Sliding Wear Response of Human Beard Reinforced Epoxy Based Composites Filled with Ferrochrome Slag

Manoranjan Behera[1*] and Dr. Srimant Kumar Mishra[2]
[1]M.Tech Scholar, GIET University, Gunupur, India
[2]Assistant Professor, GIET University, Gunupur, India
[1]20mtmt001.manoranjanbehera@giet.edu, [2]srimantmishra@giet.edu

Abstract

The prospect of employing ferrochrome slag (an industrial waste) along with human hair (a natural fiber) in epoxy as a novel material for extended life exists. In this study an effort has been made to research the possible uses of human hair, which can be easily and cheaply discovered, for creating goods with additional value. Some industrial wastes (ferro chrome slag), have been investigated for use as filler components in these composites. The goal of the current research is to understand how human hair reinforced epoxy composites with particulate fillers are developed, characterized, and worn over time. The mechanical properties of the composites are evaluated under normal test conditions. Testing for sliding wear is done using Taguchi's L9 orthogonal array design in order to estimate the influence of different process parameter on wear response of the fabricated composites. In accordance with Taguchi's experimental design, the fiber content and sliding velocity are the two factors that have the most significance on wear response of the developed PMCs. It was observed that the wear rate increases with an increase in sliding velocity, whereas it reduces with an increase in fiber content. This experiment reveals that presence of human beard along with ferro slag particles increase the wear resistance of normal epoxy.

Keywords: *Human Beard, Ferro-Chrome slag, PMCs, Mechanical Properties, Sliding Wear.*

1. Introduction

Due to the necessity to protect our environment, the idea of "eco-materials" has been more important in recent years. The definition of eco-materials encompasses "safe" material systems at all times for people and other living forms. Experiences in the past have demonstrated the necessity of characterizing materials to identify those that are secure for both short- and long-term use. It is urgently necessary to choose a material system that fits both industrial requirements and the above-described, broader concept of eco-materials. The notion of using composite materials with natural fiber reinforcing is the most appropriate one in this situation. Both for their industrial uses and for basic research, interest in natural fiber reinforced composites is rising quickly. They offer a compelling ecological substitute for glass, carbon, and other man-made fibers used in the production of composites due to their availability, renewability, low density, affordability, and good mechanical qualities. They offer a compelling ecological substitute for glass, carbon, and other man-made fibers used in the production of composites due to their availability, renewability, low density, affordability, and good mechanical qualities. Composites are essentially macro-scale materials made of two or more chemically different elements with a clear interface separating them. In order to create a composite, one or more discontinuous phases are consequently incorporated into a continuous phase. The continuous phase is referred to as the matrix, whereas the discontinuous phase is often tougher and stronger than the continuous phase and is called the reinforcement. The matrix material might be ceramic, metallic, or polymeric. The composite is known as a polymer matrix composite when the matrix is a polymer (PM). In numerous applications during the last several decades, polymers have largely taken the role of traditional metals and minerals. Because of benefits including cost savings, increased productivity, and simplicity of processing, this is attainable. For the majority of these applications, high strength/high modulus requirements are met by altering the characteristics of polymers utilizing fibers. Fibers are embedded in or bound to a matrix in fiber reinforced composite materials, which have definite interfaces (boundaries) between them. In this configuration, the fibers and the matrix both preserve their physical and chemical identities, but together they provide a set of qualities that none of the constituents operating independently could produce. The main load-bearing components are often fibers, which the surrounding matrix maintains in the proper position and orientation. Additionally serving as a load transmission medium, the matrix shields the fibers from environmental harm brought on by high temperatures, humidity, etc[1]. In a composite material, the matrix performs a variety of beneficial tasks in addition to serving as reinforcement for the fibers. Numerous fiber reinforced polymers (FRPs) provide a strength and modulus combination that is either on par with or superior to many conventional metallic materials. Many composite laminates also have exceptional fatigue strength and fatigue damage tolerance. These factors have led to FRPs becoming a significant class of structural materials, with applications in practically every material field, including home furnishings, packaging, sports, leisure, and several other weight-critical parts in the aerospace, automotive, and other sectors. The matrices in PMCs can be made of any synthetic polymer, including thermoplastics, thermosets, and elastomers. Both organic fibers like carbon and aramid and inorganic man-made fibers like glass have been extensively used for reinforcement. Due to the high cost of all these reinforcing fibers, composite materials also incorporate other, more widely distributed natural fibers including cellulose, wool, and silk. Several waste cellulosic materials, including shell flour, wood flour, and pulp, as well as cellulosic fibers including henequen, sisal, coconut fiber (coir), jute, palm, bamboo, and wood, have also been utilized as reinforcing agents of various thermosetting and thermoplastic resins. It is generally known that natural fibers give polymer matrix composites a high specific stiffness, strength, and biodegradability.

The reinforcing phase in polymer composites can be either fibrous or non-fibrous (particulates) in nature, and if the fibers come from natural sources like plants or other living things, they are referred to as natural-fibers. Researchers have recently become interested in natural fibers as reinforcement in composite materials due to their many benefits. Based on their source, these fibers can be separated into three categories: animal/protein fibers (hair, wool, silk, chitin, etc.), vegetable/plant fibers (flax, hemp, sisal, etc.), and mineral fibers (asbestos, wollastonite etc.). The use of plant fibers as reinforcement for polymers is justified by the fact that they are renewable and have good mechanical qualities. These natural fibers are less expensive than synthetic fibers used as reinforcements and have high specific characteristics and low densities. These are readily available, biodegradable, and nonabrasive in contrast to other man-made fibers. It is also recognized that natural fibers have uneven cross sections and non-uniform lengths, which distinguishes them from synthetic fibers like glass and carbon fibers and gives them a very distinctive structure.

Because of its extremely high strength and stiffness, carbon fiber is undoubtedly the most significant reinforcing material in high performance PMCs. The study by Yaodong and Kumar presents a current picture of the advances in manufacturing, structure, and characteristics of carbon fiber[2]. Natural fibre reinforced composites, a rapidly expanding subfield of PMCs with environmental consequences, are discussed by Kessler, and MR[3]. Jesson and Watts investigate the inter phase, a third phase in composite materials that is frequently disregarded [4]. They specifically discuss the crucial role of the interface and interphase area as well as how the inter phase may be assessed in PMCs. The more recent class of polymer matrix nano composites is explored by Pandey and Thostenson[5]. Their review specifically focuses on carbon nano tube reinforced polymers and their potential for several functions, as well as how the community's knowledge of the structure/property correlations in polymer nano composites has changed recently.

Satish S et al. noted that the alkaline treatment is the most appropriate way of chemical modification for natural fibers[6]. Recent research evaluated the qualities of natural fiber, hybridization of the composite, chemical processing techniques, and natural fiber uses in diverse industries. This provides a good understanding of how natural fibers are processed, as well as the characteristics of specific fibers, such as hemp, sisal, and jute, and how they are used in different sectors depending on those traits. NFPC was shown to perform better than synthetic composites since it is low density, inexpensive, and environmentally benign. Natural fiber composites are therefore very advantageous for use in both engineering and commercial applications. Natural fibers are weaker than synthetic composites, but when combined with synthetic composites, they offer excellent strength and minimal environmental impact. One method that combines these organic and synthetic fibers is hybridization, which results in the creation of hybrid composites that have a wide range of potential uses in both engineering and business. There are several methods for hybridization, including layer-by-layer stacking, layering various fibers, layering at 0°, 45°, and 90° orientations, and selective layering of fiber according to need (Arpitha et al. 2017[7]; Rajak et al. 2019[8]).Many research investigators are heavily using the use of filler materials to enhance the qualities of FRP composites. A filler material is an inert substance that may be used to increase the mechanical characteristics of composites, lower the cost of the material, and improve its performance (Aveen et al. 2019[9]; Friedrich, Zhang, and Schlarb 2005[10]). To get a nice surface finish, which would otherwise result in a coarse structure and impair the mechanical characteristics of composites, fillers are often selected along with the matrix (Gupta, Singh, and Walia 2015[11]). By lowering wear volume loss and wear rate, the hard filler materials improve tribological characteristics (Atarian et al. 2012[12]; Sun B, Yan et al 2017[13]). The hybrid composites' overall performance can be improved by using natural fillers. Rice husk, wood apple shell banana filler, eggshells, oil palm filler, basalt powder, wood sawdust, wheat husk, and coconut coir are a few of the fillers that are naturally occurring.

In view of the above-literature survey, it was observed that despite having several benefits over other natural fibers, relatively little research has been done on the ability of human hair to serve as reinforcement in polymer composites. Also study on different properties of human beard as a reinforcement with ferrochrome slag as m=filler material in polymer composites are rarely reported. However, as per the best knowledge of authors, a study on tribological properties in specifically sliding wear response in dry conditions of these composites are rarely reported. Therefore, this current investigation is focused on evaluating the effect of natural fiber (Human beard) reinforcement on dry sliding wear performance of polymer composite having industrial waste (Ferrochrome slag) particulates as filler material.

2. Experimental Details

2.1 Material

2.1.1 Matrix Material

Polymer networks are the most often used among various types of framework materials due to a number of advantages, including economic viability, ease of fabrication with little tooling costs, and exceptional room temperature capabilities. Thermoplastic or thermosetting polymer networks are both conceivable. Epoxy, polyester, vinyl ester, polyurethanes, and phenolics are the thermosetting gums that are most often used. Due to several advantages, such as its strong attachment to a variety of filaments, widespread mechanical and electrical capabilities, and excellent performance at high temperatures, epoxy resin is now the most widely used polymer in the area. Despite this, they exhibit little post-curing shrinkage and excellent synthetic safety. Epoxy was chosen as the lattice material for the current study effort due to a number of advantages it has over other thermoset polymers. It is a member of the "epoxide" family synthetically, and its official name is Bisphenol-A-Diglycidyl-Ether.

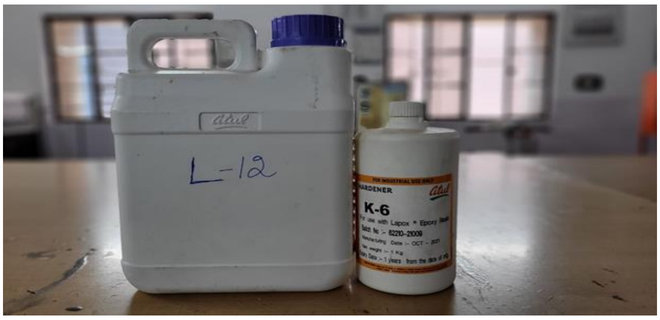

Figure 1 Epoxy (L-12) and hardener (K-6)

Components such as metals, ceramics, and polymers are used as base matrixes to retain the reinforcing materials. The special quality of epoxy resin's exceptional adhesion to a bright fiber variety, together with the fact that it gave the changed samples better mechanical and electrical capabilities at high temperatures, led to its deliberate selection. L-12 is an excellent choice for the basis matrix in the current research study due to all these benefits. Atul India Ltd. supplied the K-6 hardener and L-12 epoxy resin (Figure 1) for the project. The important attributes of epoxy are displayed in Table 1.

Table 1 Properties of Epoxy Resin L-12and K-6 Hardener

Material	Epoxy resin
Trade name	Lapox, L-12
Chemical name	Diegycidyl Ether of Bisphenol A (DGEBA)
Epoxide equivalent	182-192
Density,kg/m^3	1162

Material	Hardener
Trade name	K-6
Chemical name	Triethylene Tetro amine (TETA)
Epoxide equivalent	-
Density, kg/m^3	954
Supplier	Atul industries limited,Gujarat,India
Parts by weight	10

2.1.2 Fiber Material

Human beard hair that is commonly found in fiber form is sourced locally. It's a fiber that can be found in India for a reasonable price.

2.1.3Filler Materials

The matrix materials tend to be continuous, weaker, and softer than the filler materials. These filler materials' primary purpose is to enhance the composite's tribological, mechanical, and physical characteristics. These filler elements come in a variety of forms, including long and short fibers, whiskers, and particles. Fibers including glass, bio fibers, silicon carbide fibers, graphite fibers, and others are frequently employed. The most often utilized particles include garnet, graphite, silicon carbide (Sic), and aluminum oxide (Al_2O_3).In this study, ferro chrome slag has been employed as a filler to increase the composite's mechanical and wear resistance qualities.Ferrochrome slag is a byproduct of the production of high carbon ferrochromium alloys. SiO_2, Al_2O_3, and MgO are the primary constituents of this slag, which is created as a liquid around 1700 °C. In addition, it contains CaO, ferrous/ferric oxides, and chromium.

Figure-2:-Chopped Human Beard (Natural fiber) and Ferro chrome slag(Filler Materials)

2.2 Fabrication Process

In order to stop resin seepage, the mold was coated with a thin polyester sheet. To make it simple to remove the composite, silicon spray was used to coat the mold. For the purpose of eliminating air bubbles, epoxy was originally heated to 60°C and then cooled to room temperature. The epoxy resin was mixed with a calibrated amount of ferro chrome slag and chopped human beard for 20 minutes while being constantly swirled with a magnetic stirrer. Next, a 10:1 ratio of hardener was added, and the mixture was churned again for 10 minutes to achieve homogeneity.For the manufacturing of composites, a 200 x 20 x 10 mm^3 mold is used. The properly mixed material was than very carefully poured into the mold completely.The mixture is placed into several molds while taking into account the requirements of various testing scenarios and characterization models. Air bubbles weren't allowed to develop thanks to careful precautions. The mold was then covered with a polyester sheet that had previously been silicon coat, and the surface was rolled on using a roller to provide a consistent finish. The mold was then allowed to cure for 24 hours at room temperature. The composite was removed after curing at room temperature and kept at 80°C for 4 hours after curing.The detailed composition and the respective designation of the fabricated composites are illustrated in Table 2. The specimens are then cut to the proper proportions for the mechanical testing.

Table 2: Designation and detailed composition of composites

Designation	Composition
S1	Epoxy+3wt% Human beard Fiber+10wt% of Ferrochrome slag
S2	Epoxy+6wt% Human beard Fiber+10wt% of Ferrochrome slag
S3	Epoxy+9wt% Human beard Fiber+10wt% of Ferrochrome slag

2.3 Taguchi's Experimental Design

Taguchi's experimental design model is a critical tool for a systematic approach to reducing and optimizing design parameters, which ultimately affect the time of the repeated test run and total cost. It also investigates the impact of control elements on performance output. Sliding wear tests on composites are conducted using four parameters with three levels each: sliding velocity, sliding distance, normal load, and quantity of filler material.In accordance with Taguchi's L9 orthogonal array, the aforementioned four components and their selected levels are listed in Table 3. After determining the particular wear rate, the data are translated into a signal-to-noise ratio (S/N) in this study. To obtain the lowest wear rate, the S/N ratio should be estimated as follows:

'Smaller- the- better' characteristic: $S/N = -10 \log \frac{1}{n} \sum y^2$

The typical experimental procedure requires 81 tests to be done in order to explore four components at three levels each. However, with the aid of Taguchi's experimental design technique, it is reduced to only 9 test runs that produce the best results while saving time and money.

Table 3: Control Factors and their selected levels

LEVEL	A	B	C	D
I	1.25769	0.66988	-0.33979	-4.68821
II	-0.05633	-0.26215	0.70418	-1.62472
III	-1.93981	-1.14617	-1.10284	5.57449
Delta	3.19750	1.81605	1.80703	10.26270
Rank	**2**	**3**	**4**	**1**

2.4 Sliding wear Test

According to the ASTM-G99-17 standard, the sliding wear tests are carried out using a typical pin on-disk test rig. This apparatus, which can simulate a sliding environment, was used to gauge the newly constructed composites' resistance to dry sliding wear. The main component of the device is a revolving disc constructed of an extremely hard material, on which the pin-shaped test material's pointed end will rub when subjected to various applied loads. With a holder linked to the opposite end of the specimen, its location may be adjusted based on the desired radius of rotation.Before and after the sliding test, the specimens were cleaned with acetone to remove any debris. They were then dried and precisely weighed using a precision weight measuring device (to an accuracy of 0.01 mg). The specific wear rate (Ws) was then determined by multiplying the volume loss (DV) by the load (L) and the sliding distance (d):

$$W_s = \frac{\Delta V}{dL}$$

3. Results and Discussion

3.1 Mechanical Characterization of composites

By performing multiple characterization tests under controlled laboratory circumstances to assess different mechanical properties of the composites made for this work, a plethora of property data has been produced.

3.1.1 Tensile Strength

It is possible to explain how adding particle fillers increases tensile strength in the manner described below. The load bearing capacity of composites is increased by the presence of hard particles because the load on the matrix is transmitted to the reinforcing components. Increased load transmission to reinforcement and consequent increase in tensile strength occur with increasing filler material volume fraction.

Figure 3 illustrates how the fiber characteristics affect the tensile strength of composites. Tensile strength is discovered to improve initially for composites with 0% fiber loading and to continue to grow for composites with 3% fiber loading up to 40%. Tensile strength then increases at 6% fiber loading and continues to rise at 9% fiber loading up to 9.17%. We draw the conclusion from the experiment that the tensile strength of the composites increases in proportion to an increase in the weight percent of fiber loading.Similar findings were observed when human hair is treated with banana fibers by Thomas et al. [14] and with sisal fiber by Ansari et al. [15].

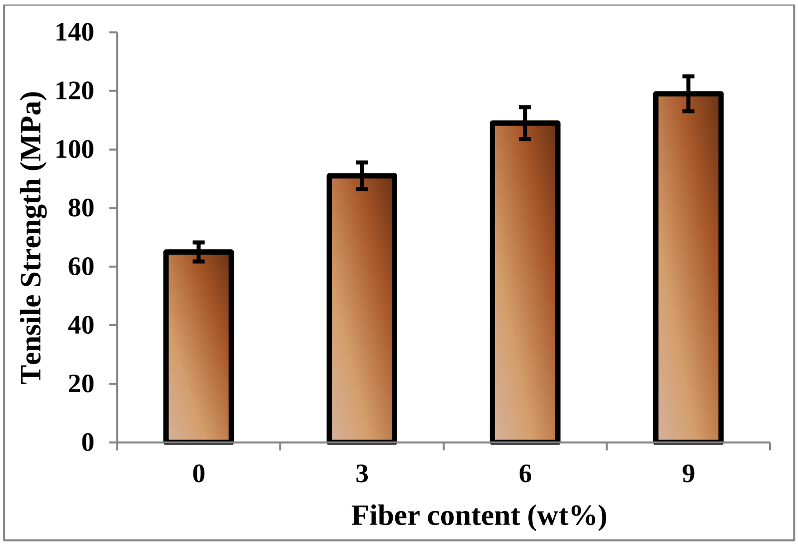

Figure 3: Effect of fiber parameters on tensile strength of composites

3.1.2 Flexural Strength

The development of novel composites with enhanced flexural properties is crucial because composite materials used in constructions are prone to failing under bending.Figure 4 illustrates how fiber parameters affect the composites' flexural strength.

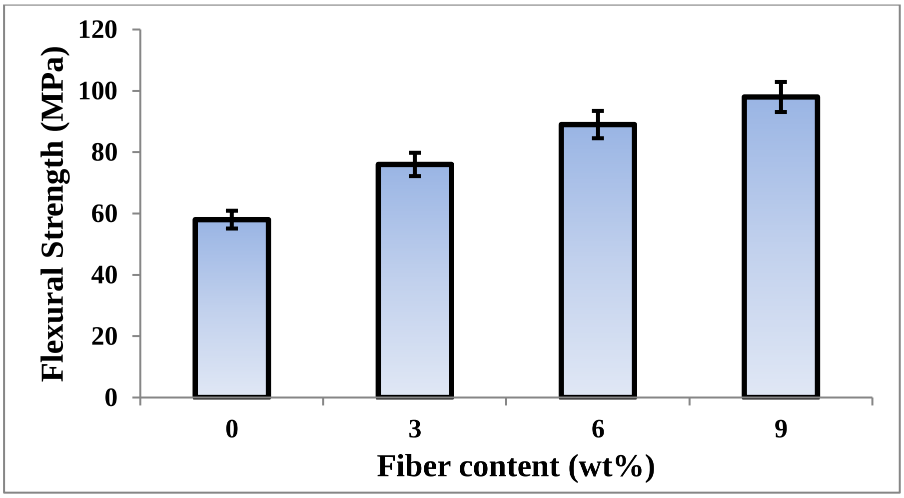

Figure 4: Effect of fiber parameters on flexural strength of composites

When the fiber content (wt%) increases from 0 to 3% the flexural strength increases up to 31.03% , and when the fiber content(wt%) increases from 6 to 9% then the flexural strength increases up to 10.11%.The current work presents the variability in flexural strength of composites. Figure 3 illustrates how the composite's flexural strength grows as fiber weight percentage increases.Similar findings were observed by Nanda et al. [16] and Choudhry et al. [17] for the increase in flexural strength.

3.1.3 Hardness

A material's hardness is determined by how well it can distribute and absorb energy during impact or shock loading. A composite's appropriateness for a given application depends on its impact or energy absorption qualities in addition to the typical design requirements. In order to build structures that are both safe and effective, it is crucial to have a solid understanding of the impact behavior of composites.

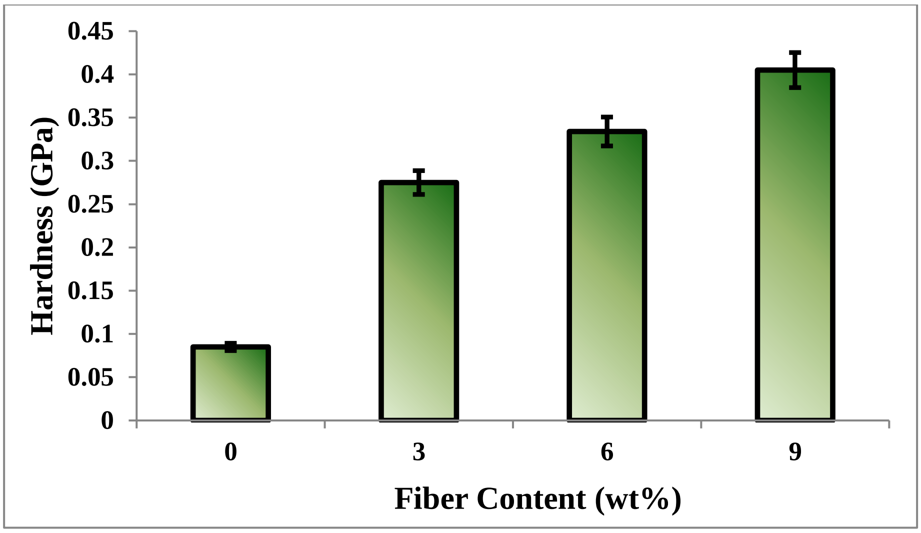

Figure 5 The influence of fiber parameters on hardness of composites

The hardness of the composites continues to rise with an increase in fiber weight percent, as seen in Figure 5.When the fiber content (wt%) increases from 0 to 3% the hardness increases up to 223.52% .Such significant enhancement in hardness in the fabricated composite may be due to the presence of ferro chrome slag particles which contain hard ceramic materials. and when the fiber content(wt%) increases from 6 to 9% then the hardness increases up to 21.25%.

Consequently, based on the above mentioned three observations, we draw the conclusion that the tensile strength, flexural strength, and hardness of the composite material are all rising with the weight % of fiber. Similar Findings were observed for the result of increase in hardness by Bhoopati et al.[18] and Senthilnathan et al.[19]

3.2Sliding wear Test Results and Taguchi Analysis

The signal-to-noise (S/N) ratios are then generated from the experimental findings. The S/N ratio in the last column of Table 4, which really reflects the average across three replications. Depending on the kind of qualities, there are several S/N ratios accessible. The loss function's logarithmic transformation may be used to compute the S/N ratio for the smallest wear rate that falls within the "smaller-is-better" feature.

The wear rate's S/N ratio is found to have an overall mean of - 0.24615 dB. The analysis is performed utilizing the well-known MINITAB 16 design of experiment programme. The five control parameters' effects on the erosion wear rate are graphically depicted in Figure 6.

Table 4: Experimental Design(L9) with specific wear rate and signal to noise ratio

Test Run	Sliding Velocity(A)	Sliding Distance(B)	Normal Load(C)	Filler Content(D)	Sp.Wear rate(Ws) (mm^3/N-m)	S/N ratio(db)
1	84	400	10	3	1.3125×10^{-9}	-2.36199
2	84	800	15	6	0.9106×10^{-9}	0.81345
3	84	1200	20	9	0.5419×10^{-9}	5.32162
4	126	400	15	9	0.4154×10^{-9}	7.63067
5	126	800	20	3	1.8559×10^{-9}	-5.37109
6	126	1200	10	6	1.3226×10^{-9}	-2.42857
7	168	400	20	6	1.4553×10^{-9}	-3.25905
8	168	800	10	9	0.6478×10^{-9}	3.77118
9	168	1200	15	3	2.0729×10^{-9}	-6.33157

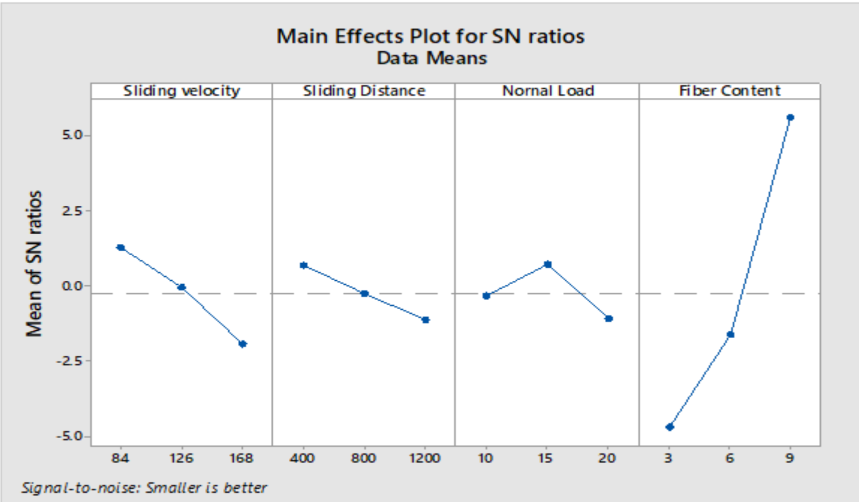

Figure 6 Effect of control factors on erosion rate

Table 5: Response table for the signal to noise ratio(smaller is better)

LEVEL	A	B	C	D
I	1.25769	0.66988	-0.33979	-4.68821
II	-0.05633	-0.26215	0.70418	-1.62472
III	-1.93981	-1.14617	-1.10284	5.57449
Delta	3.19750	1.81605	1.80703	10.26270
Rank	**2**	**3**	**4**	**1**

The S/N ratio response is shown in Table 5, and it can be inferred from it that, of all the parameters, fiber content is the most significant, followed by sliding velocity. However, the sliding distance as well as the load do not have significance effect on the sliding wear response of the fabricated hybrid composite.

4. Conclusion

This study shows an effort to utilize waste materials like natural waste (human beard) and industrial waste (ferro chrome slag) in a small proportion to develop a useful product. The following results are drawn from the experimental study of the mechanical behavior of chopped human beard hair fiber-based epoxy-based composites:

- Successful fabrication of beard hair fiber (with varying loading of 0,3,6,9 wt%) reinforced epoxy composites filled with fixed 10 wt% of ferro chrome slag were effectively possible made up by hand layup technique.
- Tensile strength, Flexural strength and Hardness increases with increase in fiber wt% due to the presence of hard ceramic particles along with randomly oriented chopped fiber which will oppose the crack propagation.
- Increased proportional fiber loading increased the sliding wear resistance in manufactured composites, demonstrating good reinforced character.
- The fiber wt% is found to be the most significant factor followed by sliding velocity on the dry sliding wear behavior of the new hybrid composite.However, the sliding distance and load not able to effect wear response of the fabricated composite.

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