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Energy based investigation of process parameters while drilling carbon fiber reinforced polymers

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Abstract

Carbon fiber reinforced polymers (CFRPs) are widely used in the aerospace industry due to their light weight, high strength, and low thermal conductivity. Drilling is a critical process that affects the quality of CFRP parts. This work studies the influence of process parameters on delamination and tool wear. Polycrystalline diamond helical drills are used in the experiments. It has been shown that drilling energy calculations can be used to set appropriate feed and speed parameters and for increasing drilling performance of CFRPs. The results also indicate the importance of thermal modeling of CFRP laminate for better understanding of the drilling process.

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Keywords: Drilling; carbon fiber reinforced polymer materials; carbide tools; tool wear; delamination; thrust force

1. Introduction

Carbon fiber reinforced polymers (CFRPs) have become a widely used material in the aerospace industry due to their superior material properties. Drilling of CFRPs is a critical process in terms of delamination. It has been shown that delamination is closely related to drilling process parameters, tool geometry, and tool wear [1, 2, 3]. Due to the abrasive nature of carbon fibers and the low thermal conductivity of the polymer matrix, rapid tool wear is a common problem in drilling of CFRP laminates. As the cutting edges of the drills wear out, forces increase, which leads to quality problems inside the hole and at the exit of the hole.

Many studies have been conducted to understand the relationship between process parameters and delamination while drilling CFRPs [4, 5, 6]. It has been observed that in order to keep thrust forces low at the hole exit, feed must be set low. It has also been observed that rotational speed does not influence the drilling forces significantly. Therefore, a high rotational speed is set in order to obtain an acceptable feed rate in the drilling process. However, especially when drilling thick CFRP laminates, setting a low feed increases the interaction time of the tool and the material, which results in rapid tool wear. Therefore, diamond coated carbide and polycrystalline diamond (PCD) are widely adopted tool materials used to drill thick CFRP laminates [7, 8, 9]. This study uses PCD drills in the twist drill form that have recently become available in the market.

Recent studies have shown the importance of thermal modeling while drilling CFRP laminates [10, 11]. The changes in temperatures inside the hole affects the material properties of the polymers. The resin system, fiber content, and sequence of laminate are important factors that must be considered in the models. In this study, drilling energy is calculated and compared for two different PCD drills. Thrust force and torque measurements are used to calculate the instantaneous power for different feed and rotational speed values. The work related to the movement of the drill can be assumed to convert into heat energy, which results in rising temperature inside the hole.

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2. Experimental setup and drill geometry

A unidirectional CFRP plate with 11 mm thickness was used in the drilling experiments. There are 72 layers in total with repeating laminate configuration of 0˚-45°-90˚-135°. Two additional CFRP layers of ±45˚ were laid at the top and bottom surfaces of the laminate. The carbon fiber content is 59%. A CNC milling machine is used to conduct drilling experiments. A back plate made from aluminum with 8 mm diameter holes was used to support holes from behind. The experimental setup and CFRP plate are shown in Fig. 1. Thrust force and torque measurements were made by using a rotational dynamometer and its charge amplifier (Kistler 9123, Kistler 5223). Experiments were performed under wet drilling conditions.

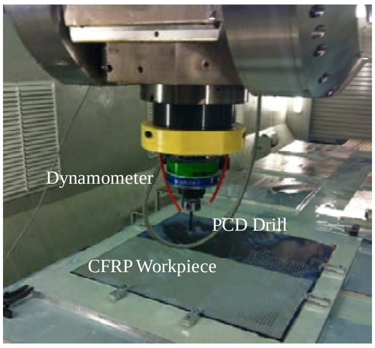
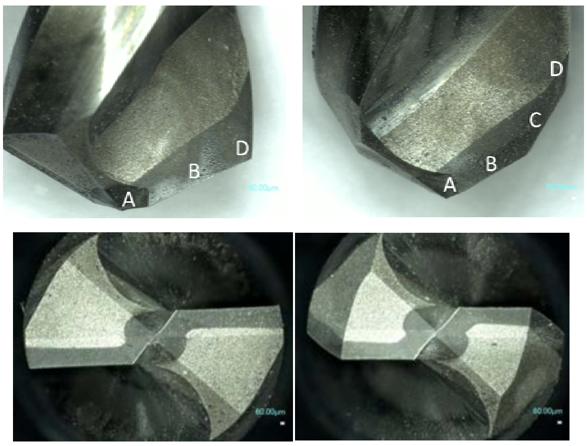


Fig 1. Experimental setup.

Two different helical PCD drills, both with 6.4 mm diameter, were used in the experiments as shown in Fig. 2. Both drills (M1 and M2) have 30° helix angle and 120° tip angle. Drill M2 has a double point angle (120°- 60°). The drills have the same chisel edge design. Different sections along the cutting edges of the drills are identified as A, B, C, and D as shown in Fig. 2.



(a) (b)

Fig 2. Helical drill geometries. a) M1, b) M2.

3. Calculation of energy during drilling

Table 1 shows the experimental drilling conditions used in this study. The feed rate is fixed at 100 mm/min in order to keep drilling time the same for each drill. Three different levels of rotational speed values are considered and three different feed values are used to fix the feed rate at the same level in all experiments. Three holes were drilled under each condition. Fig. 3 shows the thrust force and torque measurements for each condition for drills M1 and M2.

Table 1. Experimental drilling conditions

Experiment	Rotational Speed N (rpm)	Cutting Speed (m/min)	Feed f (μm/rev)	Feed rate f_r (mm/min)
1	5000	100	20	100
2	4000	80	25	100
3	3300	67	30	100

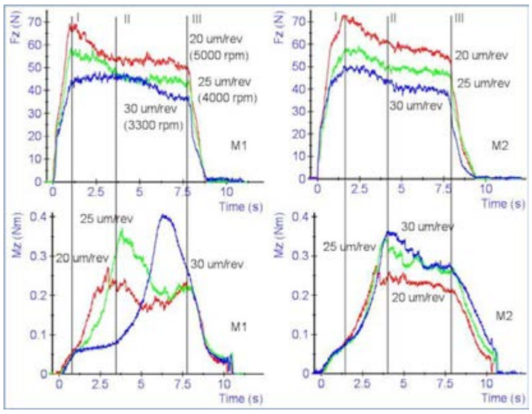


Fig 3. Measured thrust forces (F_z) and torques (M_z) for M1 and M2 as a function of process parameters.

In terms of thrust forces (F_z), similar values were measured for both drills. The drill M2 reaches peak force slightly later due to its different point angle in the secondary cutting edge. With increasing feed and decreasing rotational speed, thrust forces decrease for both M1 and M2. Thrust forces decrease as the drill proceeds in the hole, which corresponds to regions between I and II as shown in Fig. 3. While thrust forces decrease, a significant increase in torque was observed. Torque measurements reach their peak value at II except for drill M1 at experimental condition 3. After this point, torque measurements decrease and thrust force measurements remain almost constant until the drill reaches region III, where the drill tip reaches the bottom of the hole. Measured thrust force and torque measurements are used to calculate power as shown in Fig. 4(a). The forces acting on the drill in x-y directions are neglected due to their relatively low values of 5-6 N. Drilling energy (E) can be calculated by integrating the power terms with respect to time using Eq. (1) where the first term considers the influence of thrust force (F_z) and feed rate ($f.N$) and the second term considers the influence of torque