Study on Tool Wear and Cutting Force in Micro Ball-end Milling with High-speed Spindle

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Abstract

This paper deals with the characteristics of tool wear in micro ball-end milling with a high-speed spindle. In order to investigate the characteristics of flank wear, cutting tests on hardened stainless steel were carried out with ball-end mills having radii of 100μm and 500μm and a spindle speed ranging from 40 000 to 120 000min^{-1}. The test results showed the maximum width of flank wear decreased with an increase in the spindle speed for each end mill. It was also found that the cutting force component in the feed direction decreased with an increase in the spindle speed.

1 Introduction

There are urgent demands for miniaturized parts in fields such as the automotive, biomedical, and optical industries. As a method of processing such small parts, cutting with a micro ball-end mill is very important machining technology. However, the cutting performances of micro ball-end mills have not been sufficiently investigated. In particular, it is necessary to understand the tool wear characteristics of micro ball-end mills to reduce the tool wear and improve the machining accuracy. Therefore, in this study, cutting tests on hardened stainless steel were carried out by employing a special machine tool with a high-speed spindle, and the flank wear of the cutting edge was evaluated in order to investigate the tool wear characteristics of micro ball-end milling.

2 Experimental procedures

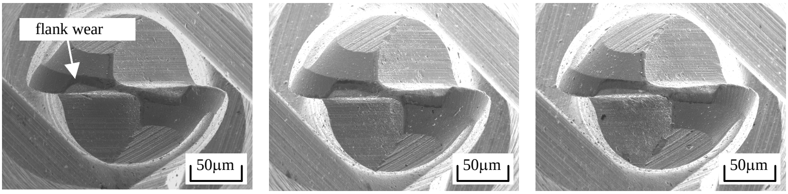
A CNC vertical milling machine (Sodick MC250L) was employed for the cutting tests. The motion resolution was 0.1μm and the spindle speed varied from 20 000 to 120 000 min^{-1}. Coated carbide ball-end mills were used for the experiments. The ball-end mills had a geometry consisting of two flutes, a helix angle of 30° and radii of 100μm and 500μm. The end mills were installed on the spindle with an overhang length of 12mm. The workpiece was hardened stainless steel (Uddeholm STAVAX) with a hardness of 52 HRC. Flat surface cutting tests were performed in a down-cut manner without any cutting fluid. The main cutting conditions are summarized in Table 1. The spindle speeds were 40 000, 80 000 and 120 000 min^{-1} and the feed amount per tooth was fixed at a constant value of 10μm. Both the axial and radial depths of cut using Tool B were set 100μm, five times greater than the 20μm depths when using Tool A.

Table 1: Cutting conditions

Tool material	Cemented carbide	
Radius of ball-end mill	Tool A 100μm	Tool B 500μm
Rake angle	30°	
Number of tooth	2	
Workpiece material	Hardened steel (52HRC)	
Rotation speed of spindle	4, 8, 12×10^4 min^{-1}	
Feed rate	10μm/tooth	
Axial depth of cut	20μm	100μm
Radial depth of cut	20μm	100μm
Cooling condition	Dry	

3 Experimental results

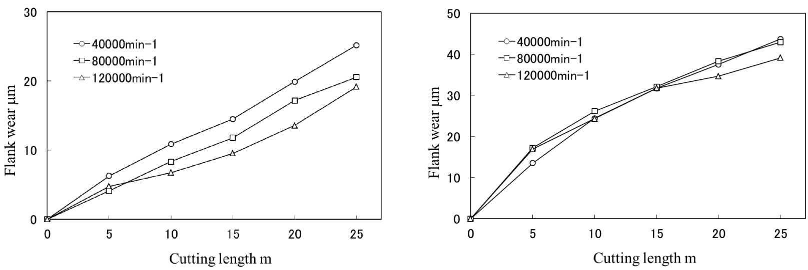
The wear patterns of cutting edges were observed with a scanning electron microscope. Figure 1 shows the flank wear of micro ball-end mills after cutting a length of 25m. It can be seen in photograph (a) that the flank wear grows in the area indicated by the arrow at the lowest spindle speed of 40 000min^{-1} and the width of the flank wear becomes progressively larger as the distance from the center of the micro ball-end mill increases. This is similar to the effect observed with a conventional ball-end mill and is caused by an increase of the tool–chip contact length [1]. However, as shown in photographs (b) and (c), the flank wear in micro end milling decreases with an increase in spindle speed, while the flank wear in conventional end milling increases [2].



(a) 40 000min^{-1} (b) 80 000min^{-1} (c) 120 000min^{-1}

Figure 1: SEM images of cutting edge of ball-end mill with radius of 100μm

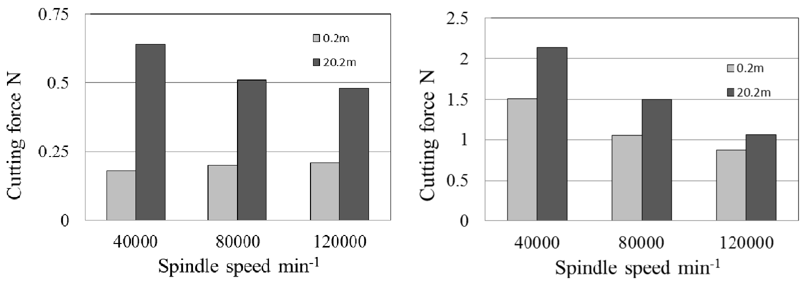
The maximum widths of flank wear were measured with a digital microscope system (HIROX KH-7700) after every 5m of cutting. Figure 2 shows the relationship between the maximum width of flank wear and cutting length at different spindle speeds. The maximum widths of flank wear increase nearly in proportion to the cutting length at all spindle speeds, and decrease with an increase in the spindle speed in the case of both ball-end mills. Comparing with the flank wear width after cutting a length of 25m, the flank wear generated on Tool A and Tool B decreased about 24% and 10% respectively, when the spindle speed was varied from 40 000 to 120 000min^{-1}. It can be understood from these results that increasing the speed spindle in micro ball-end milling is an effective way to reduce flank wear, and the reduction rate in Tool A is greater than that in Tool B.



(a) Tool A (b) Tool B

Figure 2: Relationship between maximum width of flank wear and cutting length

Figure 3 shows the average cutting force component in the feed direction during cutting. The cutting force signals were measured with a force transducer (Kistler 9256C1). As shown in Figure 3(a), the average cutting forces are almost the same regardless of the spindle speed at the start of cutting (length 0.2m). However, after a cutting length of 20.2m, the average cutting forces increase at every spindle speed. The variation in the amount of increase has a good agreement with that of the flank wear in Figure 2(a). On the other hand, the average cutting forces when using Tool B decrease with an increase in the spindle speed at both a cutting length of 0.2m and 20.2m. The variation in the increased amount is similar to that in Tool A. However, the rate of increase of cutting force in Tool A is greater than in Tool B. Whether or not the flank wear in Tool A tends to increase the cutting force compared with Tool B was investigated.



(a) Tool A (b) Tool B

Figure 3: Average cutting force in feed direction Fy

4 Conclusion

The results are summarized as follows. When the spindle speed varied from 40 000 to 120 000min^{-1}, the flank wear of the ball-end mills with radii of 100μm and 500μm decreased about 24% and 10%, respectively. The variations in the amount of increase in the cutting force using ball-end mills with radii of 100μm and 500μm have a good agreement with that of the flank wear.

References:

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