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Ultrasonic assisted drilling of composites

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Abstract
Hole-making is a primary processing method in machining glass fiber-reinforced plastics, and the hole quality has a significant effect on the following assembly operations. This research aims to investigate the effect of ultrasonic vibration on hole quality by drilling. During the hole-making process, both the thrust force and tool wear have a crucial impact on the final hole quality. The thrust force and tool wear will be affected by the superposition of ultrasonic vibration, which will also influence the hole quality inevitably. Therefore, the effect of ultrasonic vibration on thrust force and tool wear should be studied. Also, the influence of each individual factor (thrust force and tool wear) and the interaction between them on hole quality should be identified. Experiments were conducted by drilling one hundred and eighty holes with and without ultrasonic vibration. Thrust force, tool wear and hole quality were measured, and the relationships between them have been established. The results show that the ultrasonic vibration reduces thrust force and has a positive effect on the tool life while the quality of drilled holes varies. The hole quality when applying ultrasonic vibration shows a trend of improvement after drilling sixty holes.

Ultrasonic assisted drilling; GFRPs; Hole quality; Thrust force; Tool wear

1. Introduction

Glass fiber-reinforced plastic (GFRPs), a typical composite material, has been widely used in various enginnering applications, especially in aerospace and automotive industry [1-3]. And hole-making is a primary processing method in preparing GFRPs for the following assembly. The hole quality has a significant effect on the connection performance, which will eventually affect the service life of the component. The conventional drilling (CD) process is apt to some hole defects such as delamination and fiber push-out, due to the high thrust force and severe tool wear during the drilling process.

The ultrasonic vibration assisted drilling (UVD) technique has been introduced in GFRPs hole-making process because of its potential adventages in reducing thrust force and improving hole quality [4-6]. In order to obtain a comprehensive understanding of the effect of UVD on GFRPs drilling process, comparative experiments have beed carried out in this research. The effect of ultrasonic vibration on thrust force, tool wear, and hole quality are analysed.

2. Experimental procedure

2.1. Workpiece material and tool

For these experiments, the glass fiber-reinforced plastic is provided by McMaster-Carr (United States), and is made with a flame-retardant resin. The workpiece is cut into 100 mm ×100 mm parts (length and width) via a water-jet machine. The thickness is about 12 mm. The tool used is a brad point drill bit provided by Karnasch Professional Tools GmbH in Germany, which is specifically designed for composite machining. The diameter of the tool is 5mm.

2.2. Experimental setup

A DMG Sauer 20 (ultrasonic machine center) is used for drilling of the GFRPs. A dedicated fixture is designed to clamp the workpiece, and 36 holes can be drilled in one single set-up. The drill bit vibrates in a resonant mode actuated by piezoceramics. The resonant frequency of the vibration system will be detected by the machine controller and shown in control panel. An emulsion (Synergy 915) is utilized as coolant. A dynamometer (Kistler 9119AA1), related amplifier (Kistler 5070B) and NI DAQ system are configured to acquire and save the cutting force data. The entire setup is illustrated in Fig.1.

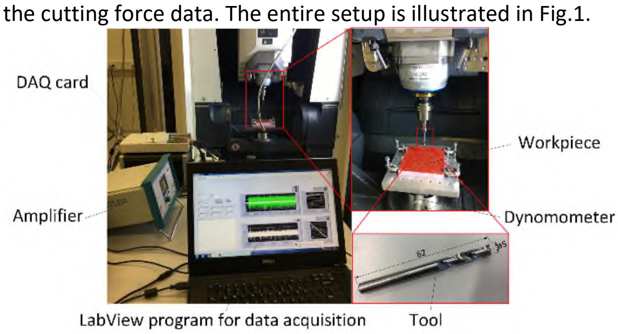

Figure 1. Illustration of the experimental setup

2.3. Process parameters

The optimal parameter combination is obtained from previous experiments [7]. Specifically, the spindle speed is 3500rpm, and the feed rate is 100mm/min. Both for UVD and CD, 180 holes are drilled. The vibration frequency indicated by the machine is 22820Hz. The vibration power is 28W.

3. Resutls and discussions

3.1. Thrust force comparison

The effect of ultrasonic vibration on thrust force are shown in Fig.2. The thrust force with vibration is lower than the thrust force without vibration. And the reduction shows an increasing trend with an increase of the number of drilled holes. The superposition of ultrasonic vibration leads to an intermittent cutting process, which is good for lubrication and heat dissipation. In this case, the tool wear of the UVD process will be also smaller and therefor the thrust force will reduce as well. These results are consistent well with Ramakumar's and Mehbudi's studies [1,5].

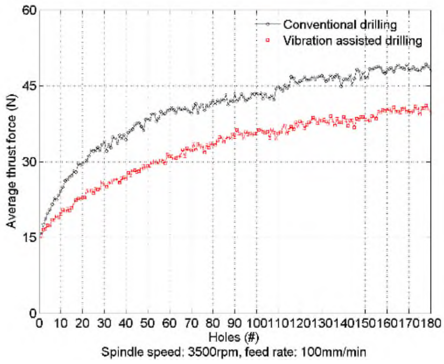

Figure 2. Effect of ultrasonic vibration on thrust force

3.2. Tool wear comparison

As shown in Fig.3, after drilling 180 holes, the tool wear of tool tip in CD is more severe than the tool wear in UVD. The maximum tool wear lenth in CD is 138.47µm, while the maximum value in UVD is 49.18µm. It can be concluded that the ultrasonic vibration has a positive effect on reducing tool wear. This will positively affect the thrust force, which has been explained in above subsection.

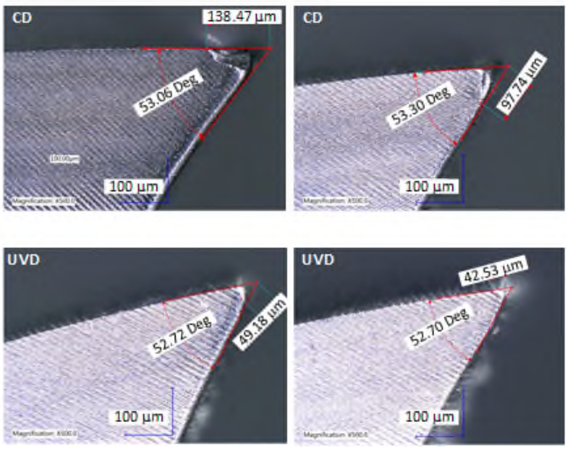

Figure 3. Effect of ultrasonic vibration on tool wear

3.3. Hole quality comparison

Fiber pull out is a main factor affecting the quality of the hole, and larger number of fibers pulled out will deteriorate the hole quality. The effect of ultrasonic vibration on hole quality is shown in Fig.4. The hole quality in CD is better than in UVD process for the first 60 holes. Afterwards, the UVD holes look better than CD holes. As described in above sections, the ultrasonic vibration has a positive effect on reducing thrust force and tool wear. Generally, it could also improve the hole quality. But ultrasonic vibration also produces a force to push the final chip out. The typical shape of chips is shown in Fig.5, it looks like a small disk. Due to the pushing force exerted via ultrasonic vibration, the cihp will be pushed out which is resulting in the outside fiber push-out. This will deteriorate the hole quality. The combined action of these two opposite effects determines the final hole quality. So, the hole quality under ultrasonic vibration shows a trend of improvement after drilling sixty holes. It is assumed that this effect is due to a weak adhesion of the surface layer to the bulk of the material. So in this case, a compromise between exit quality and tool wear will have to be made.

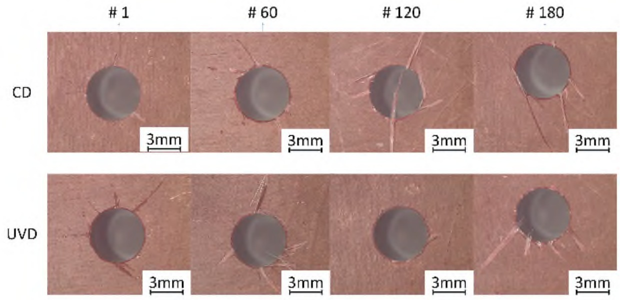

Figure 4. Effect of ultrasonic vibration on hole quality

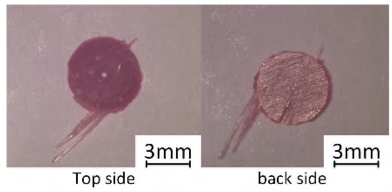

Figure 5. Typical shape of the final chip

4. Conclusions

In this paper, ultrasonic vibration assisted drilling and conventional drilling of GFRPs experiments have been carried out. And the thrust force, tool wear and hole quality have been measured and analysed. From the experimental results, the following conclusions can be drawn:

1) The ultrasonic vibration contributes to reducing the thrust force during drilling.
2) The ultrasonic vibration has positive effect on reducing tool wear.
3) Thrust force and tool wear reductions help improving hole quality while the pushing-out effect of vibration deteriates the hole quality. The final quality of the holes depends on the combined action of these two opposite effects.

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