Investigation of mechanical characteristics of GFRP composites produced from chopped glass fiber and application of taguchi methods to turning operations

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Abstract

Glass fiber-reinforced plastic (GFRP) composites take place in engineering materials owing to their low-weight and high-mechanical properties. In some cases, they need to be shaped by machining before using in industrial applications. However, when these composites are machined, many problems such as bad surface quality, rapid tool wear are encountered. Therefore, optimization of cutting parameters is essential to eliminate or minimize these problems. In this study, GFRP composites were produced by combining polyester matrix material with glass fibers (GF) having 6 mm, 6–12 mm, 12 mm fiber length, and 20%, 25%, 30% fiber ratio by weight. The tensile strengths of these composites were investigated. Turning tests were also performed with cutting speeds of 40, 80, and 120 m/min, feed rates of 0.1, 0.2 and 0.3 mm/rev, and depth of cut of 1, 2, and 3 mm, according to Taguchi L_{27} standard orthogonal array method. The effect of fiber length and ratio, and cutting parameters on cutting forces and surface roughness were analyzed. As a result of the experiments, it was observed that the reinforced polymer matrix with GF provide to increase the tensile strength. The highest tensile strength was obtained as 55.95 MPa from the composite having a fiber length of 12 mm and a fiber ratio of 25%. Besides, the feed rate was determined as the most effective parameter among the all parameters on both cutting force and surface roughness. Therefore, the feed rate should be chosen low for lower cutting force and surface roughness values.

Keywords Cutting force · GFRP composite · Taguchi · Tensile strength · Turning · Surface roughness

1 Introduction

GFRP composites are one of the most commonly used engineering materials in application areas such as aerospace, defense, construction, automotive, marine, nuclear, robot, healthcare, and chemical industries due to their easy availability, low cost, high hardness, high fracture strength [1–3]. They meet the special features of the developing technology better than traditional materials. However, their fabrication methods and fiber types influence the mechanical and tribological properties. Sivasankaran et al. [4] fabricated GFRP composites from glass fiber mat

and glass fiber woven fabrics by filament winding. The mechanical properties of GFRP composites produced with woven fabrics were found to be higher than those produced with glass fiber mat. Jawali et al. [5] fabricated short GF-reinforced nylon six composites having different weight ratios by the melting–mixing method. It was observed that wear resistance of composites increased with GF content. As the mechanical and tribological behaviors of GFRP composites are improved, their usage areas are increasing day by day and they are subjected to different processing methods [6–9].

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Although GFRP composites are shaped by different production methods, their dimensions and geometric shapes must be taken into account. In some cases, machining methods such as turning, milling, drilling are often needed to give the final shape of these composites. As GFRP composites have the anisotropic structure, problems such as rapid tool wear, bad surface quality, excessive cutting force and power consumption are encountered during machining [10–12]. These problems can be controlled with cutting parameters such as cutting tool material, feed rate, cutting speed, and depth of cut [13–15]. Sarma et al. [16] investigated the effects of feed rate, cutting speed, depth of cut, and fiber orientation angle on cutting forces. Cutting forces were determined to increase with increasing the feed rate, cutting speed, depth of cut, and fiber orientation angle. However, the cutting forces started to decrease depending on increasing cutting speed when the cutting speed was above a critical value. Işık and Kentli [17] examined the effects of cutting parameters on cutting force and the material removal rate in machining of GFRP composites at different process parameters. The results showed that optimum cutting parameters varied with the insert radius. Gill et al. [18] researched the effects of tool geometry, feed rate, cutting speed, and depth of cut on cutting forces such as tangential, radial, and feed forces in turning with carbide tools having a different radius and chip angles of GFRP composites. The tool geometry and depth of cut were expressed to have significant effects on cutting forces. Paula Davim and Mata [19] investigated the effects of cutting parameters on machinability with PCD and K15 cutting tools in the machining of GFRP composites fabricated by hand lay-up method. The specific cutting pressure decreased with increasing feed rate and cutting speed. They also observed that the PCD cutting tool performed better machinability performance than the K15 cutting tool. In another study, Davim and Mata [20] turned GFRP composites in different cutting parameters. The feed rate was found as the most effective machining parameter on surface roughness and specific cutting pressure due to the physical and statistical effect. GFRP composites fabricated by hand lay-up method provided a better processability index than those produced by the filament winding method. Hussain et al. [21] investigated the effects of fiber orientation angle, cutting tool type (K20, CBN, and PCD), feed rate, cutting speed, and depth of cut on power consumption in turning of GFRP composite pipes. In experimental results, they stated that power consumption was lower in low feed rate, cutting speed and fiber orientation angle, and medium depth of cut. They also impressed that the PCD tool performed the best in power consumption. Işık [22] examined the effects of cutting parameters such as depth of cut, feed rate, cutting speed, and tool geometry on surface roughness in machining of

GFRP composites. The cutting force and power consumption could be controlled with cutting parameters and tool materials [23–25]. Surface roughness also varies depending on cutting parameters and tool material. It was recommended that the GFRP composites should be turned at high cutting speed, low feed rate, and high depth of cut [26]. However, Kumar Parida et al. [27] stated that optimum cutting parameters for better surface quality were obtained from low feed rate, cutting speed, and depth of cut, and they stated that the most effective parameter was cutting speed. In a study conducted by Hussain et al. [28], surface roughness value increased with increasing fiber orientation angle and feed rate, and it decreased with increasing cutting speed and depth of cut. According to Gupta and Kumar [29], in turning of GFRP composites, surface roughness value decreased with increasing tool nose radius. Surface roughness value was seen to increase with increasing feed rate, cutting speed and depth of cut in their experimental results. In some studies [30, 31], it was emphasized that an increase the feed rate generally had a negative effect on surface roughness. However, this situation showed different behavior for cutting speeds and depth of cut.

When the studies are investigated, it has been seen that the effects of fiber orientation angle, composite production method, tool material, cutting parameters such as tool geometry, feed rate, cutting speed, and depth of cut on surface roughness, cutting force, power consumption, and tool wear were investigated. The optimization of cutting parameters was also made. However, it was observed that there isn't the detailed study about the production and turning of GFRP composites produced using chopped fibers of different fiber lengths and different ratios. In this study, GFRP composites having different fiber lengths and ratios were produced. The tensile strength of these composites was determined. Furthermore, these composites were turned in different cutting parameters according to the Taguchi L_{27} standard orthogonal array method. The effects of cutting parameters, fiber length, fiber ratio and tensile strength on cutting force and surface roughness were researched.

2 Materials, methodology and experimental procedure

2.1 Production and tensile test of GFRP composites

Chopped glass fibers (GFs) with different fiber lengths as reinforcement elements and Poliber brand cast polyester as the matrix material were commercially provided for the production of GFRP composites. Fiber lengths of GFs were 6 mm and 12 mm. Some properties of GF reinforcement

Table 1 Properties of GF reinforcement

Properties	Values	Units
Tensile strength	3400	MPa
Elasticity modulus	77	GPa
Application temperature limits	− 60... + 650	°C
Melting temperature	1120	°C
Specific weight	2.60	g/cm ³
Diameter of fiber	13–15	μm

Table 2 Lengths and ratios of GF reinforcement

Fiber	Values	Units
Length	6, 6–12 and 12	mm
Ratio	20, 25 and 30	%wt

elements are given in Table 1. Fiber lengths and ratios are also given in Table 2.

Chopped fibers were kept in the oven at 100 °C temperature for 2 h and removed the moisture in the fibers. The reinforcement and matrix materials were weighted with the Precisa brand XB 220A precision scale with a capacity of 220 g and a sensitivity of 0.1 mg. Then, mixtures were prepared in the determined proportions according to the combination of parameters given in Table 2. The production steps of the reinforced mixture having fiber length of 12 mm and fiber ratio of 30% weight are given in Fig. 1.

The mixture was poured into the prepared silicone mold to determine the tensile strength given in Fig. 2, and the remaining mixture was poured into a cylindrical plastic

mold having an internal diameter of 44 mm for turning tests.

The molded mixtures were cured for 24 h. Then, the composites were took out from the molds. Composites were kept at room temperature for 14 days to provide complete curing. The images of the GFRP composites produced for turning tests are given in Fig. 3.

Tensile tests were performed with Shimadzu brand universal tensile tester shown in Fig. 4 in a speed of 1 mm/min. The data obtained from the tensile tester were used for stress–strain graphs of the samples.

2.2 Turning tests and Taguchi test design

In turning of GFRP composites, a number of tests are required to determine the effects of fiber length, fiber ratio, feed rate, cutting speed, and depth of cut on cutting force and surface roughness values. For turning experiments, tungsten carbide cutting tool coated TiAlN triangular YBG205 class was used; and cutting parameters given in Table 3 were selected. These parameters were determined according to the recommended cutting parameters for cutting tools and the literature studies [15, 19–21, 23].

When turning tests are performed depending on the fiber length and ratio, and cutting parameters, 243 tests are required totally. Turning experiments were performed by designing the experimental setup according to Taguchi L₂₇, 3-level standard orthogonal array to reduce the number of tests, and to determine the effect factor of the determined parameters on cutting force and surface roughness. 27 turning tests were carried out according to

Fig. 1 Production stages of the reinforcement and matrix material mixtures

Fig. 2 Dimensions of the tensile test specimens and pouring the mixtures into the silicone mold

Fig. 3 GFRP reinforced composite materials

Fig. 4 Shimadzu brand tensile tester

this test design. The parameters and levels for Taguchi L_{27} standard orthogonal array are given in Table 4.

Turning experiments were carried out SMARC brand CAK6166B X 2000 CNC lathe. The counter diameter of

Table 3 Cutting parameters

Parameters	Units	Symbols	Values
Cutting speed	m/min	V	40, 80 and 120
Feed rate	mm/rev	f	0.1, 0.2 and 0.3
Depth of cut	mm	a	1, 2 and 3
Cutting length	mm	l	20

Table 4 Parameters and levels

Variables	Units	Levels		
		1	2	3
Fiber length	mm	6	6–12	12
Fiber ratio	%wt	20	25	30
Cutting speed	m/min	40	80	120
Feed rate	mm/rev	0.1	0.2	0.3
Depth of cut	mm	1	2	3

the machine and the distance between the tailstock were 660 mm and 2000 mm respectively and the spindle speed was in the range of 21–1620 rpm. The main motor power was 11 kW, and it was turret type 4 and vertical, and the diameter of the tailstock was 75 mm, and the tool size was 25 × 25 mm.

2.3 Determination of cutting force and surface roughness

Kistler 9257B type dynamometer was connected to CNC lathe to measure cutting forces. Signals from the dynamometer were transferred to the Kistler 5070A amplifier. Force signals from the dynamometer were transferred to the computer with DynoWare software and plotted. The experimental setup is shown in Fig. 5.

Fig. 5 The experimental setup and the measurement of cutting forces

DynoWare software calculates minimum, maximum, and average values for F_x , F_y , and F_z forces. Values to be considered among these values are the average forces. While the force in the direction of feed is only of great importance in drilling, all forces in the directions of feed, rotation, and radial are of great importance in the turning. In this direction, the cutting force must be considered in turning tests. The cutting force (F) is calculated in Eq. 1 by writing the average forces in the F_x , F_y , and F_z directions:

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2} \quad (1)$$

The roughness values of the machined surfaces of GFRP composites were measured with Time TR-110 portable surface roughness tester. This surface roughness tester was a digital display and pocket type and could be used for measuring flat and cylindrical workpieces. In the surface roughness measurement, the cut-off length was chosen as 0.8 mm. The surface roughness values were measured from four different regions over the machined surface, and their average values were calculated. Thus, average surface roughness values (R_a) were determined.

3 Experimental results and discussions

3.1 Tensile strength results

Tensile tests were carried out to determine the tensile strength of GFRP composites having different fiber lengths and ratios. Tensile specimens were produced by ASTM D638 Type I of the ASTM Standard, and the tests were performed at a speed of 1 mm/min. Stress–strain graphs obtained from the result of the test are given in Fig. 6.

Since the mechanical properties of polyester matrix materials depend on the bond between the molecules at each point, their tensile and compressive strengths are related to the bond's strength. However, the addition of reinforcing materials increases or decreases the strength of the matrix material according to the reinforcement type and properties. In tensile tests, the tensile strength of pure polyester was obtained as 24.6 MPa. For fiber length 6 mm, the tensile strengths of the composites having fiber ratios of 20%, 25%, and 30% were 36.17 MPa, 53.85 MPa, and 42.05 MPa, respectively. For fiber length 6–12 mm, the tensile strengths of the composites having fiber ratios of 20%, 25%, and 30% were 37.85 MPa, 48.6 MPa, and 47.98 MPa, respectively. For fiber length 12 mm, the tensile strengths of the composites having fiber ratios of 20%, 25%, and 30% were 43.3 MPa, 55.95 MPa, and 51.18 MPa, respectively. It was observed that tensile strengths increased in all fiber lengths with increasing fiber ratio. When tensile test results were examined, it was seen that all the samples having a 25% fiber ratio showed the highest strength. The maximum tensile strength (55.95 MPa) was obtained from the composite having a fiber length of 12 mm and a fiber ratio of 25%. In the same fiber ratio, composites having a fiber length of 12 mm exhibited a stable structure and gave the highest tensile strength. When the strain values were examined, it was seen that the strain value increased as the reinforcement ratio increased in the matrix. However, the strain values exhibited different behaviors for different fiber lengths and ratios. This could be explained by the agglomeration of fibers due to static electricity, leading to the inability to obtain a homogeneous mixture during production.

Fiber length and distribution are an important factor to be considered in tensile strength [32, 33]. Takagi and Ichihara [34] indicated that the increase in fiber length improved their mechanical properties. It was determined that the tensile strength and elasticity module increased with increasing reinforcement length and started to decrease after a critical value [35, 36]. They interpreted this because of low fiber-matrix adhesion [37].

Fig. 6 Stress–strain diagrams of the composites

3.2 Machinability results

The cutting force has a significant impact on the machinability of the materials during the turning operation. Hence, it is crucial to understand the factors that affect machinability and to evaluate their effects. The effects of cutting forces on machinability have been investigated by various researchers, and investigations have been carried out to determine the appropriate cutting conditions.

Low cutting force means less cutting tool wear, less cost, and excellent surface quality. In this direction, the effects of turning parameters such as feed rate (f), cutting speed (V), depth of cut, fiber length, and ratio on cutting force (F) were investigated according to the Taguchi method. During turning tests of GFRP composites, F_x , F_y , and F_z forces were measured with a dynamometer. The directions of the F_x , F_y , and F_z forces of the dynamometer connected to the CNC lathe are given in Fig. 7.

In Fig. 7, F_x , F_y , and F_z show the forces in directions of rotation, radial, and feed, respectively. The graph drawn by data obtained from the dynamometer is shown in Fig. 8.

Effects of fiber length, fiber rate, cutting speed, feed rate, and depth of cut on cutting force were determined

Fig. 7 F_x , F_y and F_z forces in dynamometer for turning experiments

Fig. 8 F_x , F_y and F_z force diagrams in turning of GFRP composite

Fig. 9 S/N ratios for cutting force

Fig. 10 Cutting force graph depending on turning parameters

by entering all values in Taguchi L_{27} standard orthogonal array. The effects of the turning parameters on the cutting force were converted into graphs. The signal to noise ratio (S/N) obtained for the cutting forces depending on the turning parameters is given in Fig. 9, and the cutting force graphs are given in Fig. 10.

In Fig. 9, the smallest value was chosen as the best in S/N to obtain minimum cutting force values. That means the absolute value of the ratios in the negative values on the y axis in Fig. 9 was the smallest. It can be seen well in Fig. 10.

As shown in Fig. 10, cutting forces increased with increasing the fiber length and ratio. Since the increase in fiber length increased tensile strength, it could be thought that tensile strength had an essential effect on cutting force. On the other hand, the increase of the reinforcement rate caused to decrease the tensile strength after the

reinforcement rate of 25%, but there wasn't decrease in cutting force. This is because of the cutting force increases due to the fiber ratio during turning. Similarly, the increase in feed rate and depth of cut increased the cutting forces. However, the cutting force increased with increasing cutting speed from 40 to 80 m/min and decreased with increasing cutting speed from 80 to 120 m/min. The minimum cutting force of 129.93 N was obtained from fiber length of 6 mm, fiber ratio of 20%, cutting speed of 40 m/min, depth of cut of 1 mm, and feed rate of 0.1 mm/rev. On the other hand, the maximum cutting force of 283.58 N was obtained from fiber length of 12 mm, fiber rate of 25%, cutting speed of 40 m/min, depth of cut of 3, and feed rate of 0.3 mm/rev. Because the fiber material had excellent mechanical properties, the forces on the cutting tool increased during turning. Besides, the number of materials to be removed by the cutting tool increased with

Table 5 Effect ranking on the cutting forces of the turning parameters

Levels	Fiber length	Fiber ratio	Cutting speed	Feed rate	Depth of cut
1	200.5	197.1	212.3	187.8	199.9
2	213.0	218.5	237.9	213.6	217.5
3	240.4	238.3	203.8	252.7	236.6
Delta	40.0	41.2	34.0	64.9	36.7
Effect rankings	3	2	5	1	4

increasing feed rate and depth of cut, and this situation increased the cutting forces on the cutting tool. A similar situation could be said for cutting speed up to a critical value. However, it started to behave different above this critical value. It is thought to be due to the heat generated by the friction between the cutting tool and the workpiece softening the matrix material. Similar results were reported by Paulo Davim et al. [38], Adam Khan and Senthil Kumar [39], and Kiliçkap et al. [40]. The effect of rankings of the turning parameters on the cutting force is given in Table 5.

When the effect parameters produced by the Taguchi method were taken into consideration, the effect rankings on cutting force were feed rate, fiber rate, fiber length, depth of cut, and cutting speed. In turning GFRP composites, it was observed that the most effective parameter for cutting forces was feed rate, and the least one was cutting speed. Consequently, cutting speed, feed rate and depth of cut values should be selected optimal depending on tensile strength of composite materials. If not, plastic deformation won't occur and machineability will be hard.

Surface quality is one of the most critical issues in machining. Deviations between axes, tolerances, and surface roughness are determined with surface quality for the parts to be machined. Generally, deviations depend on factors such as material, cutting tool, machine tool, and operator. Tolerances include the type of machine tool and compatibility of the workpiece and cutting tool. Surface roughness is affected by cutting tool type, tool geometry, cutting parameters, and environmental conditions. Considering the factors affecting the surface quality, surface roughness, which is closely related to the change of cutting parameters, is an essential factor. The effects of fiber length, fiber ratio, cutting speed, feed rate, and depth of cut on average surface roughness were determined by entering average surface roughness values in Taguchi L_{27} standard orthogonal test design section, and the results were analyzed. The effects of the turning parameters on the average surface roughness were converted into graphs. The signal to noise ratio (S/N) for average surface roughness is given in Fig. 11, and the average surface roughness graph is given in Fig. 12.

In Fig. 11, the smallest value was chosen as the best in S/N to obtain minimum average surface roughness values. In this context, the minimum values for S/N were obtained

Fig. 11 S/N ratios for surface roughness **Fig. 12** Surface roughness graph depending on turning parameters

when levels of the fiber length, fiber ratio, cutting speed, feed rate, and depth of cut were 1. The maximum values for S/N were obtained when the level of fiber length was two and levels of the fiber ratio, feed rate, and depth of cut were 3.

In Fig. 12, the average surface roughness value for the fiber length of 6 mm was quite low. The average surface roughness value for the fiber length of 6–12 mm was higher than the fiber length of 6 mm and 12 mm. In this context, the worst surface quality was obtained from 6–12 mm fiber length. The reason might be that a fiber length of 6 mm and 12 mm reinforcement materials could not be homogeneously mixed. On the other hand, the surface roughness value on the machined surfaces increased with increasing fiber rate. It is thought that the fiber reinforcement elements don't get wet enough in the matrix. Giridharan et al. [37] also determined that poor bonding between matrix and reinforcement occurred with high fiber length and ratio. Therefore, high fiber content increased surface roughness.

When the effect of cutting speed, feed rate and depth of cut on the average surface roughness value was examined, it was seen that the average roughness value of the machined surfaces increased with increasing the values of these four factors.

The lowest average surface roughness value was measured as 2.95 μm from fiber length of 6 mm, fiber rate of 20%, cutting speed of 40 m/min, depth of cut of 1 mm, and feed rate of 0.1 mm/rev parameters. The highest average surface roughness value was measured as 5.48 μm from fiber length of 6 mm, fiber rate of 30%, cutting speed of 120 m/min, depth of cut of 3 mm, and feed rate of 0.3 mm/rev parameters.

Taguchi's standard orthogonal array method successfully analyzed the effects of turning parameters on average surface roughness as being in the cutting force. The effect rankings of the turning parameters on the average surface roughness values are given in Table 6.

The effect rankings of the turning parameters on the average surface roughness values were feed rate, cutting speed, fiber ratio, depth of cut, and fiber length. In turning GFRP composites, it was observed that the most effective parameter for average surface roughness was feed rate; and the least one was fiber length.

In turning experiments carried out according to the Taguchi standard orthogonal array method, the results obtained from both experimental studies and the Taguchi method are given in Table 7. It was seen from Table 7 that the obtained actual and estimated values were close to

each other. This situation showed that the Taguchi standard orthogonal array method provided excellent performance in turning experiments.

4 Conclusion

In this study, GF reinforcements having fiber lengths of 6 mm, 6–12 mm, and 12 mm were mixed with polyester matrix materials at the weight ratio of 20%, 25%, and 30% to obtain GFRP composite materials. The tensile strengths of composites were investigated. In addition, turning tests according to Taguchi standard orthogonal array method were performed in different cutting speed, feed rate, and depth of cut parameters. The effects of turning parameters on cutting force and surface roughness were analyzed. The results were as follows:

- Increasing fiber length and fiber ratio increased tensile strength. GFRP composites having a fiber length of 12 mm had higher tensile strength than the fiber length of 6 mm and 6–12 mm. The highest tensile strengths were obtained from the fiber ratio of 25%.
- The increase in fiber length, fiber ratio, feed rate, and depth of cut increased the forces on the cutting tool. On the other hand, the cutting force increased with increasing cutting speed from 40 m/min to 80 m/min, and it decreased with increasing cutting speed from 80 m/min to 120 m/min. The lowest cutting force was obtained from fiber length of 6 mm, fiber ratio of 20%, cutting speed of 40 m/min, depth of cut of 1 mm, and feed rate of 0.1 mm/rev parameters. The highest cutting forces were obtained from the fiber length of 12 mm, fiber ratio of 25%, cutting speed of 40 m/min, depth of cut of 3 mm, and feed rate of 0.3 mm/rev parameters. The most effective parameter on cutting force was feed rate and then fiber ratio. The least effective parameter was cutting speed.
- The average surface roughness values increased with increasing the fiber ratio, cutting speed, feed rate, and depth of cut. While the best average surface roughness value was obtained from the fiber length of 6 mm, fiber ratio of 20%, cutting speed of 40 m/min, depth of cut of 1 mm, and feed rate of 0.1 mm/rev,

Table 6 Effect ranking on the average surface roughness of the turning parameters

Levels	Fiber length	Fiber ratio	Cutting speed	Feed rate	Depth of cut
1	4.257	4.137	3.971	3.838	4.214
2	4.566	4.479	4.534	4.346	4.366
3	4.340	4.547	4.657	4.979	4.582
Delta	0.309	0.410	0.686	1.141	0.368
Effect rankings	5	3	2	1	4

Table 7 Experimental (actual) and estimated values

Exp.	Fiber length	Fiber ratio	Cutting speed	Feed rate	Depth of cut	Cutting force (N)		Surface roughness (μm)	
						Actual	Estimated	Actual	Estimated
1	1	1	1	1	1	129.93	125.564	2.95	2.86704
2	1	1	1	1	2	135.48	143.226	3.06	3.01815
3	1	1	1	1	3	165.63	162.250	3.11	3.23481
4	1	2	2	2	1	186.20	198.324	4.31	4.28037
5	1	2	2	2	2	219.13	215.986	4.33	4.43148
6	1	2	2	2	3	243.99	235.010	4.72	4.64815
7	1	3	3	3	1	225.94	223.211	5.06	5.10370
8	1	3	3	3	2	246.29	240.873	5.29	5.25481
9	1	3	3	3	3	251.75	259.896	5.48	5.47148
10	2	1	2	3	1	223.15	228.587	4.92	4.88037
11	2	1	2	3	2	247.85	246.250	5.01	5.03148
12	2	1	2	3	3	269.11	265.273	5.23	5.24815
13	2	2	3	1	1	154.13	151.047	3.98	4.20370
14	2	2	3	1	2	164.58	168.710	4.25	4.35481
15	2	2	3	1	3	188.78	187.733	4.90	4.57148
16	2	3	1	2	1	208.24	205.161	4.11	4.09370
17	2	3	1	2	2	222.27	222.823	4.23	4.24481
18	2	3	1	2	3	239.32	241.846	4.46	4.46148
19	3	1	3	2	1	187.98	182.877	4.15	4.14370
20	3	1	3	2	2	204.13	200.540	4.38	4.29481
21	3	1	3	2	3	210.87	219.563	4.42	4.51148
22	3	2	1	3	1	252.35	251.814	4.53	4.43370
23	3	2	1	3	2	273.86	269.476	4.59	4.58481
24	3	2	1	3	3	283.58	288.500	4.70	4.80148
25	3	3	2	1	1	230.97	232.304	3.92	3.92370
26	3	3	2	1	2	244.26	249.966	4.15	4.07481
27	3	3	2	1	3	276.03	268.990	4.22	4.29148

the worst value was obtained from the fiber length of 6 mm, fiber ratio of 30%, cutting speed of 120 m/min, depth of cut of 3 mm, and feed rate of 0.3 mm/rev. It was found that the most effective parameter for average surface roughness was feed rate, and the least effective parameter was fiber length.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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