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The Effects of Drilling Operation on the Surface Roughness of Modified GFRP Composites

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The use of fiber reinforced composites with thermoset matrix is widespread in many areas ranging from sports products to multiple industries. This prominence, aside from the lightness of composites, can be attributed to their high mechanical resistance, good corrosion resistance, and strength density ratios that are favorable over their metal counterparts. Although their final states are approached with various single step methods, they often require secondary operations such as turning, milling or drilling. Because composite materials are not homogeneous, machining process may give rise to negative outcomes like the tearing of fibers or damages on the matrix. Composites with thermoset matrix are also brittle materials. Thus, during machining, they are processed by breaking which is not favored for production. Modified glass fiber reinforced composite (GFRP) materials, which are produced with thermoset matrix epoxy resin, are drilled in this study. Previous studies on this field had focused on the processes of turning and milling regarding the products' surface roughness. Therefore, surface roughness of holes, which were drilled according to different parameters by using L 18 matrix prepared with Taguchi's design of experiment on modified GFRP part, having 30% fiber glass, were investigated. This particular study takes on the drilling process which is also essential to manufacturing of the final products of GFRP, in the same framework. In the experiments, the influence of changing spindle speed and feed rate in different drill diameters on the inner surface of the hole, were evaluated using different cutting tools. As a result, the surface roughness of the drill, produced by the uncoated drilling bit with a diameter of 4 mm, spindle speed of 200 rpm and feed rate of 720 mm/min, was determined to be optimal.

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1. Introduction

Optimizing the mechanical properties of composite materials and its reinforcement in any way is attained by using fiber material. In addition, matrix material is used to distribute tension over composite material, protect the fiber and make the product take its exact structure [1].

One of the reinforcement materials, that is a component of composite materials, is fiber glass. Negative outcomes such as breaking of glass fibers, damage to the matrix and delamination on the surface, emerge as a result of orientation managing these reinforcement components during machining, adversely influencing surface quality. Another problem that arises in accordance with machining is the quick corrosion of cutting tools due to the hard and abrasive nature of composite materials. A qualified machined surface cannot be achieved through machining with worn cutting tools, due to cutting forces and heat increase in cutting areas [2–4]. Glass fibers as reinforcement materials are particularly preferred in that field (as reinforcement material) due to their low costs and high resistance properties [1].

One of the studies on evaluating the surface roughness of fiber reinforced composite materials, in which besides the surface roughness of milled pieces, the corrosion of cutting tools, and the change in cutting forces were investigated, pioneered by Hocheng et al. [5]. Studies on the surface roughness of both glass fiber and carbon fiber reinforced materials are evaluations about the milling process. Following a combined consideration of these, it has been found that the feed rate and surface roughness are directly [6–11], but cutting speed and surface roughness are inversely [7–11] proportional. Studies on milling aside, studies on the drillability of fiber reinforced composite materials are found to be on delamination [12–16], cutting force [15, 16], and surface roughness [16] upon investigation. Studies on drilling process are focused rather than on delamination and cutting force.

On the other hand, this study is on assessing the surface roughness inside the hole. In assembling, products with low surface roughness under standard working conditions have longer product life circles.

2. Experimental procedure

GFRP materials with 30% surface modification of $250 \times 250 \times 4.8$ mm^3 were produced with vacuum assisted resin transfer molding (VARTM) in this study. 43.86% epoxy resins (EPIKOTE 828) and 25.44% hard-

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ener (F-205) were supplied from Huntsman. 0.70% accelerator benzyl dimethyl amine (BDMA) was supplied from Sigma-Aldrich. E-glass glass fiber fabric was supplied from camelyaf® şişecam. (3-aminopropyl) triethoxysilane (APTES), hydrochloric acid (HCl) were used for surface modification. With the chemicals supplied from Sigma-Aldrich, GFRP material with 90° angle in-between fibers and 500 g/m^2 weight per unit are used.

VMC-550A CNC milling machine with cutting speed of 6000 rpm and maximum feed ratio of 4000 mm/min was used in experiments. The independent variables were cutting parameters and cutting tools. The chemical components 0.9% C, 4.1% Cr, 4.9% Mo, 1.8% V, 6.3% W, and 4.8% Co for cutting tools were used. HSS-E and TiN coated bits of 4, 5, and 6 mm diameters were used as tools. Bit angles of tools are 135°. Table I shows parameters used in the experiment. Experiments were conducted without use of cooling fluids. The parameters of the table were determined according to Taguchi's design of experiment. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi has used signal-noise (S/N) ratio as the quality characteristic of choice [17, 18]. There are three categories of quality characteristics in the analysis of the S/N ratio. In this study surface, roughness was promoted as the smallest value, which is the reason why the S/N ratio was used according to the criterion the smaller-the-better, in order to minimize the response.

TABLE I

Parameters used in experiment

Parameters	Unit	1 Level	2 Level	3 Level
(A) surface condition		TiN	uncoated	
(B) drill diameter	[mm]	4	5	6
(C) spindle speed	[rpm]	2000	2800	3600
(D) feed rate	[mm/min]	240	480	720

Surface roughness measurements were conducted with Taylor Hobzon precision, Form Talysurf 500 surface roughness measurement device. In these measurements, sampling length (cut-off) was set as 4×0.8 mm^2 and with 5 repetitions for each hole. Surface roughness measurements (R_a) have been made from the entrance point of the tools towards their exit point, parallel to drill's machining direction (as seen in Fig. 1). Figure 2 depicts a photograph of the inside of a hole.

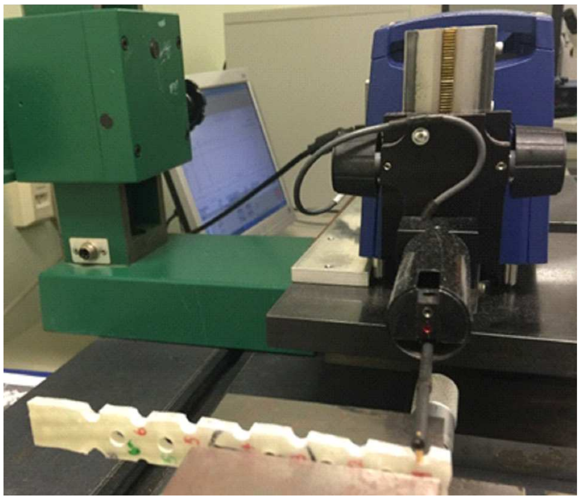

Fig. 1. Surface roughness measurement.

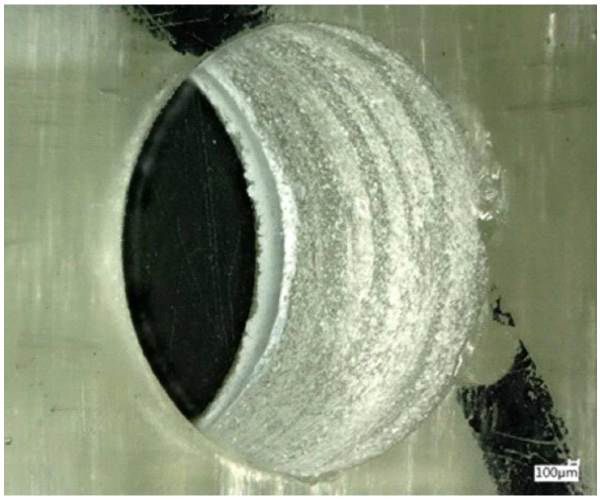

Fig. 2. Photograph of inside of a hole taken by Keyence VHX-5000 measurement microscope.

3. Results and discussion

As a result (in accordance with) of the experimental studies, the distribution of the measured surface roughness (R_a) has varied between 0.6373 and 14.1622 μm. This range is a result of the negative influence of tearing of glass fibers that damages the matrix surface quality [2–4]. After all, these are difficulties faced with machining of composite materials [2]. Besides the tearing of glass fibers and damage on the matrix, another hardship of machining is the quick wearing of cutting tools due to the hard and abrasive nature of composite materials [2–4]. In order to prevent this, each cutting tool has been used only in three drilling processes. Hence, the wearing of the tools in decreasing surface quality can be disregarded.

Surface roughness measurements in Fig. 2 are found using uncoated drilling tool, with manufacturing parameters of 4 mm drill diameter, 2800 rpm spindle speed, and 240 mm/min feed rate in drilling. This process is repeated three times, and the change in surface roughness, as shown in graph, is the result of glass fibers tearing.

Spindle speed and feed rate were more important factors in the four chosen factors for 30% modified GFRP. The most significant one was feed rate as slope gradient was very high in Fig. 4. It could be seen that choosing the lowest feed rate (720 mm/min), the highest spindle speed (3600 rpm), the biggest drill diameter (6 mm) and uncoated surface condition result in the optimum factor level combination for getting the lowest surface roughness during the drilling process. Drilling tool surface condi-

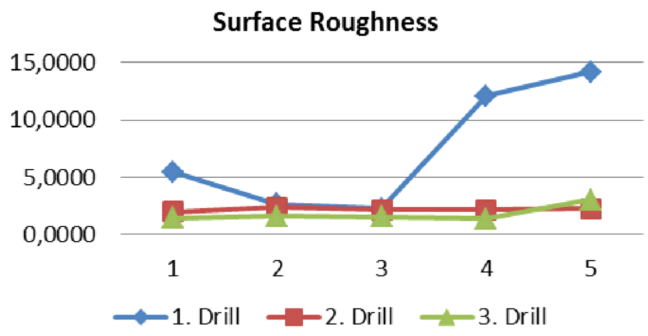

Fig. 3. Surface roughness of 3 holes manufactured under the same parameters.

tion, TiN coated or uncoated, and drill diameter were not influential factor on modified GFRP part.

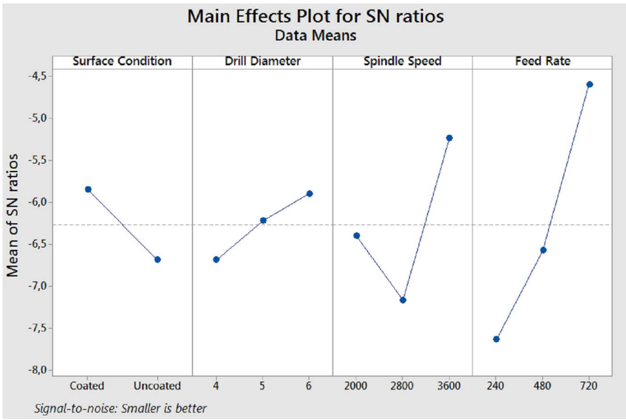

Fig. 4. Main effects plot for 30% unmodified GFRP.

It is known that delamination decreases when fiber surface of composite materials with constant glass fiber reinforcement percentages are modified [19]. Surface modification also has positive impact on surface roughness measurements. This positive influence also increases the product life span and the performance of GFRP products. Figure 2 depicts a photograph of the inside of a hole.

4. Conclusion

In this study, the change of surface roughness (R_a) of work piece dependent on surface condition of drill, drill diameter, spindle speed, and feed rate in 30% modified GFRP was experimentally investigated.

- Influence of the coating of drilling bit being HSS or TiN is insufficient;
- Increasing the feed rate decreases the surface roughness measured;
- Decreasing spindle speed increases surface roughness measurements;
- Modification of glass fiber has decreased the surface roughness measured just as did the delamination measurements;
- There are limited studies on the measurement of surface roughness on the modified GFRP composites. It is certain that the holes, which have got nominal surface roughness, will have longer life cycles according to Griffith's theorem.

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