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Effect of Drilling Tool Geometry on Machining of Hybrid Composites

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Abstract

The increasing demand on industries to machine difficult-to-cut materials with precision and accuracy requires the manufacturers to improve their ability to machine. This necessitates a deeper comprehension of how tool geometries affect cutting performance. Mechanical fastening with precision is most important in structures joining. With the advancement of materials science technology, hybrid composites are considered to be one of the most widely used materials for engineering applications. One of the advantages in using hybrid composite materials is that the characteristics of these materials can be managed to a greater extent by selecting different matrix and fibers. As geometry of the drilling tool exhibits an important role in making better quality holes and less damage, therefore analyzing, and evaluating the performance of drill is very important. In this paper, the effect of drill geometry on machining of hybrid fiber reinforced polymer (FRP) is reported. The quality of the hole surface was assessed by measuring the surface roughness of the hole. Two specially designed drills with different helix angles and double point angles in addition to conventional drill i.e., twist drill was experimented. The results obtained from the experiments indicate that drilling free from delamination can be achieved by the appropriate selection of drill geometry and drilling operation variables. Also, the combined effect of helix angles and double point angles will be crucial for axial force (Thrust). Further, drilling process variables such as feed rate and rotational speed of the spindle are investigated, exhibiting that feed rate is dominating the damage of the surface.

Keywords

Machining, Drill bits, Composites, Double point angle, Drilled hole quality, Nanotechnology

Introduction

Now a day, most metals and alloys are being replaced by composite materials for various uses. Fibre reinforced composites are becoming an important material option because of their intrinsic property to be customized across any application. Their higher specific weight relative to rigidity has enabled them for crucial applications like automotive, aeronautics, and defense. Conventional drilling of composites varies considerably in numerous ways than drilling traditional alloys and metals [1]. Composites drilling mechanism differs significantly from the mechanics of traditional materials. Appropriate selection of drilling parameters is difficult because of the combination of a soft matrix and rigid fibres. Velayudham et al. [2] found that composite materials pose great challenges during machining because of two or more distinct phases. Moreover, in composite machines, the material behaviour is not just anisotropic and heterogeneous; nevertheless, it also relies on matrix and fiber volume fraction, and on the characteristics of reinforcement and matrix.

During machining, the tool experiences alternatively reinforcement and matrix materials, therefore composites machining requires notable attention on the wear resistance and configuration of cutting tools [3]. Out of various machining processes, hole making operation is considered to be extensively used process, as many numbers of holes should be made in assembly applications such as mechanical fasteners. During drilling process, various damages will result such as cracking of the matrix, fibre push out and pull out, interlayer cracks and push out delamination besides surface defects usually found in drilling of metals and alloys.

This introduction delves into the intersection of nanotechnology and the optimization of drill tool geometry, emphasizing their collective impact on achieving precision in the machining of hybrid composites. As we venture into this sophisticated realm, the integration of nanotechnology offers unprecedented opportunities for enhancing the performance and efficiency of machining processes. Hybrid composites, renowned for their combination of various materials, demand a nuanced approach to drilling tool geometry—one that aligns seamlessly with the capabilities afforded by nanotechnology. This study delves into the impact of drilling tool geometry on the machining process of hybrid composites, further enriched by the integration of nanotechnology for comprehensive analysis. The insights gained regarding optimal tool geometries and nano-enhanced analysis methodologies could improve manufacturing processes, leading to more efficient and cost-effective production in relevant sectors.

Drilling of FRP composite laminates needs specific tools and techniques to control the hole quality. It is established that the degree of surface damage relies mainly on the operation variables, particularly feed rate when drilling composites [4]. Also, it was reported that the extent of damage is associated with thrust force, but the thrust force is dominant over delamination [5]. It was also found by Chen [6] that by appropriate selection of dill geometry and cutting parameters the drilling may be damage free. Also, it is observed that most of the strategies related to machining focus on thrust force, one of the key contributing reasons to delamination. The thrust force can be minimized to a greater extent by modifying the drill geometry and controlling the feed rates, but feed rate controlling will result in lesser productivity and therefore modifying the drill geometry will be the best alternative for controlling the thrust force. Armarego and Zhao [7] established that during drilling, more than half of the thrust produced is attributable to the chisel edge. The fuzz or fibrils formed by traditional drills can be reduced to a greater extent by drilling the holes in the centre and forcing the chips against the walls. One of the most important factors that affects how well a drill performs is the geometry of the drill [8, 9].

Abrao et al. [10] found that increasing the spindle speed decreases the delamination and a pair of low feed with maximum speed and appropriate drill point angle will minimize the delamination to a maximum possible extent. Palanikumar et al. [11] investigated the variation of delamination with relation to feed, speed, and point angle. The variables that affect the delamination were analyzed by response surface methodology using various plots and observed that delamination at the entrance is minimized by drilling at high speed. Gaitonde et al. [12] studied drilling of carbon and glass FRP composites i.e., hybrid composites and found that the mechanics of machining hybrid composites require further studies for good understanding of hybrid composites. Hence, the primary objective of this work is to analyze the impact of different drill bit configurations on hole geometry and thrust force during drilling. CMM was employed to assess the cylindricity and circularity whereas surface roughness tester (Mitutoyo make) was employed to evaluate the roughness of the hole surface.

Experimentation

For the present work, two drilling tools with different configurations are manufactured for drilling hybrid composites on CNC machines. Drilling is performed on hybrid composites at different spindle speeds and feeds with conventional drill i.e., twist drill and the specially designed drill bits. Drilling tool parameters like helix angle and point angle were varied to analyze the influence of the geometry of drill on the quality of hole being drilled (Table 1). Specifications of the twist drill i.e., Tool A are: Helix angle - 30°, Number of flutes - 2, web thickness - 2 mm, and point angle - 118°. The signature of specially designed drills (Solid carbide twist drill) i.e., Tool B and Tool C are: Helix angle - 20°, Number of flutes - 2, web thickness - 2 mm, and point angle (double point angle) - 145° and 90°. Helix angle - 35°, Number of flutes - 2, web thickness - 2 mm, and point angle (double point angle) - 130° and 60°. Figure 1, figure 2 and figure 3 show conventional drill i.e., conventional tool (Tool A) and specially designed drills such as (Tool B) and (Tool C), respectively.

Drilling operations are performed under various conditions using CNC machine on the hybrid composite work piece with different tools. Drilling dynamometer (Digital) was employed

Table 1: Geometry of drill bits.

Tools	Point angle	Helix angle	Web thickness	Number of flutes
Conventional tool (Tool A)	118°	30°	2	2
Tool B	145° and 90°	20°	2	2
Tool C	130° and 60°	35°	2	2

Figure 1: Conventional tool (Tool A).

Figure 2: Specially designed drill (Tool B).

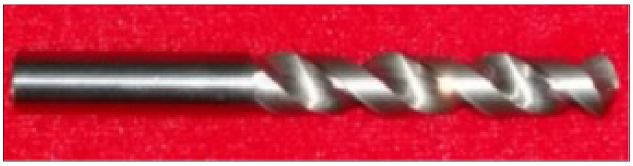

Figure 3: Specially designed drill (Tool C).

Figure 4: Experimental set-up.

to evaluate the axial force (thrust) for different experimental trials. During drilling, a lot of powder particles and air borne dust was generated which was cleaned by a vacuum blower. Figure 4 shows the experimental set-up which was arranged to machine hybrid composite materials. Figure 5 depicts CMM (GX600) employed for measuring geometry of the drilled hole i.e., cylindricity and roundness by sensing discrete points on the hole surface with a probe. The surface roughness tester (Mitutoyo Make) is portable measuring equipment for assessment of surface roughness according to Rq, Ra, Rt, and

Figure 5: Hole geometry measurement using CMM.

Rz were employed to evaluate the surface finish of the hole being drilled as shown in figure 6.

Results and Discussion

The results obtained by machining hybrid composites with various drills are shown in table 2, table 3, and table 4. The output responses i.e., roundness, cylindricity, surface roughness and thrust force were plotted on graphs for different trials.

From figure 7, it is noticed that the axial force is least if hole making operation is performed by tool C and when the holes are drilled by tool A, there is maximum axial force. This is mostly due to the single point angle of tool A. When the hole making operation is carried out by conventional tool, the cutting is not taking place instead; the material is pushed aside in the middle by the drill's chisel edge, as it goes down. Further, at chisel edge area the cutting action is relatively low because of lower speeds and higher negative rake angles

Table 2: Table of results obtained from tool A.

Exp. No.	Full factorial	Plan of experiments	Speed (rpm)	Feed (mm/rev)	Thrust force (kgf)	Roundness	Cylindricity	Surface roughness (μm)
1	1	1	640	0.08	21	0.0044	0.0068	5.11
2	1	2	640	0.13	31	0.0055	0.0080	3.35
3	1	3	640	0.20	51	0.0065	0.2061	8.01
4	2	1	1120	0.08	19	0.0071	0.0096	2.54
5	2	2	1120	0.13	35	0.0017	0.0067	6.61
6	2	3	1120	0.20	45	0.0047	0.0139	4.93
7	3	1	1760	0.08	17	0.0075	0.0051	12.64
8	3	2	1760	0.13	22	0.0065	0.0073	7.15
9	3	2	1760	0.20	25	0.0021	0.0063	5.64

Table 3: Table of results obtained from tool B.

Exp. No.	Full factorial	Plan of experiments	Speed (rpm)	Feed (mm/rev)	Thrust force (kgf)	Roundness	Cylindricity	Surface roughness (μm)
1	1	1	640	0.08	15	0.0027	0.0062	2.35
2	1	2	640	0.13	26	0.0075	0.0074	6.91
3	1	3	640	0.20	36	0.0098	0.0061	3.66
4	2	1	1120	0.08	18	0.0000	0.0107	4.56
5	2	2	1120	0.13	23	0.0037	0.0073	4.98
6	2	3	1120	0.20	28	0.0087	0.0059	8.41
7	3	1	1760	0.08	22	0.0000	0.0092	11.38
8	3	2	1760	0.13	19	0.0000	0.0162	10.42
9	3	2	1760	0.20	28	0.0080	0.0036	2.11

Table 4: Table of results obtained from tool C.

Exp. No.	Full factorial	Plan of experiments	Speed (rpm)	Feed (mm/rev)	Thrust force (kgf)	Roundness	Cylindricity	Surface roughness (μm)
1	1	1	640	0.08	16	0.0000	0.0000	1.69
2	1	2	640	0.13	20	0.0053	0.0053	2.24
3	1	3	640	0.20	21	0.0000	0.0000	4.81
4	2	1	1120	0.08	19	0.0000	0.0000	2.52
5	2	2	1120	0.13	21	0.0000	0.0000	2.48
6	2	3	1120	0.20	20	0.0000	0.0000	3.54
7	3	1	1760	0.08	20	0.0000	0.0000	2.36
8	3	2	1760	0.13	18	0.0000	0.0000	4.51
9	3	2	1760	0.20	16	0.0000	0.0000	3.75

Figure 6: Surface roughness measurement.

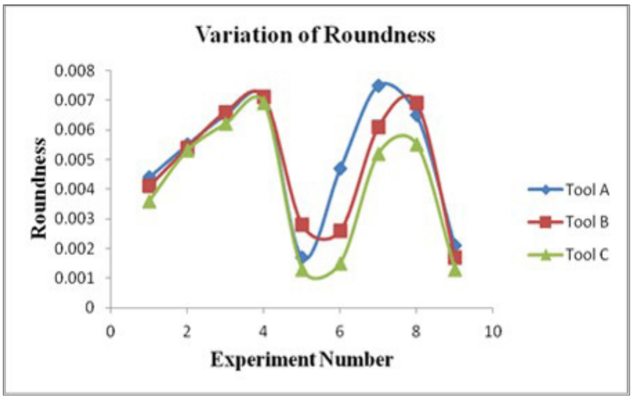

Figure 8: Experiment number vs roundness.

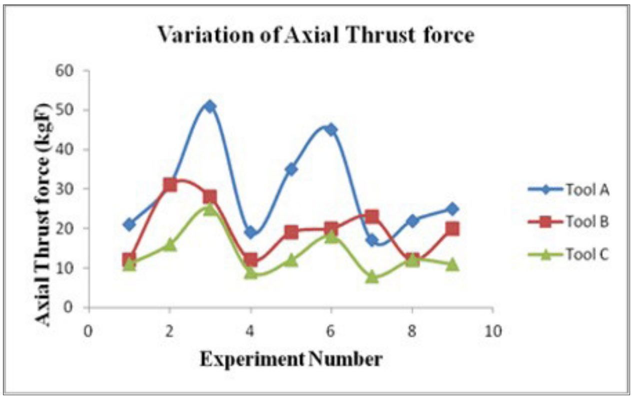

Figure 7: Experiment number vs axial force (thrust).

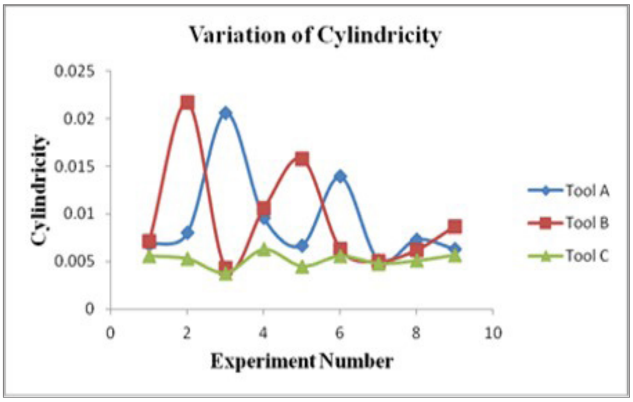

Figure 9: Experiment number vs cylindricity.

resulting in the indentation process. Because of this, the chisel edge of conventional twist drill is subjected to higher thrust force values.

The axial force obtained by drill (Tool C) is lower compared to available twist drill (Tool A) and specially designed drill (Tool B). The mechanism of cutting by tool C configuration is the principal reason for lower values. Because of the positive radial rake angle, the cutting force which is radial in nature pulls the fiber towards the center from the outer diameter. However, at the periphery of drill the axial rake angle has a maximum value. Therefore, an axial force which is in upward direction is acting on the fibers, resulting in lower thrust force. Hence, tool C geometry drill performs better when compared to the other tools.

From figure 8, it is observed that roundness of drilled hole obtained by tool C is minimum compared to roundness of the holes obtained by other tools i.e., tool A and tool B. Roundness of the hole increases at high feeds and speeds. As drilling progresses, the roundness of hole decreases. The main reason for the reduction in the roundness values by tool C is the reduction in drill eccentricity.

Figure 9 shows that the drilled hole cylindricity obtained by tool C is least in comparison with tool A and tool B. Even at maximum feed, tool C makes the fibre completely sheared. This is because minimum generation of heat took place because of stress induced due to the shearing action.

From figure 10, it is inferred that the hole surface roughness produced by drill (Tool C) is lower as compared to tool A and tool B. At higher speeds and feeds, the drilled hole surface roughness is minimum. With increasing feed

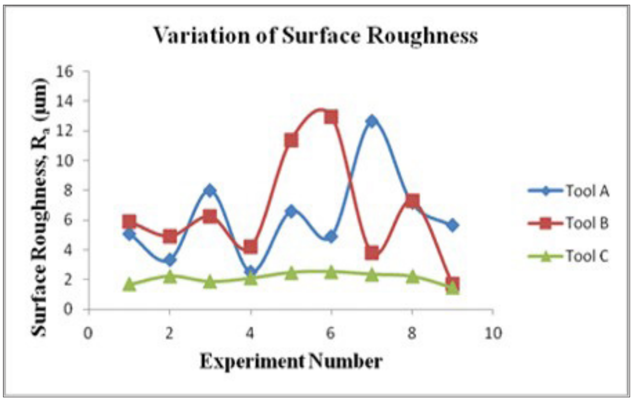

Figure 10: Experiment number vs surface roughness.

rate, there is a decrease in surface roughness; because at this speed there is a significant effect of the flute and primary relief angle, which results in rounding of the edge with a minimum decrease in roughness.

Conclusions

The following conclusions are made:

- It is found that the specially designed drill (Tool C) exhibits an excellent performance compared to tool A and tool B under similar drilling conditions.
- Lower feed rates are suitable for drilling hybrid composites because lower feed rates minimize the axial thrust force. But this leads to thermal deterioration of soft matrix and will not be appropriate for industrial applications where production is most important.
- Tool C produces holes with lower surface roughness values as compared to available twist drill (Tool A) and specially designed drill (Tool B).
- Tool C produces a good surface finish at maximum rotational speed of the spindle and feeds, since minimum value of helix angle results in more work required for the facilitation of the initial penetration.
- Out of various machining variables considered, a 0.20 mm/rev of feed rate and a 1760 rpm of spindle speed produces excellent hole quality.
- The geometry of the specially designed drill has a strong impact on the experimental readings used for assessing the quality of the hole drilled.

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None.

Conflict of Interest

None.

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