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Investigation of Wear Behaviour of 3WT% SIC Fiber Metal Laminate Composite

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Abstract:- The present study delves into the experimental examination of a composite laminate comprised of Basalt fiber intertwined with Aluminium. Basalt, an igneous rock primarily constituted of plagioclase and pyroxene minerals, demonstrates remarkable potential when amalgamated with Aluminium—a silvery, malleable metal within the boron group. Their synergistic combination augments the mechanical properties significantly, rendering it applicable across various engineering domains. Employing the hand lay-up technique, the Basalt-Aluminium laminate is meticulously fabricated, and to bolster its abrasive and enduring attributes, a 3Wt% infusion of silicon carbide is introduced. To evaluate its resistance to wear, the Basalt-Aluminium laminate undergoes rigorous examination via a pins-on-disc apparatus, utilizing the Taguchi methodology (L9 Orthogonal Array) to determine the optimal number of trials. The results garnered from individual sample pieces are further refined and optimized employing the Grey Relational Analysis (GRA). Complementary to the wear tests, the material specimens are subject to scrutiny through Scanning Electron Microscope (SEM) imaging, facilitating a comprehensive exploration of their wear characteristics. This composite material exhibits promising potential for deployment in high-wear environments such as brake callipers, clutch plates, conveyor belts, and analogous settings, where durability and resilience are paramount considerations.

Keywords: *Fiber Metal laminate, Aluminium laminate, Basalt-Aluminium.*

1. Introduction

Across various engineering domains, there exists a considerable demand to substitute established materials such as steels and cast iron due to their inherent robustness in mechanical and thermal aspects. Addressing the intricacies and challenges encountered by engineers involves exploring natural fibers capable of mirroring or equalling the properties of current materials. This pursuit focuses on assessing wear properties through the utilization of basalt-aluminum composites. Investigative efforts include the examination of wear rates via the pin-on-disk test applied to the Al–Li/Sic metal matrix composite. Employing the Archard law aids in estimating wear volume per cycle during experimentation, while the development of a finite element model aims to elucidate wear parameters, encompassing coulombic friction and material behavior variations due to thermal property alterations as elucidated by the author. [1]

The study delves into the frictional behavior of aluminum 7075, employing laser surface texturing as a surface engineering technique. Subsequent to this treatment, the material undergoes pin-on-disc wear testing. Observations focus on the micro dimples created through laser surface texturing, consolidating the findings. Notable enhancements in the properties of aluminum 6061 and 7075 alloys are noted during this exploration. The pattern exhibiting the least coefficient of friction garners detailed scrutiny by the author for further analysis. [2] This study extensively discusses a comparative analysis between pin-on-disc testing and dynamometric tests. The author delineates specific testing conditions and presents accurate test outcomes. The material pairs primarily involve non-asbestos organic material and a low met. [3]

Within this paper, the author advocates for pin-on-disc testing concerning clutch facing material, elucidating essential aspects such as temperature, normal pressure, and sliding velocity crucial for achieving the desired

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coefficient of friction. Detailed discussions of the obtained results ensue. [4] The paper predominantly revolves around the graphite structure subjected to pin-on-disc testing alongside copper-free friction material. Predictions regarding temperature, pressure, sliding distance, and velocity precede the experimentation. Post-testing, variations in size, shape, and wear properties are meticulously scrutinized. [5]

This publication expounds upon replacing cast iron brake blocks in railway systems with composite brake blocks, elucidating the wear and tear induced by braking. Pin-on-disc wear testing involving a steel wheel is employed, tailoring temperature ranges and distances as per requirements. The ensuing outcomes are meticulously discussed. [6] The author's objective here lies in reducing emissions and wear rate during automotive braking. Aiming to minimize wear rate, the author explores novel materials, including one disc treated with WC/CoCr coating using the HVOF technique and another employing a nitriding technique. Pin-on-disc experiments yield wear rates and coefficients of friction, extensively discussed within. [7]

This study investigates the mechanical behavior of Basalt fibre-reinforced epoxy (BFRE) and a novel type of fibre metal laminates (FMLs), analyzing tensile and bending loads. Highlighting the potential benefits of using MGP (Metal-Graphite Particles) in applications requiring high stiffness is a key proposition. [8] Examining aluminum 6061 as a matrix and basalt fiber as reinforcement, the study fabricates Basalt fibre reinforced aluminum metal matrix composites via Stir Casting techniques. Utilizing a Pin on Desk apparatus, wear resistance is evaluated, optimizing specific parameters—sliding velocity, normal load, and basalt fiber reinforcement percentage—through Grey Relation Analysis (GRA). [9]

The author introduces optimal machining parameters for a non-traditional machining process, employing PCA (Principal Component Analysis) and grey relation analysis to determine ideal machining variables. Jet pressure and jet transverse speed are identified as influential factors affecting surface roughness, material removal rate, and kerf angle. [10] Noteworthy is the inverse relationship observed between wear rate and reinforcement increment. [11-13] The author further explores the process of parameter optimization using Taguchi's method and principal component analysis, demonstrating that this methodology significantly improves output parameters based on experimental results. [14]

2. Methodology

2.1. Material specimen preparation

The basalt fibre was used as a reinforcement in this study, it can be used in a variety of applications such as non-flammable coverings, corrosion-resistant pipelines etc. Basalt is an igneous rock that is created by the rapid cooling of molten lava which gets exposed on the earth's surface. Basalt fibers are used in a variety of forms, including rolls, chopped fibers & powder. The 5000 series Aluminium is used, which is a white silvery material that is light weight & malleable. The epoxy resin Araldite LY 556 and the hardener Aradur HY 951 is used, it has excellent flexural and adhesive properties. Silicon carbide is a silicon and carbon-based semiconductor with high hardness and wear resistance. It is used in MOSFETs, grinding wheels and bullet-proof vests. Natural fibre composites can be made quickly and easily using hand layup technique. Despite its slowness, the fabrication process is ideal for all kinds of fibres. The layup procedure in this work entails hand-stacking each basalt fibre ply, aluminium on top of successive basalt layers, where epoxy resin and silicon carbide are blended together and it is used as an adhesive applied in between the basalt aluminium layers, finally the composite is finely packed using compression moulding technique, which eliminates air pockets between plies.

2.2. Taguchi Method

Dr. Genichi Taguchi, the founder of Taguchi optimization technique, developed a method for designing experiments about how each and every distinct parameter affects the mean & variance of a process which defines how the process is functioning. Taguchi proposed a method which uses an orthogonal array in order to organize the parameters which affect the experiment. The orthogonal array provides a set of well-balanced, minimum number of experiments followed by Signal-to-Noise ratios (S/N), which are log functions of the desired output which serve as an objective function for optimization, this method helps in data analysis and prediction of optimum results, With Taguchi optimisation technique 9 experiments are done using the L9 orthogonal array as tabulated in Table 1 respectively.

Table 1. Generated L 9 Orthogonal Array

Trial	TIME TESTED (sec)	RPM	LOAD (kg)
1	1620	500	4
2	1620	600	5
3	1620	700	6
4	1365	500	5
5	1365	600	6
6	1365	700	4
7	1170	500	6
8	1170	600	4
9	1170	700	5

3. Testing of composites

3.1. Pin on disk tribometer

The pin on disk tribometer is a device which is used to perform wear analysis of a material such as metals, fibres, composites etc. The wear test is performed on the material in order to validate its wear properties when subjected to real world scenarios. A typical pin on disk tribometer setup is shown in figure 1, In order to perform the wear analysis, the samples are prepared as per ASTM G99 followed by grinding of the specimen as per the machine specification provided by the lab which is 10mm cylindrical test bits, further an aluminium rod is attached on the test piece in order to meet the length specifications of the tribometer as shown in figure 2 respectively.

Figure 1. Parts of Pin on Disk Tribometer

Figure 2. Specimen with Aluminium Attachment

The wear rate and specific wear rate are calculated using the below equations, the wear volume, wear velocity, wear rate, specific wear rate is calculated as shown in the equation 1,2,3,4 respectively.

Wear volume = $\frac{change\ in\ weight}{density}$ (1)

Wear velocity = $\frac{2*\pi*R*N}{60}$ (2)

Where, R = sliding radius, N = Disc RPM

Wear rate = $\frac{wear\ volume}{wear\ velocity*time}$ (3)

Specific wear rate = $\frac{wear\ volume}{wear\ velocity*load*time}$ (4)

4. Result and Discussion

4.1. Result of Pin on disk tribometer

The coefficient of friction values for the tested 3Wt% Sic composite specimens (S1-S9), is shown in figure 3. The above COF data are used to generate the mean, S/N ratio values and graphs, as shown in table 2, 3. The signal to noise graph for COF, Specific Wear Rate & Wear Rate are shown in figure 4, 5, 6 respectively.

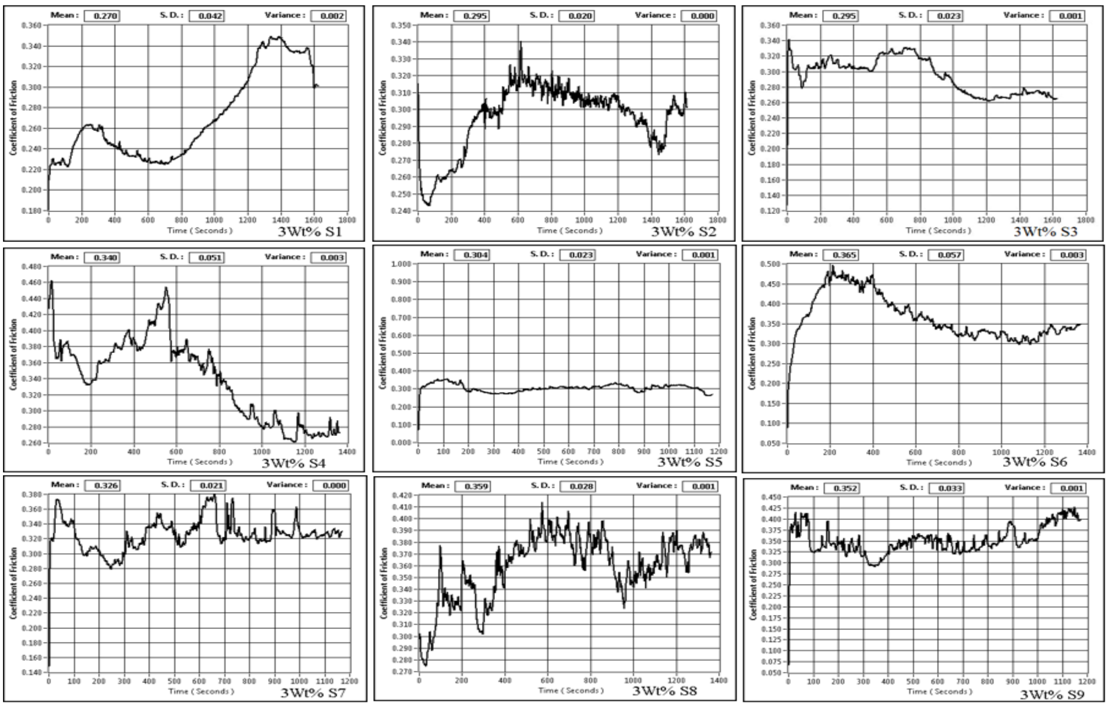

Figure 3. Pin on Disk Test Results

Table 2. Response Table for 3wt% Sic Signal to Noise Ratios (Smaller is better)

LEVEL	TIME	SPEED	LOAD
1	9.234	10.160	9.675
2	9.489	9.948	9.681
3	10.860	9.476	10.227
Delta	1.626	0.684	0.552
Rank	1	2	3

Table 3. Response Table for 3wt% Sic for Means

LEVEL	TIME	SPEED	LOAD
1	0.3457	0.3120	0.3313
2	0.3363	0.3193	0.3290
3	0.2867	0.3373	0.3083
Delta	0.0590	0.0253	0.0230
Rank	1	2	3

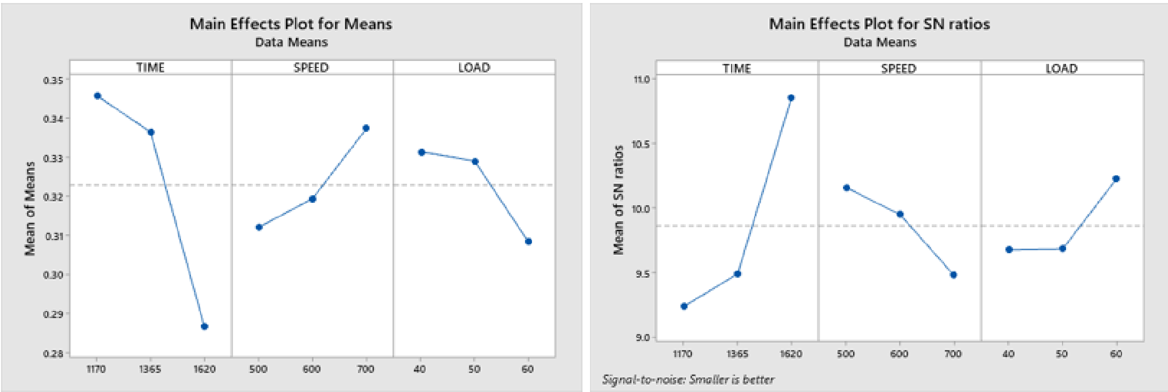

Figure 4. Signal to Noise graph for COF

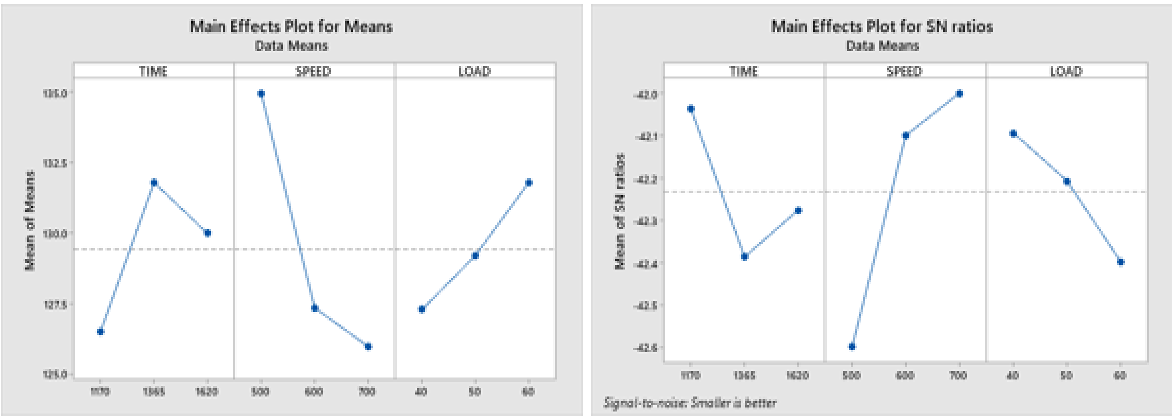

Figure 5. Signal to Noise graph for Specific Wear Rate

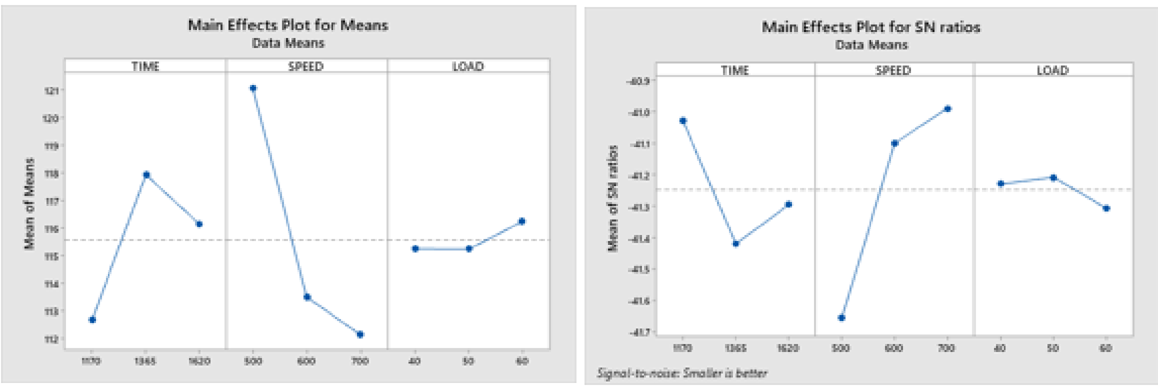

Figure 6. Signal to Noise graph for Wear Rate

4.2. Grey relational analysis

Grey relational analysis derived from the design of experiments, in general the grey relational analysis is a method to analyse and identify the samples of similar or of varying composition from the various aspects of its nature. The average grey relational grades output values as shown in table 5 are calculated from the table 4 which represents COF, wear rate & Specific wear rate values of S/N Ratio, Grey Relational Coefficient & Grey Relational grade respectively.

Table 4. 6wt% Sic calculated S/N Ratio Output Values

S/N Ratio			Grey Relational Coefficients (GRC)			Grey Relational Grade
Specific Wear Rate (mm^2 /kg)	COF	Wear Rate (mm^3/m)	Specific Wear Rate (mm2 /kg)	COF	Wear Rate (mm3/m)	
Smaller - Better	Smaller - Better	Smaller - Better	Smaller - Better	Smaller - Better	Smaller - Better	
131.2609	11.3727	119.2197	0.4893	0.3333	0.4473	0.4233
125.9773	10.6036	111.9996	0.658	0.4145	0.6579	0.5768
132.7165	10.6036	117.1585	0.457	0.4145	0.4923	0.4546
140.9045	9.3704	126.9261	0.3333	0.6799	0.3333	0.4489
129.9925	10.3425	114.4295	0.5214	0.4518	0.5679	0.5137
124.4907	8.7541	112.4502	0.7287	1	0.6391	0.7893
132.694	9.7356	117.1335	0.4575	0.5715	0.4929	0.5073
126.0904	8.8981	114.0492	0.6532	0.9009	0.5803	0.7115
120.7356	9.0691	106.7562	1	0.8061	1	0.9354

Table 5. 3wt% Sic Average Grey Relational Grades Output Values

Average Grey Relational Grades			
1	0.4849	0.4598	0.6413
2	0.5840	0.6007	**0.6537**
3	**0.7180**	**0.7264**	0.4919
Max-Min	0.2331	0.2666	0.1618
	TIME	RPM	LOAD

Table 6. Optimised Value for 3wt% Sic Specimen

SPECIMEN	TIME (S)	RPM	LOAD (Kg)	SPECIFIC WEAR RATE (mm^2 /kg)	COF	WEAR RATE (mm^3/m)
3Wt% Sic	1170	700	5	120.7356	9.0691	106.7562

4.3. Scanning Electron Microscopic Analysis

The Scanning Electron Microscope (SEM) analysis is done in order to study the microscopic behaviour of the fabricated basalt aluminium composite specimen in detailed. The 3wt% Sic specimen of sample S9 as shown in table 6 is analysed in detailed.

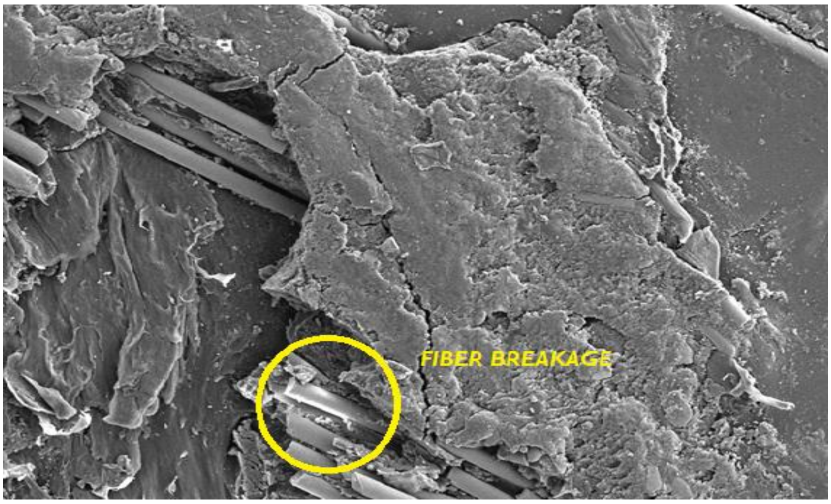

Figure 7. SEM Analysis

From figure 7 it is observed that fiber breakages are observed in the composite laminates. It is mainly due to the improper resin-hardener curing time which may be avoided by properly fixing it based on literature.

5. Conclusion

The tests for wear are conducted with the help of pin on disc apparatus, the results obtained for each trial helps us to determine the S/N ratio of wear rate, specific wear rate & COF of the tested samples. By analysing the results, GRA parameters like speed, time & load are optimised respectively. The addition of filler material silicon carbide has been proven to increase the wear resistance of the composite material. The surface of the tested samples is SEM analysed to find the cause of wear on the materials surface.

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