Drilling Performance Evaluation of CFRP Plate for Workpiece Clamping Methods

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Abstract

Carbon-fiber-reinforced plastics (CFRPs) are a typical material for lightweight parts in the aerospace or automotive industry. CFRPs are composed of carbon fiber and polymer matrix; therefore, their material properties can be adjusted by the ratio and type of fiber and polymer. When the desired composite materials properties are determined, CFRP parts are formed to a near net-shape by stacking CFRP prepreg layers. CFRPs are widely used for the skin parts of aerospace or automotive products because a CFRP part is manufactured by the stacking process; therefore, the near net-shape CFRP part is formed to a plate shape of comparatively small thickness. To create the final shape, a mechanical machining process such as drilling, routing, or milling is required to join or assemble with other parts. However, when the thin plate shape is machined, machinability is diverse with the clamping method. Conventional clamping methods such as vice are not suitable for the clamping plate shape. Therefore, in this study, machining performance is evaluated for the CFRP drilling process. Various clamping methods such as using various jig shapes and a universal fixture module were used for drilling a CFRP plate. Cutting force, vibration, AE signal, and dimensional displacement were measured to evaluate the machinability of the CFRP drilling process. Finally, the machined quality of the CFRP hole such as the delamination at hole exit and surface roughness of the hole wall are observed for various clamping conditions.

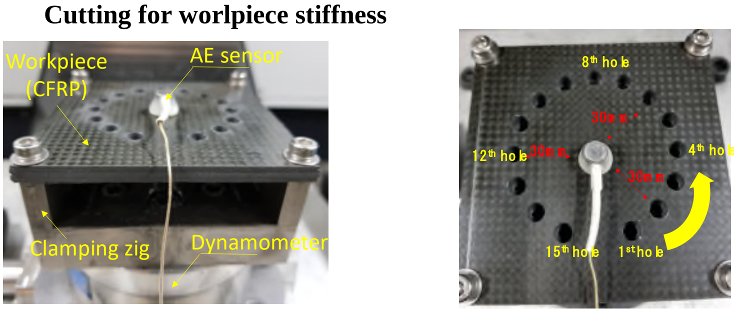
1 Introduction

Carbon-fiber-reinforced plastics (CFRPs) are a widely used composite material for lightweight transportation parts in the aerospace or automotive industry. CFRP parts are applied by plate-shaped components in aerospace or automotive parts. Therefore, the forming process creates a near-net-shape plate and a post-machining process completes the final shape using the routing and drilling process. The plate-shaped workpiece can be affected easily by the cutting force because it exhibits a low stiffness compared to a bulk-shaped workpiece. When the CFRP plate is machined, machining vibration and workpiece deformation can reduce machining quality. Therefore, workpiece stiffness and fixture methods are important to improve the machining quality of a CFRP plate. CFRPs exhibit various stiffnesses according to fiber type, polymer matrix type, and forming process. Furthermore, a complex-shaped fixture zig is required because aerospace and automotive parts exhibit a curved shape. In particular, the fixture structure of a universal fixture system can be deformed by the cutting force owing to its low stiffness. In this study, the cutting force and AE signal are measured for various CFRP plates and clamping methods.

2 Experiments and results

To investigate the cutting workpiece stiffness and clamping method, a thin plate workpiece and universal clamping device were used. Machining evaluation using the thin plate-shaped workpiece of different stiffnesses is introduced in the first section, and a universal clamping device of relatively low stiffness is evaluated in the second section.

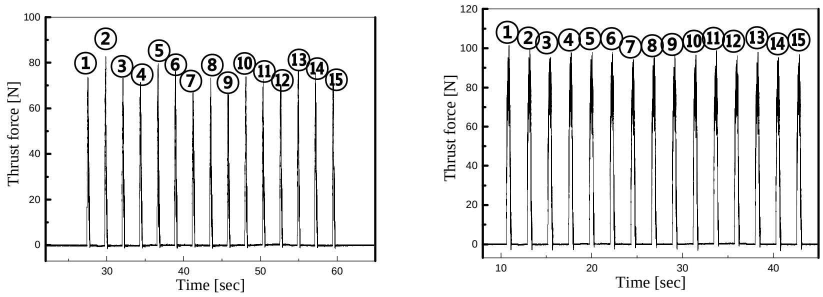
2.1 Cutting for worlpiece stiffness



(a) (b)

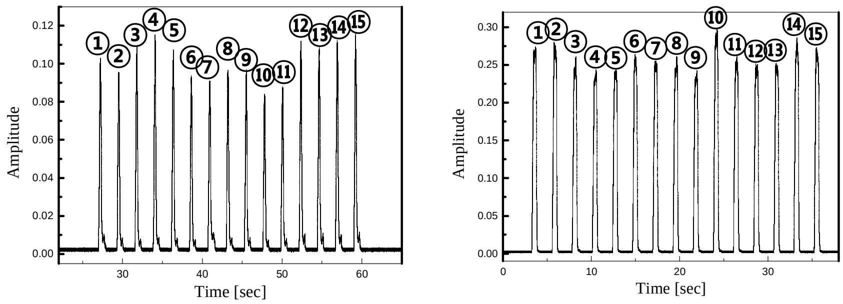
Figure 1: Experimental setup. Clamping zig, dynamometer, and AE signal for measuring cutting signals (a) and position of 15 machined holes (b).

CFRP parts are typically applied for outer skin parts in the aerospace and automotive industries. CFRP skin parts constitute a large area and small thickness. A large but thin plate can be deflected and vibrated easily by the thrust force of the drilling process. Defection and vibration during drilling decrease the machining quality such as hole accuracy, roughness, and delamination. In this study, two different CFRP plates were used. One is the CFRP plate that is manufactured by resin transfer molding (RTM), and the other is the CFPR plate fabricated by autoclaving. The RTM CFRP plate consists of T300 graded carbon fiber of thickness 3 mm. The autoclave-formed CFRP consists of T1000 graded carbon fiber of thickness 5.7 mm. For the drilling process, the spindle speed is 6,000 rpm and the feed is 0.1 mm/rev. The cutting force and acoustic emission (AE) signal were measured for each CFRP plate. Figure 1 shows the experimental setup for measuring the cutting force and AE signal. A dynamometer is located under the clamping zig, and an AE sensor is attached on the CFRP plate at the center point. Fifteen holes were machined around the center AE sensor. Figure 2 shows the cutting force signals for the RTM plate and autoclave plate. The thrust force magnitude at the RTM plate is lower than that of the autoclave CFRP plate because the RTM plate exhibits a low stiffness. Furthermore, the variation in cutting force for the 15 holes is higher at the RTM plate because the plate had deformed during drilling. Figure 3 shows the AE signals for the RTM plate and autoclave plate. The variation in AE signal for the 15 holes is higher at the RTM plate as cutting force signal. Therefore, when the plate thickness is small and the plate stiffness is low, deformation and vibration can increase owing to the cutting force.



(a) (b)

Figure 2: Cutting force signals for 15 holes. Cutting force signal for RTM plate (a) and autoclave plate (b).



(a) (b)

Figure 3: AE signals for 15 holes. AE signal for RTM plate (a) and autoclave plate (b).

2.2 Cutting for universal clamping device

The outer skin parts in the aerospace and automotive industries are typically curved for an aerodynamic design. Therefore, fixture zigs are required for machining. Conventional fixture zigs are exclusive and applied only for typical designs. Recently, however, universal zigs have been proposed to apply diverse designs with movable clamping structures. The universal zig clamps various shape, but the clamping stiffness is relatively low compared with the traditional fixture zig. In this study, the cutting force and deflection of the zig structure were measured in a universal fixture zig. Figure 4 shows experimental setup for the universal-type fixture. To investigate the deformation of the zig structure, a universal zig with multiple posts is used. The CFRP plate is drilled on a steel plate that is clamped using nine universal fixture posts. The cutting force was measured using a dynamometer on the steel plate, and the deformation of the universal fixture post was measured as the moving displacement of the steel plate on the universal fixture posts. The moving displacement of the steel plate was measured using a laser interferometer as shown in fig. 4 (b). The results indicate a cutting force of 73 N, and a displacement of 16 μm; therefore, the stiffness of the nine universal fixture posts was approximately 4.6 N/μm.

(a) (b)

Figure 4: Experimental setup. Universal-type fixture zig (a) and deformation measurement during drilling using laser interferometer (b).

3 Conclusion

Cutting signals were measured for various CFRP plates and clamping methods. The cutting force and AE signal were measured for two different CFRP plates of different fibers, manufacturing processes, and thicknesses. The plate with low stiffness demonstrated a low cutting force, and its variation in cutting force and vibration signal were more sensitive to the drilling position and clamping method. The clamping stiffness of the universal clamping device was measured using a dynamometer and laser interferometer. The measured stiffness was approximately 4.6 N/μm, which was much lower than the stiffness of machine tools. Therefore, when a workpiece can be deformed easily, the workpiece stiffness and clamping device are important before establishing the machining strategy.

References

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