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Free-form curves cutting using flexible circular saw

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ABSTRACT

A flexible circular saw, which can be used in a novel machining process for high-speed carbon fiber-reinforced plastic (CFRP) plate cutting, was developed. In this process, the saw is deflected like a bowl-like shape. A cross-section of the saw body then forms a circular arc. A curved line can therefore be cut without interference by the bowl-like deflection. In addition, the radius of the cross-section of the saw body can be controlled by adjusting the deflection. This process therefore allows curves to be cut with a varied radius using a single saw. This process can carry out high-speed curved-line cutting with a feed rate of 3 m/min on a CFRP plate. However, it is difficult to cut free-form curves using a flexible circular saw. Therefore, in this research, a new technique that can cut free-form curves using a flexible circular saw was proposed. Then, a cutting test applying the technique was carried out.

1. Introduction

The demands for carbon fiber-reinforced plastic (CFRP) for industrial applications continue to increase. CFRP products usually need to be machined (trimming process) after the curing of laminated prepregs. An abrasive water jet or endmill cutting is often used for the trimming process, but these processes present problems regarding machining efficiency and cost [1–6].

Here we propose a flexible circular saw as the core of a new process for CFRP plate cutting. A normal circular saw has many cutting edges, and it rotates at a high rotational speed [7], providing high-speed cutting (feed rate 3000 mm/min) on a CFRP plate that is approximately three times faster than the speed of other machining processes [8]. However, a circular saw is designed for straight-line cutting [9]. It is thus difficult to cut a curved line without interference between the saw body and the machined surface. One way to avoid this interference would be to bend the circular saw to fit the target curved line.

When the saw body is bent simply along the curve to cut, it causes fatigue failure of the saw body by cyclic deformation, because the cyclic bending is forced by the rotation of the saw. Therefore, in this process, a circular saw is deflected like a bowl-shape. This deflection can be realized by displacing the saw with a circular force while the center is held. A cross-section of a flexible saw's body making a circular arc is shown in Fig. 1. Curved lines could be cut without interference by the bowl-like deflection.

A band saw is similar to a circular saw. It is thought that the band saw can cut a curved line as well as the circular saw if the saw body is deflected to fit the target curve. However, it is difficult to apply the band saw to this process. The structure of the band saw machine tends to be bigger than that of the circular saw machine because the band saw blade is driven by two big pulleys. In addition, the width of the cut-off region of the workpiece should be smaller than the pulley diameter. In contrast, the drive mechanism of the circular saw is simple, and the saw body or drive mechanisms do not present an obstacle to the cutting process if the workpiece size is large. Therefore, the circular saw was chosen.

In our previous study, it was confirmed analytically that the flexible circular saw can cut a constant curvature line without interference by using FEM. In addition, the flexible circular saw can cut a constant curvature line on a CFRP plate with high accuracy [10]. However, the application for free-form curves using the flexible circular saw had not previously been realized.

In this paper, a new technique enabling free-form curves to be cut using a flexible circular saw was proposed, and in order to confirm the feasibility, a cutting test using the technique was carried out.

2. Free-form curve cutting using a flexible circular saw

It is difficult to cut free-form curves such as those combining concave and convex shapes using a flexible circular saw because it causes interference between the machined surface and the saw body. Therefore, in order to be used for practical cutting, a new technique for the machine tool that allows free-form curves to be cut using the saw is proposed.

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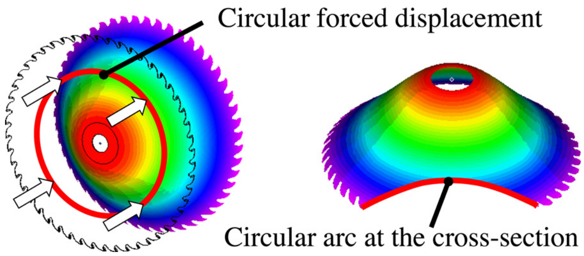

Fig. 1. Schematic of a flexible circular saw to cut a curved line.

2.1. Free-form curve-cutting technique

A circular saw has a difference between the width of the saw body and the width of the cutting edge. The width of the cutting edge is larger than the width of the saw body in order to avoid friction between the machined surface and the saw body, as shown in Fig. 2(a). This clearance is called the set teeth. The proposed technique utilizes this set teeth. The saw body can deflect within this set teeth without interference while cutting, as shown in Fig. 2(b). The curves can then be cut continuously by changing the deflection of the saw body and the direction of the saw successively, as shown in Fig. 2(c). Specific procedures for the technique are shown as Fig. 3.

(a) Find the next location of the preceding cutting edge along the target curve where the distance from the current point is incremental step Δl.
(b) The circular arc of the saw body should be tangential to the target curve at the next location of the preceding cutting edge. In addition, the deflection of the saw body should be defined so as not to interfere with both sides of the machined surface, A and B. In addition, the next location of the following cutting edge should be on the target curves.
(c) The saw then moves forward with a linear interpolation of the change of the deflection and the direction of the saw body.
(d) The above procedure is repeated.

If the target curves fulfill C1 continuity (means that the first derivatives, or tangents, are identical), this free-form curve-cutting technique can theoretically be applied to any curves (e.g. NURBS curves, etc.).

In order to deepen understanding the proposed technique, when the technique is applied to free-form curve-cutting, specific examples of the resulting motion of the saw are shown in Figs. 4 and 5. Fig. 4 shows a motion of the saw when a combination of two tangentially connected circular arcs with radius R5000 mm is cut. Solid lines show the shapes of the cross-section of the saw body. The process proceeds in the order of I–IX. A broken line shows the target shape. A dotted line is a line that is offset from the target shape by 1 mm. The 1-mm offset corresponds to the set teeth. Therefore, to intersect the solid line and the broken line or the dotted line shows interference with the saw body and the machined surface. All lines in the figure show a circular arc, but all lines do not appear as circular arcs because the scale is different between the horizontal axis and the vertical axis to make viewing easier. From I to IV, the radius of the saw becomes large as the process proceeds. Then, at V, which is the halfway point of this technique, the radius of the saw reverses. At this point, the radius of the saw reaches a maximum, and the saw body departs the farthest from the product. Finally, from VI to IX, the saw eventually fits the target shape as the radius of the saw becomes small. The saw changes its shape and direction within the set teeth. It is clear that the cross-sections of the saw body do not interfere with the machined surfaces. In addition, it is

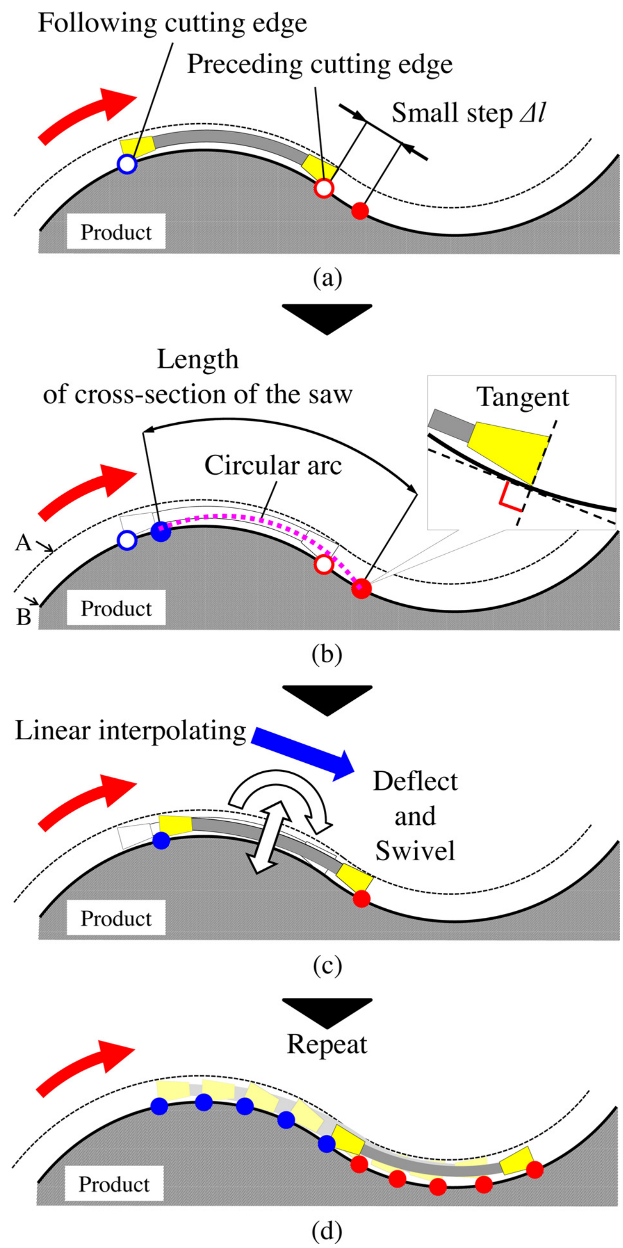

Fig. 3. Procedure for the free-form curve-cutting technique.

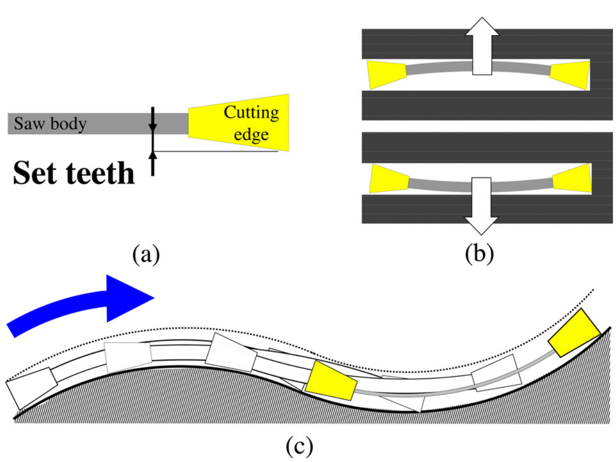

Fig. 2. Free-form curve-cutting technique.