
Investigation of Wear Behaviourof 6 Wt% Silicon Carbide Fiber Metal Laminate Composite

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Abstract:-This study undertakes an empirical investigation into a composite laminate comprising Basalt fiber and Aluminum. Basalt, an igneous rock primarily composed of plagioclase and pyroxene minerals, is amalgamated with Aluminum, a silvery, malleable, non-magnetic, and ductile metal from the boron group. This amalgamation enhances the mechanical properties of Aluminum, rendering it suitable for a wide array of engineering applications. The meticulous hand lay-up technique is employed to fabricate the Basalt-Aluminum laminate. To augment its abrasive and enduring characteristics, a 6% weight infusion of silicon carbide is introduced. To evaluate the wear resistance of the Basalt-Aluminum laminate, a pin-on-disc apparatus is employed, with the number of trials meticulously arranged using the Taguchi methodology employing an L9 Orthogonal Array. Subsequently, the obtained results for each specimen are optimized using the Grey Relational Analysis (GRA) technique. Further examination of the tested material samples is carried out through scanning electron microscopy (SEM) imagery to dissect the intricate nuances of wear characteristics. This material exhibits substantial potential for application in environments prone to frequent wear, such as brake calipers, clutch plates, conveyor belts, and analogous scenarios.

Keywords: *Basalt fiber, Aluminum, Grey Relational Analysis (GRA), scanning electron microscopy (SEM), Design for Manufacturability (DFM), finite element method (FEM), tribometer, ASTM G99, coefficient of friction (COF), signal-to-noise (S/N).*

1. Introduction

The employment of the pin-on-disc testing methodology stands as a preeminent approach within the realm of tribological analysis, particularly in the intricate assessment of material behaviors within composite materials. Concretely, the study delves into the meticulous examination of a composite material comprising Basalt and Aluminum through pin-on-disc testing, thus facilitating the determination of specimen wear resistance and the coefficient of friction. These fundamental metrics serve to elucidate the material's mechanical capabilities and, consequently, its prospective applications. Within this erudite exposition, the author embarks on a journey into the application of silicon carbide, renowned for its profound prowess in augmenting material properties when judiciously applied to the surface of high-speed steel. Subsequently, a series of pin-on-disc tests are meticulously conducted, and the resulting data are subjected to thorough scrutiny. The ensuing discourse encompasses an extensive and comprehensive examination of the findings, while also delving into the intricate nuances and formidable challenges encountered during the intricate pin-on-disc testing process[1].

This scholarly discourse offers a plethora of profound insights pertaining to material behavior, particularly when confronted with the amalgamation of various elements such as aluminum and silicon carbide during the rigors of pin-on-disc wear analysis. It underscores the imperative necessity of subjecting metal matrix composites to varying loads and a spectrum of speed ranges within the purview of wear analysis[2][16]. The paper underscores the paramount significance of subjecting a diverse array of composite materials to rigorous scrutiny. For instance, it meticulously investigates Al6061-SiC composites both before and after subjecting them to the exacting demands of pin-on-disc dry sliding wear analysis, encompassing a comprehensive examination of pertinent parameters such as hardness, sliding distance, and weight reduction. The results of these meticulous investigations are thoroughly dissected[3].

Within the confines of this scholarly endeavor, the intricate material behavior of carbon nanotubes and glass fiber-reinforced polymers, in tandem with the judicious utilization of epoxy, is explored. Structural alterations are subjected to meticulous examination through cutting-edge techniques, including but not limited to ultra-scanning electron microscopy, X-ray diffraction, and atomic force microscopy, all of which yield results of a precision and intricacy beyond reproach. Furthermore, the expansive gamut of mechanical and wear properties is subjected to an exhaustive and comprehensive scrutiny[4]. This scholarly composition offers a deeply detailed exploration of a metal matrix composite that comprises aluminum, copper, magnesium, and titanium dioxide. The material's behavior under the rigorous conditions of wear testing is elucidated, with a particular focus on the pivotal role of titanium dioxide in mitigating wear rates. Theoretical predictions and intricate calculations, facilitated by the utilization of orthogonal array methodology, are methodically tabulated to harmonize with practical observations[5][18]. The author meticulously elucidates the key considerations that necessitate thorough evaluation before subjecting materials to wear testing, notably encompassing phenomena such as ploughing, interface cracking within the matrix, and particle removal. Experimental setups are detailed, and results are methodically compared against an aluminum particulate-reinforced epoxy-matrix composite, which has undergone rigorous pin-on-disc wear analysis[6].

In this comprehensive exposition, the author embarks upon a series of meticulously orchestrated experiments comparing copper, brass, and aluminum alloy pins within the context of pin-on-disc wear tests. These tests are executed under conditions of constant contact pressure and sliding speeds, accompanied by a profound examination of the coefficient of friction across a spectrum of compositions and associated material composition adjustments[7]. This paper further embarks upon the utilization of the hand layup compression molding process, characterized by its capacity to substantially enhance tensile, flexural, and impact properties. The resulting hybrid sandwich structure finds particular applicability in high-strength commercial automobile components, such as floorings, frames, and bonnets[8]. Moreover, the author introduces the employment of a computer-aided Design for Manufacturability (DFM) system for decision-making within the complex realm of composite design. Additionally, the integration of knowledge-based engineering techniques and finite element method (FEM) simulations serves to empower designers in their quest to achieve desired outcomes with minimal requisite revisions[9].

Notably, the incorporation of silicon carbide is incontrovertibly proven to ameliorate wear behaviour and also their mechanical properties were studied. [11-13, 20]. Effect of profile angle on welding parameter were studied [14]. Furthermore, the author undertakes a profound exploration of parameter optimization utilizing Taguchi's method and principal component analysis, thereby demonstrating tangible enhancements in output parameters [10][17][15]. Natural fiber and Kevlar composite were fabricated and their mechanical behaviours were analysed [21-23].

2. Materials and methods

2.1. Materials

Throughout the course of this investigation, basalt fiber has emerged as a pivotal reinforcement material, illustrating its exceptional versatility across an extensive spectrum of applications, encompassing non-combustible coverings, corrosion-resistant pipelines, and clutch plates. Basalt, originating from the cooling of molten lava upon its exposure to the Earth's surface, serves as the foundation for these remarkable fibers, which manifest in various forms, including rolls, chopped strands, and powdered variants. The composite material under scrutiny is meticulously fashioned from 5000 series aluminum mesh, an alloy distinguished by its lustrous white-silver appearance, lightweight properties, and remarkable malleability. The adhesive binding this composite material consists of the epoxy resin Araldite LY 556, coupled with the hardening agent Aradur HY 951, renowned for its superlative flexural properties, adhesion capabilities, and fatigue resistance.

Silicon carbide, a semiconductor rooted in silicon and carbon, sets itself apart through its exceptional hardness, wear resistance, as well as its remarkable chemical and thermal shock resistance properties. Its multifarious applications span MOSFETs, abrasive grinding wheels, and a myriad of other technical uses. The fabrication of natural fiber composites is expedited through the adoption of this rudimentary technique. While the process may be deemed leisurely, its applicability extends to an extensive spectrum of fiber materials. The procedural aspect of this endeavor encompasses the manual stacking of each basalt fiber ply into a designated configuration, subsequently ensconcing aluminum sheets atop successive layers of basalt. The intermediary bonding agent, comprised of epoxy resin and silicon carbide amalgam, plays a pivotal role in this assembly. The composite is then painstakingly consolidated via the compression molding technique, ensuring the eradication of any residual air pockets intercalated between the plies.

2.2. Methods

Dr.Genichi Taguchi, an eminent Japanese scientist, is widely acclaimed for pioneering the Taguchi method, an intricate approach tailored for the design of experiments, with the aim of comprehensively understanding the nuanced impact of individual parameters on both the mean and variance of a process, thereby elucidating its operational dynamics. Taguchi introduced a groundbreaking methodology that leverages orthogonal arrays to systematically structure the myriad parameters affecting the experiment. These orthogonal arrays provide a meticulously balanced ensemble, thereby minimizing the requisite number of experiments while maximizing the informational yield. Subsequently, Signal-to-Noise ratios (S/N) are computed, representing logarithmic transformations of the desired output variables. These S/N ratios serve as an objective function for optimization, facilitating meticulous data analysis and the precise prediction of optimal outcomes. Notably, the Taguchi optimization technique streamlines this process by orchestrating nine strategically selected experiments using the L9 orthogonal array, as outlined in Table 1 for reference.

Table 1. GeneratedL 9Orthogonal 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

2.3. Theoretical background

2.3.1 Pin on disk tribometer

The pin-on-disk tribometer serves as a highly advanced apparatus employed for conducting wear analysis on a diverse spectrum of materials, spanning metals, fibers, composites, and the like. This wear assessment is of paramount importance in determining the material's susceptibility to undergo erosion and deterioration when exposed to real-world operational conditions. Figure 1 depicts an exemplary configuration of the pin-on-disk tribometer setup. To execute the wear analysis, the specimens are meticulously prepared in strict accordance with the exacting standards stipulated in ASTM G99. Subsequently, the specimens are subjected to grinding procedures conforming to the precise specifications mandated by the laboratory. These specifications dictate the utilization of 10mm cylindrical test specimens, and an aluminum rod is intricately affixed to the test piece to adhere to the tribometer's specified length criteria, as illustrated in Figure 2.

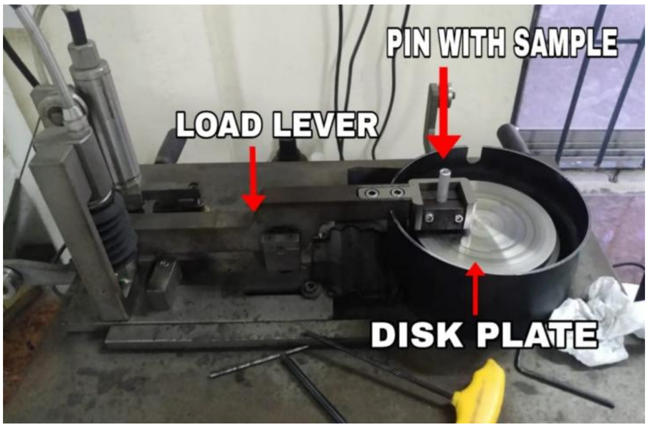

Figure. 1 Parts of Pin on Disk Tribometer

Figure. 2 Specimen with Aluminium Attachment

The quantification of wear rate and specific wear rate is ascertained by employing the ensuing mathematical expressions. The computation of wear volume, wear velocity, wear rate, and specific wear rate is executed in strict accordance with the formulations delineated as equations 1, 2, 3, and 4, respectively.

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

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

Where,

R = sliding radius, N = Disc RPM

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

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

3. Results and Discussion

3.1. Result of Pin on disk tribometer

The coefficient of friction data associated with the investigated composite specimens, each containing a 6 weight percent infusion of silicon carbide and denoted as S1 to S9, has been graphically depicted in Figure 3. This graphical representation serves to elucidate and illustrate the distinctive frictional attributes exhibited by each of these specimens.

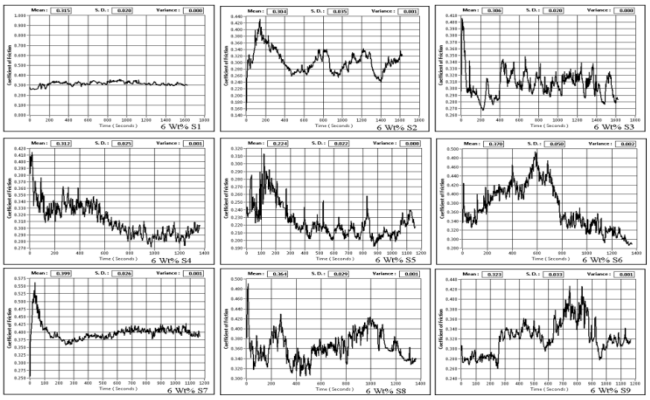

Figure. 3 Pin on Disk Test Results

The aforementioned coefficient of friction (COF) data serves as the basis for the derivation of mean values and signal-to-noise (S/N) ratio metrics, which are presented in Tables 2 and 3. Subsequently, graphical representations of the S/N ratios for COF, Specific Wear Rate, and Wear Rate are depicted in Figures 4, 5, and 6, respectively.

Table 2. Response Table for 6wt% Sic Signal to Noise Ratios (Smaller is better)

Level	TIME	SPEED	LOAD
1	8.858	9.377	9.149
2	10.583	10.705	10.092
3	10.221	9.579	10.420
Delta	1.724	1.328	1.271
Rank	1	2	3

Table 3. Response Table for 6wt% Sicfor Means

Level	TIME	SPEED	LOAD
1	0.3620	0.3420	0.3497
2	0.3020	0.2973	0.3130
3	0.3083	0.3330	0.3097
Delta	0.0600	0.0447	0.0400
Rank	1	2	3

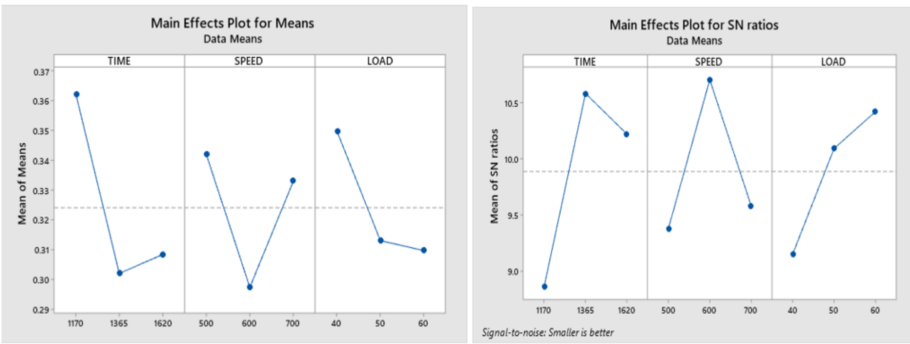

Figure. 4 Signal to Noise graph for COF

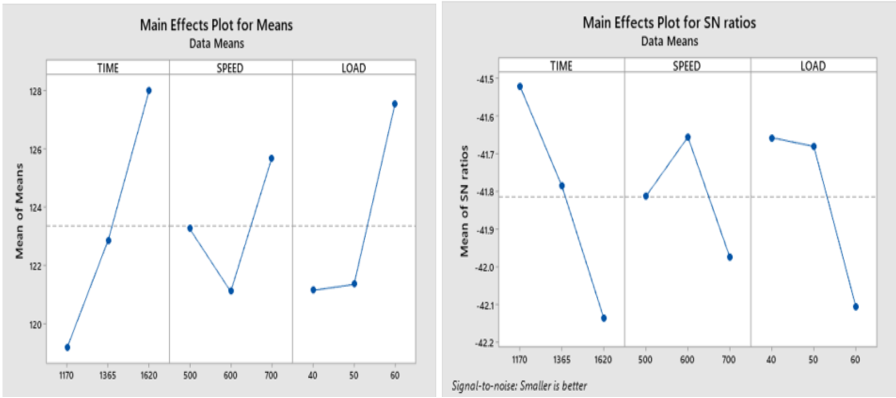

Figure. 5 Signal to Noise graph for Specific Wear Rate

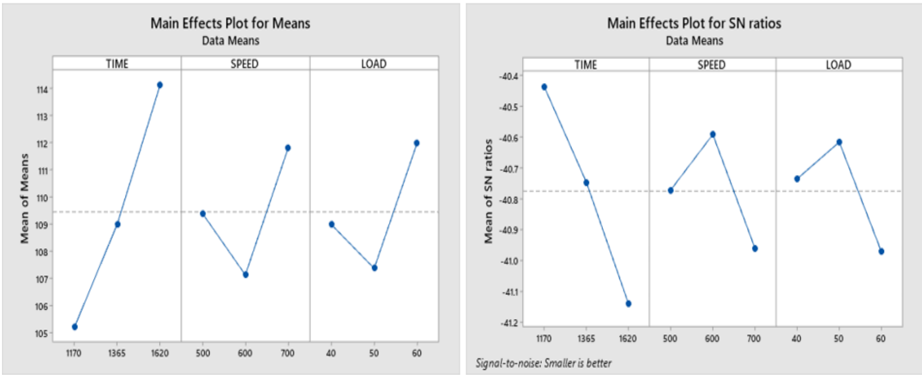

Figure. 6 Signal to Noise graph for Wear Rate

3.2. Grey relational analysis

Grey relational analysis, derived from the tenets of experimental design, constitutes a sophisticated methodology applied for the meticulous examination and discrimination of samples with analogous or disparate compositional attributes across multifarious dimensions of their inherent characteristics. The calculation of mean grey relational grades, as expounded in Table 5, is conducted with precision using the dataset laid out in Table 4, which comprehensively encompasses relevant metrics encompassing coefficients of friction (COF), wear rates, and specific wear rates. These metrics are further subjected to evaluation through the prism of signal-to-noise (S/N) ratios, Grey Relational Coefficients, and culminate in the intricate computation of Grey Relational Grades.

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	
127.922	10.0338	115.8797	0.4307	0.5498	0.382	0.4542
121.4732	10.3425	107.4917	0.598	0.5149	0.6212	0.578
134.6566	10.2856	119.0623	0.3333	0.521	0.3333	0.3959
120.8574	10.1169	106.8742	0.621	0.5399	0.6512	0.6041

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	
127.0328	12.995	111.4665	0.448	0.3333	0.4791	0.4201
120.7054	8.636	108.6618	0.627	0.7928	0.5713	0.6637
121.0024	7.9805	105.4345	0.6155	1	0.7338	0.7831
114.7986	8.778	102.4158	1	0.7587	1	0.9196
121.7131	9.8159	107.7316	0.5895	0.5774	0.6103	0.5924

Table 5. 6wt% Sic Average Grey Relational Grades Output Values

	Average Grey Relational Grades		
1	0.4760	0.6138	**0.6791**
2	0.5626	**0.6392**	0.5915
3	**0.7650**	0.5506	0.5330
Max-Min	0.2890	0.0886	0.1461
	TIME	RPM	LOAD

Table 6. Optimised Value for 6 wt% Sic Specimen

SPECIMEN	TIME (S)	RPM	LOAD (Kg)	SPECIFIC WEAR RATE(mm^2 /kg)	COF	WEAR RATE (mm^3/m)
6Wt% Sic	1170	600	4	114.7986	8.7780	102.4158

3.3. Scanning Electron Microscopic Analysis

A comprehensive and rigorous scrutiny through Scanning Electron Microscope (SEM) has been methodically conducted to meticulously dissect the intricate microscopic intricacies inherent in the fabricated composite specimen of basalt and aluminum. The specimen, presently under close examination, embodies a composite constitution enriched with 6wt% of silicon carbide (SiC) and is specifically denoted as "sample S8," as elucidated in Table 6. A thorough and all-encompassing inspection has been meticulously performed on these specimens to discern the most minute particulars. Upon scrupulous examination of Figures 7 and 8, it becomes overtly evident that noticeable instances of fiber fractures, voids, and fiber extractions have become manifest within the specimen. These manifestations can be attributed to suboptimal curing durations and the incongruous amalgamation of resin and hardener components. To rectify these issues and ensure the structural soundness of the laminate, it is of utmost importance to facilitate an appropriate curing period.

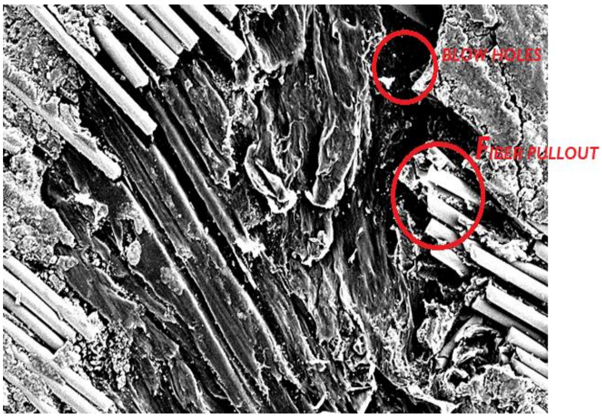

Figure. 7 SEM Image of the Composite Specimen

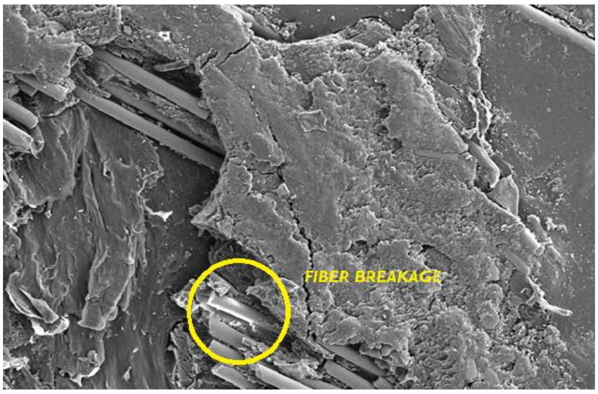

Figure. 8 SEM Image of Fiber Breakage

4. Conclusions

A comprehensive wear evaluation is meticulously executed employing a pin-on-disc apparatus, wherein each experimental trial yields invaluable data for the quantitative assessment of the Signal-to-Noise (S/N) ratio pertaining to wear rate, specific wear rate, and the Coefficient of Friction (COF) with regard to the subjected specimens. The discernment of optimal operational parameters, including rotational speed, duration, and applied load, is subsequently achieved through a thorough analysis of the acquired results employing the Graphical Representation of Area (GRA) methodology.

The empirical incorporation of silicon carbide as a reinforcing filler material has been substantiated to confer a remarkable augmentation in the wear resistance of the composite material under scrutiny. Consequently, this augmentation significantly fortifies the material's durability and longevity, rendering it better suited for arduous and demanding applications. Moreover, the morphological characteristics of the examined specimens' surfaces are rigorously scrutinized via Scanning Electron Microscopy (SEM) to elucidate the underlying mechanisms responsible for the observed wear phenomena, thus offering valuable insights into the wear behavior of the materials at a microstructural level.

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