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Meltem Altin Karataş

Bolu Abant İzzet Baysal University, Gerede Vocational School, Machinery and Metal Technology Department, 14900 Bolu, Turkey
Corresponding author. E-mail: meltemaltin@ibu.edu.tr

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EVALUATION OF EFFECT OF MACHINING PARAMETERS ON SURFACE ROUGHNESS IN DRILLING OF GLASS FIBER REINFORCED POLYMER (GFRP) COMPOSITE MATERIAL WITH DIFFERENT DRILL BITS

In the present study, the arithmetical mean roughness (*Ra*) values obtained as a result of drilling glass fiber reinforced polymer (GFRP) composite material produced in fiber orientation angles (0°/90°) with different drill bits in a 5-axis CNC controlled vertical machining center, were analyzed. The experimental design was applied with the Taguchi method. The drilling experiments were performed using Minitab 19 software according to the Taguchi L_{18} orthogonal array. The test results were evaluated based on the signal-to-noise (S/N) ratio. Two different drill bits (HSS and carbide), three different spindle speeds (750, 1000, 1500 rpm) and three different feed rates (0.05, 0.10, 0.15 mm/rev) were selected as the control factors. The effect levels of the control factors on *Ra* were found by applying analysis of variance (ANOVA). A confidence level of 95.62% was obtained with ANOVA analysis. The lowest *Ra* value was 1.279 µm at the spindle speed of 1500 rpm and the feed rate of 0.05 mm/rev using a carbide drill bit. The drill bit type was obtained as the parameter with the highest effect with a rate of 61.33%.

Keywords: glass fiber reinforced polymer composite, drilling, surface roughness, Taguchi method

INTRODUCTION

In recent years, the interest in laminated composites has been rising rapidly, and the composite industry has seen tremendous development in developed countries [1]. Composites replace traditional materials in the weight-effective market due to their high strength-to--weight ratio and lighter weight [2]. Composites are becoming an indispensable part of daily life as they are employed to produce items such as bicycles, tennis rackets, and car bumpers, with their greatest use in aircraft structures by companies such as Boeing and Airbus [1]. Glass fiber reinforced polymer (GFRP) composites, one of the several types of composite materials, are widely used in the maritime (ship and submarine hulls) industry as well as in the aerospace industry due to their excellent corrosion resistance and non--conductive properties.

The processing of GFRP composites differs from traditional materials because of their heterogeneous and anisotropic features [3]. Composites exhibit different processing behaviors because they consist of two phases (fiber and matrix) [4]. Of all the machining operations performed on composites, drilling is the most common one [3]. Mechanical drilling with a drill bit is preferred because it is convenient and economical to produce riveted and bolted connections in all drilling operations for assembly purposes during assembly processes [5]. Moreover, traditional high-speed steel (HSS) and carbide drills are widely used for machining polymeric composite materials [6].

Surface quality is an important factor in machining operations, and surface roughness has been the main research parameter of many studies. Surface quality is an important design quality and a precise fit is a causal factor in fastener load and fatigue load. Apart from tolerance, the correct selection of machining parameters is necessary to control the surface roughness [7]. Surface roughness is an essential factor in tribology; as it directly affects the mechanical properties of materials, it is used to evaluate the quality of the manufacturing operation in evaluating material surfaces [8].

Many researchers have conducted various studies on composite materials with different compositions [9-15]. Kumar et al. discussed the machining of GFRPs with drill bits of different geometry (HSS, carbide tipped straight shank and eight-facet carbide drills). In their experimental study they obtained the lowest average surface roughness of 0.384 µm at a low feed rate (0.02 mm/rev) and a high spindle speed (1500 rev/min) with an eight-faced carbide drill bit [7]. El-Sonbaty et al. reported that the drill diameter affects the surface roughness with the advancement in drilling a GFRP composite, and the surface roughness is minimized when a high fiber volume ratio and high cutting speed are used [16]. Eneyew and Ramulu stated that the lowest surface roughness values were obtained at a cutting speed of 4500-6000 rpm and the feed rate of 0.064 mm/rev in drilling carbon fiber-reinforced polymer (CFRP) composite material [17]. Durão et al. drilled a CFRP composite material using drills with different geometries and obtained smoother surfaces using helical drills compared to stepped drills [18]. In their study on the drilling of CFRP composite material, Miller et al. determined a low *Ra* value with a high cutting speed and low feed rate [19]. Geier and Szalay investigated the effects of machining parameters on the axial cutting force, delamination and surface roughness of unidirectional CFRP composite material after machining with a special diamond coated twist drill and a solid carbide end mill (helical milling). They concluded that solid carbide end mills with optimum cutting conditions could produce higher quality holes than the special diamond-coated twist drill when not taking into consideration tool wear [20]. Heisel and Pfeifroth examined the effect of the point angle of a drill tool and increasing cutting speeds on machining forces and drill hole quality. They ascertained that the rise in cutting speed does not cause a change in hole quality and when point angles greater than 180° are used, the hole quality is best at the entrance and low at the exit [21].

In most of the works on the machinability of GFRPs, surface roughness is seen as an important machining parameter that should be kept at a minimum. In this study, an experimental study was carried out on the drilling of GFRP composite material using two drill bits with different geometries, three different spindle speeds and three different feed rates. An attempt was made to determine the optimum surface roughness values obtained at different spindle speeds and different feed rates. It is thought that the surface roughness results obtained by drilling GFRP composite material produced in $(0°/90°)_s$ orientation with different types of drill bits under different machining parameters will contribute to the literature.

MATERIAL AND METHOD

Workpieces

GFRP composite material, frequently preferred in the aerospace industry, was used as the workpiece in the drilling experiments. The workpiece used in the experiments was produced with a 50% fiber volume ratio using epoxy resin (in black) with 40 layers of prepreg material, 150×50×5 mm in size, $(0°/90°)_s$ fiber orientation angle, 280 gr/m^2 area weight. It was produced by the vacuum bagging method (Fig. 1).

Fig. 1. Image of GFRP composite material

Experimental study

Drilling processes of the GFRP composite material were performed in a Focus Seiki DL (5) 450 brand 2010 model 5 axis CNC controlled vertical machining center (Fig. 2). In the study, drilling was carried out using two different 8 mm diameter drill bits (HSS and carbide), three different spindle speeds (750, 1000, 1500 rpm) and three different feed rates (0.05, 0.10, 0.15 mm/rev). Before drilling, a 2×90° countersink was drilled to prevent damage to the material. The experiments were performed in dry conditions without the use of coolant. A new drill bit was used after each drilling operation. Among the drill bits used in the experiments, the HSS drill bit was a Ruko, DIN 338, VA type, HSSE-Co 5 helical drill bit. The carbide (diamond) drill bit was a Karcan, DIN 6535, HA type drill bit.

Fig. 2. Images of drilling process of GFRP composite material

In this study, a PhaseView optical profilometer device, which produces a three-dimensional surface profile, was employed to evaluate the average surface roughness values of the workpiece as a result of drilling the GFRP composite material in a 5-axis-CNC controlled vertical machining center. For each cut, three different surface roughness measurements were made from the regions in a 2500×2500 μm area on the cut surface. The *Ra* value was obtained by taking the arithmetic average of the surface roughness values obtained from three regions.

As the design and analysis method, the Taguchi method was used. The drill type, spindle speed and feed rate were selected as the processing parameters whose effects on the drilling of GFRP composite material will be investigated, and machining experiments were carried out at the levels given in Table 1. The L_{18} (2^1x3^2) orthogonal array was chosen to specify the optimum machining parameters and their effects on *Ra* (Table 2).

Optimum levels of the drilling parameters were determined among the various machining parameters with the Taguchi experimental design method. Analysis according to the Taguchi method was performed with Minitab 19 software. The most effective machining parameter was determined by analysis of variance (ANOVA).

TABLE 1. **Processing parameters and levels used in drilling experiments**

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
M	Drill type		Carbide	HSS	-
N	Spindle speed	[rpm]	750	1000	1500
F	Feed rate	[mm/rev]	0.05	0.10	0.15

TABLE 2. **Taguchi L_{18} orthogonal array**

Exp. Nr.	Drill type	Spindle speed	Feed rate
	M	*N* [rpm]	*F* [mm/rev]
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3

RESULTS AND DISCUSSION

The Taguchi method is generally used in the optimization of processing parameters. In this method, the number of tests is significantly reduced by utilizing orthogonal arrays, and the effects of uncontrollable factors are minimized. Thus, with a smaller number of experiments, the test costs are reduced. In the Taguchi method, the S/N ratio was preferred as the quality characteristic since a higher signal-to-noise (S/N) ratio corresponds to better quality characteristics. Therefore, the optimum level of machining parameters is the one with the highest S/N ratio. In this study, the "smaller is better" approach was chosen to calculate the appropriate S/N ratio to obtain the lowest average surface roughness (Equation (1)) (Table 3).

$$\text{Smaller is better: } S/_N = -10\,log\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right] \quad (1)$$

TABLE 3. **Experimental results and S/N ratios obtained according to Taguchi L_{18} orthogonal array**

Exp. Nr.	*M*	*N*	*F*	*Ra*	S/N *Ra*
		[rpm]	[mm/rev]	[µm]	[dB]
1	Carbide	750	0.05	1.836	–5.275
2	Carbide	750	0.10	1.958	–5.836
3	Carbide	750	0.15	2.080	–6.359
4	Carbide	1000	0.05	1.300	–2.276
5	Carbide	1000	0.10	1.755	–4.886
6	Carbide	1000	0.15	2.048	–6.224
7	Carbide	1500	0.05	1.279	–2.137
8	Carbide	1500	0.10	1.535	–3.719
9	Carbide	1500	0.15	1.754	–4.881
10	HSS	750	0.05	2.541	–8.098
11	HSS	750	0.10	3.081	–9.774
12	HSS	750	0.15	4.163	–12.387
13	HSS	1000	0.05	2.443	–7.757
14	HSS	1000	0.10	2.660	–8.496
15	HSS	1000	0.15	2.712	–8.666
16	HSS	1500	0.05	2.090	–6.401
17	HSS	1500	0.10	2.255	–7.061
18	HSS	1500	0.15	2.633	–8.409
			Minimum	1.279	–12.387
			Maximum	4.163	–2.137
			Average	2.229	–6.591

When Table 3 is examined, it is seen that the lowest *Ra* value was obtained in Experiment 7. The lowest *Ra* was obtained at a high spindle speed and low feed rate [7, 17, 19]. The lowest *Ra* value was 1.279 µm at the spindle speed of 1500 rpm and feed rate of 0.05 mm/rev using a carbide drill bit. A better surface quality is achieved with carbide tools compared to conventional HSS since GFRP composite materials are inherently considered abrasive [19]. In addition, the effects of the *M, N* and *F* control factors on *Ra* were examined by means of the S/N ratio response table. The optimum level for *Ra* was obtained as $M_1N_3F_1$ (Table 4, Fig. 3). When the average of the *Ra* values obtained from 18 experiments are compared with the surface roughness values obtained with the optimum levels, an improvement of 42.62% was achieved in the *Ra* value.

TABLE 4. **Response chart for (a) mean values and (b) S/N ratios for *Ra***

		Means [µm]		
Average surface roughness [Ra]	Level	*M*	*N*	*F*
	1	**1.727***	2.609	**1.914***
	2	2.731	2.153	2,207
	3		**1.924***	2,565
	Difference	1.004	0.685	0.650
	Rank	1	2	3

	S/N ratios [dB]		
Level	*M*	*N*	*F*
1	**–4.621***	–7.955	**–5.324***
2	–8.561	–6.384	–6.629
3		**–5.435***	–7.821
Difference	3.939	2.520	2.497
Rank	1	2	3

*Parameter with statistically significant effect

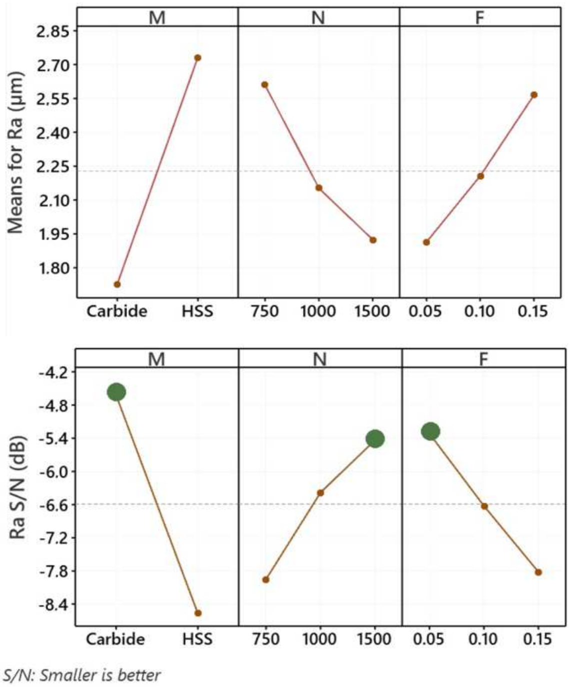

Fig. 3. Mean value and S/N ratio graphs for *Ra*

ANOVA was applied to determine the effect of the drilling parameters on the variable factors in the drilling of GFRP composite material at p 0.05 significance and a 95% confidence level. The ANOVA results for *Ra* are given in Table 5. The effect of the drill bit type, spindle speed and feed rate on *Ra* was 61.33%, 17.07% and 16.44%, respectively.

TABLE 5. **ANOVA results for *Ra***

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contru-bution [%]
M	1	69.837	69.8375	69.8375	55.95	0.002*	61.33
N	2	19.442	19.4417	9.7209	7.79	0.042*	17.07
F	2	18.718	18.7181	9.3591	7.5	0.044*	16.44
*M*N*	2	0.249	0.2487	0.1243	0.1	0.907	0.22
*M*F*	2	0.243	0.2427	0.1214	0.1	0.909	0.21
*N*F*	4	0.398	0.3983	0.0996	0.08	0.984	0.35
Error	4	4.993	4.9927	1.2482			4.38
Total	17	113.88					100.00

S = 1.1172 R^2 = % 95.62 R^2 (adj) = % 81.37
*Parameter with statistically significant effect

CONCLUSIONS

In this experimental study, the effect of the drilling parameters on the average surface roughness (*Ra*) as a result of drilling glass fiber reinforced polymer (GFRP) composite material with different drill bits in a vertical machining center under different processing parameters was investigated and optimum levels of machining parameters were determined for the minimum average surface roughness. It was ascertained that the *Ra* value decreased at a high spindle speed and low feed rate. The lowest *Ra* value obtained on the hole surface of the GFRP composite material was 1.279 µm. The optimum level for *Ra* was obtained as $M_1N_3F_1$. An improvement of 42.62% was achieved in the *Ra* value by machining when employing the optimum machining parameters. As for the results obtained from ANOVA, the effect of the drill bit type, spindle speed and feed rate on *Ra* was 61.33, 17.07 and 16.44%, respectively.

REFERENCES

[1] Kalita K., Ghadai R.K., Bansod A., Sensitivity analysis of GFRP composite drilling parameters and genetic algorithm-based optimisation, International Journal of Applied Metaheuristic Computing 2022, 13(1), 1-17.

[2] Kalita K. et al., Free vibration analysis of laminated composites by a nine node isoparametric plate bending element, Advanced Composites Letters 2016, 25(5), 108-116.

[3] Nayak B.B. et al., Parametric optimization in drilling of GFRP composites using desirability function integrated simulated annealing approach, Materials Today: Proceedings 2021, 44, 1983-1987.

[4] Palanikumar K., Prakash S., Shanmugam K., Evaluation of delamination in drilling GFRP composites, Materials Manufacturing Processes 2008, 23(8), 858-864.

[5] Tsao C., Hocheng H., Chen Y., Delamination reduction in drilling composite materials by active backup force, CIRP Annals 2012, 61(1), 91-94.

[6] Abrao A. et al., The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite, Materials Design 2008, 29(2), 508-513.

[7] Kumar D., Singh K., Zitoune R., Experimental investigation of delamination and surface roughness in the drilling of GFRP composite material with different drills, Advanced Manufacturing: Polymer Composites Science 2016, 2(2), 47-56.

[8] Dobes J. et al., Effect of mechanical vibration on Ra, Rq, Rz, and Rt roughness parameters, The International Journal of Advanced Manufacturing Technology 2017, 92(1), 393-406.

[9] Karataş M.A., Gökkaya H., A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials, Defence Technology 2018, 14(4), 318-326.

[10] Karatas M.A., Gokkaya H., Nalbant M., Optimization of machining parameters for abrasive water jet drilling of carbon fiber-reinforced polymer composite material using Taguchi method, Aircraft Engineering Aerospace Technology 2019, 92(2), 128-138.

[11] Karataş M.A., Motorcu A.R., Gökkaya H., Optimization of machining parameters for kerf angle and roundness error in abrasive water jet drilling of CFRP composites with different fiber orientation angles, Journal of the Brazilian Society of Mechanical Sciences Engineering 2020, 42(4), 1-27.

[12] Karataş M.A., Motorcu A.R., Gökkaya H., Study on delamination factor and surface roughness in abrasive water jet drilling of carbon fiber-reinforced polymer composites with different fiber orientation angles, Journal of the Brazilian Society of Mechanical Sciences Engineering 2021, 43(1), 1-29.

[13] Nekrasov S. et al., Research on the manufacture and strength of the innovative joint of FRP machine parts, Journal of Manufacturing Processes 2021, 72, 338-349.

[14] Altin Karataş M., Investigation of friction performance and surface integrity of aramid fiber-reinforced polymer matrix composite, Polymer Composites 2021, 42(12), 6349-6361.

[15] Akıncıoğlu S., Investigation of effect of abrasive water jet (AWJ) machining parameters on aramid fiber-reinforced polymer (AFRP) composite materials, Aircraft Engineering Aerospace Technology 2021.

[16] El-Sonbaty I., Khashaba U., Machaly T., Factors affecting the machinability of GFR/epoxy composites, Composite Structures 2004, 63(3-4), 329-338.

[17] Eneyew E.D., Ramulu M., Experimental study of surface quality and damage when drilling unidirectional CFRP composites, Journal of Materials Research and Technology 2014, 3(4), 354-362.

[18] Durão L.M.P. et al., Drilling tool geometry evaluation for reinforced composite laminates, Composite Structures 2010, 92(7), 1545-1550.

[19] Miller J., Eneyew E.D., Ramulu M., Machining and drilling of carbon fiber reinforced plastic (CFRP) composites, SAMPE Journal 2013, 49(2), 36-47.

[20] Geier N., Szalay T., Optimisation of process parameters for the orbital and conventional drilling of uni-directional carbon fibre-reinforced polymers (UD-CFRP), Measurement 2017, 110, 319-334.

[21] Heisel U., Pfeifroth T., Influence of point angle on drill hole quality and machining forces when drilling CFRP, Procedia CIRP 2012, 1, 471-476.

