Research Journal of Recent Sciences ISSN 2277-2502
Vol. **2(8),** 47-51, August **(2013)** *Res.J.Recent Sci.*

Effect of Process Parameters on Delamination, Thrust force and Torque in Drilling of Carbon Fiber Epoxy Composite

Nagaraja[1]*, Mervin A Herbert[1], Divakara Shetty[2], Raviraj Shetty[2] and B Shivamurthy[2]
[*1]Department of Mechanical Engineering, National Institute of Technology Karnataka, Srinivasa Nagar, Surathkal, Mangalore-575025, INDIA
[2]Dept. of Mechanical and Manufacturing Eng., Manipal Institute of Technology, Manipal University, Manipal-576 104, Karnataka, INDIA

Available online at: www.isca.in
Received 15th March 2013, revised 1st May 2013, accepted 3rd July 2013

Abstract

Drilling is the most frequently used machining process for carbon fiber reinforced polymer (CFRP) composite laminates owing to the need for structural joining. Delamination is a major problem associated with drilling of CFRP composites. Therefore, it is important to investigate and minimize the drilling induced delamination that can affect structural integrity of materials, assembly tolerance, mechanical properties of produced parts, and the quality of drilled holes. Thrust force has been cited as the main cause of delamination. The damage caused at the entrance and the exit of the drilled hole is characterized by delamination factor. In this paper, the drilling tests are carried on bi-directional carbon fiber reinforced epoxy composite (BCFREC) laminate by using high speed steel drill at different feed rate and spindle speed. The study reveals that delamination tendency, thrust force and torque increase with the increase in feed rate and spindle speed. The drilling - induced delamination is visualized and measured by using high resolution scanner.

Keywords: Drilling, delamination, feed rate, thrust force, torque, high speed steel, carbon fabric epoxy composite.

Introduction

The use of carbon fiber reinforced polymer composites (CFRP) in dynamic structures has significantly increased in the last decades due to their unique properties such as low weight, high strength and stiffness, excellent fatigue and corrosion resistance and low thermal expansion coefficient. Since CFRP composites exhibit such superior mechanical properties, they are advantageous for use in automobile, aerospace, aeronautical, defense, ships, machine tools, sports equipment, power generations, oil and gas industries and transportation structures[1].

Drilling of CFRP composite laminates, irrespective of the application area, is considered a critical operation owing to its tendency to delaminate when subjected to mechanical stress. With regard to the quality of machined components, the principal drawbacks are related to surface delamination, fiber/resin pullout, de-bonding, inadequate surface roughness of the hole wall, and micro-cracking. Among the defects caused by drilling, delamination appears to be the most critical[2,3]. Delamination is the defect in composite structure, and it occurs mainly due to localized bending in the zone situated at the point of attack of the drill. In order to mitigate this problem, it is necessary to develop procedure to select appropriate process parameters.

In practice, it has been observed that the push-out delamination is more severe than that associated with peel-up[4]. Hence, most of the researchers paid attention to the delamination associated with push-out during drilling of CFRP composite laminates. The visualization and assessment of the inter-ply delamination in composites is very difficult and still a challenging task. Hence non-destructive examination of composites materials to obtain size, shape and location of delamination is desirable. In general, computerized tomography (CT), optical microscopy, scanning and digital photography techniques are widely used for investigating the delamination in drilling of composite materials using various drills[5].

Several researchers have studied analytically and experimentally the cases in which delamination in drilling have been correlated to the thrust force during exit of the drill. Higher thrust force induces more extensive delamination to the workpiece[6,7]. Koenig etal studied in 1985 the machining of fiber reinforced plastics and concluded that a high feed rate of drilling will cause a crack around the exit edge of the hole[8]. Chen proposed delamination factor to characterize the drilling induced delamination of CFRP composite laminates[9].

It is observed that there is very little work that has been reported on the influence of cutting parameters on delamination and thrust force during drilling of BCFREC laminate using HSS twist drill. Hence, the authors made an attempt to investigate the effects of feed rate and spindle speed on push-out delamination, thrust force and torque generated during drilling of BCFREC laminate using HSS drill bit of 6 mm diameter and standard point angle of 118^o.

Material and Methods

Material: Bidirectional plain weave type carbon fiber of areal density of 200 $g\text{-}m^{-2}$ supplied by Hindoostan Technical Fabrics Ltd., India, was used as reinforcement. Epoxy resin (LAPOX

ARL-135) and hardener (LAPOX AH-335) were supplied by Atul India Ltd., Gujarat.

Preparation of test specimen: The BCFREC laminate of 200 mm × 200 mm × 3 mm was fabricated by hand lay-up followed by compression moulding technique at room temperature. The resin content of the composite laminate is maintained around 50 Wt. % and post curing of the composite laminate is carried out at 80^{O}C about 8 hours. The advantage of using BCRFEC laminate is that it has maximum stiffness and strength in all direction.

Experimental method: A Matsuzawa micro-hardness testing machine (Model No MMT-X7A, Japan) is used for measuring Vickers hardness of the BCFREC specimen. Tensile strength of the specimen is measured as per ASTM: D 638, using a universal testing machine (Lloyd LR100 K, UK). The three point bending technique is used for measuring the flexural properties of the BCFREC specimen as per ASTM: D 790-10. The inter-laminar shear strength (ILSS) is investigated according to ASTM: D 2344 (short beam shear test method) by universal testing machine (Instron 3366). The displacement method is used for measuring the density of the composite specimen as per ASTM: D 792-08, using an electronic balance (Mettler Toledo USA)[10]. The drilling experiments on BCFREC specimen of size: 75 mm × 200 mm× 3mm are carried out using AMS drill tap Vertical-DTC 250/SPARK machining centre. A HSS drill of 6 mm diameter with 118 ^{o} tip angle is used for conducting the drilling experiments. The thrust force and torque generated during drilling of BCFREC are measured by 9257BAKISTLER dynamometer. The drilling induced delamination defects are examined by using high revolution scanner.

Delamination factor (F_d) of the BCFREC laminate is estimated by using the equation:

$$F_d = D_{max}/D_{nom} \quad (1)$$

Where, D_{max} is the maximum diameter and D_{nom} is the nominal diameter of the drilled holes respectively.

Results and Discussion

Effect of feed rate and spindle speed on delamination: The mechanical properties of BCFREC laminate used for studying the effect of feed rate and spindle speed on drilling induced delamination, thrust force, and torque generated during drilling are recorded in table 1. The average values of the mechanical properties are recorded by testing five samples in each case. The effect of feed rate and spindle speed on delamination of BCFREC laminate is presented in table 2. It is observed that the delamination increases with increase in feed rate and spindle speed (table 2, figure 1 and figure 4).

The push-out delamination that appears at the drill holes exit periphery due to the thrust force applied to the uncut plies exceeds the inter-ply bonding strength. A smaller tool feed reduces the thrust force, resulting in smaller chips and delamination[11]. The feed rate is one of the cutting parameters of greatest interest in drilling.

Generally, as the feed rate becomes faster, an improvement in productivity can be achieved. Numerous studies have observed that thrust force (or delamination) increases with feed rate[8]. The extent of drilling induced delamination damage obtained by using the high resolution scanner is shown in figure 9. The extent of delamination is an average taken from three measurements along the perimeter of the delamination. It is clear from the photograph that the highest damage due to delamination in BCFREC laminate is observed in the spindle speed of 1800 rpm and the feed rate of 0.01mm/rev.

According to basic principles of fracture mechanics, first postulated by Griffith in 1920, the thrust force from the work piece as drilling proceeds supplies the energy required for incremental extent of delamination during drilling, plus the increased strain energy of the body as a result of the crack propagation. It is also evident from the investigation that there exists a positive relationship between thrust force and delamination (figure 6). The decreasing thrust force during drilling operation may be one of key methods for minimizing the damage caused by the delamination during drilling. The investigation also reveals that there exists a correlation between drilling- induced delamination and torque (figure 8).

Effect of feed rate and spindle speed on thrust force and torque: The experimental results of thrust force and torque generated during drilling of BCFREC laminate using HSS drill for different spindle speed and feed rate are presented in the table 2. The thrust force is one of key indexes to describe machinability of composite laminates owing to the fact that it directly affects the quality of drilled holes, especially during drilling-induced delamination[12]. The study reveals that the thrust force and the torque increase significantly with feed rate and spindle speed while drilling BCFREC laminates (figures 2, 3, 5 and 7). The increase in thrust force is due to rubbing action between the chip and the tool surface, created by increased thickness of the chip and the reduced clearance with the drill surface. The increase in torque with increase in feed rate and spindle speed is due to higher friction between the chip and the drill surface.

Table- 1
Mechanical properties of bi-directional carbon fiber reinforced epoxy composite

Density ($g.cm^{-3}$)	Vickers hardness	Tensile strength (MPa)	Young's modulus (GPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Interlaminar shear strength (MPa)
1.34	155	590	52	3	550	55	20

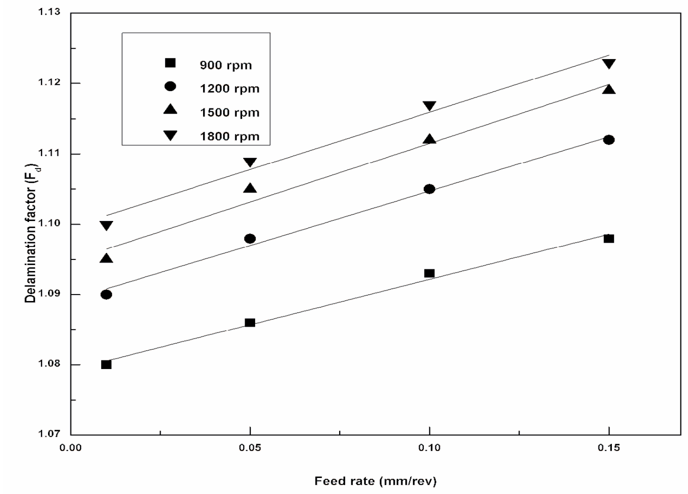


Figure- 1
Delamination v/s Feed rate

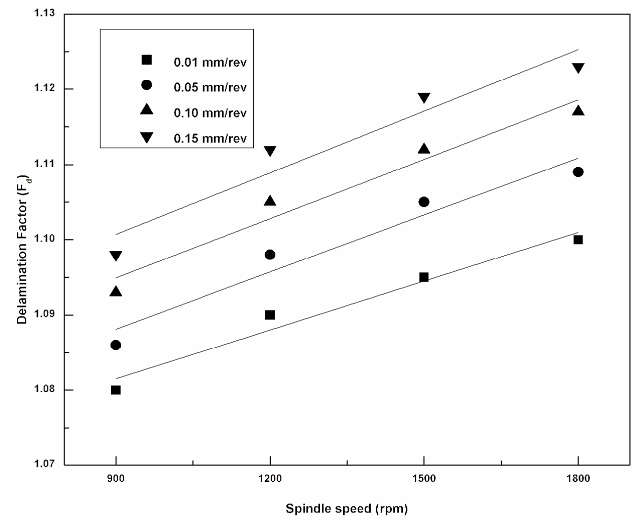


Figure-4
Delamination v/s Spindle speed

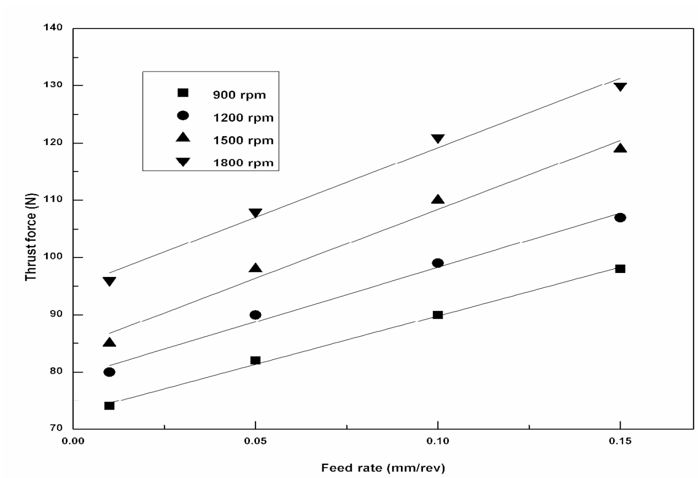


Figure-2
Thrust force v/s Feed rate

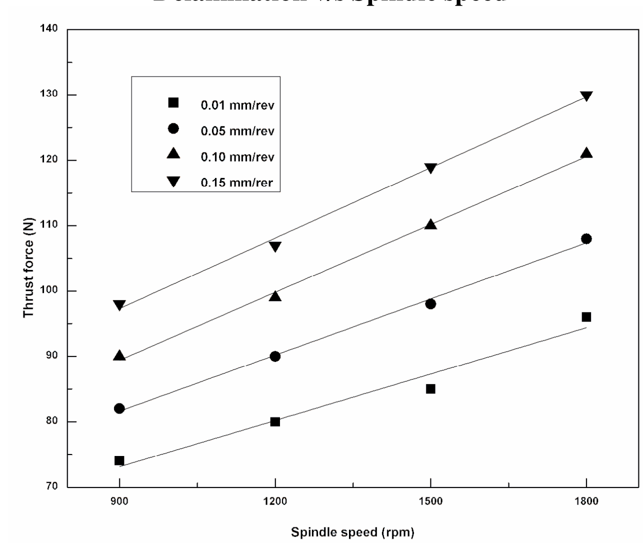


Figure-5
Thrust force v/s Spindle speed

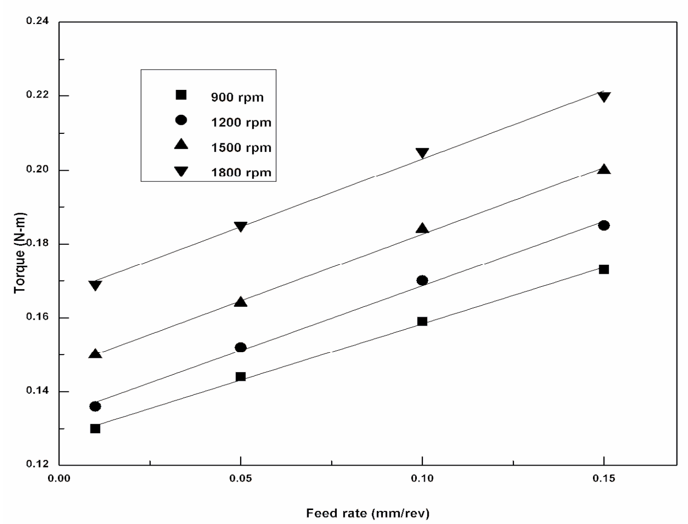


Figure-3
Torque v/s Feed rate

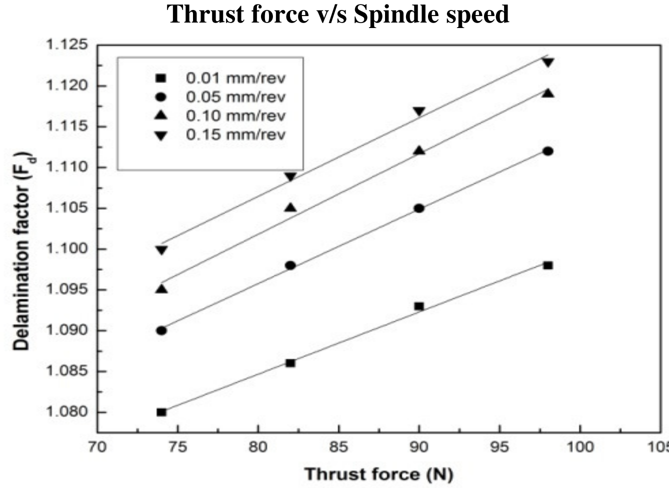


Figure-6
Delamination v/s Thrust force

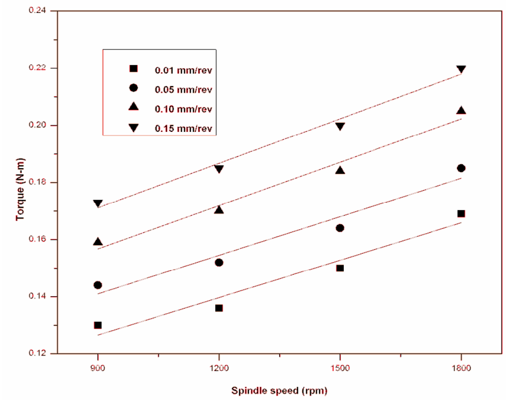


Figure-7
Torque v/s Spindle speed

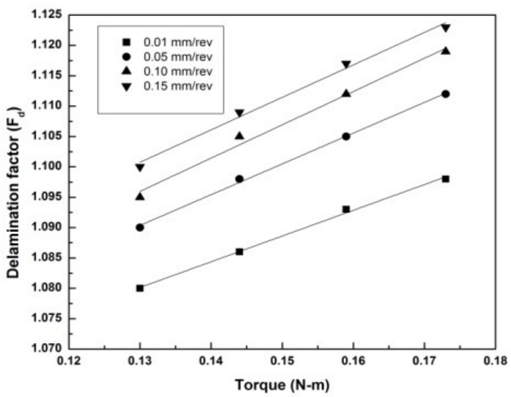
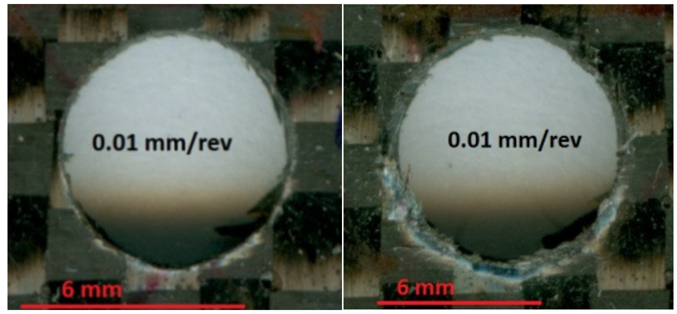


Figure-8
Delamination v/s Torque



(a) **(b)**

Figure-9
Photographic image of drilling - induced delimitation on BCFREC laminate (a) at drilling speed of 900 rpm and (b) 1800 rpm

It is observed from the investigation that the maximum magnitude of the thrust force, torque and delamination are obtained at the feed rate of 0.15 mm/rev in the range of spindle speed studied (table 2). It is also observed from the investigation that the effect of spindle speed on thrust force and torque in drilling of BCFREC laminate is not significant because the rate of increase in thrust force and torque with increase in spindle speed is in the decreasing trend. It is evident from the results that better quality of drilled holes are obtained at lower spindle speed [900 rpm] in range of feed rate studied.

Table-2
Experimental results of delamination, thrust force, and torque for different feed rate and spindle speed during the drilling of BCFREC using HSS drill

Trial No	Spindle Speed (rpm)	Feed rate (mm/rev)	Delamination factor (F_d)	Thrust force (N)	Torque (N-m)
1	900	0.01	1.08	74	0.13
2	900	0.05	1.086	82	0.144
3	900	0.1	1.093	90	0.159
4	900	0.15	1.098	98	0.173
5	1200	0.01	1.09	80	0.136
6	1200	0.05	1.098	90	0.152
7	1200	0.1	1.105	99	0.17
8	1200	0.15	1.112	107	0.185
9	1500	0.01	1.095	85	0.15
10	1500	0.05	1.105	98	0.164
11	1500	0.1	1.112	110	0.184
12	1500	0.15	1.119	119	0.2
13	1800	0.01	1.1	96	0.169
14	1800	0.05	1.109	108	0.185
15	1800	0.1	1.117	121	0.205
16	1800	0.15	1.123	130	0.22

Conclusion

Drilling of BCFREC laminate using HSS drill with different feed rate and spindle speed is studied for the purpose of minimizing the damage caused by delamination. The study reveals that the drilling induced delamination of composite material can be visualized and measured by using high resolution scanner. The results obtained reveal that the delamination factor increases with both cutting parameters, which means that the composite damage is bigger for higher cutting speed and feed.

The feed rate is observed to make the largest contribution to delamination, thrust force and torque. The study reveals that there is a positive correlation between thrust force, torque and delamination. Furthermore, the study indicates that the effect of spindle speed on thrust force and torque is not significant and lower feed rate has to be used for higher spindle speed in HSS drill in order to reduce the delamination damage.

References

1. GuuY.H., Hocheng H.,Tai.N. and Liu S.Y., Effect of Electrical Discharge Machining on the Characteristics of Carbon Fiber Reinforced Composites, *Journal of Material Scienc*e, (**36**)**,** 2037-2043 (**2001**)

2. Arul S. and Vijayaraghavan R., The Effect of Vibratory Drilling on Hole Quality in Polymeric Composites, *International Journal of Mechanical Tools Manufacture,* (**46**)**,** 252-259 (**2006**)

3. Abrao, AM Faria,PE., Compos Rubio J.C., Reis P and Paulo Davein J., Drilling of Fiber Reinforced Plastics: A review, *Journal of Materials Process Technology*, (**186**)**,** 1-7. **(2007**)

4. Khashaba U A., Delamination in Drilling GFR-Thermoset Composites, *Composites Structure,* (**63**)**,** 313-327 (**2004**)

5. Gaitonde V N., Karnik S R., Compos Rubio J., Esteves Corriia, A., Abrao,A M and Paulo Devim J., Analysis of Parametric Influence on Delamination in High Speed Drilling of Carbon Fiber Reinforced Plastic Composites, *Journal of Materials Processing Technology,* (**203**)**,** 431-438 **(2008)**

6. Hockeng H, and Dhoran C.K.H., Delamination during Drilling in Composite Laminates, *Transaction of ASME Journal of Engineering for Industry,* **(112),** 236-239 **(1990**)

7. H. Hockeng H., and Tsao C.C., Comprehensive Analysis of Delamination in Drilling of Composite Materials with Various Drill Bits, *Journal of Materials Processing Technology*, **(140),** 335-339 **(2003)**

8. Koenig W, Wulf C, Grass P., and Willerscheid H, Maching of Fiber Reinforce Plastics, *Manufacturing Technology CIRP Annual*, **32(2),** 537-548 **(1985)**

9. Chen W.C., Some Experimental Investigations in the Drilling of a Carbon Fiber Reinforced Plastic (CFRP) Composite Laminates, *International Journal & Machine Tools and Manufacturing*, **37(8),** 1091-108 (**1997)**

10. **S**hivamurthy B.K, Udaya Bhat, and Anandhan S, Mechanical and sliding wear properties of multi-layerd laminates from glass fabric/graphite/epoxy composites, *Materials and Design*,**(44),**136-143 **(2013)**

11. Jain S., and Yang D.C.H., Delamination Free Drilling of Composite Laminates, *ASME Journal of Engineering for Industry*, **(116),** 475-481 **(1994)**

12. Khashaba U.A., El-sobaty I.A. ,Selmy AL.and Megahed A.A., Machinability Analysis in Drilling Woven GFR/Epoxy Composite: Part I Effect of Machining Parameters on Composites: *Compos., Part A,* **(41),** 391-400 **(2010)**