To approximately estimate the quantity and density of composite properties

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studied in this work, the volume weighted average of both the matrix and reinforced properties were considered, whence applying the rule of mixture, given the fibre weight fraction, W_f, matrix, W_m, and the density of composites, ρ_c, can be calculated by the following equation (Yerbolat, et al, 2018).

$\rho_c = \rho_f W_f, + \rho_m W_m$ (2)

Density of Al = 2.7gm/cm$^{3;}$

Density of Si = 2.33gm/cm^3

Volume of SCPF = 2.54cm^3

Density of Fibre= 0.132gm/cm^3 (Ihueze, and Okafor, 2014)

The dimension of the SCPF sample: Height = 10mm; Diameter = 18mm; Volume = 2.5cm^3

Q = W x d x v (3)

Where: q = Quantities; d = Densities; W= Weight fractions and v = volume.

Sample

Q(Al) at 88%wt = 0.88 x 2.7 x 2.54 = 6.035gm

Q(Si) at 12%wt = 0.12 x 2.33 x 2.54 = 0.710gm

Q(CPF) at 10 %wt = 0.1 x 0.132 x2.54 = 0.0335

Density: $d_c = d_m \times w_m + d_f \times w_f$ (4)

Where: d_c, - Density of the composites

d_m - Density matrix phase

d_f - Density reinforcing phase respectively.

W_m, - matrix weight fraction and

W_f- Weight fraction reinforcing phase.

Design of Experiment

This work takes into cognizance four controlling factors such as weight fraction, particle size, time and temperature. Each factor includes three scales, labelled 1, 2, and 3, for low, medium, and high standards.When there are four factors and three levels for each factor in the scientific experiment, the L9 orthogonal array and Taguchi method are applied (Sharma, et al, 2005; Dar, et al, 2018). Table 3 below shows the elements that were taken into consideration when creating the motorcycle clutch levers and their weights.

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TABLE 3. Experimental design and different mechanical property sets.

S/N	Process parameters (Fabricating factors)	Level			Unit
		1	2	3	
1	A: Weight Fraction	2.5	5	10	%
2	B: Particle Size	50	70	90	µm
3	C: Soaking Time	5	10	15	Min.
4	D: Casting Temperature	520	580	640	Degree

A distinct standard of experimental design that calls for a lower number of trials from which orthogonal arrays are required is necessary to determine the primary components' impact on production. The minimal number of tests to be carried out must be specified using the formula below before choosing an orthogonal array (Yusuff, et al, 2021).

$N_{tag} = 1+NV*(L-1)$ (5)

Where N_{tag} = No. of trials to be performed
NV = No. of factors; L = No. of levels
In this work, NV = 4 and L = 3; Hence $N_{tag} = 1+ 4 (3-1) = 9$

From the calculation above Nine (9) trials were to be performed; Consequently, the preferred OA should have at least 9 rows representing 9 trial runs, having selected the matching OA, the level combinations were used to choose the trials, and each experiment was carried out as needed. The output in this instance includes performance variables documented for each trial run for Signal-to-Noise (S/N) Ratio analysis. Factors that a designer can control (design parameters) and those that a designer cannot control (noise factors also known as environmental factors) are among those that Taguchi ranked as having a high impact on production quality. The mean and variability of the trial outcome are both carefully considered for the study. This environmental factor depends on the valued uniqueness of the production/procedure to be effectively enhanced. The signal-to-noise (S/N) ratio is studied, there are often three options for this performance uniqueness; hence, the smaller, the higher, and the nominal-the-better. Depending on the category of performance characteristics, each response's ratio is calculated using a different baseline, but regardless of the category, a higher S/N ratio corresponds to a better performance characteristic.

The wear factor is the -smaller-the-better-performance feature in this study. When all of the signal-to-noise ratios for each run of the experiment have been calculated, Taguchi suggests using a graphical method to analyze the data. Depending on the features being examined, Throughout the experiment, the S/N ratio reduces the number of data points. The estimated S/N ratio demonstrates that smaller-is-better fits in for maximal wear behaviour.

Mean squared deviation MSD is used in measuring the variance of valued characteristics as expressed below.

$$MSD = \frac{1}{n}\sum_{k=0}^{n}\left(\frac{1}{y_t}\right)2 \qquad (6)$$

The analysis of variance (ANOVA), a typical method for examining these data, was utilized to identify the statistically significant elements. But the Taguchi robust design methodology does this with a more straightforward graphical method. The impacts of each component may be distinguished because the L9 experimental design is orthogonal.

The average SN (SNav) ratio and mean (Mms) feedback for individual factors during each test level are computed by analyzing each mechanical property's control matrix that has been examined using such data.

Given that the orthogonal array experimental design was preferred, it is necessary to differentiate the results of each parameter and display the control matrix to calculate the average environmental factor responsible for the individual parameter at each one of the 3 levels of the experiment. This will be done in the analysis of the four mechanical tests that were performed in this scientific work.

Table 4: Summary of Taguchi Designs

Orthogonal Array	L9(3^4)
Parametres:	4
Runs:	9
Columns of L9(3^4) range: 1 2 3 4	

Using three-factor levels and measurable qualities as quality characteristics, the Taguchi Robust design technique was used to evaluate attributes a method for determining the best signal-to-noise ratio combinations (Low, medium, high).

The calculated environmental factors for the quality attributes were analyzed, and the most effective control factor values were identified for the parameters. The number of data points within a trial is condensed by the signal-to-noise ratio. The mean squared deviation, or MSD, is a measurement of the variance of quality characteristics as expressed in the equation below (Ihueze, and Okafor, 2014).

$$MSD = \sum_{1=t}^{n}\frac{1}{{y_t}^2}$$

Expt. No	A: (%)	B: (µm)	C: (Min)	D: (^{O}C)	Specimen Replicates *Wear Response* (g/min) Expt#1	Expt#2	Trial #3	Mean	Mean *Wear* Response g/min	SN-ratio
1	2.5	50	5	520	2.40	2.47	2.50	2.46	0.162	-48.3399
2	2.5	70	10	580	2.40	2.45	2.50	2.45	0.164	-49.3213
3	2.5	90	15	640	2.38	1.43	2.48	2.10	0.800	-50.1904
4	5	50	10	640	1.98	2.00	2.05	2.01	0.250	-50.1307
5	5	70	15	520	1.85	1.98	1.95	1.93	0.270	-48.3928
6	5	90	5	580	1.84	1.88	1.92	1.88	0.283	-49.3519
7	10	50	15	580	1.48	1.49	1.51	1.50	0.450	-49.2843
8	10	70	5	640	1.42	1.46	1.49	1.46	0.480	-50.1635
9	10	90	10	520	1.40	1.29	1.30	1.33	0.566	-48.4308

$S/N = -10\log_{10}MSD$ (7)

Consequently, the rule states that an orthogonal array's degree of freedom (DOF) must be greater or equivalent to the number of selected quality criteria (Shunmugasundaram, et al, 2020),
can be determined using the following formula stated below:

$(DOF)R = P \times (L-1)$ (8)
Degree of freedom = (DOF)R
Factor Number = P
Level Number = L
⇨ $(DOF)R = 3(3 - 1) = 6$

Wear response of SCPF composite.

Table 5: For mechanical properties, trial outlay and variable sets

S/N	Fabricating factors	Levels				Observed Value
		1	2	3	Units	
1	Weight Fraction	2.5	5	10	%	Wear Rate
2	Particle Size	50	70	90	µm	
3	Soaking Time	5	10	15	min	
4	Casting Temperature	520	580	640	Degree	

Employing equation (6) As shown in the accompanying tables, the mean standard deviation MSD was calculated.

$$SNratio_{exp1} = -10 \times \log\left\{\frac{1}{3}\left[\frac{1}{(2.40)^2} + \frac{1}{(2.47)^2} + \frac{1}{(2.50)^2}\right]\right.$$

RESULTS AND DISCUSSION

Presentation of Results

After all the experiments, the following results were recorded, as seen in tables 6, 7, 8, 9, 10 and 11

Table 6: Matrix design experimental for Wear test using SCPF composite (ASTM G99)

Table7: Average outcomes from studies 1 through 9 for levels 1-3 of the Weight fraction (A)

Valued Factor level qualities	The average response to various trials	Reaction rate
SNav1	$\frac{A1+A2+A3}{3}$	2.337
Mms1	$\frac{A1+A2+A3}{3}$	-49.284
SNav2	$\frac{A4+A5+A6}{3}$	1.980
Mms2	$\frac{A4+A5+A6}{3}$	-49.292
SNav3	$\frac{A7+A8+A9}{3}$	1.430
Mms3	$\frac{A7+A8+A9}{3}$	-49.293

Table8: Average outcomes from studies 1 through 9 for levels 1-3 of the Particle Size (B)

Valued Factor level qualities	The average response to various trials	Reaction rate
SNav1	(B1+B4+B7)/3	2.020
Mms1	(B1+B4+B7)/3	-49.252
SNav2	(B2+B5+B8)/3	1.930
Mms2	(B2+B5+B8)/3	-49.293
SNav3	(B3+B6+B9)/3	1.770
Mms3	(B3+B6+B9)/3	-49.324

Table 9: Average outcomes from studies 1 through 9 for levels 1-3 of the soaking Time (C).

Valued Factor level qualities	The average response to various trials	Reaction rate
SNav1	(C1+C6+C8)/3	1.913
Mms1	(C1+C6+C8)/3	-49.285
SNav2	(C2+C4+C9)/3	1.930
Mms2	(C2+C4+C9)/3	-49.294
SNav3	(C3+C5+C7)/3	1.843
Mms3	(C3+C5+C7)/3	-49.289

Table10: Average outcomes from studies 1 through 9 for levels 1-3 of the Temperature (D)

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Value Factor level qualities	The average response to various trials	Reaction rate
SNav1	(D1+D5+D9)/3	1.901
Mms1	(D1+D5+D9)/3	-48.388
SNav2	(D2+D6+D7)/3	1.943
Mms2	(D2+D6+D7)/3	-49.319
SNav3	(D3+D4+D8)/3	1.837
Mms3	(D3+D4+D8)/3	-50.162

Table11: Response Table for wear strength of CPF-reinforced composites based on the principle that smaller equals better quality

Reaction	Environmental Factor				Means			
Level	A: (%).	B: (µm).	C: (Min).	D:(^{O}C).	A: (%).	B: (µm).	C: (Min).	D:(^{O}C).
1	2.337	2.020	1.913	1.901	-49.284	-49.252	-49.285	-48.388
2	1.980	1.930	1.930	1.943	-49.292	-49.293	-49.294	-49.319
3	1.430	1.770	1.843	1.837	-49.293	-49.324	-49.289	-50.162
Delta	0.91	0.25	0.09	0.11	1.01	0.07	0.0091.77	
Rank	1	2	4	3	2	3	4	1

Wear properties of composite

The wear rate lowers with an increase in the weight percentage of carbonated plantain fibre particles. The composites had a significantly higher wear resistance than silumin attributable to the addition of CPF, which has a higher SiO2 content that serves as a load-bearing component. As the ratio of carbonated plantain fibre content rises, the composite's rate of wear lowers. Figure 2 shows that adding more carbonated plantain fibre to a composite reduces the amount of matrix material that deforms in response to a load, which lowers the wear rate for the higher CPF content composite. This finding is consistent with (Suleiman et al. 2018), the observation that the wear rates decreased from 0.027 g/min in the alloy to 0.0096 g/min.

The graphs below demonstrate that at constant applied stress, the wear loss of pure aluminium is high when compared with that of carbonized plantain fibre composites.

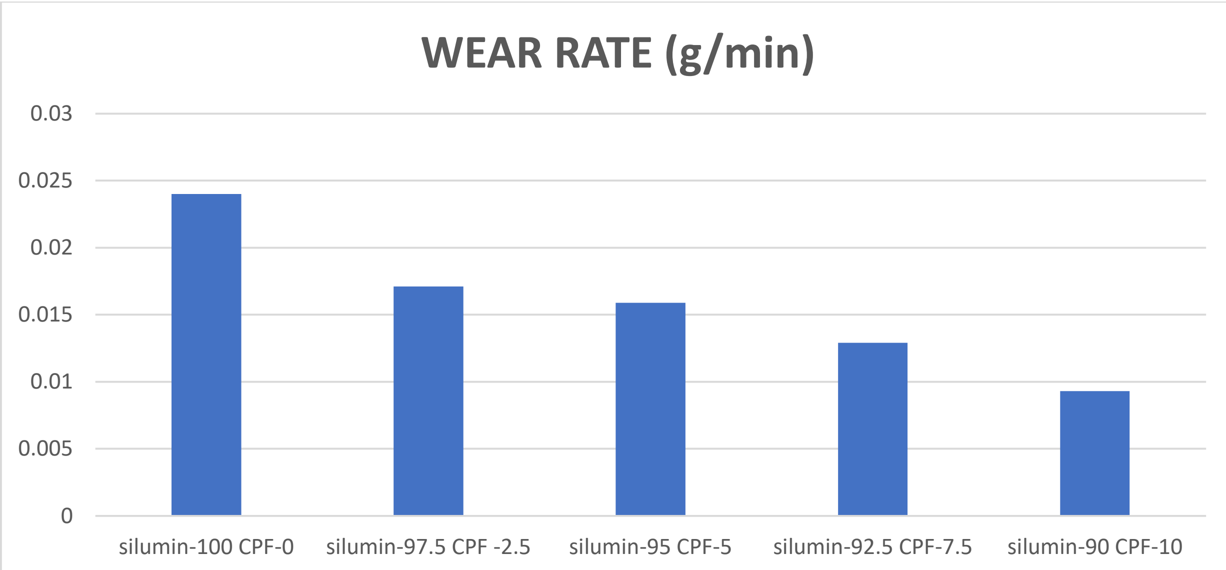

Figure 2. Weight percentage and wear loss of Silumin- carbonized plantain fibre composites.

The average environmental factor ratios and mean of the response tables are calculated against experiment levels for each of the four control parameters. It has been demonstrated that the control factors fibre-weight fraction (parameter A), has a more significant impact on signal-to-noise ratios when compared with casting temperature (parameter D). Casting temperature on the other hand has a stronger effect on means, this makes it more relevant than other control parameters.

Radharamanan and Ansui (2001) state that the main effects plots are used to determine the optimum control factor setting, and that the response table for mean and the reaction table for environmental factor ratio are used to estimate the expected response. Equation (8) represents the expected response model.

$$PV = AVR + (A_{opt}-AVR) + (B_{opt}-AVR) + (C_{opt}-AVR) + (D_{opt}-AVR) + ... + AVR\,(n^{th}{}_{opt}) \qquad (8)$$

Where PV stands for a predictable reaction, AVR for an average reaction, Aopt for a mean value of reaction at factor A's optimal setting, B_{opt} for a mean value of reaction at factor B's optimal setting, Copt for a mean value of reaction at factor C's optimal setting, and D_{opt} for a mean value of reaction at factor D's optimal setting

Evaluation of predictable wear responses based on ideal conditions.

The prediction reaction model using (8) is given as:

PV_{wear}= -49.290 + (- 49.293 + 49.290) + (-49.324+49.290) +(-49.294+ 49.290) + (-50.162 + 49.290) = -50.203 g/min

TABLE 12 Predictable optimal strength of composites and optimal control parameter setup

Composites Quality	Control variable	Optimal Level	Optimal Conditions	Predictable wear Optimal Strength
Carbonized Plantain Fiber	A B C D	3 3 2 3	10 90 10 640	-50.203 g/min

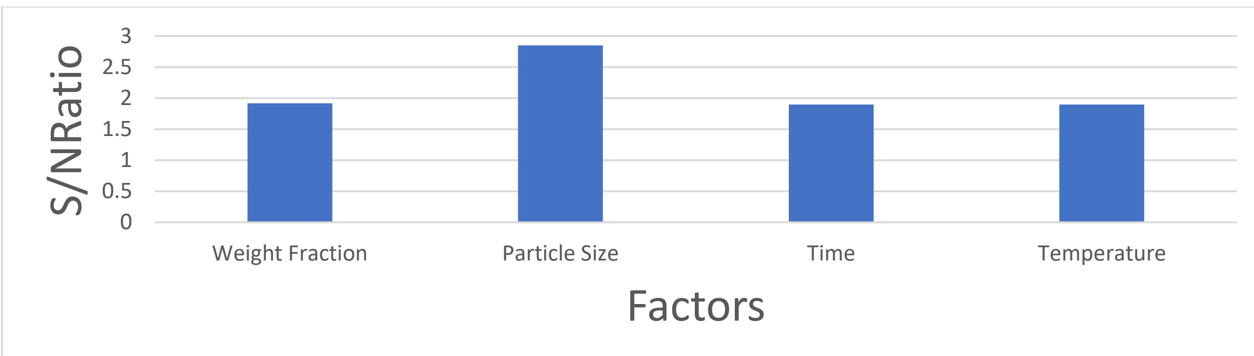

Figure 3: Plots of the main effects for S/N Ratio-SCPF.

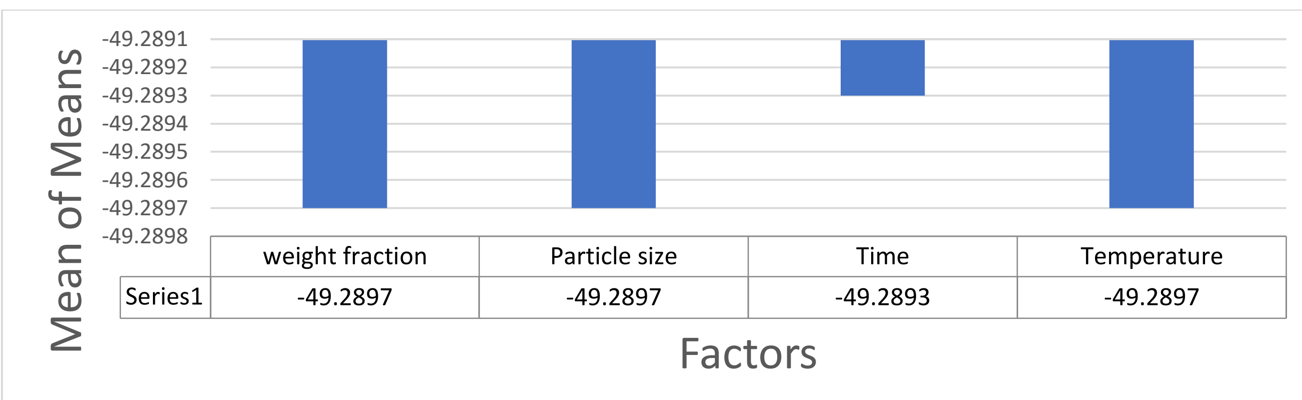

Figure 4: Plots of the main effects for means-SCPF

SUMMARY AND CONCLUSION

When the control parameters (weight fraction of fibres, the particle size of fibres, soaking time of silumin, and casting temperature) are set to 10 weight per cent, 90 millimetres, 10 minutes, and 640 OC degrees respectively, that carbonized plantain fibre-reinforced silumin matrix composite has the optimal wear rate of negative 50.20g/min.

The findings demonstrated that as the weight fractions of carbonized plantain fibre grew, so did the wear rate of the composites that were created. A good option for imported reinforcers like Al2O3, TiC, SiC, B4C, etc., CPF, which is agricultural waste, is readily available, affordable, and environmentally safe. It is therefore recommended that Silumin reinforced with carbonized plantain fibre ash particulate be used in tribological areas in automobile applications, like motorbike clutch lever

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