Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(2) (2022) 97-100
DOI: 10.22060/mej.2021.20145.7186

Optimization of Carbon Fiber Reinforced Composite Grinding Process by Response Surface Method

S. M. Mousavi[1], A. Sazgar[2]*, V. Fallahpour[1]

[1] Atomic Energy Organization of Iran, Tehran, Iran
[2] Nuclear Fuel Cycle Research School, Nuclear Science and Technology Research Institute, Tehran, Iran

ABSTRACT: Today, the usage of composite materials in various industries such as aerospace, transportation, construction, etc. has increased. Therefore, an adequate understanding of the production processes and assembly of these materials is inevitable. Machining is one of the common processes in assembling composite parts. This process includes two categories of traditional and non-traditional machining processes and grinding is one of the traditional methods. Grinding is one of the applicable machining processes for the finishing of composite parts. Many parameters such as feed rate, depth of cut, tool geometry, fiber direction, and abrasive particles material and size are effective on the machined surface. In this study, the effect of grinding parameters including feed rate, depth of cut, abrasive particles size, and fiber orientation on the surface quality of Carbon Fiber Reinforced Polymer has been evaluated. The experiments were designed by Response Surface Method in Minitab software V.19. The results showed that abrasive particles' size and depth of cut are the most effective parameters on the machined surface roughness. The feed rate and fiber direction are of secondary importance, respectively. Also, the scanning electron microscopy images confirm these results. Finally, it was suggested to use 50µm of the depth of cut, 200mm/min of feed rate, perpendicular to fiber direction and course abrasive particle to achieve a roughness of less than 5µm.

Review History:

Received: Jun. 13, 2021
Revised: Jul. 31, 2021
Accepted: Aug. 25, 2021
Available Online: Sep. 07, 2021

Keywords:

Carbon fiber reinforced composite
Grinding
Surface roughness
Depth of cut
Feed rate

1- Introduction

Machining of Carbon Fiber Reinforced Composites (CFRPs) is a complex process due to the heterogeneity of the composite material and the abrasiveness of the reinforcement. Therefore, it's important to understand the effect of process parameters. In the grinding process, many parameters such as feed rate, depth of cut, tool material, abrasive particle size, workpiece material, and fiber orientation affect the machined surface quality. Mousavi et al. [1] investigated the effect of parameters affecting the machined surface roughness in CFRP shafts and concluded that the depth of cut and the size of the abrasive particles are the most important parameters affecting the grinding of CFRP shafts. Park and Nakagawa [2] studied the grinding of CFRP with a diamond tool. They concluded that the smoothest machined surface is obtained in 90° of the fiber orientation. Hu and Zhang [3] investigated the grindability of unidirectional CFRPs. They studied the effect of fiber orientation and grinding parameters such as depth of cut, feed rate, and grinding wheel speed. In this research, comprehensive studies have been performed on a unidirectional CFRP. The experiments were designed by the response surface method. The effect of machining parameters including depth of cut, feed rate, fiber orientation, and abrasion particle size on machined surface roughness was investigated.

2- Materials and Methods

In this study, the effect of parameters: the depth of cut (0.5-0.5 mm), feed rate (10-200 mm/min), the angle between fiber orientation and cutting direction (0-90 degrees), and abrasive particle grain size (coarse and fine grain) on the grinding of a unidirectional flat CFRP was investigated. The composite part consisted of 12K carbon fiber and A-bisphenol epoxy thermoset resin. The workpiece was produced by filament winding process. In all experiments, coolant fluid was used due to toxic fumes from burning the polymeric matrix and machining dust. The tools were white aluminum oxide with two coarse and fine grains. Surface roughness was measured and recorded 3 times for each sample in the direction perpendicular to the fibers' orientation. The average measured roughness is also recorded as the final roughness of each sample.

3- Results and Discussion

As mentioned, the surface roughness of each sample was measured at least 3 times and its average roughness

*Corresponding author's email: Asazgar@aeoi.org.ir

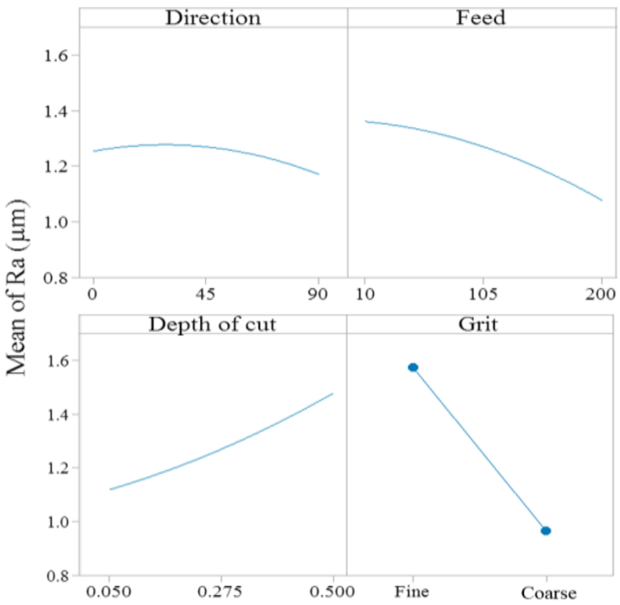

Fig. 1. Phase velocity dispersion curves for a steel pipe with outer diameter of 220 mm and wall thickness of 4.8 mm

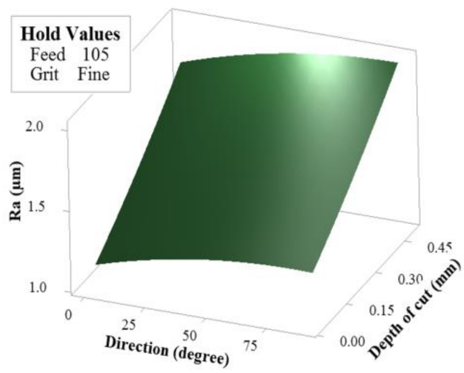

Fig. 2. The surface plot of the effect of depth of cut and of fiber orientation. Test conditions: feed rate 105 mm/min, fine grind wheel.

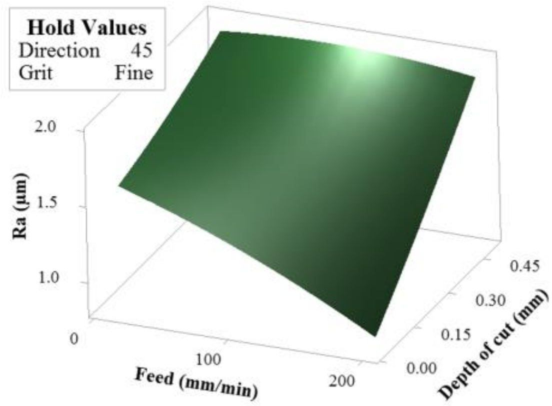

Fig. 3. The surface plot effect of depth of cut and feed rate. Test conditions: 45° fiber direction, fine grind wheel.

was recorded. The machined surface roughness results at the central point indicate that the experimental data are repeatable. Table 1 presents the conditions of tests with their average roughness. According to the obtained surface roughness data, the following results have been obtained. Fig. 1 shows the main effect of the parameters and the trend of surface roughness changes with them.

According to Fig. 1, the steepness of each curve indicates the importance of the parameter. Therefore, the abrasive particles' size is the most effective parameter on machined surface roughness, followed by the depth of cut, feed rate, and fiber orientation, which are the most important parameters affecting surface roughness, respectively. Fig. 2 shows the simultaneous effect of fiber orientation and depth of cut.

In Fig. 2, as the depth of cut increases, the surface roughness increases. In this way, with increasing depth of cut, the engagement of the tool with the workpiece will increase, and eventually, the frictional forces will rise. Increasing the frictional force also increases the cutting heat, which can lead to thermal damage. Also, the slight effect of fiber orientation is ignored [3]. Fig. 3 shows the simultaneous effect of depth of cut and feed rate on machined surface roughness.

As shown in Fig. 3, the feed rate has an inverse effect on surface roughness. Due to the high rotation speed of the grinding wheel, the linear speed of the abrasive particles passing through the surface is very high. At low feed rates, a particle passes through certain regions several times, which is much higher than high feed rates. This will increase the temperature of the cutting zone, which will lead to heat damage. Fig. 4 also shows the optimal values of parameters in order to achieve the minimum machined surface roughness.

According to Fig. 4, by selecting the proposed values, the minimum surface roughness of 0.3 µm can be achieved. Of course, it should be noted that the desirability factor in these conditions is equal to 1, which indicates that it can be easily achieved a smooth and uniform surface. In order to confirm the quantitative results presented in this report, Fig. 5 is machined surface Scanning Electron Microscope (SEM) pictures that have the lowest surface roughness.

As shown in Fig. 5, by selecting the coarse grind wheel, the minimum depth of cut can be achieved to the desired machined surface roughness.

4- Conclusions

In this study, the effect of depth of cut, feed rate, abrasive particle size, and cutting direction on surface roughness

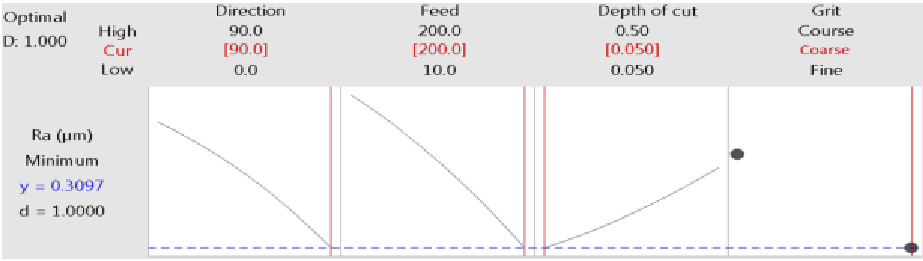

Fig. 1. Phase velocity dispersion curves for a steel pipe with outer diameter of 220 mm and wall thickness of 4.8 mm

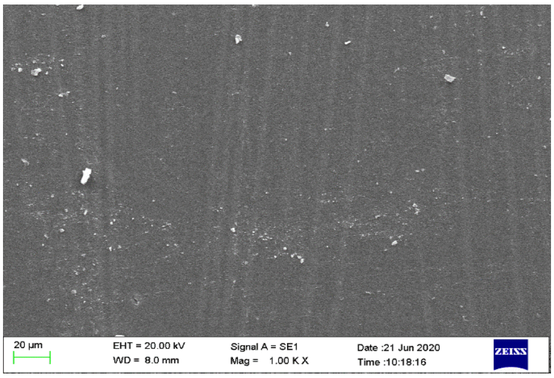

Fig. 3. The surface plot effect of depth of cut and feed rate. Test conditions: 45° fiber direction, fine grind wheel.

in the grinding process of unidirectional CFRP has been investigated. The following results can be inferred:

- Abrasive particle grain size, depth of cut, feed rate were the most influential parameters on surface roughness, respectively.

- Due to the adhesion of the polymer matrix, the coarse grind wheel has given better results than the fine grind wheel due to the better repulsion of the chips and flow of coolant fluid.

- By increasing the depth of cut due to the increase in the engagement of the grinding wheel and the workpiece, the machining forces and especially the friction increase. As a result, the heat of the cutting area rises. Rising temperatures will also cause thermal damage.

- Increasing the feed rate despite the depth of cut will reduce the surface roughness. Due to the high speed of rotation of the grinding wheel, at a low feed rate, each particle passes through a cutting zone several times and increases the temperature of that region, which will cause thermal damage.

- By selecting rougher grain, minimum depth of cut, higher feed rate, and 90° between the fibers direction and the cutting direction, as well as the use of coolant with a surface roughness of less than 1 micrometer was achieved in the grinding process of unidirectional CFRPs.

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HOW TO CITE THIS ARTICLE

S. M. Mousavi, A. Sazgar, V. Fallahpour, Optimization of Carbon Fiber Reinforced Composite Grinding Process by Response Surface Method, Amirkabir J. Mech Eng., 54(2) (2022) 97-100.

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