

TEMPERATURE AND THRUST FORCE ANALYSIS ON DRILLING OF GLASS FIBER REINFORCED PLASTICS

by

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Composite materials are widely used today in many sectors. Glass fiber reinforced plastic composite materials are one of those. Glass fiber reinforced plastic composite materials are preferred due to their high thermal and tensile strength. Although consist of glass fiber reinforced composite materials from multiple layers reduces the machinability of these materials, drilling is a common method of machining for these materials. However, when the drilling parameters are not carefully selected, the material integrity is deteriorated and the desired drilling quality cannot be obtained. In this study, the effect of drilling temperature and thrust force on the material integrity was investigated. The drill bit angle, spindle speed and feedrate parameters are used for the temperature and thrust force analysis.

Key words: *glass fiber reinforced plastic, thrust force, drilling temperature, feedrate, spindle speed*

Introduction

Recently, the glass fiber reinforced polymer (GFRP) composite materials have been used in many industries including aerospace, defence, automotive, marine, chemical processing equipments, etc. due to their inherent properties such as high strength-to-weight and stiffness ratios, high damping, good corrosion resistance and low thermal expansion [1-3]. The structure of these materials consists of the combination of glass fiber as reinforcements and polymer matrix. Glass fibers provide lightweight, stiffness and strength to the composite laminates while the polymer matrix binds the fibers to gather thus transferring load to reinforced fibers, and providing protection from environmental attack to fibers [4, 5]. Due to their many advantages, they are being used to replace conventional metallic materials and machining these materials has become an important subject for manufacturers. Among other machining processes, GFRP composites are generally subjected to drilling operations due to the need for assembly structures. However, some problems like delamination, tool wear, surface roughness, hole quality and chip characteristics impair the machinability of these materials.

In drilling operations of GFRP materials, the hole quality, delamination factor and thrust forces are mostly affected by the cutting speed, feed rate and the geometry of the cutting tool in drill bit angle. The cutting forces are generally reduced at high levels of cutting speeds and increased with feed rate and tool dimensions [6-8]. Most of the experimental studies on drilling of GFRP materials are generally focused on the analysing of the drilling forces [9-13]. The delamination damages are increased at high cutting speeds due to thermal softening of

materials at high temperatures. Some other studies have also been conducted for modelling of delamination errors, cutting forces and optimization of drilling parameters for a detailed discussion [14]

In this contribution, the effects of drill bit angle, spindle speed and feed rates on the thrust force and cutting temperatures were investigated.

Materials and methods

Experimental study

Glass fiber reinforced plastics (GFRP) supplied by Cosmo Composite was used as the target material in this study. The specimens were prepared in the dimensions of $150 \times 150 \times 25 \text{ mm}^3$. Table 1 shows the mechanical properties of this composite, respectively.

Table 1. Mechanical properties of GFRP

Properties	σ_{\max} [Nmm ⁻²]	Impact resistance [kJm ⁻²]	E modulus [Nmm ⁻²]	Elongation [%]	Density [gcm ⁻³]
GFRP	144	92.53	9749	1.9	1.65

In the experiments, a JOHNFORD – 800 CNC vertical machining centre with the maximum speed of 5000 rpm and the spindle power of 15 kW was used. In order to precisely measured the process temperature, CNC codes were created by determining the hole centres in the 3-D model created in the solidwork program. The point drill identifies the centers of the thermocouple holes. Then drill holes with a drill diameter of 3 mm and a thermocouple at a depth of 20 mm, fig. 1.

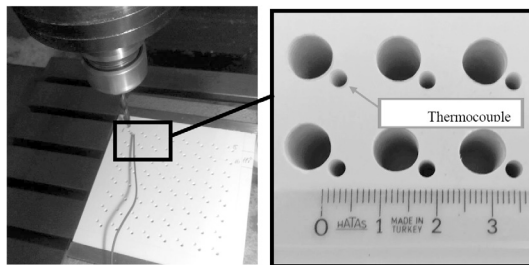


Figure 1. Drilling of thermocouple holes

The experiments were performed by using 8-mm-diameter HSS drill bits with the helix angle of 35° and the point angles 118° , 125° , 130° , and 140° . For whole experiments, cutting fluids were not used. Table 2 shows the machining conditions. A full factorial experimentation was applied by using the parameters and their factor levels given in tab. 2 [3, 15].

Table 2. Experimental conditions of GFRP

Parameters	Level 1	Level 2	Level 3	Level 4
Drill bit angle [$^\circ$]	118	125	130	140
Spindle speed [rpm]	200	300	400	500
Feed rate [mm.rev ⁻¹]	0.050	0.075	0.100	0.125

Temperature measurement

The thermocouple method was used to simultaneously measure temperature measurement during drilling operations. Especially T-type thermocouple has been used in temperature measurement method which is a frequently used as dynamic temperature measurement in orthogonal machining operations.

Then, the temperature data was transferred to the PC with 1 data per second speed. In this way the temperature change in the drilling edge is simultaneously observed. Particular attention has been paid to ensuring that the thermocouples measuring penetration temperatures are closest to the hole edge. This distance has been set at the lowest 0.5 mm, fig. 2.

Measurement of thrust force

In the drilling process, the force data is taken from the workpiece through contact between the workpiece and the load cell. In the system, CAS LS-2 a multichannel amplifier for transferring the signals called LoadCell, LoadCell to the data reading card (CAS CI-1500 INDICATOR) and finally the software compatible with the Windows operating system for the processing and graphics of the data.

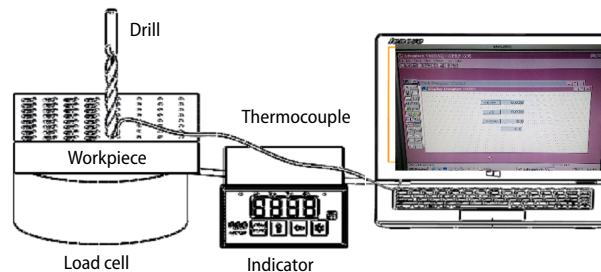


Figure 2. The test system of drilling temperature and thrust force

In order to get the loadcell data to be confidently in the experiments, the workpiece was fixed from 6 points with $M8 \times 15$ bolts on loadcell.

Materials and methods

Thrust force analysis

Glass fiber reinforced composite materials are one of the important classes of materials that change conventional engineering materials due to their excellent properties compared to metallic materials. The join of structures is an important concern. Normally the structures are joined by drilling and riveting and or by using fasteners. The effective joining is achieved by using proper drilled holes in the workpiece material. Due to the thrust developed during drilling, many common problems exist, such as fiber breakage, matrix cracking, fiber/matrix debonding, fiber pull-out, fuzzing, thermal degradation, spalling and delamination. The quality of the hole obtained in drilling is mainly depending upon thrust force. In drilling of composite laminates, the uncut thickness to withstand the drilling thrust force decreases as the drill approaches the exit plane [16].

In this context, the effect of drilling parameters on the thrust force is discussed. In figs. 3 and 4 obtained from the test results, the effects of drilling parameters on thrust force are seen. Figure 3 shows the effect of the spindle speed and the feed rate on the thrust force. It is observed here that although the increase in the spindle speed does not have a significant effect on the thrust force, the thrust force increases significantly with the increase in the feed rate. In

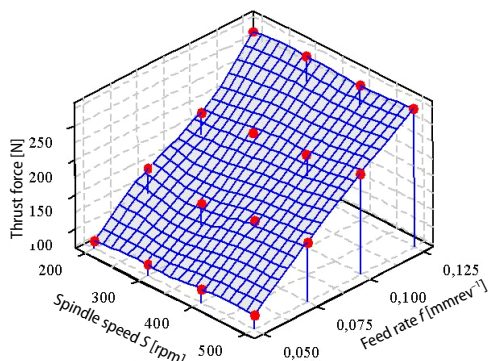


Figure 3. Thrust force variation via feed rate and spindle speed of drill bit angle 130°

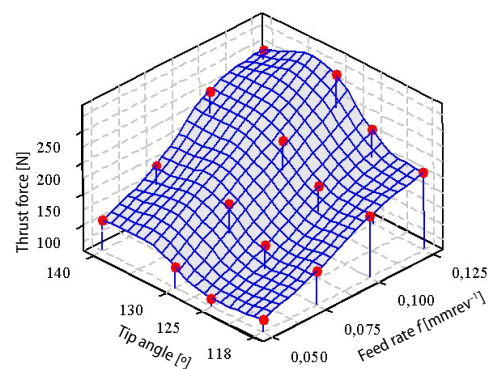


Figure 4. Thrust force variation via feed rate and tip angle of spindle speed 400 rpm

fig. 3, the values of the maximum thrust force occur at a feed rate of 0.125 mm/rev in every four cycles. The reason for this is that as feed rate is increased in previously reported studies, the amount of material increased and the amount of material removed increases in unit time in the workpiece. It has been suggested that more energy needs arise due to this increase [17, 18].

In fig. 4, the thrust force of the drill bit angle is affected. Here, the thrust force is increased due to the increased tip angle. The highest thrust force value at this point was found to be 267.028 N at widest drill bit angle. This increase is thought to cause the expanding drill bit angle to make it difficult for the drill to thrust into the workpiece and to increase thrust force.

Temperature analysis

In this study, the analysis of the temperature was one of the main concern. Since the target materials was a plastic composite, it was important to control the cutting zone temperature for the material integrity. Thus, the controlling of the heat generation is getting seriously important phenomena in the drilling of plastic composites. The diverse drilling parameters were extremely major factor of heat generation in drilling operation as previously reported several studies. The most important point that these previous studies were especially focused on non-plastic materials [19-21]. Apart from the literature, this study fulfils the lack of a gap in drilling of GFRP composite materials with different tool tip angle values. The drill tip angle is an important factor for a proper drilling operation as known [20]. For instance, the drill tip angle should be 118° for steel alloys. In order to achieve a proper drilling operation, an appropriate tip angle should be selected for target material properties. The optimum tip angle for GFRP has not determine yet. Then we want to determine the optimum tip angle amount with the other common effective parameters (spindle speed and feedrate). The effects of drilling parameters on the drilling temperatures were illustrated in figs. 5 and 6. As shown from fig. 5, the temperature is tendency of increase with increasing tool bit angle, while it was decreased with feed rate parameter. The highest temperature was recorded as 69.609°C at 140° bit angle and 0.050 mm/rev feed rate conditions. An increase in feed rate leads to shorter contact time between workpiece material and cutting tool, and the lower temperatures are recorded [17]. It is difficult to ensure the penetration of the drill bit to the GFRP materials at high bit angle. Therefore, the friction and cutting time increase with bit angles so higher temperatures are generated.

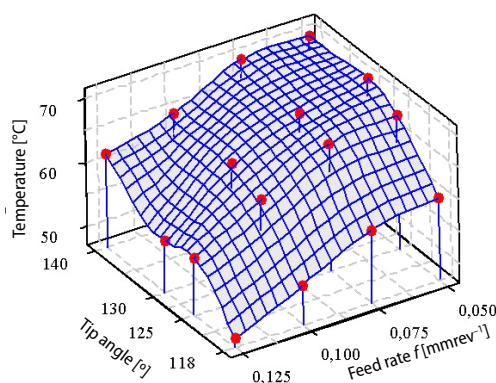


Figure 5. Temperature variation via feed rate and tip angle of spindle speed 200 rpm

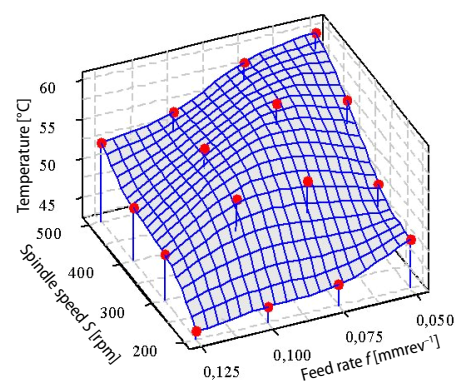


Figure 6. Temperature variation via feed rate and spindle speed of drill bit angle 140°

Figure 6 shows that the temperature is increasing with spindle speed. Since the spindle speed directly changes the cutting speed, therefore the higher temperatures are occurred as expected.

Figure 7 shows the measured temperature during drilling obtained at 200 rpm and 0.05 mm/rev experimental conditions. It can be seen from the figure that the change in the temperature based on the drill travel distance presents similar trend for all drill bit angles. The temperature are tendency of increase up to 160 seconds (20 mm distance) linearly. After this point, the highest temperature values are measured here, since the distance between the drill movement ranges of 160-180 seconds comes closest to the thermocouple.

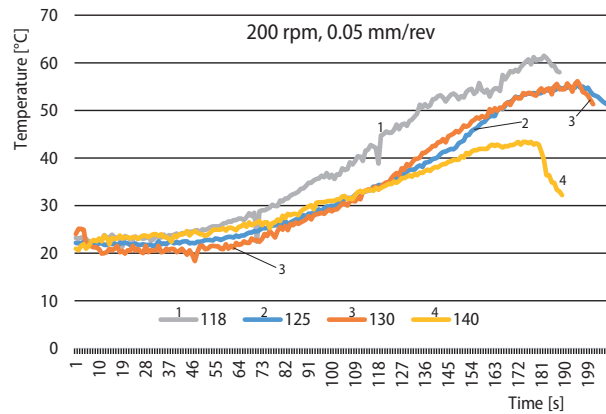


Figure 7. The variation in the temperature based on the drill travel distance for all drill bit angles

After this point, the highest temperature values are measured here, since the distance between the drill movement ranges of 160-180 seconds comes closest to the thermocouple.

Analysis of variance

The purpose of the analysis of variance (ANOVA) is to investigate which drill parameter significantly affects thrust force, and temperature. Based on the ANOVA, the relative importance of the each drill parameters on the responses were statistically gained. The analysis is carried out for the level of significance of confidence is 95%. Table 3 shows the results of the ANOVA analysis for the drill process, respectively. This table indicates the percentage contribution of each factor on the total variation, indicating their degree of influence on the results. The greater the percentage contribution, the greater the influence a factor has on the performance. According to tab. 3, the feed rate was found to be the major factor affecting thrust force (80.54%), whereas the tip angle and spindle speed factors affect thrust force by 14.23% and 0.44%, respectively. Also, tab. 3 shows the results of the ANOVA for drill temperature. It can be found that the tip angle is again the most significant drilling parameter for affecting temperature (28.93%). The spindle speed affects the temperature by 5.42%. The feed rate has less effect on temperature (4.88%).

Table 3. The ANOVA results of experimental parameters ($p < 0.05$)

	Feed rate	Spindle speed	Tip angle
Thrust force [N]	80.54 %	0.44 %	14.23 %
Temperature [°C]	4.88 %	5.42 %	28.93 %

Conclusions

Through this research, the following conclusions can be summarized as follows.

- When the thrust force and temperature results are evaluated together, it is determined that the feed rate is the most effective parameter.
- It has been determined that the spindle speed factor has no significant effect on temperature and thrust force.
- In the drilling of GFRP composite materials, small drill bit angles should be preferred,
- In GFRP drilling, the effect of spindle speed and feed rate and the results are observed to be parallel to the current lithography.

- Based on the analysis of variance results, the highly effective parameters on all responses were determined. Namely, the feed rate parameter is the main factor that has the highest importance on the thrust force, whereas the tip angle was found the most important factor on temperature.

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