

## Research Article

# Degradation Analysis of Jute Fiber Reinforced Waste Tile Powder-Filled Polymer Composite on Wear Characteristics

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In this study, a polymer composite is made using chemically treated jute fiber and waste floor tile powder as an alternative source for roof tile application. The wear qualities were examined at various ages, and the outcomes were optimized. In order to improve the wetting properties of the jute fiber, it was chemically treated. MINITAB software was used to develop Taguchi method parameters such as jute fiber percentage, waste tile powder percentage, and NaOH chemical treatment using the MINITAB software. It was determined that hardness was the most important characteristic in terms of wear properties after the specimens were subjected to ageing and abrasion wear testing and hardness tests were carried out as per normal protocols. As a result of the waste tile powder addition, the surface and core pore formation rates were reduced and the wear index rates were low. Jute fiber with 15%, 9% tile powder, and 5% NaOH treatment were found to have the lowest wear index of the other specimen compositions tested, according to the wear index. Specimen made with 5% jute fiber addition, 9% tile powder inclusion, and 10% NaOH treatment, on the other hand, had more hardness. Degradation of the fibers and delamination are side effects of the ageing process. The wear resistance of the surface was increased by the use of waste tile powder.

## 1. Introduction

There are a variety of modern ideas and materials being developed in an effort to create better roofing options. Researchers focus on extending the life of roofing materials by decreasing the degradation of the materials in diverse climatic situations. When exposed to normal environmental conditions, the material will begin to degrade after three to five years. Jute fiber-reinforced polymer composite was explored by [1], who found that rosewood dust boosted thermal stability while padauk wood dust improved adhesion with the matrix. When NaOH treatment of jute fiber and nanoclay inclusion in polymer composites were investigated by [2], they found that the mechanical and vibration characteristics were affected by the concentration of NaOH treat-

ment and inclusion of nanoclay. Improved matrix adhesion was achieved after NaOH treatment. While investigating the material's mechanical and thermal properties, researchers [3] discovered that adding fillers reduced both the material's tensile and flexural qualities while increasing its hardness. Jute fiber and epoxy matrix packed with silicon carbide powder were treated by [4] and characterised for mechanical properties. Reinforcement was added and the SiC particle size had a greater impact on the mechanical properties, which resulted in the installation of reinforcement. It was shown that the mechanical and thermal properties of jute fibers in epoxy composites decreased after exposure to moisture; however, the chemically modified samples showed greater interfacial adhesion than untreated jute fiber samples. A study done by [5] discovered that jute

fiber in epoxy composite was found to be superior to fiber reinforced polyester resin in terms of mechanical qualities, as well as wear resistance. Jute fiber was combined with 304 steel wire mesh, and dynamic characteristics were evaluated, with superior tensile and flexible strengths with 45 orientation wire mesh, according to [6]. It was shown that the SEM pictures of fibers treated with jute fiber modification show better adherence than untreated fibers. The mechanical characteristics and void formation of the treated fibers are affected. Researchers in 2020 used an alkali-treated jute fiber to strengthen a bioepoxy composite and investigated its mechanical properties. Alkali-treated fiber was shown to have improved mechanical capabilities, particularly tensile and flexural qualities. Compressive and tensile strength of jute fiber added epoxy composites were tested and found to increase with the addition of fibers, which can be utilised for construction purposes, partition boards, windows and door frames, and other structural applications. By altering jute fiber surface characteristics with alkaline and benzoyl chloride, [7] were able to conduct abrasive wear tests on jute fiber-reinforced composites. Using chemically treated fibers, wear resistance was found to be significantly improved. Tiles created from recycled bricks and roof tiles exhibit a 13.7-gloss-unit improvement when 15% of the waste is added, according to a study published in 2020 by Filho et al. It has been observed that the thermal time constant of PV roof tiles can be improved by insulating the roof, which results in a longer period of time for the cells to heat and cool. Composites made from laterite tiles and palm broom fibers displayed 12 percent average water absorption and  $1221 \text{ N/mm}^2$  average tensile strength after 28 days of curing in [8] experiments. According to [9], the inclusion of 5 percent coal fly ash in the roof tile composite resulted in better mechanical and physical qualities necessary for roof tiles. This study by [10] employed ceramic waste to produce roof tiles by the geopolymerization reaction process and found that the waste is rich in silica and alumina, which boosts its potential for manufacturing roof tiles by the geopolymerization method. Compared to traditional roof tile production, this approach minimises  $\text{CO}_2$  emissions. An investigation of the performance of solar roof tiles reinforced with phase change materials by [11] discovered that in winter days, the energy output is 4.1% greater than solar roof tiles without phase change materials. Sludge incorporated fired clay roof tiles were found to be 22.9 percent stronger than traditional tiles when it came to transverse breaking strength, with up to 20 percent clay replacement acceptable for reduced water absorption standards, and 20 percent sludge-incorporated tiles reduced the indoor temperature by 2.8 percent than traditional tiles. Polymer composites reinforced with seashell powder and waste plastic particles were shown to have a higher wear resistance when these materials were used, according to [12], some improvement in the wear resistance was achieved by using seashell powder. With ageing analysis, [12] investigated how the mechanical properties of a PS fiber-reinforced polymer composite filled with palm seed powder changed. They found that the hardness of PS fibers with 15% palm seed powder increased by 30% when compared to the PS fibers with

10% palm seed powder. It has been shown that silica sand has a greater impact on the wear rate and limits pore forms, which also reduces water absorption and boosts the wear resistance of hybrid polymer composites, according to Parkunam et al. According to [13], the minimum water intake levels were discovered to be 10 wt% jute fiber, 30% waste plastic particle addition, and 10% NaOH treatment for a polymer composite with jute fiber reinforcing. [14] gave a common fiber with few advantages, despite the fact that it also has some significant disadvantages as a solution for reduced mechanical properties. An alternative to traditional roofing materials is created by reinforcing jute plants' natural fibers. Waste tile powder filler is employed because pore formation is the most common fault in composites with natural fiber reinforcing. Following typical ageing procedures, the material's wear rate and hardness are assessed, and the findings are evaluated using ANOVA to determine the degree of discrepancy between the actual results and those anticipated using fuzzy logic.

## 2. Materials and Methods

Many natural and synthetic fibers are reinforced into the polymer matrix and their properties were tested for various applications. The mechanical qualities of materials degrade as they are exposed to the outside world. An alternative roofing tile material must have features such as less water absorption, abrasion, and corrosion as well as good strength and wear resistance in order to compete with traditional roofing tiles. Abrasion wear properties must be increased if the material is used on roofs, where it will be subjected to higher wear. Naturally occurring jute fiber is utilised as reinforcement in this project. Jute fiber is obtained via retting, stripping, and drying jute plants, all of which are included in the extraction process. The final jute fiber can either be utilised as raw long strands or woven into a cloth and then used as reinforcement for other materials [15, 16]. Various amounts of sodium hydroxide (NaOH) are employed in this experiment to cure woven jute fibers. Untreated fibers are hydrophilic and have poor wetting qualities when supplemented with polymers. The NaOH treatment is applied to all of the weaved fibers, and then, they are thoroughly cleaned and dried.

Hard powder fillers are commonly used to enhance the material's wear properties. The more porous a material is, the more faults it has and the lower its characteristics will be. Fillers will reduce the porosity and improve both the surface and core characteristics of the material by increasing its density [17, 18]. In this project, discarded tile powder is employed as a filler in predetermined amounts. Micron-sized ceramic tiles are ground and powdered to produce the tile powder, which is sieved at various stages of grinding. The powder is sieved to ensure a consistent particle size. Clay, silica, and a small amount of feldspar or flint make up the porcelain tile. Porcelain tiles are made up of silica and clay, which contribute to its hardness, corrosion resistance, and abrasion resistance. The hand layup technique is followed by compression moulding, which results in the

TABLE 1: L9 experimental design with results.

Jute fiber percentage	Percentage of tile powder	Chemical treatment	Wear index in g/min	Shore D hardness
5	3	No treatment	0.27	79
5	6	5% NaOH	0.19	82
5	9	10% NaOH	0.15	83
10	3	5% NaOH	0.26	73
10	6	10% NaOH	0.21	77
10	9	No treatment	0.12	81
15	3	10% NaOH	0.26	69
15	6	No treatment	0.19	72
15	9	5% NaOH	0.11	77

creation of the composite. Porosity due to blow holes can result from hand layups without compression moulding. They are expelled and completed in accordance with prescribed dimensions after curing. The wear and hardness qualities of the fabricated specimens were examined using ANOVA and fuzzy logics, and the results were optimized.

**2.1. Ageing Process.** After a period of exposure to weather, the materials must be examined for their physical and mechanical qualities in applications like roof tiles. A material's tensile strength can be affected by its exposure to the elements. As a result, hygrothermal ageing is used in which the materials are subjected to thermal heating and cooling conditions as prescribed by the standards, which takes a longer period of time. Testing for mechanical strength was done after the ageing process. The ageing process was carried out in accordance with CSN EN ISO9142 requirements, which called for temperatures ranging from 70°C to -40°C with humidity levels ranging from 50% to 90%. After 16 hours in a deterioration chamber with 90 percent humidity, the specimens were kept at a reduced temperature for three hours before being kept at their highest temperature for five hours with 50 percent humidity. One cycle is completed by repeating this procedure for the whole 24 hours. The specimens are subjected to a wear test after ageing for 35 cycles, which equals 840 hours.

**2.2. Abrasive Wear Test.** The ASTM G99-17 technique is followed in order to determine a material's wear resistance [19–21]. The pin on the disc wear tester was used to determine the wear index of the material under consideration. Abrasive wear tests and sliding wear tests are the most commonly used for polymer composites, and they are both performed at the same time. Abrasive wear is measured by bringing the specimen into direct contact with the rotating disc, while sliding wear is measured by coating the disc with a layer of abrasive particles of the same grit size and subjecting the material to abrasive wear. During this task, the specimen is subjected to an abrasive wear test with a load of 10 N and a disc speed of 100 rpm for a total of 9 minutes under various conditions. The specimens are trimmed so that they will fit into the pin of the wear testing device. The original weights of the specimens are recorded before they are subjected to testing. The remaining testing parameters, such

as the sliding velocity distance and the temperature, were kept at 10 rad/sec, 75 metres, and 30 degrees Celsius, respectively, throughout the experiment. Equation (1) was used to calculate the wear index (or wear rate).

$$\text{Wear Index (WI) in } \left( \frac{\text{grams}}{\text{Minute}} \right) = \frac{W_1 - W_2}{T} \times 1000, \quad (1)$$

where  $W_1$  is the weight of the sample before test in grams,  $W_2$  is the weight of the sample after test in grams, and  $T$  is the time of test cycle in minutes

**2.3. Shore D Hardness.** As part of a comprehensive evaluation of a polymer composite's wear qualities, hardness must also be taken into consideration. Adding ceramic powders, metallic additives, etc., to polymer composites improves their hardness [22–24]. Polymer composite hardness cannot be adjusted by heat treatment procedures, unlike metals, which can be made harder by adding fillers or heat treating. The Shore D hardness tester, which is compact and provides immediate hardness readings, is used to measure the hardness of the samples in this study. The hardness of the samples is determined using the ASTM D2240 method. The indenter on the hardness tester is a hardened steel rod with a conical tip angle of 30 [1]. Using a continuous 5 kg load, a specimen is tested in five separate sites and the average readings are recorded. Table 1 shows the average hardness values of the composites with various compositions.

### 3. Results and Discussion

Taguchi's method was utilised to determine an experimental design in which a new composite was to be made using the proposed method; there are nine distinct designs that can be generated by modifying the combination of input elements, which are entered into MINITAB. The experimental outcomes of the nine designs are then fed and examined through regression analysis after they have been defined as input factors. When compared to other methods, Taguchi requires fewer experimental variables and yields more accurate results in fewer runs.

TABLE 2: Process attributes and steps.

Sl. No.	Attributes	Units	Steps		
			1	2	3
1	Constitution of jute fiber	Wt.%	10	20	30
2	Constitution of waste tile powder	Wt.%	5	10	15
3	Chemical concentration	%	No treatment	5	10

TABLE 3: Analysis of variance for wear and hardness.

ANOVA for abrasive wear						
Source	DF	Adj SS	Adj MS	F value	P value	
Regression	3	0.017833	0.005944	15.11	0.006	
Jute fiber percentage	1	0.002017	0.002017	5.13	0.073	
Waste tile powder percentage	1	0.015	0.015	38.14	0.002	
Chemical treatment	1	0.000817	0.000817	2.08	0.209	
Error	5	0.001967	0.000393			
Total	8	0.0198				
ANOVA for hardness						
Source	DF	Adj SS	Adj MS	F value	P value	
Regression	3	158.833	52.9444	128.78	<0.0001	
Jute fiber percentage	1	60.167	60.1667	146.35	<0.0001	
Waste tile powder percentage	1	96	96	233.51	<0.0001	
Chemical treatment	1	2.667	2.6667	6.49	0.051	
Error	5	2.056	0.4111			
Total	8	160.889				

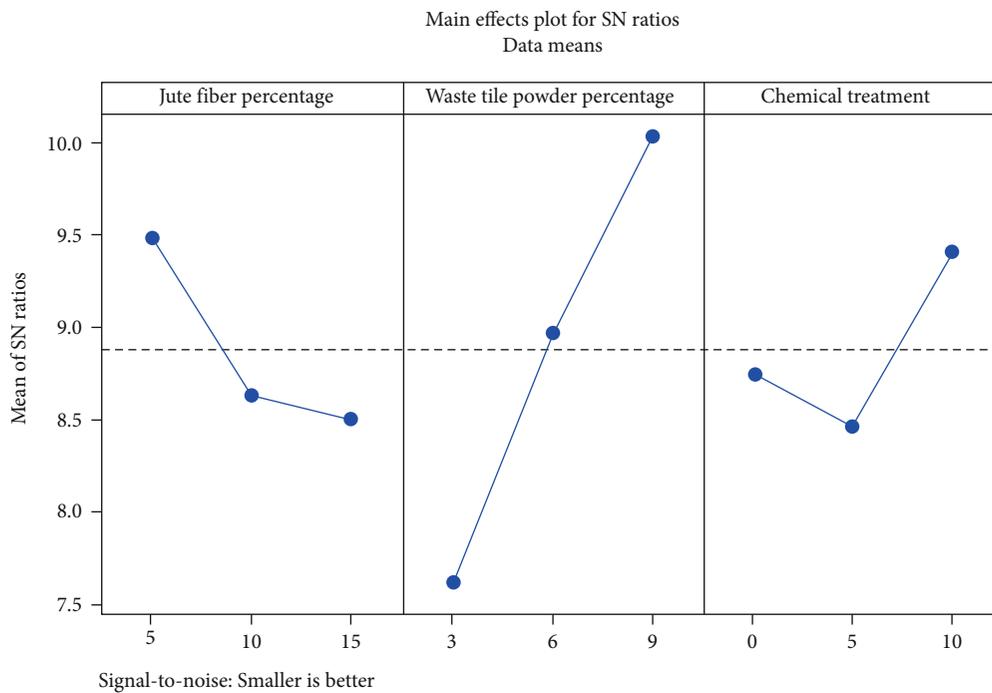


FIGURE 1: Main plot for effectiveness.

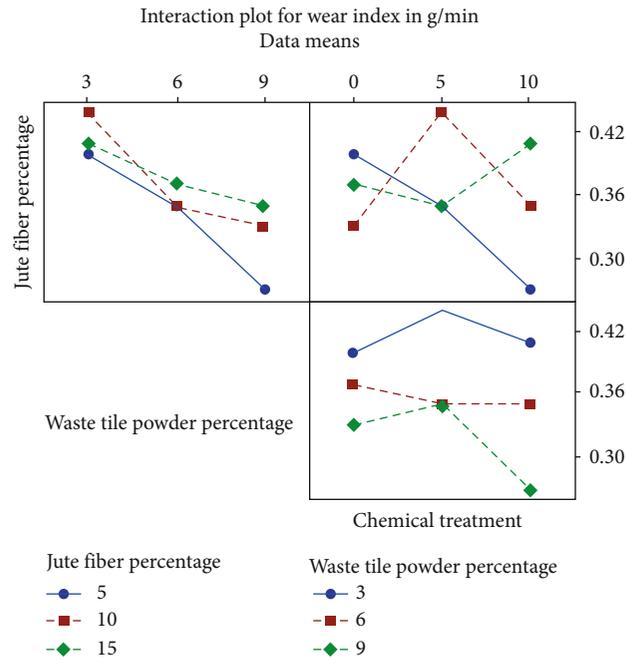


FIGURE 2: Plot to determine the interactions.

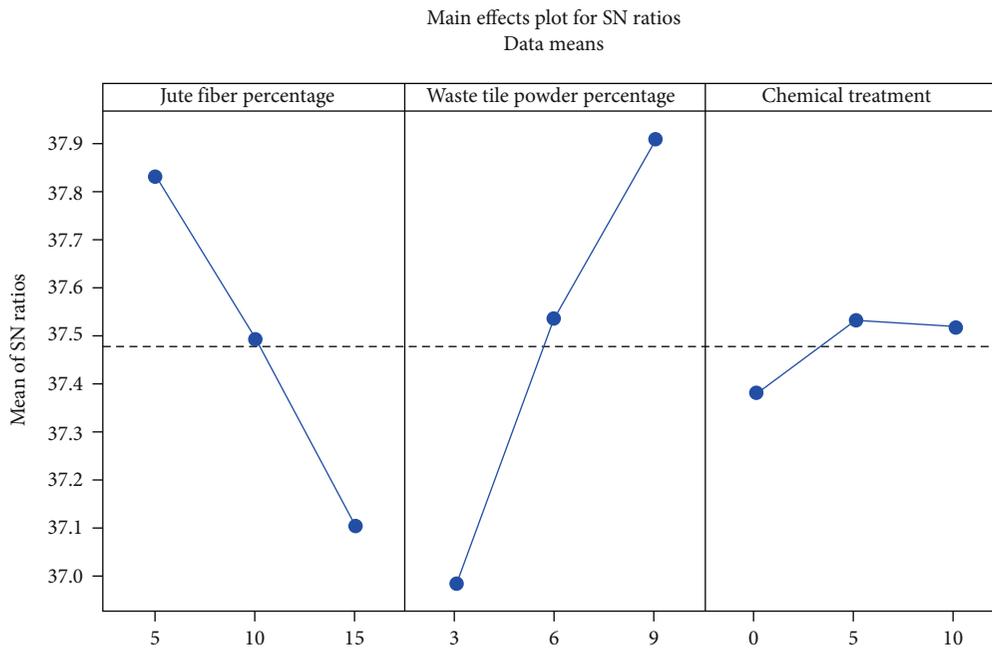


FIGURE 3: Main effect plot.

$$\begin{aligned} \text{Wear Index in g/min} &= 0.4383 + 0.00367 (\text{Jute Fiber Percentage}) \\ &\quad - 0.01667 (\text{Waste Tile Powder Percentage}) \\ &\quad - 0.00233 (\text{Chemical Treatment}), \end{aligned} \tag{2}$$

$$\begin{aligned} \text{Shore D Hardness} &= 72.556 - 0.6333 (\text{Jute Fiber Percentage}) \\ &\quad + 1.333 (\text{Waste Tile Percnetage}) \\ &\quad + 0.1333 (\text{Chemical Treatment}). \end{aligned} \tag{3}$$

Regression equations (2) and (3) were derived from the MINITAB software while ANOVA was used to improve the results. Taguchi's orthogonal array was used to create the experimental design. The regression equation is constructed based on the uploaded data. Using these two equations, we can get the relationship between the wear index in g/min and the Shore D hardness.

There are three tiers of input factors indicated in Table 2. Using MINITAB software, Taguchi's experimental design—L9 orthogonal array—was built, and the input

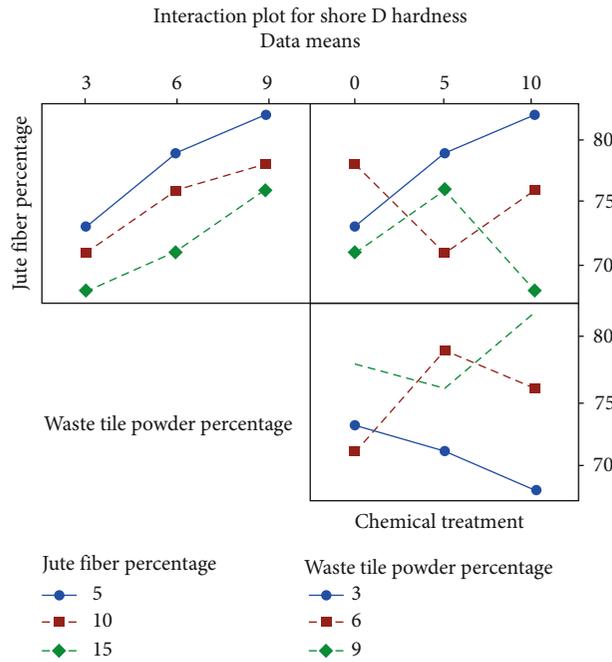


FIGURE 4: Interaction plot.

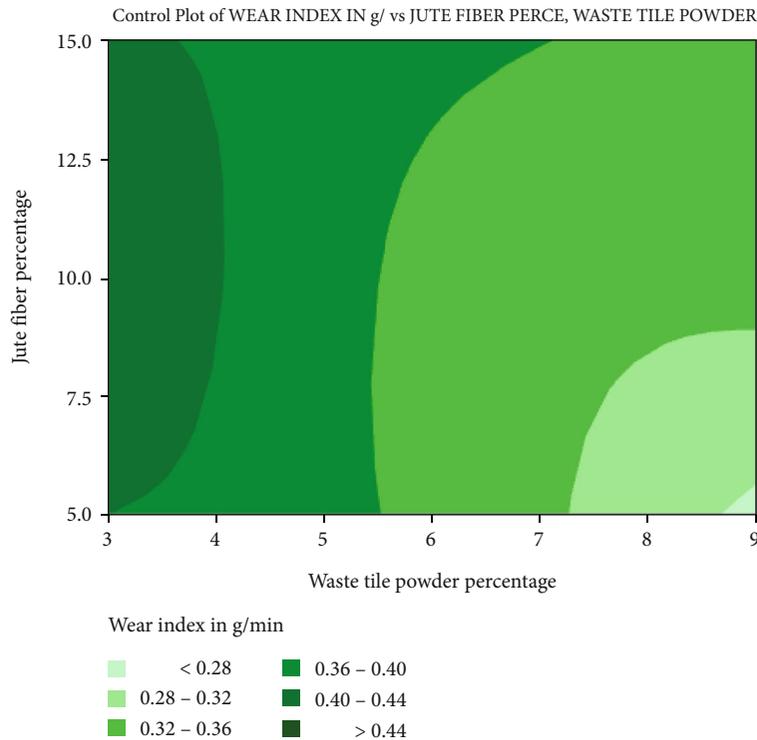


FIGURE 5: Contour plot for minimum wear index.

factors were shuffled in nine different combinations. The input variables were recognised as jute fiber, waste tile powder, and chemical treatment for the fiber, and the composite samples were manufactured by hand layup in accordance with the design. Table 1 lists the wear index and hardness findings from the experiments. The results were entered into

the regression analysis software. As a result of conducting regression analysis, the most significant input element can be identified, as well as the model's relevance. Table 3 shows the ANOVA data for wear index and hardness, and the Fisher value establishes which component has the most impact on the output. Both equations (2) and (3) are

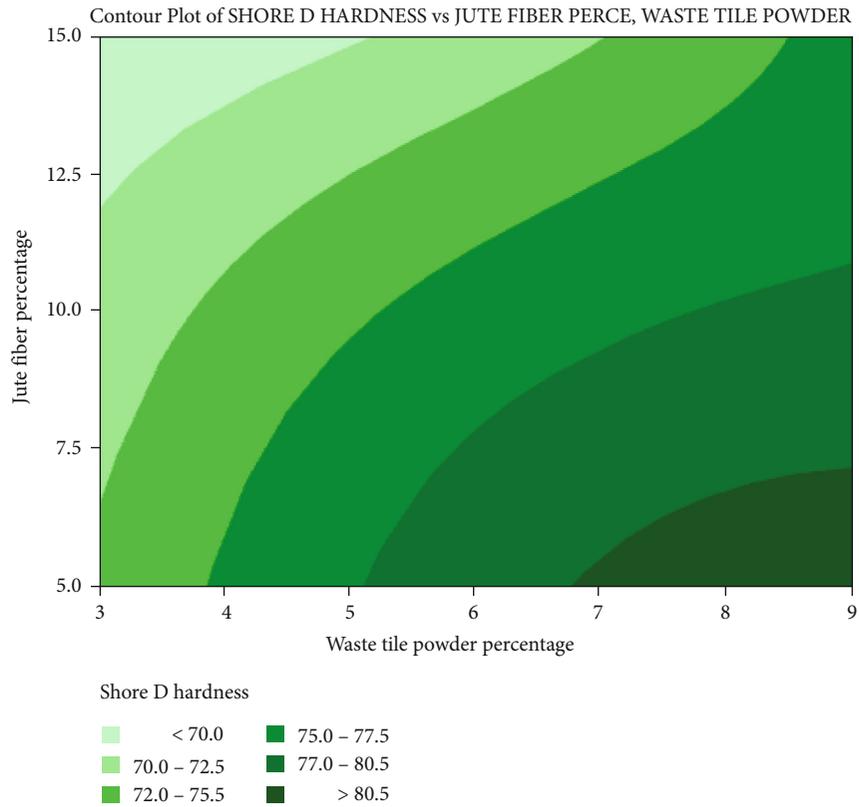


FIGURE 6: Contour plot for higher hardness.

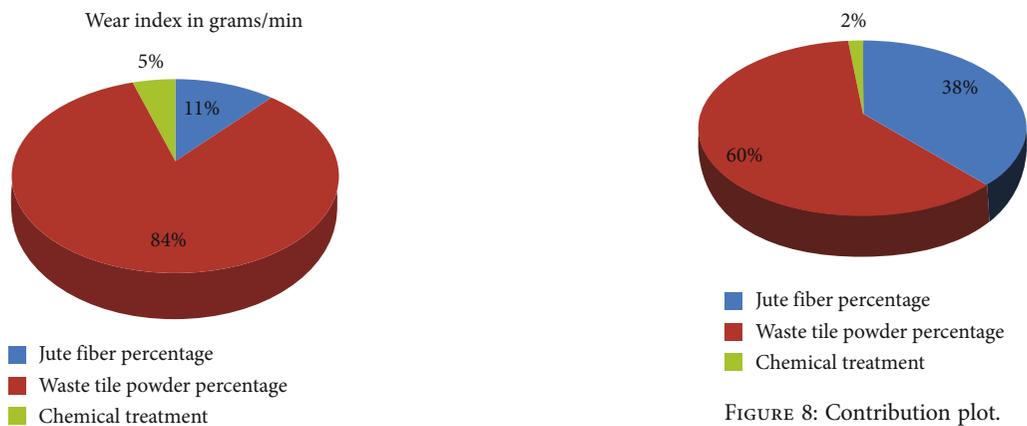


FIGURE 8: Contribution plot.

FIGURE 7: Plot to determine the contribution of factors for optimum results.

regression equations for wear and hardness. Waste tile powder has the greatest impact on both outputs, according to the ANOVA table data. The hardness of a material’s surface determines its wear resistance. If the material’s surface is less firm, the rubbing material will be able to readily remove the material’s surface. So, if the material is more robust, it can withstand greater wear and tear. The hardness and wear resistance of this composite are influenced by the inclusion of waste tile powder. Hardness is increased when ceramics are applied to any other material, which is why ceramic tiles have a higher hardness than other materials. Although the

fibers have been treated with chemicals, their attachment to the matrix will not be as strong as with synthetic fibers. Only to a limited extent will the fibers’ binding characteristics be improved by chemical treatments. Using the regression square value, we were able to calculate that the model’s significance is 90.07 percent and 98.72 percent, respectively, for the wear index and hardness.

The results of a regression analysis can be verified using a variety of charts. If you look at the main effect and interaction plots for wear index in Figures 1 and 2 and for Shore D hardness in Figures 3 and 4, you can get a sense of the relative importance of the various variables. Figures 5 and 6 exhibit contour plots for wear index and hardness, respectively, which demonstrate the optimal input factor for

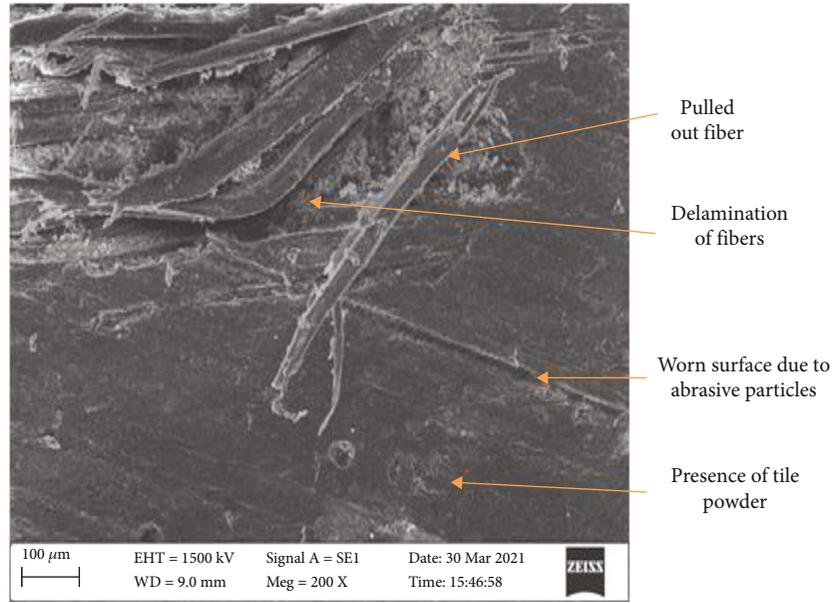


FIGURE 9: Microstructural image of the composite.

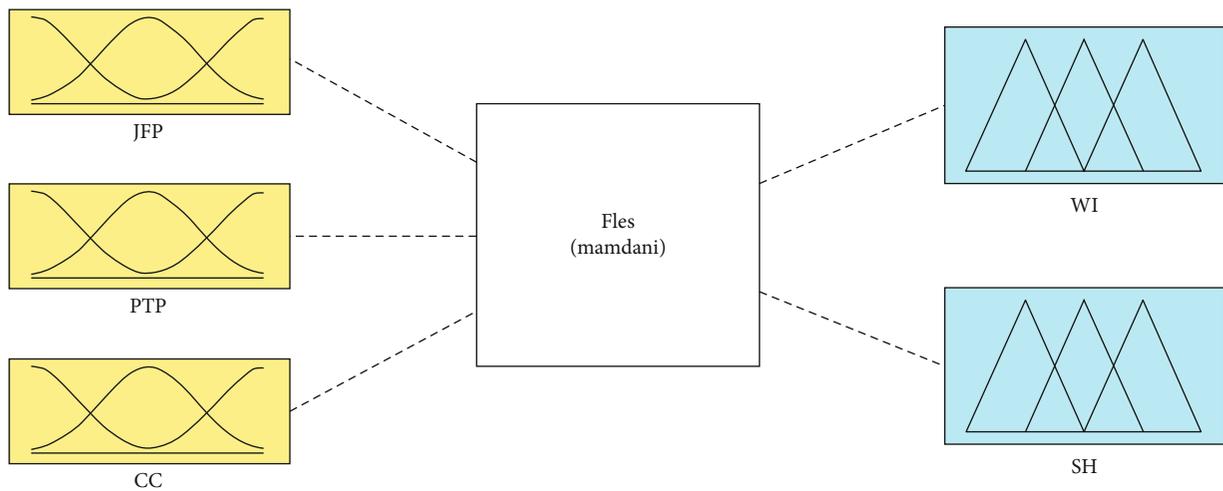
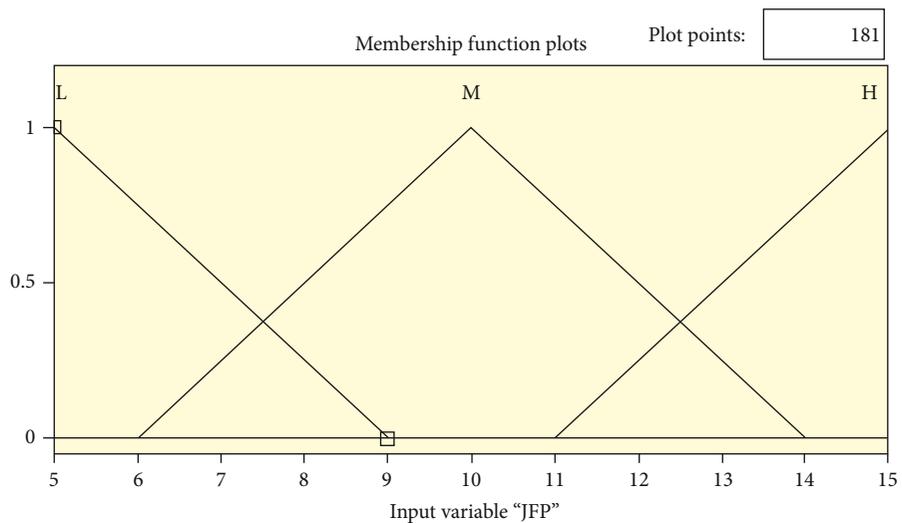


FIGURE 10: Input, process, and output model of a fuzzy logic system.

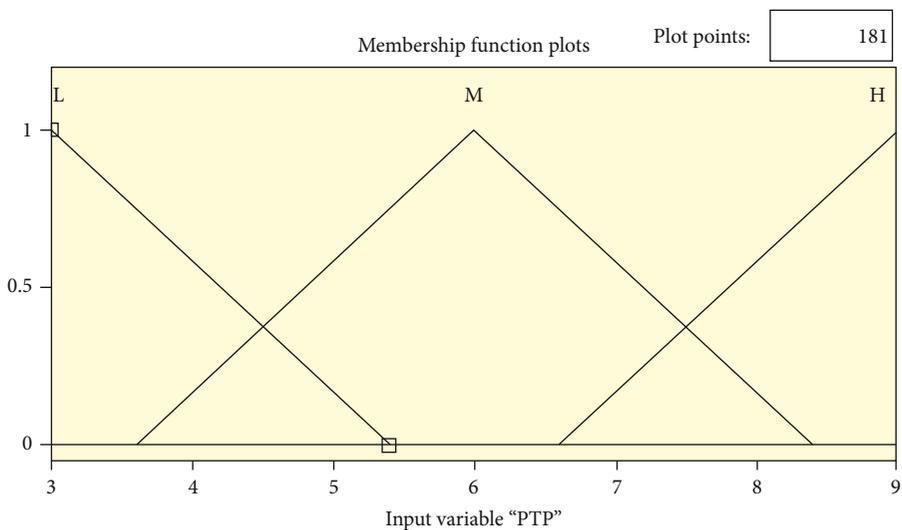
achieving the desired result. Figures 7 and 8 provide a pie chart depicting the contribution of each input component to each output. Fillers, such as ceramic powders, may help to improve surface qualities like wear and hardness by providing additional tensile strength. During the curing process, these fillers help to prevent or limit the creation of tiny pores. Curing causes the trapped air in composites to rise to the surface, where it tries in vain to escape. Composite surfaces might have pores that are filled with resin or left as they are because of the air that is escaping from them. Addition of fillers enhances surface characteristics and reduces the number of pores by filling the blowholes and decreasing the number of pores on the surface. Maximum use of tile powder and minimum use of jute fiber are necessary to get the lowest wear index and highest hardness outcomes. Contour plots can confirm this.

**3.1. Microscopic Analysis.** SEM pictures are taken and analysed to study the specimen’s microstructure. It was taken on the surface that is exposed to abrasive wear testing. Figure 9 shows that the friction caused by the abrasive particles causes the jute fibers to be yanked out of their initial position. Because of this, it was clear that the fiber-matrix bond was not strong enough to survive the wear and tear of the rubbing. In some cases, the delamination may be caused by old age. The sample is free of defects like blow-holes and cracks, indicating that it was manufactured correctly. In addition to being located on the surface, the waste tile powder was also found in the sample’s core.

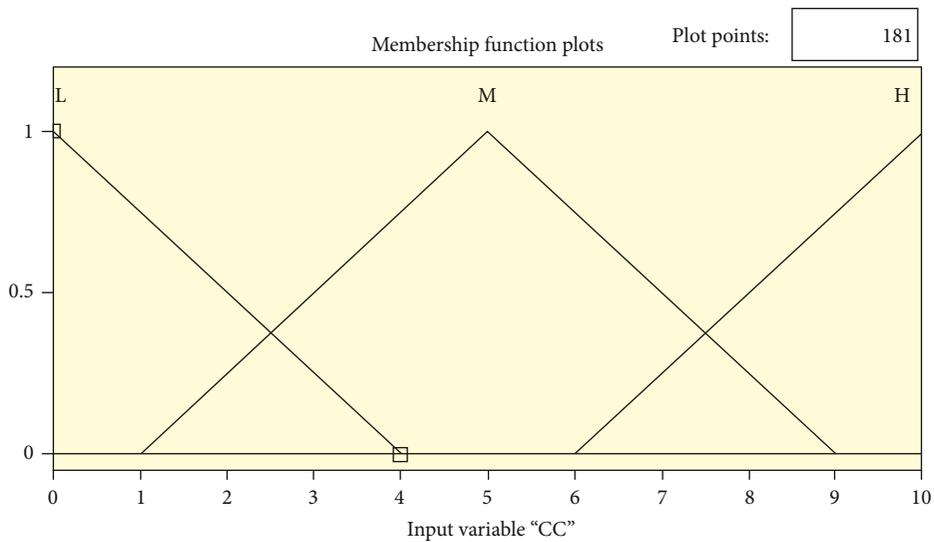
**3.2. Fuzzy Logic Optimization.** In addition to the ANOVA analysis, Matlab was used to perform the optimization with fuzzy logic. Numerous inputs and multiple outputs are possible in a



(a)

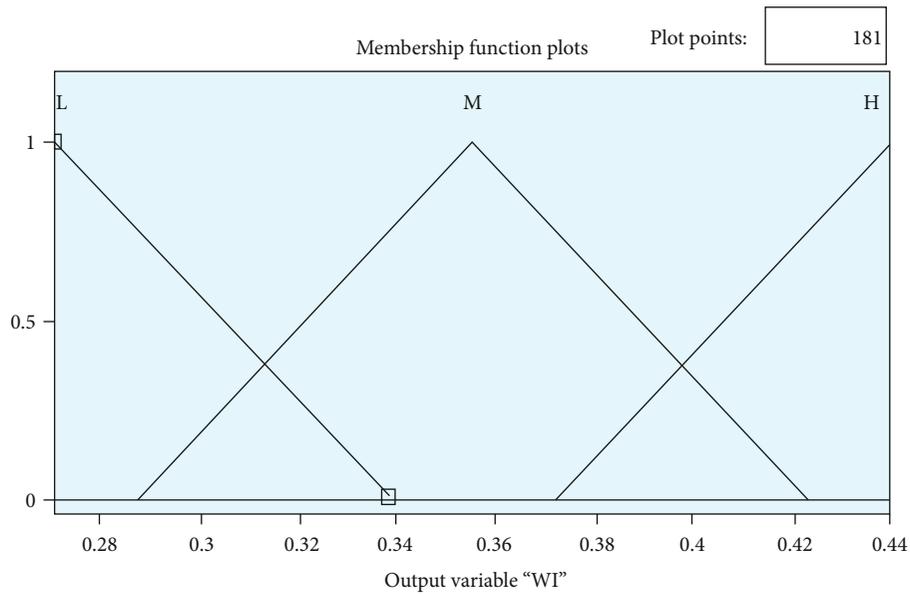


(b)

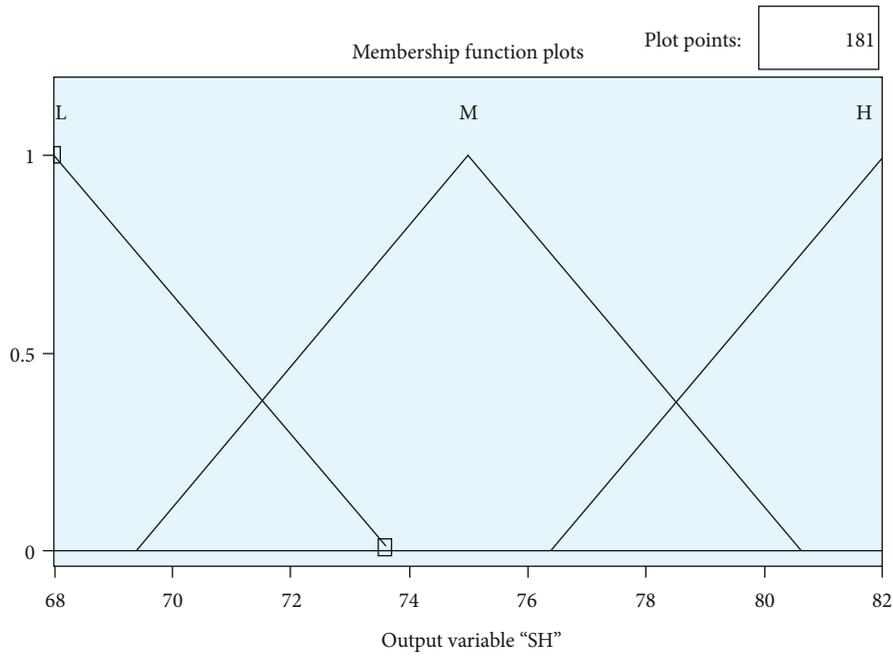


(c)

FIGURE 11: Continued.



(d)



(e)

FIGURE 11: Input and output levels with membership function plots.

fuzzy logic system. Figure 10 depicts an example of fuzzy logic. Three inputs and two outputs were processed in this case. When a set of rules are supplied to the Mamdani, it uses those rules to make predictions about what the output values will be. Fuzzification and defuzzification take happen in the input and output sections, respectively [25]. The current variables are used to specify the range of the input and output values, and the membership functions are defined. Accuracy may be affected as membership functions are added. Figures 11(a)–11(e) show the membership functions for the input and output taken. Low, medium, and high levels of input were available for the user to choose from [26]. The rule editor supplied a rule for

each input. The criteria are formulated based on the outcomes of experiments and information gleaned from the literature. Figure 12 shows the fuzzy logic rule set, while Table 4 shows the fuzzy logic predicted values and the actual experimental values. There is a breakdown of the difference between the experimental and anticipated values in that table. Shore D hardness had an accuracy of 97.91 percent, and wear index had an accuracy of 96.76 percent in this example, which is satisfactory. Figures 13 and 14 show the actual test readings and anticipated values shown on a graph, with error bars appended to show the percentage of variance. All samples, with the exception of one or two, exhibit very little variation from the projected values. In

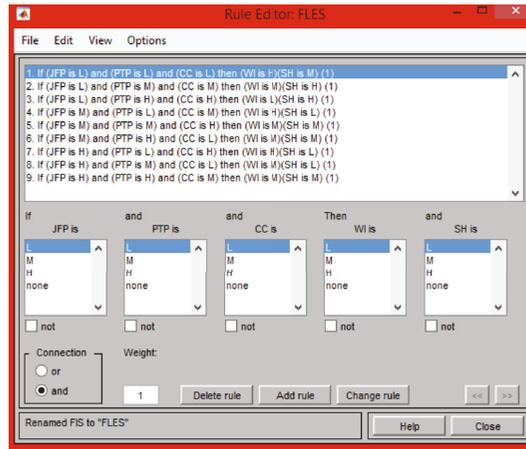


FIGURE 12: Rules framed in rule editor.

TABLE 4: Error percentage between actual experimental values and predicted values.

Specimen number	Wear index (grams/min)			Shore D hardness		
	Actual value	Fuzzy predicted	Error%	Actual value	Fuzzy predicted	Error%
1	0.4	0.418	4.306	73	75	2.667
2	0.35	0.35	0.000	79	80.2	1.496
3	0.27	0.29	6.897	82	80.2	2.195
4	0.44	0.41	6.818	71	69.8	1.690
5	0.35	0.35	0.000	76	75	1.316
6	0.33	0.35	5.714	78	75	3.846
7	0.41	0.41	0.000	68	69.8	2.579
8	0.37	0.35	5.405	71	69.8	1.690
9	0.35	0.35	0.000	76	75	1.316
Error percentage			3.2378			2.0883
Accuracy percentage			96.7622			97.9117

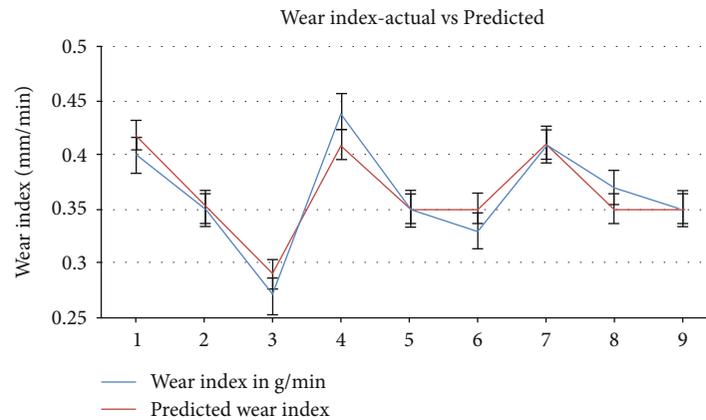


FIGURE 13: Graph between actual wear index and predicted values.

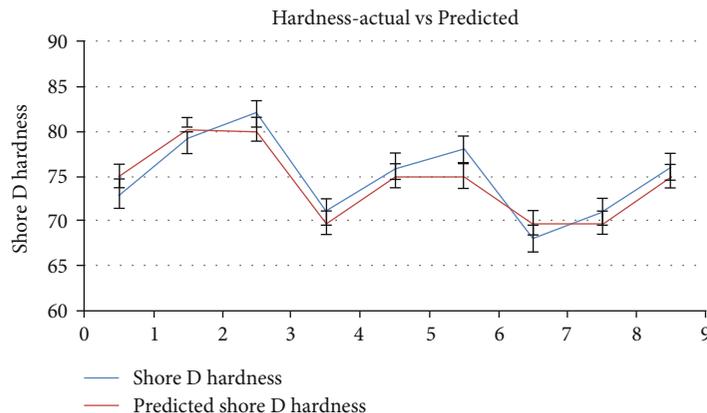


FIGURE 14: The graph between actual Shore D hardness and predicted hardness values.

other words, it shows that the sample was made and evaluated correctly and that the model is important.

#### 4. Conclusion

To achieve a lower wear index, a high proportion of ceramic powder formed by powdering waste tiles should be used, and the influence of this powder should be the greatest when compared to the addition of jute fiber or the chemical treatment applied to the tiles. In this study, the jute fiber and waste tile powder were used as reinforcement in an epoxy matrix, and the composite samples were made using the hand layup method, which was described previously. The wear index of the generated samples was determined by executing an abrasive wear test on a pin on a disc wear testing machine. The results were then analysed. When employing a Shore D hardness tester, the Shore D hardness of the samples can be determined immediately from the results. Prior to conducting the wear and hardness tests, the samples were subjected to an ageing procedure in which they were maintained at higher temperatures for a specific duration of time and then cooled for a specific period of time while maintaining a regulated level of humidity during the process. After the experiments were completed, the findings were entered into the programme for ANOVA analysis in order to determine the affecting input factor and the optimum value. The findings of the regression predicted that the inclusion of waste tile powder will increase the wear resistance and hardness of the final product. The specimen composition including 15 weight percent jute fiber, 9 weight percent waste tile powder, and jute fiber that had been treated with 5 percent NaOH had the lowest wear index when compared to the other specimen compositions tested. At the same time, specimens created with a 5 weight percent jute fiber addition, a 9 weight percent tile powder inclusion, and a 10 percent NaOH treatment have a higher hardness than those manufactured without these additions.

For extra support, a fuzzy logic optimization procedure was followed, in which the difference between the software's predicted and actual value was calculated, and the accuracy was finally determined to be within an acceptable range of error. Microstructural analysis performed after the wear test

confirmed the presence of tile powder all over the surface, and delamination occurred as a result of the wear test. The ageing process weakens the fiber, resulting in a reduction in its stiffness and strength. It is also possible to broaden the scope of the job by conducting tests to assess the tensile and flexural modulus of the steel, as well as corrosion analyses. Engineers can select the appropriate material for the correct application in real life based on the results of these tests.

#### Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

#### Disclosure

It was performed as a part of the employment at Hawassa University, Ethiopia.

#### Conflicts of Interest

The authors of this article declare that we have no conflict of interest.

#### Acknowledgments

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