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右　川　太一郎
Taichiro UKAWA
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1. Preface

I participated in “17th International Conference on Precision Engineering” held in Kamakura, Kanagawa Prefecture on November 12 to 16, 2018. I made an oral presentation on the subject “Experimental Investigations on Micro-end-milling of Hardened Die Steel Damage Mechanism of Left －hand Helix Tool－”.

2. Presentation summary

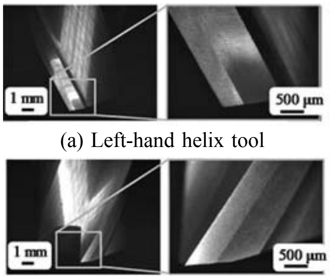
2.1 Introduction

Precision parts are in high demand in the machinery, electronic, and medical industries. Precision machining technologies are used in micromachining to manufacture these parts. Meanwhile, the demand for micro-end-milling for products is increasing, leading to further research and development. Therefore, this research focuses on mechanical machining using a micro-end-mill. Experiments about a variety of cutting phenomena that occur during actual machining processes were conducted to achieve high machining accuracy, high finished-surface quality, and long tool life. In the examinations, micromachining using a left-hand helix tool achieved high-accuracy and high-grade machining. Finishing with a left-hand helix tool reduces burrs and increases machining accuracy. However, re-biting of chips occurred during cutting. In this research, the damage mechanism in the micro-end-milling of hardened die steels using a left-hand helix tool was investigated. Cutting experiments were conducted to measure cutting force and observe the removed chips.

2.2 Experimental method

A large-size 10-mm-daimaeter tool (Fig. 1) was prepared to investigate the cutting phenomena in detail and determine the damage mechanism. A standard right-hand tool was also prepared. The same cutting phenomena were expected to see in both tools, so the flute shape was the same with only a difference in size from the small-diameter end mill. The workpiece material was hardened die steel (JIS: SKD61, HRC53). Table 1 shows the cutting conditions. A high-precision machining center was used for the cutting test and the cutting force with a dynamometer (Fig. 2).

Cutting force $F_{ze}(t)$ which is absolute value was estimated. Time t was set to zero at the moment when the cutting edge contacted the workpiece. Here, the cutting force was proportional to section area $A(t)$ in the chip before deformation. Specific cutting resistance K_z was estimated by dividing cutting force $F_z(t)$ measured in the z direction by section area $A(t)$ when the cutting



(a) Left-hand helix tool

(b) Right-hand helix tool

Fig. 1　End-mills

Fig.2　Schematic of cutting test

Table 1　Cutting condition

Spindle speed N_s min^{-1}	500 (15.7 m/min)
Feed rate f_t μm/tooth	300
Radial depth of cut R_d μm	200
Axial depth of cut A_d mm	10
Cutting length L m	0.5
Cutting direction	Up-cut
Coolant	Dry air

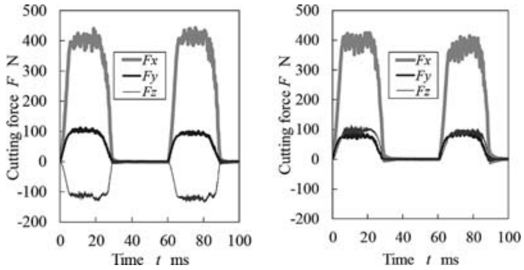
force was constant.

2.3 Results and discussion

Figure 3 shows a comparison of the cutting forces measured during one tool rotation. Two peaks according to the number of flutes in the end-mill can be confirmed for the both tools. The changes in cutting force F_x and F_y are almost same. However, the direction of F_z is different. F_z with a negative direction, which is the direction of the tool pushing the workpiece, can be measured with the tool with left-helix angle flutes. However, the positive direction force can be measured with the tool with right-helix angle flutes. Thus, measurement of the force is governed by the helix angle direction of the flutes. Figure 4 shows a comparison of cutting force F_z during one flute cutting. Here, the absolute value of the left-hand helix tool was evaluated in the estimation. With the left-hand helix tool, a small bump was founded in the end of the constant part of the section area and a delay in decreasing cutting force. However, such tendency was not observed with the right-hand helix tool, while the cutting force changed with the section area was found. The small bump might be caused by material stock on the cutting flutes and the delay might be due to tool deformation. Figure 5 shows scanning electron microscope (SEM) images of the removed chips. The material stock could not be seen at the bottom part of the chip from the left-hand helix tool. On the other hand, it was not observed with the right-hand helix tool. These phenomena might prevent the need to remove chips and cause tool damage. The influence of this tendency is more important in micro-end-milling.

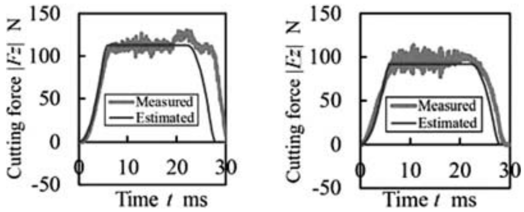
2.4 Summary

Material stock at the bottom part of the chip was observed with the left-hand helix tool. On the other hand, it was not observed with the right-hand helix tool. This phenomenon might prevent removal of chips and cause tool damage.



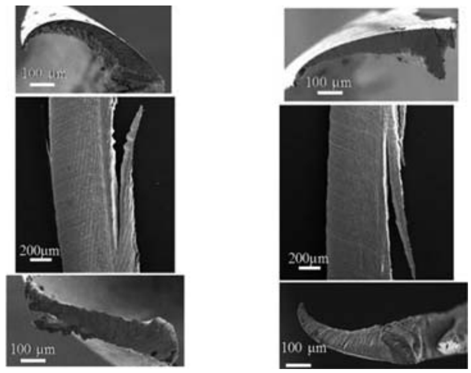
(a) Left-hand helix tool (b) Right-hand helix tool

Fig. 3 Comparison of cutting force measured during one tool rotation.



(a) Left-hand helix tool (b) Right-hand helix tool

Fig. 4 Evaluation of cutting forces.



(a) Left-hand helix tool (b) Right-hand helix tool

Fig. 5 SEM images of removed chips.

3. Acknowledgement

I would like to express my sincere gratitude to Associate Professor Keiji OGAWA for giving me an opportunity to participate in the international conference and giving me useful advices.