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Machinability test of CFRP drilling process using ultrasonically assisted machining

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Abstract
Ultrasonic-assisted machining has been used to reduce cutting force compared to conventional machining. In carbon fiber reinforced plastics (CFRP) drilling process, excessive thrust force causes delamination at the hole exit because the thrust force pushes the carbon fiber laminates. Therefore, CFRP drilling requires limited thrust force to prevent delamination, but the limited thrust force restricts the increase in feed rate for improved productivity. In this study, ultrasonic-assisted drilling was used to improve machining quality with a developed ultrasonically actuated tooling kit. The results show that the thrust force and delamination factors at the hole exit were reduced by approximately 40% and 25%, respectively, at drilling conditions of 4,000 rpm and 0.03 mm/rev. Tool wear and surface roughness of the drilled surface were analyzed to test the machinability of ultrasonic-assisted drilling in CFRP for various spindle speeds and feed conditions.

Carbon fiber, Delamination, Thrust force, Machining defect, Machined surface, Surface roughness

1. Introduction

Carbon fiber reinforced plastics (CFRP) are composite materials that consist of carbon fibers and a polymer matrix.[1] Owing to their lightweight and high-strength properties, CFRPs are widely used for lightweight parts in the aerospace and automotive industries.[2] CFRP is made of a stacking structure of several unidirectional layers to compensate for fiber orientation effects.[3] When a CFRP is drilled, the thrust force pushes the carbon fiber laminates, and excessive thrust force causes delamination between laminate layers.[4] Therefore, thrust force is one of the constraints in the CFRP drilling process to improve machining quality. However, limited thrust force also becomes an obstacle to increased feed rate because high feed rate causes high thrust force.[5] Ultrasonic-assisted machining (UAM) has been used to reduce thrust force.[6] In this study, UAM is applied in the CFRP drilling process to improve machining quality. Ultrasonic drilling units have been developed for CFRP drilling, and thrust force and delamination factors were measured to analyze the machinability of CFRP.

2. Experiments and Results

2.1. Experiments

Table 1 shows the experimental conditions for ultrasonic drilling. As a workpiece, CFRP used for aerospace parts is machined. The CFRP has a thickness of 16 mm and is composed of a T1000-grade fiber and epoxy polymer matrix. The stacking sequence is [Woven / -45° / 90° / -45° / 0° / 45° / 90° / 45° / 0° / 0° / 45° / -45° / 90° / -45°…]s. The cutting tool is the SSD060 model of the WIDIN company. The tool is made of tungsten carbide material with a diameter of 6 mm. The spindle speed is 4,000 rpm and feed rates are 0.01, 0.03, 0.05 mm/rev. The feed rates were designed by considering the vibration amplitude of the ultrasonic actuator at the tool tip. The ultrasonic actuator has a 36.5 kHz frequency and 15 μm amplitude. When the feed rate is 0.03 mm/rev, the cutting edge of the tool moves down 15 μm per revolution because the tool has two cutting edges. Therefore, the feed conditions are 0.01, 0.03, 0.05 mm/rev in order to analyze low and high feed speeds, and the same feed speeds with vibration amplitude. The drilling thrust force and delamination factors were measured in the drilling process.

Table 1 Experimental conditions.

Component		Value
CFRP workpiece	Staking Sequence	[Woven / -45° / 90° / -45° / 0° / 45° / 90° / 45° / 0° / 0° / 45° / -45° / 90° / -45°...]s
	Carbon fiber	T1000
	Thickness	16 mm
Tool conditions	Model	SSD060, WIDIN
	Diameter	6 mm
	Material	Uncoated Tungsten Carbide
	Point angle	118
	Number of flute	2
Machining conditions	Feed	0.01, 0.03, 0.05 mm/rev
	Spindle speed	4,000 rpm
Ultrasonic vibration	Frequency	36.5 kHz
	Amplitude	15

2.2. Experimental results

Figure 1 shows the thrust force measurement results. Each thrust force was calculated by averaging the force values

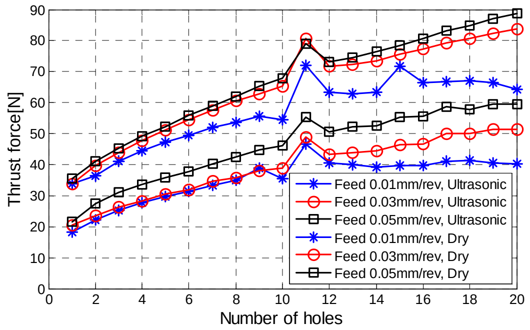

Figure 1. Thrust force for various feed conditions in conventional and ultrasonic-assisted drilling.

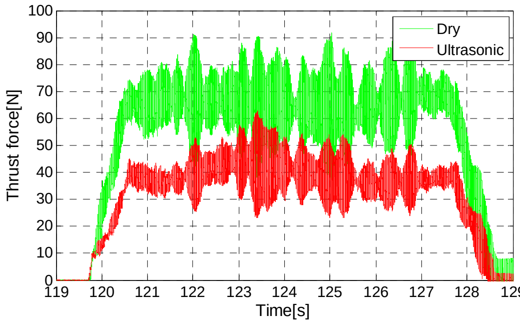

Figure 2. Thrust force at feed rate 0.03 mm/rev in conventional and ultrasonic-assisted drilling.

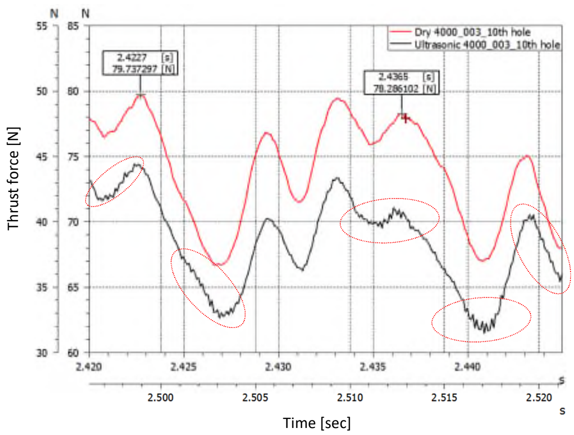

Figure 3. Thrust force in short period in conventional and ultrasonic-assisted drilling.

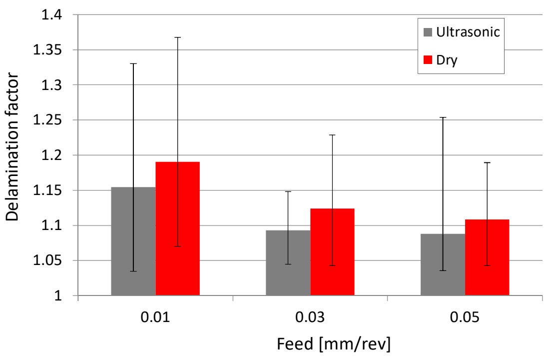

Figure 4. Delamination factors for various feed conditions in conventional and ultrasonic-assisted drilling.

during one holemaking process at fully engaged status, which means that the drilling tool has fully entered the drilled hole. The thrust force was measured using a tool dynamometer for the drilling process (KISTLER 9272). The thrust force was measured for 20 holemaking procedures at each drilling condition. When the number of machined holes increased, the thrust force increased because the tool has worn down. Moreover, when the feed rate increased, the thrust force increased because the chip removal volume increased at high feed speed. Comparison of the thrust force in ultrasonic and conventional drilling showed that the thrust force decreased at every feed condition. In particular, the reducing effect is most effective when the feed rate is 0.03 mm/rev. At feed rate 0.01 mm/rev, the average cutting force is 56.6 N in the conventional drilling process and 35 N is in the ultrasonic-assisted drilling process; thus, the cutting force decreased by approximately 37%. At feed rate 0.03 mm/rev, the cutting force in the conventional drilling process is 64.7 N, whereas the ultrasonic drilling process reduced cutting force by 40% to 39.2 N. When the feed is higher than the vibration amplitude, the cutting force is lower compared with the conventional process, but the reduction rate was less effective compared to other conditions.

Figure 2 shows the thrust force at the 10th holemaking process. The high cutting force is the conventional dry drilling process and the low cutting force is the ultrasonic-assisted drilling at feed rate 0.03 mm/rev. The cutting force of the dry drilling process is 65 N while that of ultrasonic drilling is 40 N. Figure 3 shows the thrust force during 0.02 second period to compare the conventional and ultrasonic processes. The short-period vibration was measured in the ultrasonic-assisted drilling process. Figure 4 shows the delamination factors of 20 holes in CFRP. Under UAM conditions, the delamination factors decreased. When the feed rate was 0.03 mm/rev, the delamination factor showed the largest decrease of 25% from 1.124 to 1.092.

3. Conclusion

Various feed conditions were compared for CFRP drilling using a conventional drilling process and UAM. The feed conditions were selected by considering the ultrasonic vibrating amplitude. The cutting force was measured for various feed conditions and ultrasonic vibration. The cutting force was decreased by ultrasonic-assisted vibration. When the vibration amplitude and drilling down speed are similar, the cutting force decreased by approximately 40%. The vibration in the cutting motion was helpful in reducing the cutting force. The reduced cutting force decreased delaminationby 25%.

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