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

Engin ÜNAL [*1]

[*1]Mechanical Engineering Department, Faculty of Technology, Firat University Elazig, Turkey

[*] Corresponding author; E-mail: enginunal@firat.edu.tr

Composite materials are widely used today in many sectors. Glass fiber reinforced plastic (GFRP) 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 (GFRP), thrust force, drilling temperature, feedrate, spindle speed.*

1. 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.

2. Materials and Methods

2.1. 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 150x150x25 mm^3. Table 1 shows respectively the mechanical properties of this composite.

Table 1. Mechanical properties of GFRP

Properties	σ_{max} [$N.mm^{-2}$]	Impact Resistance [$kJ.m^{-2}$]	E Modulus [$N.mm^{-2}$]	% Elongation	Density [$g.cm^{-3}$]
GFRP	144	92.53	9749	1.9	1.65

In the experiments, a JOHNFORD – 800 CNC vertical machining center 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 centers in the 3D 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 (Figure 1).

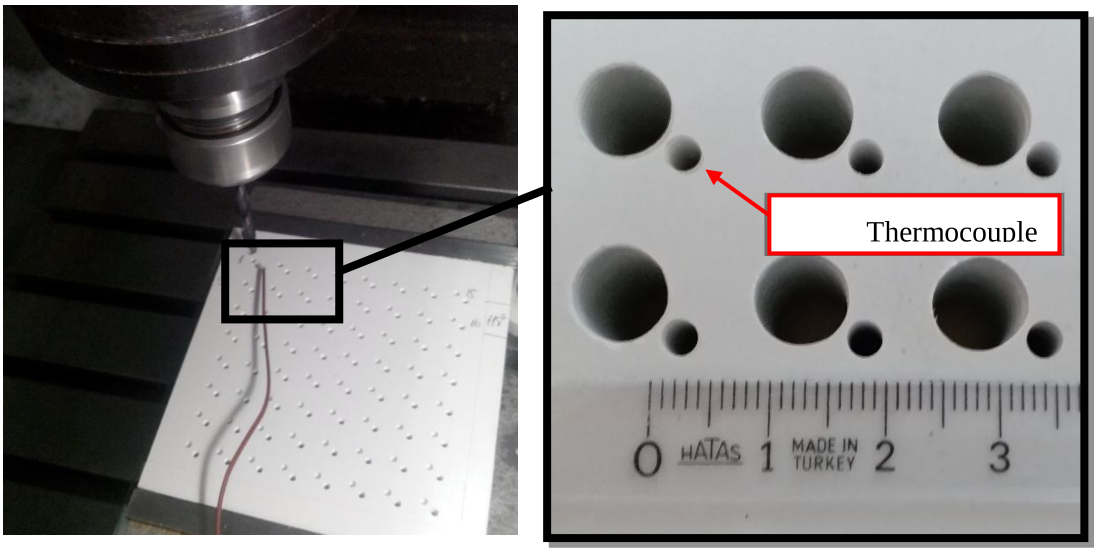

Figure 1. Drilling of thermocouple holes

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 Table 2 [3, 15].

Table 2. Experimental conditions of GFRP

Parameter	Level 1	Level 2	Level 3	Level 4
Drill bit angle [°]	118	125	130	140
Spindle speed [rpm]	200	300	400	500
Feedrate [mm.rev^{-1}]	0.050	0.075	0.100	0.125

2.2. 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 1data / sec 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 0.5mm (Figure 2).

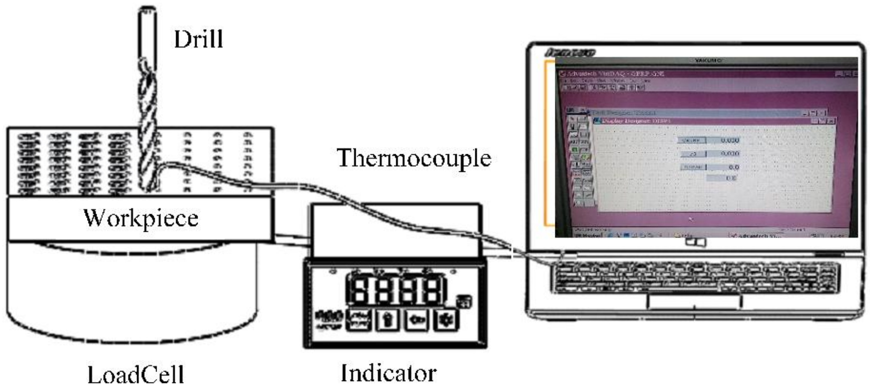

Figure 2. The test system of drilling temperature and thrust force

2.3. 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.

In order to get the loadcell data to be confidently in the experiments, the workpiece was fixed from 6 points with M8x15 bolts on loadcell.

3. Materials and Methods

3.1. 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 Figure 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, the values of the maximum thrust force occur at a feed rate of 0.125 mm.rev^{-1} 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].

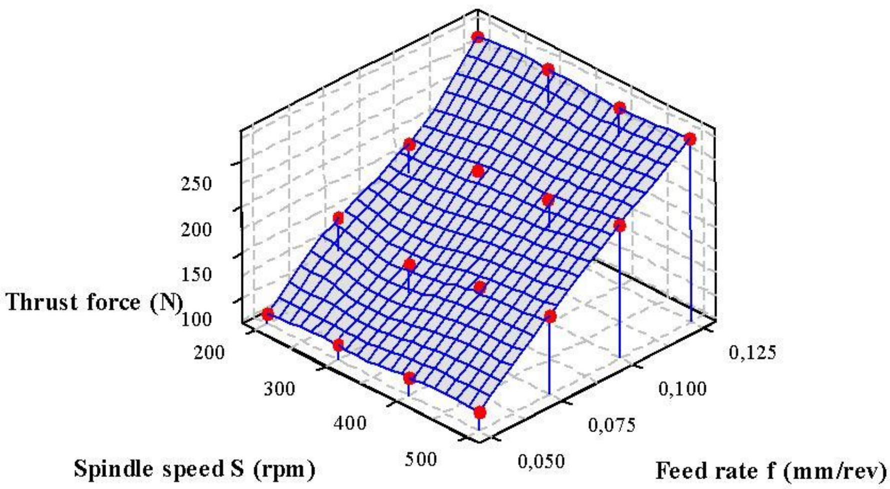

Figure 3. Thrust force variation via feed rate and spindle speed of drill bit angle 130°

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.

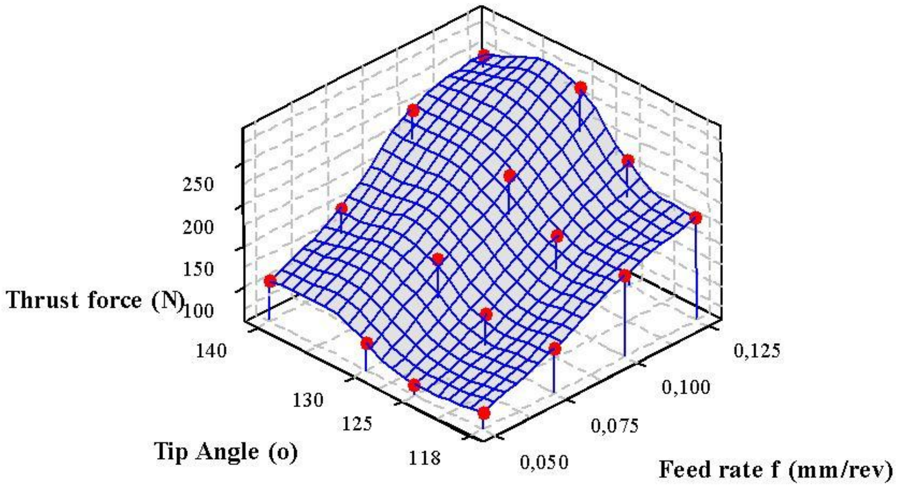

Figure 4. Thrust force variation via feed rate and tip angle of spindle speed 400 rpm

3.2. 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 degree 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 $mm.rev^{-1}$ feed rate conditions. An increase in feed rate leads to shorter contact time between workpice material and cutting tool, and the lower temperatures are recorded [17]. On the other hand, 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.

On the other hand, Fig. 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.

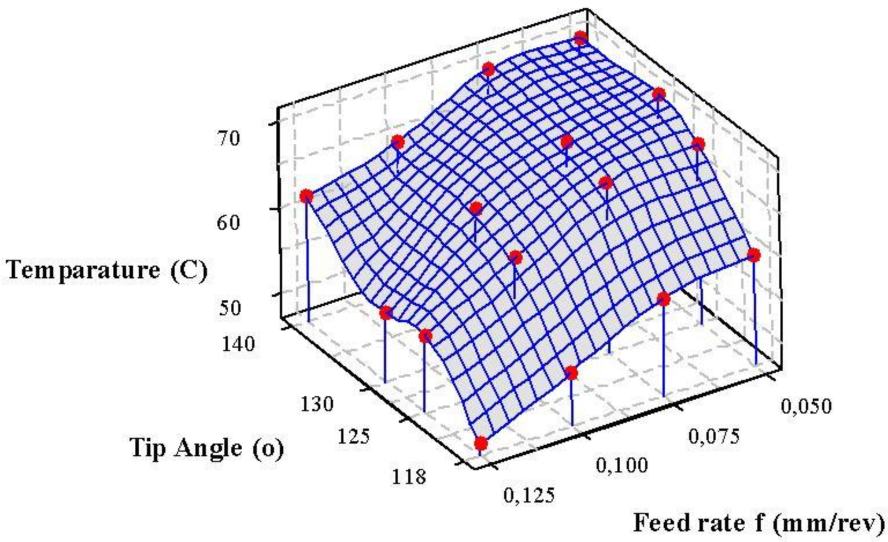

Figure 5. Temperature variation via feed rate and tip angle of spindle speed 200 rpm

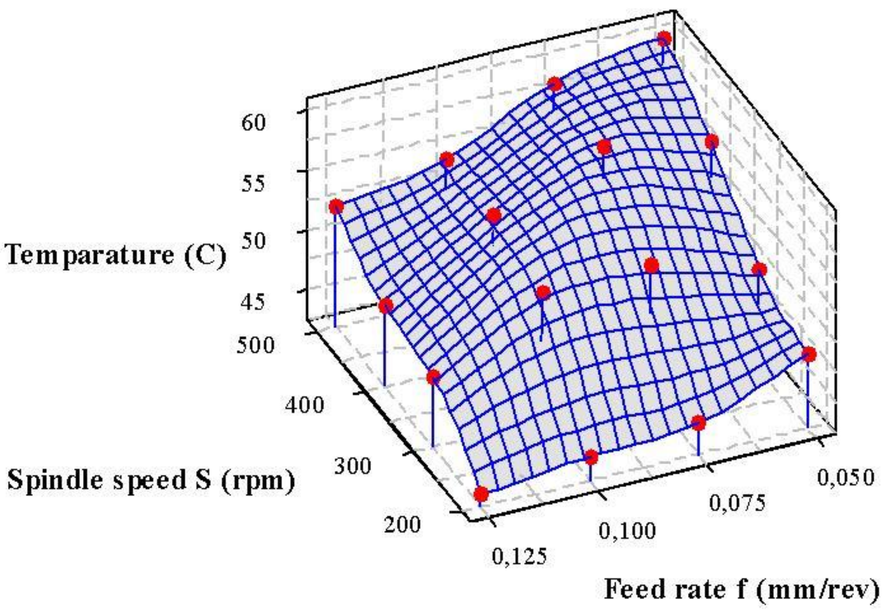

Figure 6. Temperature variation via feed rate and spindle speed of drill bit angle 140°

Figure 7 shows the measured temperature during drilling obtained at 200 rpm and 0.05 $mm.rev^{-1}$ 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 s (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 s comes closest to the thermocouple.

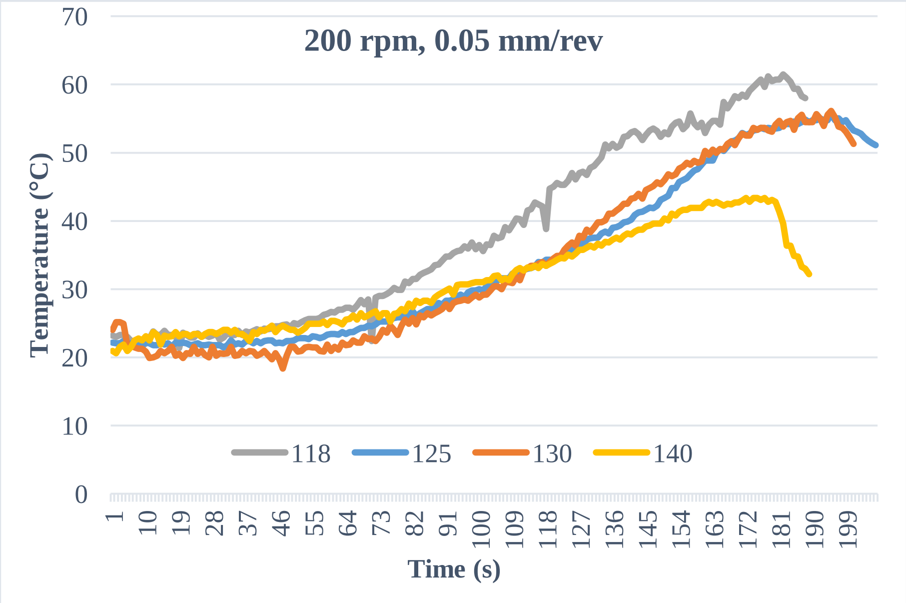

Figure 7. The variation in the temperature based on the drill travel distance for all drill bit angles

3.3. Analysis of Variance (ANOVA)

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 Table 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 Table 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. 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 %

4. Conclusions

Through this research, the following conclusions can be summarized:

- 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 (ANOVA) 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.

References

[1] Grilo, T.J., et al., Experimental Delamination Analyses Of CFRPs Using Different Drill Geometries, *Compos. Part B Eng.*, *45* (2013), 1, pp. 1344–1350

[2] Kumar, D., et al., Experimental Investigation Of Delamination And Surface Roughness In The Drilling Of GFRP Composite Material With Different Drills, *Adv. Manuf. Polym. Compos. Sci.*, *2* (2016), 2, pp. 47–56

[3] Zarif Karimi, N., et al., Effect Of The Drilling Process On The Compression Behavior Of Glass/Epoxy Laminates, *Compos. Struct.*, *98* (2013), pp. 59–68

[4] El-Sonbaty, I., et al., Factors Affecting The Machinability Of GFR/Epoxy Composites, *Compos. Struct.*, *63* (2004), 3–4, pp. 329–338

[5] Xu, Q., et al., Influence Of Fiberglass Mesh On Flammability Of EPS Used As Insulation Of Buildings, *Therm. Sci.*, *2016* (2016), January

[6] Ramirez, C., et al., Tool Wear Monitoring And Hole Surface Quality During CFRP Drilling, *Procedia CIRP*, *13* (2014), pp. 163–168

[7] Hufenbach, W., et al., Optimisation Of The Rivet Joints Of The CFRP Composite Material And Aluminium Alloy, *J. Achiev. Mater. Manuf. Eng.*, *20* (2007), 1–2, pp. 119–122

[8] Singh, I., et al., Drilling Of Uni-Directional Glass Fiber Reinforced Plastics: Experimental And Finite Element Study, *Mater. Des.*, *29* (2008), 2, pp. 546–553

[9] Fernandes, M., Cook, C., Drilling Of Carbon Composites Using A One Shot Drill Bit. Part I: Five Stage Representation Of Drilling And Factors Affecting Maximum Force And Torque, *Int. J. Mach. Tools Manuf.*, *46* (2006), 1, pp. 70–75

[10] Lin, S.C., Chen, I.K., Drilling Carbon Fiber-Reinforced Composite Material At High Speed, *Wear*, *194* (1996), 1–2, pp. 156–162

[11] Chen, W.C., Some Experimental Investigations In The Drilling Of Carbon Fiber-Reinforced

Plastic (CFRP) Composite Laminates, *Int. J. Mach. Tools Manuf.*, *37* (1997), 8, pp. 1097–1108

[12] Chandrasekharan, V., et al., A Mechanistic Approach To Predicting The Cutting Forces In Drilling: With Application To Fiber-Reinforced Composite Materials, *J. Eng. Ind.*, *117* (1995)

[13] Chandrasekharan, V., *A Model To Predict The Three-Dimensional Cutting Force System For Drilling With Arbitrary Point Geometry*, University of Illinois at Urbana-Champaign, 1996

[14] Abrão, A.M., et al., Drilling Of Fiber Reinforced Plastics: A Review, *J. Mater. Process. Technol.*, *186* (2007), 1–3, pp. 1–7

[15] Sunny, T., et al., Experimental Studies On Effect Of Process Parameters On Delamination In Drilling GFRP Composites Using Taguchi Method, *Procedia Mater. Sci.*, *6* (2014), Icmpc, pp. 1131–1142

[16] Rajamurugan, T. V., et al., Modelling And Analysis Of Thrust Force In Drilling Of GFRP Composites Using Response Surface Methodology (RSM), *Procedia Eng.*, *38* (2012), pp. 3757–3768

[17] Ramesh, M., et al., Influence Of Tool Materials On Thrust Force And Delamination In Drilling Sisal-Glass Fiber Reinforced Polymer (S-GFRP) Composites, *Procedia Mater. Sci.*, *5* (2014), pp. 1915–1921

[18] Karaca, F., et al., Influence Of Orthopaedic Drilling Parameters On Temperature And Histopathology Of Bovine Tibia: An In Vitro Study, *Med. Eng. Phys.*, *33* (2011), 10, pp. 1221–1227

[19] Bono, M., Ni, J., The Effects Of Thermal Distortions On The Diameter And Cylindricity Of Dry Drilled Holes, *Int. J. Mach. Tools Manuf.*, *41* (2001), 15, pp. 2261–2270

[20] Kalidas, S., et al., Experimental Investigation Of The Effect Of Drill Coatings On Hole Quality Under Dry And Wet Drilling Conditions, *Surf. Coatings Technol.*, *148* (2001), 2–3, pp. 117–128

[21] Bono, M., Ni, J., A Method For Measuring The Temperature Distribution Along The Cutting Edges Of A Drill, *J. Manuf. Sci. Eng.*, *124* (2002), 4, pp. 921–923