

**INVESTIGATION OF FACTORS HAVING EFFECT ON DEFORMATION
IN DRILLING OF GLASS FIBER REINFORCED COMPOSITE MATERIALS**

Yahya Hışman ÇELİK¹, İhsan PİLATİN²

¹Mechanical Engineering Department, Faculty of Engineering-Architectural, Batman University,
Turkey, E-mail: yahyahisman.celik@batman.edu.tr, yahyahisman@gmail.com.

²English Lecturer of Batman University, Turkey

Abstract

Glass fiber reinforced plastic (GFRP) composite materials are used in various fields because of their superior properties. The drilling process is the method mostly used in processing GFRP composites in chipping form. Since they are hard and abrasive, there appear problems in drilling these materials. The damages in entrance and exit of the holes are the most important of these problems. Therefore, in this study, drilling of GFRP composite material produced via lay-up method was executed at the cutting speeds of 60, 90 and 120 m/min; and at feed rate values of 100, 200 and 300 mm/min; and by means of drill at 4, 7, 10 mm possessing point angles 90°, 118° and 140° without using cutting fluid. Depending on the damage in entrance and exit of the holes, deformation factor was calculated. It was observed that the damage occurring in the exit of the holes was greater than that of the entrance of the holes. It was found out that the minimum deformation occurred at low cutting speed and feed rates.

Key words: GFRP; Composites; Drilling; Surface Roughness; Deformation.

1. INTRODUCTION

Glass fiber reinforced composite materials (GFR) produced by means of various methods are found in the field of applications much more than any other engineering materials in industry (Tsao and Hocheng, 2003). Because, they have properties such as light in weight, low thermal conductivity, resistant to corrosion, low cost and have high specific strength etc. (Kılıçkap, 2010a; Mohan et al., 2007). Nevertheless, due to its non-homogeneous and anisotropic specialties, these composites are difficult to be able to machine (Palanikumar et al., 2008).

GFR composite materials are especially used for drilling operation of secondary applications due to the need for assembly structures (Hocheng and Tsao, 2005). Some problems occur on materials during drilling. These problems are delamination, tool wear, surface roughness, hole quality, chip characteristic (Abdul Budan et al., 2011). One of the major problems is delamination, which is because of the heterogeneity of fiber and matrix (Faraz et al., 2011; Tsao, 2008). Delamination leads to diminishing the structural integrity of the joints and it causes poor assembly tolerance (Palanikumar et al., 2012; Grimmer and Dharan, 2010; Seif and Khashaba, 2007). Delamination and others damage effect drilling parameters, tool properties and structure of composite materials (Mihai-Bozgon and Paul, 2011).

Numerous studies have been conducted on the delamination and surface roughness in drilling composite materials. Rao et al. (2008) performed analyses about the influence of drilling parameters (feed rate, spindle speed) of the damage. Palanikumar (2010) developed a mathematical model to predict the delamination factor and surface roughness in drilling composite materials. He indicated that not only the increase in spindle speed reduced the surface roughness and delamination but also the

most influential parameters influencing the surface roughness and delamination were feed rate. Influence over delamination of spindle speed and feed rate have been examined by Kılıçkap (2010b, 2010c). He found similar result as Rao (2008) and Palanikumar (2010). In addition, delamination and surface roughness are effected by drilling geometry and materials of tool. Increase in point angle increases delamination. Decrease in point angle increases surface roughness. Drill diameters have less influence than feed rate (Kumar et al., 2012; Işık and Ekici, 2010; Kılıçkap, 2010d; Rankumar et al. 2002). However, most effective parameters for delamination is feed rate because the increase of feed rate increases the thrust force. Therefore, delamination occurs in the entrance and the exit of hole (Faraz et al. 2011; Tsao, 2008; Tsao and Hocheng, 2003). To determinate the damage in drilling, not only experimental study but also modeling and optimization processes has been conducted over composite materials. Lathe et al. (2011) conducted the modeling and optimization of process parameters for delamination in drilling GFR composite materials. They have obtained the formulation of delamination factors. They took spindle speed, feed rate and drill diameter for formulate of delamination factors into account. Lathe and Senthilkumar (2010) performed the modeling and analysis of surface roughness parameters in drilling composites using fuzzy logic. As input parameters of fuzzy logic were selected by spindle speed, feed rate and drill diameter, output parameters were selected by the surface roughness. They determined that the increase of spindle speed reduced the surface roughness and the increase feed rate and drill diameters increased the surface roughness. In another study, Lathe and Senthilkumar (2009) used fuzzy logic for analyses of thrust force in drilling GFR composites. They found that increasing of spindle speed reduced thrust force and increasing feed rate and drill diameter increased thrust force. Karnik et al. (2008) used artificial neural network for delamination in drilling carbon fiber reinforced plastic. Mishra et al (2010) conducted the neural network approach for estimation the residual tensile strength after drilling unidirectional GFR plastic laminates.

When performed experimental study was examined, all parameters seemed to be accounted as individual. Therefore, an experimental study was conducted for delamination in drilling of GFRP composite materials. At the experimental study, all parameters (feed rate, spindle speed, drill diameter, point angle) were taken into account for delamination.

2. MATERIAL AND METHOD

2.1. Material

To carry out the experimental study, GFR composite materials produced by hand layup methods were used. This material consisted of a density of 1.9 gr/cm^3 , an angular of among fibers 90° , mat shapes and 18 layers. Mechanical properties of GFRP composite materials are given in Table 1.

Table 1. Mechanical properties of GFRP composite

Parameters	Values
The tensile strength (N/mm^2)	300
The pressure strength (N/mm^2)	500
The bend strength (N/mm^2)	400
The module of elasticity (N/mm^2)	20

2.2. Drilling process and cutting tools

Drilling experiments were carried out by means of HUMMER VMC-1000 CNC milling machine because it was strong, new, without vibration and useful. In addition, at the experimental study, 4 mm, 7 mm and 10 mm diameters HSS drills which had different point angles (90°, 118°, and 140°) were used.

2.3. Delamination

Delamination factors vary depending on cutting parameters. It is observed that the entrance and the exit of hole. To determine of delamination around holes, it is necessary to know the maximum diameter in delamination zone. Delamination factory (F_d) is determined by following equations (Abrao et al., 2008; Davim et al., 2004).

$$F_d = (d_{max}/d) \quad (1)$$

In which, " d_{max} " is maximum diameter of the delamination zone and " d " is diameter of drill. Deformations around the hole are given in Fig. 1.

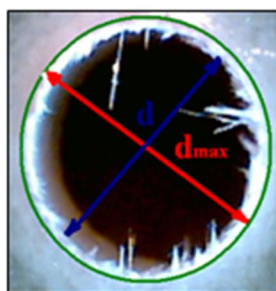


Fig.1. Determination of the deformation factor

2.4. Experiments

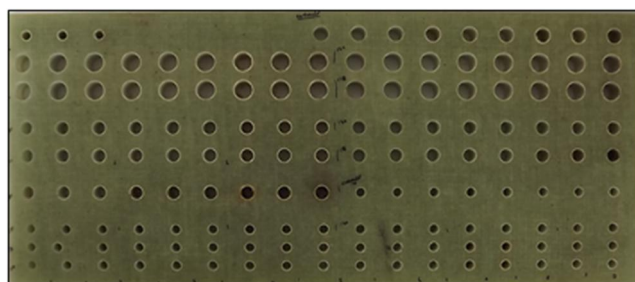
The specimens 500x500x10 mm in size were fixed to Hummer VMC-100 CNC machine. For each test, three cutting tools were employed. After three tests, the drill was changed to avoid tool wear due to absence of cutting fluids. Experiments were performed at different drilling parameters. The drilling parameters are given in Table 2. To determine the delamination factors of the entrance and the exit of hole, a Nikon Epiphot 200 optic microscope was used for cutting parameters. Delamination factors were calculated with regard to the deformation occurring at the entrance and the exit.

Table 2. Drilling parameters and values

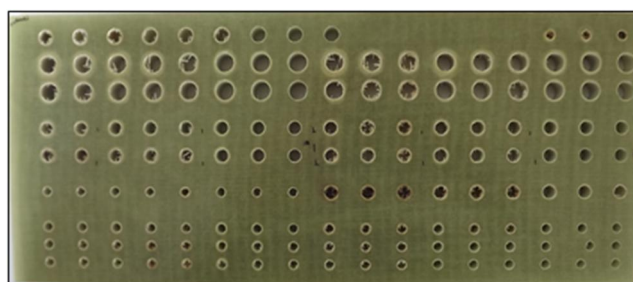
Cutting speed (m/min)	Feed rate (mm/min)	Drills diameter (mm)	Point angles (°)
60	100	4	90
90	200	7	118
120	300	10	140

3. EXPERIMENTAL RESULTS

To determine the minimum deformation of the GFRP composite material, a number of experiments were conducted. Totally 148 holes were drilled in the experiments. It was observed that the deformation increased during machining of these materials since cutting parameters, cutting forces and stresses were affected by Karpat et al. (2012). In connection with this case, it can easily be seen that the deformation in the exit of the hole is greater than the deformation in the entrance. The images of entrance and exit of holes obtained as the result of drilling are given in Fig. 2a and b.



a) Entrance of holes



b) Exit of holes

Fig.2. Drilled samples image

The deformation change is given in Fig. 3, depending on the drill with 7 mm diameter and drill point angle for 90 m/min cutting speed and feed rates in the entrance of the hole.

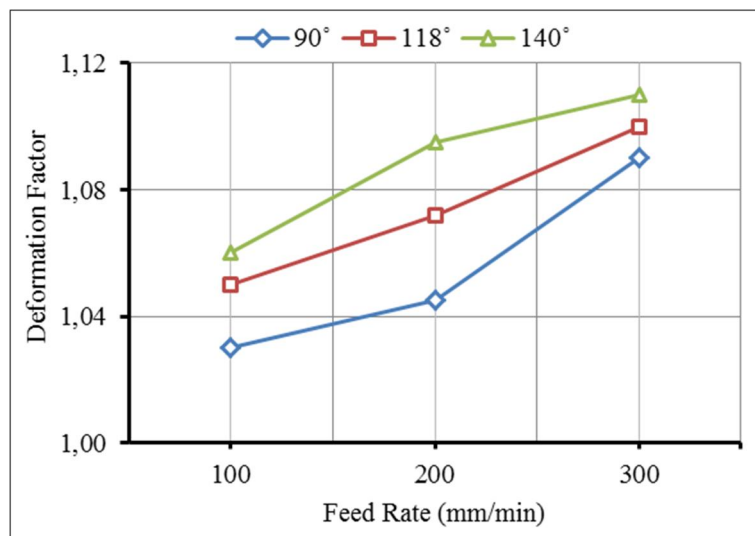


Fig.3. Determining of the deformation factor for different feed rates and point angles

It was observed that the deformation factor also increased as the feed rate was increased. Furthermore, increased drill point angle raised the deformation factor. Minimum deformation was found as 1.03 with 90° point angle drill and at 100 mm/min. Feed rate. Maximum deformation was figured out as 1.11 with 140° point angle drill and 300 mm/min. Feed rate.

The deformation changes in the entrance of the hole are given in Fig. 4 with respect to 7 mm diameter drill and drill point angle for 200 mm/min feed rate and cutting speed. Feed rate and drill point angle as well as increase in cutting speed caused the increase of deformation factor.

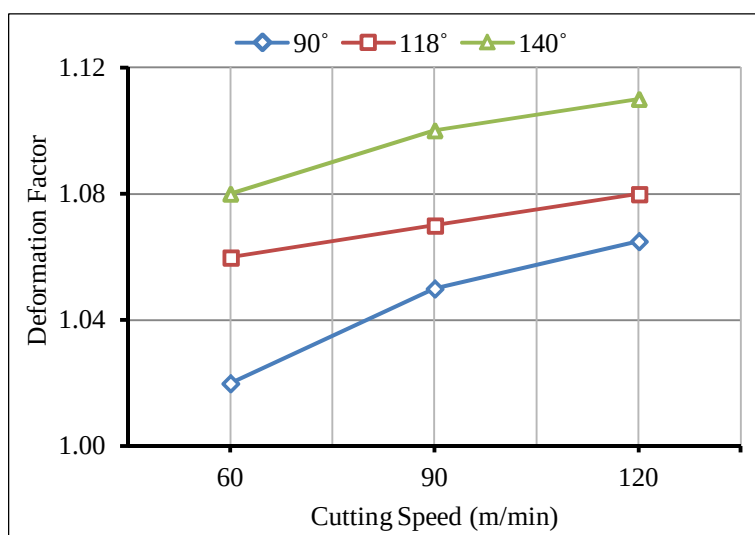


Fig.4. Determining of the deformation factor for different cutting speeds and point angles

Minimum deformation was calculated as 1.02 with 90° point angle drill for 60 m/min. Cutting speed. On the other hand, maximum deformation was found as 1.11 with 140° point angle drill for 120 m/min. Cutting speed.

The effect of drill diameter on deformation in the entrance of the hole is given in Fig. 5 depending on the feed rate and in Fig. 6 depending on cutting speed. The increase of feed rate, cutting speed and drill point angle in addition to the increase in drill diameter all caused the increase in deformation factor. Minimum deformation was approximately worked out as 1.02 at the case when drill point angle was 90°, cutting speed was 60 m/min., feed rate was 100 mm/min. and the drill diameter was 4 mm. Maximum deformation was found approximately as 1.16 when drill point angle was 140°, cutting speed was 120 m/min. feed rate was 300 mm/min. and the drill diameter was 10 mm.

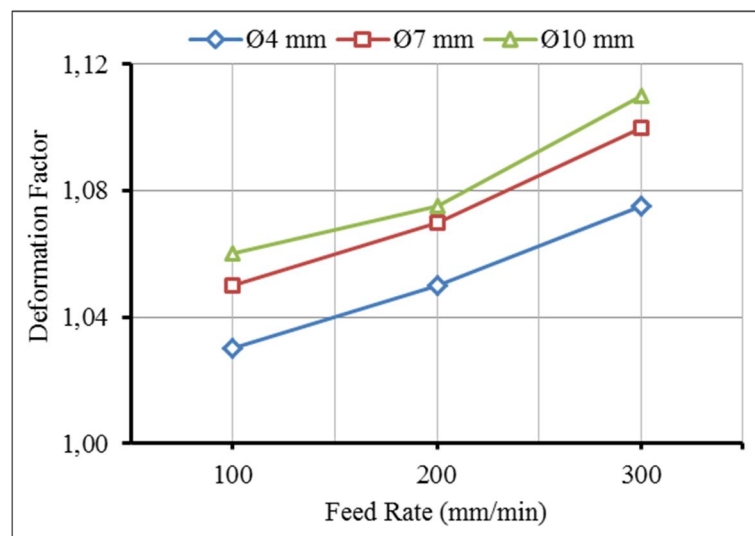


Fig.5. Determining of the deformation factor for different feed rates and drill diameter at 90 m/min cutting speed and 118° point angles

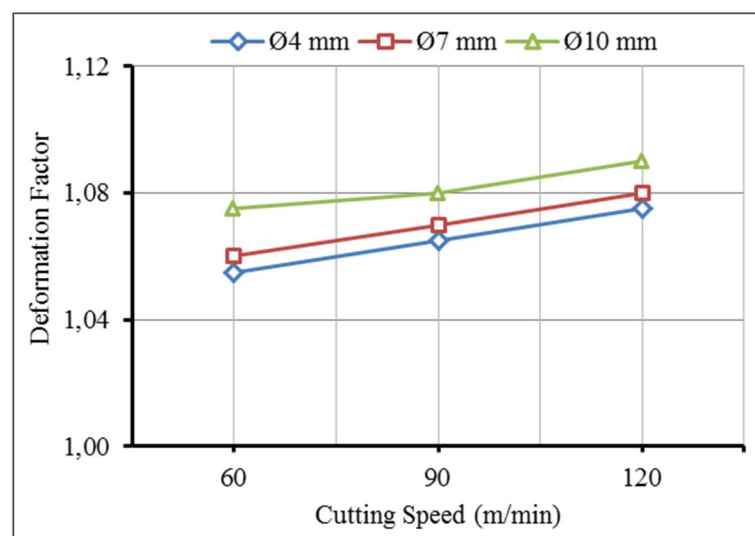


Fig.6. Determining of the deformation factor for different cutting speeds and drill diameter at 200 mm/min feed rate and 118° point angles

As in the entrance of the hole, the factors increasing the deformations increased deformation in the exit of the hole as well. However, in connection with drilling forces and stresses, it was observed that the deformations occurring in the exit of the holes were greater than those in the entrances. The deformation changes occurring in the hole exits are given in Fig. 7-10 depending on the drilling parameters.

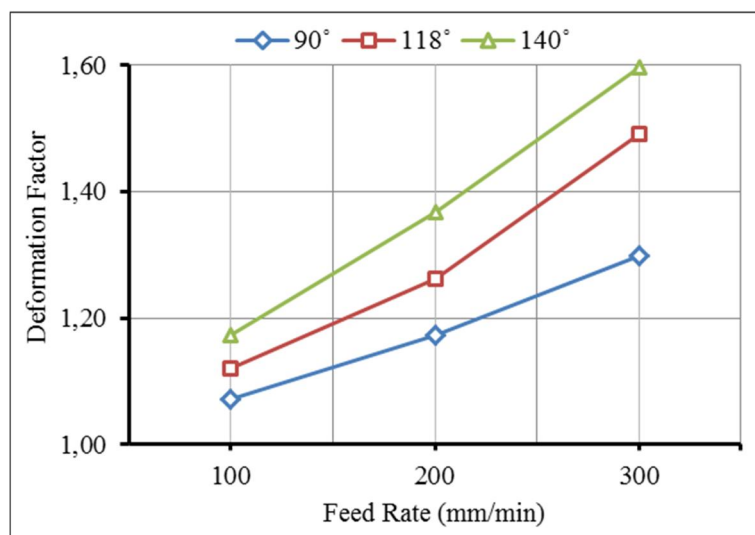


Fig.7. Determining of the deformation factor for different feed rates and point angles at 90 m/min cutting speed and Ø7 mm drill diameter

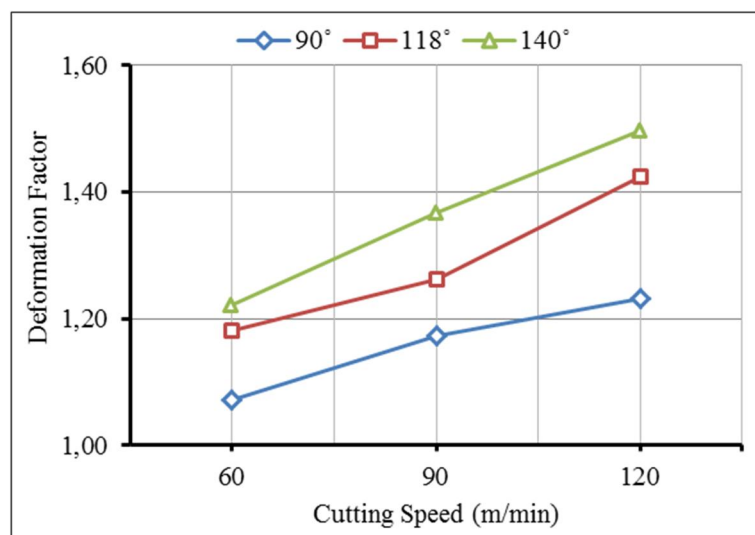


Fig.8. Determining of the deformation factor for different cutting speeds and point angles at 200 mm/min feed rate and Ø7 mm drill diameter

Increase in feed rate, cutting speed, drill point angle and drill diameter at the hole exit caused the increase in deformation factor. Minimum deformation was approximately worked out as 1.02 at the

case when drill point angle was 90° , cutting speed was 60 m/min., feed rate was 100 mm/min. and the drill diameter was 4 mm. However, Maximum deformation was found approximately as 1.74 when drill point angle was 140° , cutting speed was 120 m/min. feed rate was 300 mm/min. and the drill diameter was 10 mm.

It is thought that when the feed rate is high, this causes to apply more strength to the material being drilled, therefore, this causes the fibres of the composite material, which are in layers, fly off (Krishnamorty et al., 2009). It is thought that the cutting speed, drill point angle and drill diameter increase raises the friction between the drill and surface, which will cause both the tool and material to heat, and this will cause deformation during drilling.

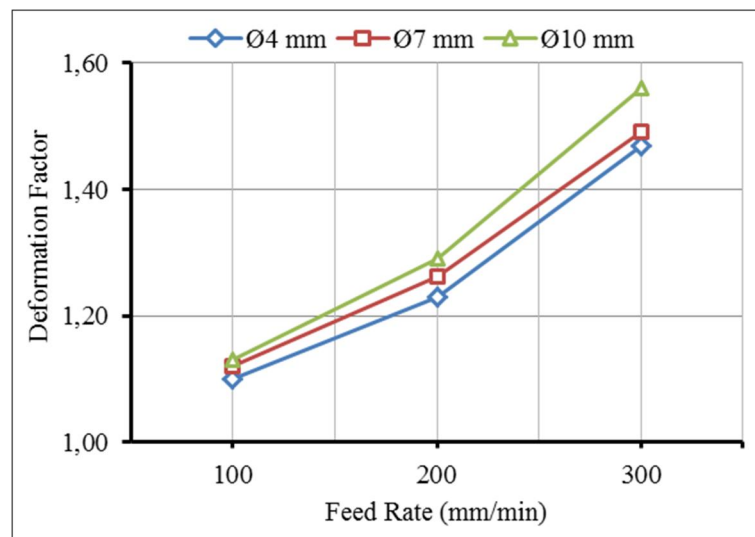


Fig.9. Determining of the deformation factor for different feed rates and drill diameters at 90 m/min cutting speed and 118° point angles

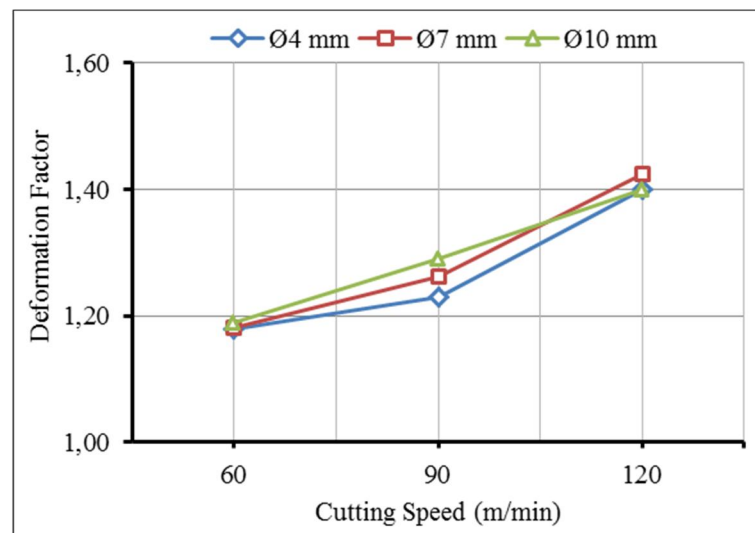


Fig.10. Determining of the deformation factor for different cutting speeds and drill diameters at 200 mm/min feed rate and 118° point angles

4. CONCLUSION

In this study, the effects of cutting speed, feed rate, drill diameter and drill point angles on deformation occurring hole entrances and exits during drilling of GFRP composite material was investigated. The following results were found depending on the data obtained:

- It was seen that feed rate, cutting speed, drill point angle and drill diameter affected deformation factor.
- It was observed that the most important factor having an effect on deformation was feed rate, while the least influential effect was drill diameter.
- The minimum deformation at both hole entrance and exit was obtained when the drill point angle was 90°, cutting speed was 60 m/min., feed rate was 100 mm/min. and drill diameter was 4 mm.
- The maximum deformation at both hole entrance and exit was obtained when the drill point angle was 140°, cutting speed was 120 m/min., feed rate was 300 mm/min. and drill diameter was 10 mm.

REFERENCES

- Abdul Budan, D & Basavarajappa, S & Prasanka Kumar, M & Ajith, GJ 2011, *Influence of fibre volume reinforcement in drilling GFRP laminates*, J. Eng. Sci. Tech. 6(6), 733-744.
- Abrao, AM & Campos Rubio, JC & Faria, PE & Davim, JP 2008, *The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite*, Mater. Des. 29, 508-513.
- Davim, JP & Reis, P & António, CC 2004, *Drilling fiber reinforced plastic (FRPs) manufactured by hand lay-up: influence of matrix (Viapal VUP 9731 and ATLAC 382-05)*, J. Mater. Proc. Tech. 155(156), 1828-1833.
- Faraz, A & Heymann, T & Biermann, D 2011, *Experimental investigation on drilling GFRP epoxy composite laminates using specialized and conventional uncoated cemented carbide drill*, Mater. Manuf. Proc. 26, 609-617.
- Grimmer, CS & Dharan, CKH 2010, *Enhancement of delamination fatigue resistance in carbon nanotube reinforced glass fiber/polymer composites*, Compos. Sci. Tech. 70, 901-908.
- Hocheng, H & Tsao, CC 2005, *Effects of special bits on drilling induced delamination of composite materials*, Int. J. Mach. Tools & Manuf. 46, 1403-1416.
- Işık, B & Ekici, E 2010, *Experimental investigations of damage analysis in drilling of woven glass fiber-reinforced plastic composites*, Int. J. Adv. Manuf. Tech. 49, 861-869.
- Karnik, SR & Gaitonde, VN & Campos Rubio, J & Esteves Correia, A & Ambão, AM & Paulo Davim, J 2008, *Delamination analysis in high speed drilling of carbon fiber reinforced plastic (GFRP) using artificial neural network model*, Mater. Des. 29, 1768-1776.
- Karpat, Y & Bahtiyar, O & Değer, B 2012, *Mechanistic force modeling for milling of unidirectional carbon fiber reinforced polymer laminates*, Int. J. Mach. Tools & Manuf. 56, 79-93.
- Kılıçkap, E 2010a, *Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite*, Exp. Sys. Applica. 37, 6116-6122.
- Kılıçkap, E 2010b, *Analysis and modeling of delamination factor in drilling glass fiber reinforced plastic using response surface methodology*, J. Compos. Mater. 45(6), 727-736.

- Kılıçkap, E 2010c, *Determination of optimum parameters on delamination in drilling of GFRP composites by Taguchi method*, Indian J. Eng. Mater. Sci. 17, 265-274.
- Kılıçkap, E 2010d, *Investigation into the effect of drilling parameters on delamination in drilling GFRP*, J. Reinforced Plastic & Compos. 29(23), 3498-3503.
- Krishnamorthy, A & Boopathy, SR & Palanikumar, K 2009, *Delamination analyses in drilling of GFRP composites using response surface methodology*, J. Compos. Mater. 43(24), 2885-2902.
- Kumar, S & Chauhan, SR & Rakesh, PK & Singh, I & Davim, JP 2012, *Drilling of glass fiber/vinyl ester composites with fillers*, Mater. Manuf. Proc. 27, 314-319.
- Latha, B & Senthilkumar, VS 2009, *Analysis of thrust force in drilling glass fiber reinforced plastic composites using Fuzzy Logic*, Mater. Manuf. Proc. 24, 509-516.
- Latha, B & Senthilkumar, VS 2010, *Modeling and analysis of surface roughness parameters in drilling GFRP composites using Fuzzy Logic*, Mater. Manuf. Proc. 25, 817-827.
- Latha, B & Senthilkumar, VS & Palanikumar, K 2011, *Modeling and optimization of process parameters for delamination in drilling glass fiber reinforced plastic (GFRP) composites*, Mach. Sci. Tech. 15, 172-191.
- Mihai-Bozgan, L & Paul, X 2011, *Experimental analysis of drilling fiber reinforced composites*, Int. J. Mach. Tools & Manuf. 51, 937-946.
- Mishra, R & Malik, J & Singh, I & Paulo Davim, J 2010, *Neural network approach for estimating the residual tensile strength after drilling in unidirectional glass fiber reinforced plastic laminates*, Mater. Des. 31, 2790-2795.
- Mohan, NS & Kulkarni, SM & Ramachandra, A 2007, *Delamination analysis in drilling process of glass fiber reinforced plastic (GFRP) composite materials*, J. Mater. Proc. Tech. 205-271.
- Palanikumar, K & Prakash, S & Shanmugam, K 2008, *Evaluation of delamination in drilling GFRP composites*, Mater. Manuf. Proc. 23, 858-864.
- Palanikumar, K 2010, *Modeling and analysis of delamination factor and surface roughness in drilling GFRP composites*, Mater. Manuf. Proc. 25, 1059-1067.
- Palanikumar, K & Latha, B & Senthilkumar, VS & Paulo Davim, J 2012, *Analysis on drilling of glass fiber-reinforced polymer (GFRP) composites using grey relational analysis*, Mater. Manuf. Proc. 27, 297-305.
- Rankumar, J & Malhotra, SK & Krishnamurthy, R 2002, *Studies on drilling of glass/epoxy laminates using coated high-speed steel drills*, Mater. Manuf. Proc. 17(2), 213-222.
- Rao, BS & Rudramoorthy, R & Srinivas, S & Rao, BN 2008, *Effect of drilling induced damage on notched tensile and pin bearing strengths of woven GFR-epoxy composites*, Mater. Sci. Eng. 472, 347-352.
- Seif, MA & Khashaba, UA & Rojas-Oviedo, R 2007, *Measuring delamination in carbon/epoxy composites using a shadow moiré laser based imaging technique*, Compos. Struc. 79, 113-118.
- Tsao, CC & Hocheng, H 2003, *The effect of chisel length and associated pilot hole on delamination when drilling composite materials*, Int. J. Mach. Tools & Manuf. 43, 1087-1092.
- Tsao, CC 2008, *Experimental study drilling composite materials with step-core drill*, Mater. Des. 29, 1740-1744.