Ultrasonic-vibration-assisted Micromachining of Composite Materials

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Abstract

Recently, the use of composite materials like CFRP (carbon fiber reinforced plastic) has become widespread in industrial fields because of their remarkable characteristics. However, CFRP is one of difficult to machine materials. The conventional machining of CFRP generally leads to tool wear and low quality of the machined surface. In particular, micromachining techniques such as micro-drilling processes have the problem of low rigidity of cutting tools.

In order to overcome these problems, the ultrasonic-vibration-assisted machining of CFRP is proposed in this study. The cutting force is expected to decrease when axial-directional ultrasonic vibration is applied to the tool as a result of the intermittent cutting process with a large acceleration over a short period, which shown by H. Isobe [1]. The reduction in the cutting force results in an improvement in the machining accuracy and the suppression of the delamination.

The cutting chips which adhere to the cutting edge and plug up to the drilled hole sometimes cause tool breakage. In order to remove the chips from the cutting area, the application of cavitation's cleaning effect to the cutting process, which proposed by H. Ogawa [2], is also proposed in this study. The ultrasonic vibration is applied to the cutting fluid using a specially designed ultrasonic vibration horn. The cavitation generated around the cutting point prevents the chips from adhering to the tool and drilled hole, so it is expected to ensure higher machining efficiency and better machining accuracy.

This paper discusses small hole drilling tests on CFRP to verify the effect of tool-vibration drilling, cavitation-aided drilling, and their combination (hybrid drilling). The delamination, easily occured at the outlet of a machined hole, can be reduced by applying ultrasonic vibration. With respect to the cutting force, hybrid method can reduce the thrust force by 30% compared to conventional drilling. The experimental

results show that the proposed method is useful for the efficient and accurate drilling. reduce the thrust force by 30% compared to conventional drilling.

1 Cavitation-aided machining

When hydraulic pressure decreases beyond vapor pressure at a certain temperature, a liquid evaporates and bubbles occur. Similar to evaporation, cavitation is a phenomenon wherein a liquid phase changes into a gas phase. Cavitation changes liquid phase to the gas phase by accelerating liquid at a constant temperature, which causes the liquid pressure to decrease. In this research, we used the cleaning effect produced by the vibration of an ultrasonic vibration horn and the shock wave from the destruction of cavitation bubbles. There is a possibility that the cavitation generated around the cutting tool will prevent chips from adhering to the tool. Hence, cavitation-aided machining is expected to ensure higher machining efficiency and better processing accuracy.

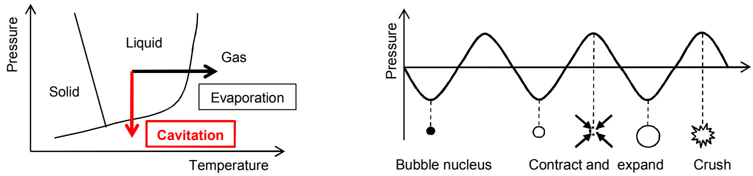

Fig.1 Explanations of cavitation phenomenon

2 Experiment

Using a cemented carbide drill bit, we verified the effect of ultrasonic vibration-aided machining through drilling tests. The experimental apparatus is shown in Fig.2. The machining conditions are listed in Table 1, and the conditions for the each ultrasonic vibration generation machine are listed in Table 2.

Table 1 Machining conditions

Tool rotational speed	8000 min^{-1}
Axial feed rate	80 mm/min
Depth of hole	3.2 mm
Cutting fluid	water-soluble oil

Table 2 Ultrasonic-vibration-assisted condition

	Frequency kHz	Amplitude µm
Tool vibration	70.0	5.0
Cavitation	42.0	4.8

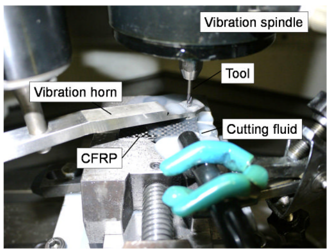

Fig.2 Experimental apparatus

The condition of each tool after drilling 50 holes is shown in Fig.3. Cavitation-aided machining is able to prevent chips from adhering to the tool with or without tool vibration. This is because cavitation enhanced the flow properties of the cutting fluid. However, the tool wear progressed at the same speed under each condition.

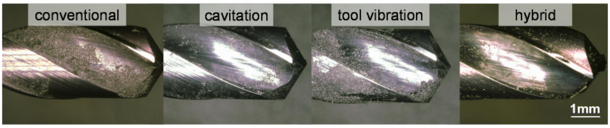

Fig.3 Micrographs of drill bits after drilling 50 holes

With respect to the cutting force, the hybrid machining, which simultaneously utilizes both tool-vibration and cavitation-aided machining, can reduce the thrust force of drilling by up to 40% compared to conventional drilling, as shown in Fig.4. However, the peak value of the cutting force is not steady during hybrid vibration drilling. This indicates that the synergy effect between the tool vibration and the cavitation is not often achieved. We need to determine the best condition to realize this synergy effect of ultrasonic vibration.

In terms of machining accuracy delamination, burr formation, and un-cut carbon fibers easily occur when machining composite materials [4]. A quantitative evaluation is required to assess the effect of ultrasonic-vibration-assisted machining. The delamination factor F_d, F_a, and F_{da}, which suggested by D. Liu [5], has been used to characterize the level of damage to the exit of the drilled hole on CFRP.

$$F_d = \frac{D_{max}}{D_{hole}}, \qquad F_a = \frac{A_{delami}}{A_{hole}}, \qquad F_{da} = F_d + \frac{A_{delami}}{A_{max} - A_{hole}}\left(F_d{}^2 - F_d\right)$$

Figure 5 shows the comparison of the delamination factors. In hybrid machining, delamination is reduced about 15% compared to conventional machining. When evaluating the damage to the composite material at the exit of the drilled hole, the F_{da} is more useful and effective factor than F_d or F_a.

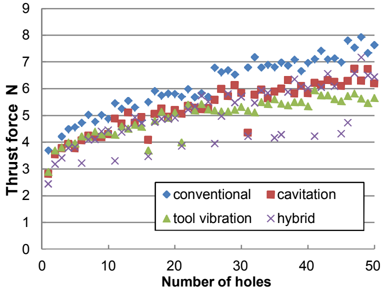

Fig.4 Difference between thrust forces

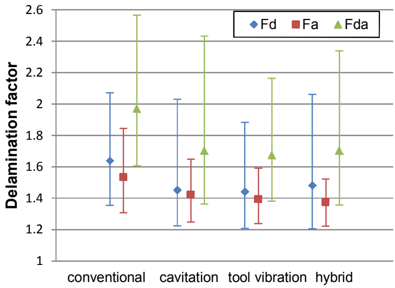

Fig.5 Comparison of delamination factors

3 Conclusion

The effect of ultrasonic-vibration-assisted machining on CFRP was experimentally evaluated through several tests. The results obtained were as follows:

1) Cavitation-aided machining generates a convective flow in the cutting fluid around the cutting area and prevents cutting chips from adhering to the tool with or without tool vibration.
2) Tool-vibration-assisted machining cuts the carbon fiber smoothly and reduces the cutting force.
3) Hybrid ultrasonic-vibration-assisted drilling, which simultaneously utilizes both tool-vibration and cavitation-aided machining, is the most effective in terms of the cutting force and machining accuracy. However, we still need to determine the best cutting condition to realize the synergy effect.

The experimental results show that the proposed method is useful for the efficient and accurate drilling of CFRP. In future work, these results can be utilized to enhance the production efficiency and accuracy in the aerospace, motor, and machine industries.

References

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