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Basic research on the precision cutting characteristics of polycarbonate - Effects of cutting conditions and rake angle on cutting -

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Abstract
This paper aims to clarify resin cutting phenomena using a highly accurate and efficient cutting method. The cutting speeds and rake angles ware varied in orthogonal cutting of polycarbonate and investigated the tool temperatures, cutting force, and chip formation processes. Resin cutting exhibited much fewer shear deformations than metal cutting; moreover, the temperature was insensitive to the cutting speed. It was also found that tools with a larger rake angle produced more positive thrust forces. The thrust force decreased with increasing chip ejection direction and changed from positive to negative at tool rake angles around 20°. At a critical rake angle, the tool is unaffected by thrust forces.

Polycarbonate, resin cutting, photo elasticity, cutting temperature, stress distribution

1. Introduction

In recent years, the use and application of resins has increased dramatically in the automobile and the electrical and electronic industries, following the widespread use of touch panels, the advent of heads-up displays and a rapid increase in the need for high-performance functional resin films. Such panels and films need to be made to very high accuracy and have a high flatness. At present, they are manufactured by cutting them from resin plate. Cutting resin is quite different in many ways from metal cutting, including the facts that the material can melt from heat, lose transparency, and undergo cracks or deformation [1]. If resin is to be cut with great accuracy, first the mechanisms involved in cutting resin must be understood, and the appropriate cutting conditions and geometric design of the cutting tools must be established. However, only a few studies have been conducted, on the cutting of resin materials [2,3]. At present, cutting resin at manufacturing sites is only performed on the basis of trial-and-error. In view of above, the mechanisms for cutting resin materials have been examined in this study.

2. Experimental Overview

In this study, a general-purpose lathe customized with an inverter was used for varying the cutting speed and performed orthogonal cutting of a polycarbonate disk mounted on a spindle shown in figure 1. Machinability and adhesion are significantly influenced by resin cutting temperatures, whereas cutting force and chip forming efficiency are affected by the tool geometries. Therefore, the cutting speed and tool rake angle ware varied and examined the surface conditions of the cut tools; namely, their cutting force, ejected chips, properties of finished surface, and cutting temperatures. Other cutting conditions referred the practical conditions employed at production sites.

The experimental conditions are summarized in Table 1. Uncoated carbide tools were used in the experiments. The cutting force was measured with a dynamometer (Kistler 9227) and analysed the results by analysis software (Kistler Dyno Ware). The finished surfaces and chips ware observed with a digital microscope and the chip formation processes was observed with a high-speed camera. Cutting temperatures were determined using a high-quality thermal imaging camera.

3. Observation of chip formation processes

Figure 2 shows the example images of the chips ejected during the experiments. No chip was melted or changed by the increased cutting speed and rake angle. The chip thickness also remained unchanged. The cutting ratio was approximately 0.9 under all conditions. However, the chip formation processes captured by the high-speed camera revealed that the direction of the chip formation depended on the rake angle. As shown in Figure 3, tools with a smaller rake angle produced chips along the tool surfaces, whereas those with a larger rake angle

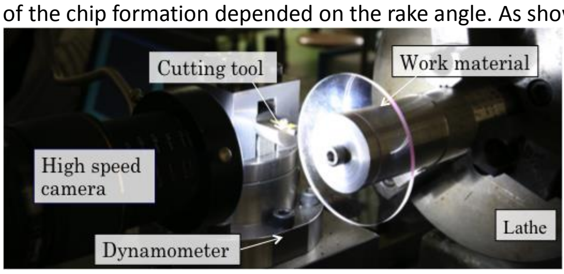

Figure 1. Schematic drawing of experimental equipment

Table1. Cutting conditions

Cutting speed m/min	100, 200, 400, 800
Feed mm/rev	0.05
Rake Angle dgree	-10, 0, 10, 20, 30, 40
Relief angle degree	15
Workpiece	Polycarbonate
Thickness of workpiece	3
Tool	Carbide

formed chips (being highly bent) away from the tool surfaces.

Experimental findings demonstrated that resin cutting rarely causes shear deformations (unlike metal cutting) and the contact area between the tool and chip is very small.

4. Temperature measurements

As mentioned above, no chip was melted during the experiments. However, controlling the cutting temperature is important because any softening or melting of the chips or work materials significantly impairs the machining accuracy. Therefore, the cutting temperature near the cutting point was measured by a thermal imaging camera. Regarding the cutting temperature, the maximum temperatures of the tool were determined from the temperature distribution images taken by the camera. Figure 4 shows an example of a thermal image during the cutting and the measurement result of the cutting temperature near the cutting point. The cutting temperature differs by a maximum of just 30°C over an eightfold increase in cutting speed (from100 m/min to 800 m/min). In addition, the work material never reached the polycarbonate softening temperature (230°C) under any condition, because the polycarbonate cutting generated almost no shear deformation and the contact area between tool and chip was very small as explained earlier. Cutting temperatures tended to decrease as the rake angle increased. These temperature variations were likely caused by plastic deformation heat rather than differences in the chip formation direction shown in Figure 3, because tools with smaller rake angles produced more bent chips.

5. Association of rake angles and cutting speeds with cutting force

As described in the previous subsection, the chip formation directions were changed as the rake angle increased; thus, the cutting force was measured and investigated the effects of rake angle and cutting speeds on cutting phenomena. The results are shown in Figures 5. The cutting force and thrust force were largely unaffected by cutting speeds; however, both force components decreased as the rake angle increased. Figure 6 shows the total forces of cutting and thrust at a cutting speed of 100 m/min. As the thrust increased, the reactive forces acting on the tools increased; as it decreased, the additive forces acting on the material increased. The thrust force was zero at a rake angle of 20°. Thus, highly accurate measurements and a flat cutting surface are achievable using a 20° rake tool with no thrust force.

6. Conclusion

In this study, it was clarified that how the cutting speeds and tool rake angles affect the cutting phenomena in polycarbonate cutting. First we varied the cutting speed and observed no melting or adhesion of the work material. Moreover, no significant difference was observed in the cutting temperature and cutting force. In fact, the cutting phenomena were barely affected by cutting speeds. Second, we varied the rake angle of the tools during the cutting and found differences in cutting temperature, cutting force, and the direction of chip formation. It was also found that a critical rake angle at which the thrust force was zero. This suggests the importance of designing resin cutting tools with proper rake angles. It considers that these findings will assist the design of end mills, which are typically used for resin cutting. Although adhesion is often considered the primary issue in resin cutting, no adhesion was found in this study. We attribute this phenomenon to differences in tool wear and chip formation between end-mill and turning. Several manufacturers have pointed out that adhesion (particularly resins) is caused by tool wear. To solve this problem, we must further investigate the affect of tool wear on cutting conditions.

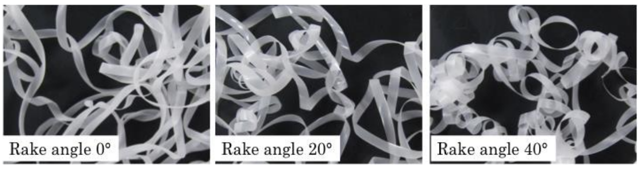

Figure 2. Microphotograph of chips

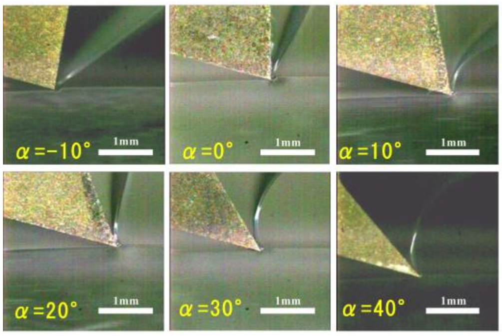

Figure 3. View of cutting processes with high-speed camera (v=100m/min)

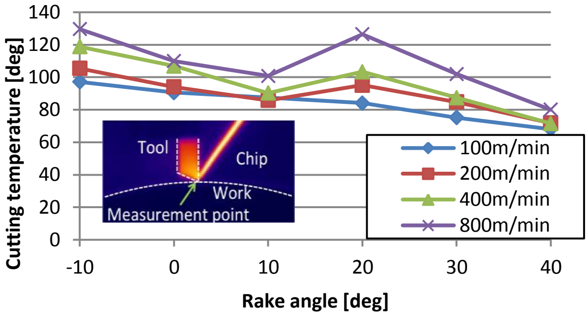

Figure 4. Relationship between rake angle and cutting temperature

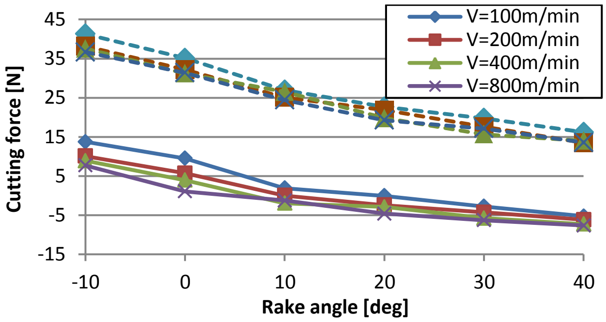

Figure 5. Relationship between rake angle and cutting force (dashed line: cutting force, solid line: thrust force)

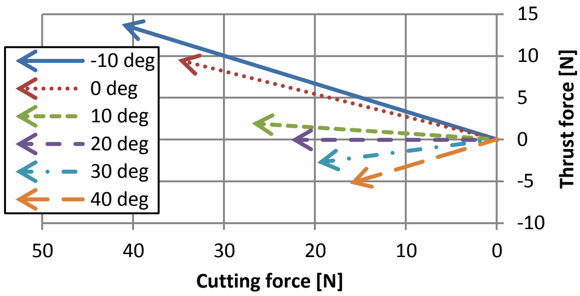

Figure 6. Vector of cutting force and thrust at a cutting speed

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