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Turning of Magnetic $CuFe_2O_4$ Ferrite

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ABSTRACT

$CuFe_2O_4$ ferrite was machined with cermet tools to clarify the machinability. The tool wear became the smallest at the cutting speed of 90m/min with the depth of cut of 0.2mm. The surface roughness became larger with increasing the cutting speed and the chamfer angle of tool. The tool with the chamfer angle of 15° showed the smallest wear. The surface roughness increased almost proportionally with the increase of chip size. The tool wear reduced with increasing feed in the depth of cut not more than 0.2mm.

Keywords : Turning, Ferrite, Tool wear, Machinability, Cutting speed, Tool performance, Surface roughness

1. Introduction

Ferrite materials have been widely used for many fields owing to an excellent magnetic property. They are manufactured by sintering process after forming. Typically the additional machining processes are necessary for the complex shaped workpiece after the sintering, because only sintering process is not suitable for attaining the desired shapes and dimensions[1,2].

Because of their brittleness and high hardness, the materials are usually ground with a diamond wheel as a final process. However, the material removal rate must be increased to improve the productivity for economic justification[3].

Since the hardness of $CuFe_2O_4$ ferrite is lower than that of the other magnetic ferrites, it is believed that the cutting of $CuFe_2O_4$ ferrite with single edge tool is a feasible method which would present advantages. It may reduce the machining cost, enhance productivity and apply for complicated parts.

In this study, turning of the $CuFe_2O_4$ ferrite was performed with cermet tools to clarify the machinability, the optimum tool geometry and the optimum cutting conditions.

2. Experimental procedure

The physical and mechanical properties of the $CuFe_2O_4$ ferrite machined are shown in Table 1.

All tests were run wet, and a water-soluble type of coolant with dilution rate of 1:40 was poured from the rake face side of the tool in CNC lathe.

The Vickers hardness and flexural strength of the cermet tool used were 170 and 1800MPa, respectively. Except for investigating the effect of the chamfer on cutting edge in view of tool wear, the tool geometry of all tools was −5, −5, 5, 5, 15, 15, 0.8mm with no chamfer. In the case of examining the effect of the cutting edge chamfer, the cutting edge was chamfered by grinding and lapping. Three different chamfered angles of 25°, 15°and 5°with a constant width of 0.2mm were tried to compare with the tools without the chamfer.

To investigate the effect of cutting conditions on the machinability, the cutting conditions were varied as shown in Table 2.

Since the crater wear did not occur in all tests, only the maximum flank wear width was measured by means

Table 1 Mechanical properties of $CuFe_2O_4$ ferrite

Shore hardness	Bending strength (MPa)	Bulk density (kg/m^3)	Porosity (%)	Fracture toughness (MPa · m$^{1/2}$)	Grain size (μm)
84	201	3320	1.2	2.6	2.1

Table 2 Cutting conditions used

Cutting speed, V	30, 60, 90, 120 m/min
Feed, f	0.02, 0.04, 0.06, 0.08, 0.1 mm/rev.
Depth of cut, t	0.1, 0.2, 0.3 mm

of a tool maker's microscope. After turning for a fixed duration, the surfaces machined were examined using a microscope and a surface roughness tester.

The size of the chips generated during turning was acquired by measuring the mean size of 80 chips captured on the linear line of SEM's display.

3. Experimental results and discussion

Fig. 1 shows the relation of the flank wear and cutting length at different cutting speeds in the case of using the commercially produced cermet tools. The tool wear at the cutting speed of 90m/min is the smallest in all cutting lengths. Though the initial wear at the cutting speed of 60m/min is similar to that observed at 90m/min, the wear rate with the increase of cutting length at the cutting speed of 60m/min is higher than that observed at 90m/min. At significantly lower or higher cutting speeds than 90m/min, the initial wear levels and wear rates become larger with comparison to that at 90m/min. Therefore, it is believed that the cutting speed of 90m/min is the best in view of tool life.

Fig. 2 shows the typical wear patterns at the cutting speeds of 30, 90 and 120m/min at the same feed and depth of cut as Fig. 1. The tool retained a sharp edge at the cutting speed of 30m/min, but fine grooves appeared on the worn surface along the turning direction. It is evident that the carbide grains are removed from the flank face due to plowing by the chips generated during cutting. However, at the cutting speed of 90m/min which exhibited the smallest tool wear, the flank surface was smooth due to abrasive wear, showing the small edge chipping. The wear pattern of the tool in the case of 60m/min appeared to be a middle tendency of those at the cutting speeds of 30 and 90m/min, not shown in this figure. The tool at the cutting speeds of 120m/min showed severe edge wear, exhibiting very roughly worn flank surface, in which a large number of carbide grains had been broken away from tool surface.

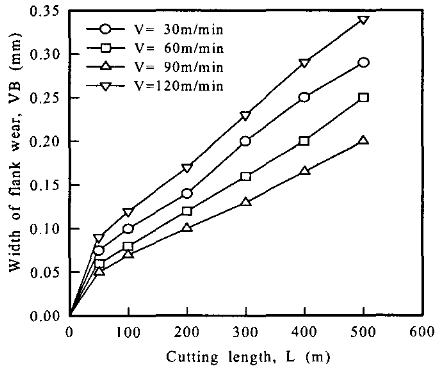
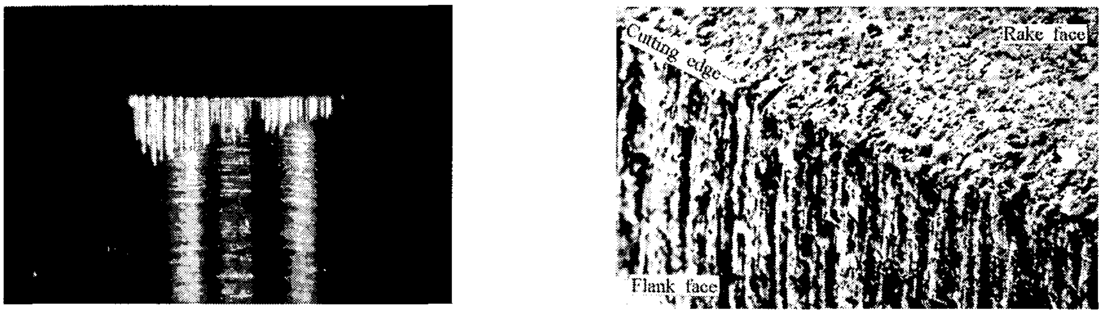


Fig. 1 Effect of cutting speed and cutting length on flank wear width in turning of ferrite with cermet tool
f=0.06mm/rev., t=0.2mm

Fig. 3 shows the variation of the size and shape of the chips at two different cutting speeds. The chips generated during cutting at 30m/min consist primarily of small granular type, however, almost all chips at 90m/min are large lump type. At the cutting speed of 60m/min, the chips consist of both small granular and large lump types. It is thought that the cracks which nucleate in the vicinity of the tip of the cutting edge grow more deeply into the surface to be machined at higher cutting speed, consequently generating larger chips due to larger fracture scale.

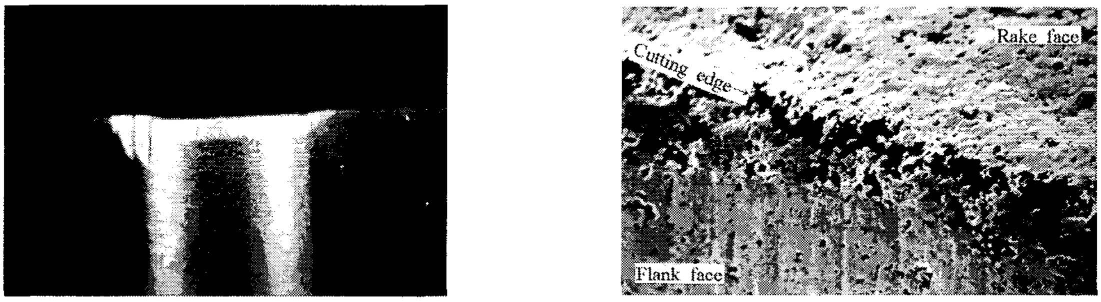
On the other hand, the machined surfaces after cutting are shown in Fig. 4. The surface finish at the cutting speed of 30m/min is relatively good, but that at 90m/min is poor, leaving the uncut regions in the machined surface due to the subsurface fracture. The surface finish at the cutting speed of 60m/min appeared to be a middle tendency of those at the cutting speeds of 30 and 90m/min, not shown in this figure. The workpiece fractures on smaller scale at the lower cutting speed, resulting in the better surface finish.

From Figs. 2, 3 and 4, it is thought that the shape and size of chips govern the tool wear pattern. At the cutting speed of 30m/min, because the fracture during cutting occurs on small scale and the removal of the chips becomes worse, the number of chips trapped in the tool-workpiece interface is increased, consequently causing more severe tool wear due to plowing the carbide grains. These facts suggest that the best machinability at 90m/min is the result of both the decreased real contact area at the tool-workpiece interface because of the larger fracture scale and the ease of chip removal owing to larger chip size. At the cutting speed of 120m/min, the temperature on wear land and the impact energy during cutting is increased. It is for this reason that the wear patterns in the Fig. 2 (e) and (f) show the increases of both the edge wear and the removal of carbide grains from tool surface.



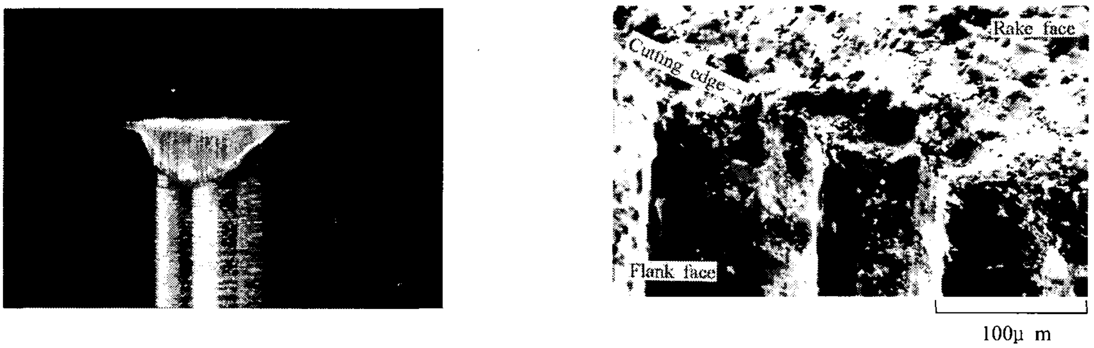
(a) V=30m/min, L=500m

(b) high magnification of (a)



(c) V=90m/min, L=500m

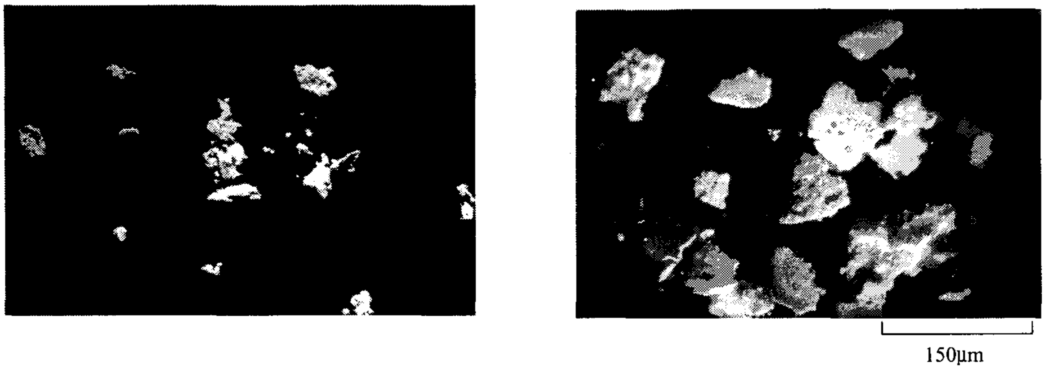
(d) high magnification of (c)



(e) V=120m/min, L=500m

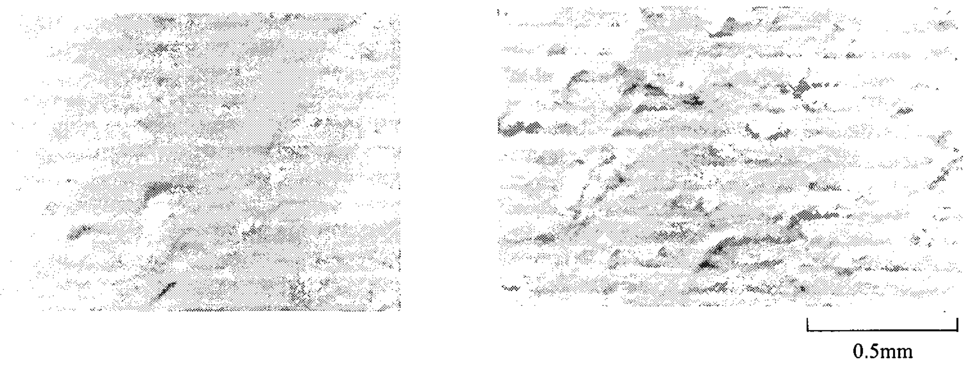
(f) high magnification of (e)

Fig. 2 Typical wear pattern of cermet tools after turning Cu ferrite at different cutting speeds (Micrographs, b, d, & f show the central corner position of each tool.)
f=0.06mm/rev., t=0.2mm



(a) V=30m/min (b) V=90m/min

Fig. 3 Photographs of chips formed after turning Cu ferrite at different cutting speeds f=0.06mm/rev., t=0.2mm, L=200m



(a) V=30m/min (b) V=90m/min

Fig. 4 Photographs of surface turned with cermet tool at different cutting speeds f=0.06mm/rev., t=0.2mm, L=200m

The effects of the cutting speed and cutting length on surface roughness are shown in Fig. 5. As the cutting speed decreased, the surface finish becomes better in all lengths of cut. At the cutting speed of 120m/min, the slope of surface roughness curve with respect to cutting length is the largest, whereas the slope at the other cutting speeds is similar to those at the cutting speeds of 100m/min and higher. At the cutting speeds of 60 and 100m/min, the surface finish in the cutting length range of 30 to 100m is seen to improve with the increase of cutting length. This is because in this region the worn pattern of tool becomes stable for the machined surface. However, at the above cutting speeds, the surface roughness is increased with increasing the cutting length as the cutting is proceeded over the cutting length of 100m.

From these results, it is evident that the fracture scale and chip size have an important role on tool wear. Thus, to change the fracture scale for chip formation, the cutting tests at different feeds and depths of cut were performed.

Fig. 6 shows the effect of feed on flank wear at various depths of cut. The flank wear of the tool at the depth of cut of 0.2mm is the lowest with all the feeds tested. At the depth of cut of 0.1mm, the flank wear with small feeds becomes very severe, but the wear reduces significantly with increasing feed. However, at the depth of cut of 0.3mm, the flank wear becomes larger with the increase of feed. These results show that the higher the feed, the larger is the effect

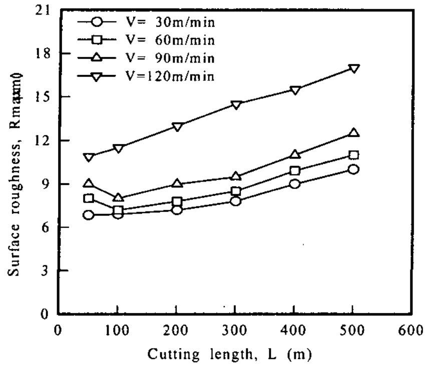


Fig. 5 Effect of cutting speed and cutting length on surface roughness
f=0.06mm/rev., t=0.2mm

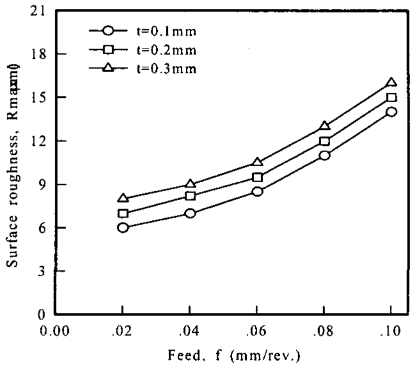


Fig. 7 Effect of feed and depth of cut on surface roughness
V=90m/min, L=300m

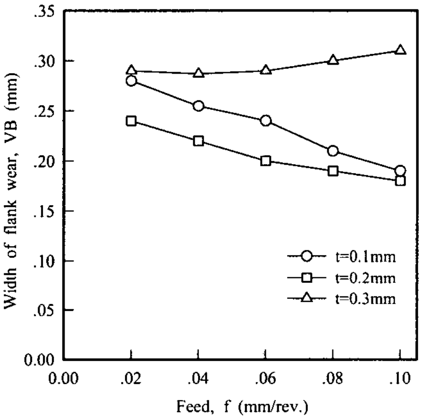


Fig. 6 Effect of feed and depth of cut on flank wear width
V=90m/min, L=500m

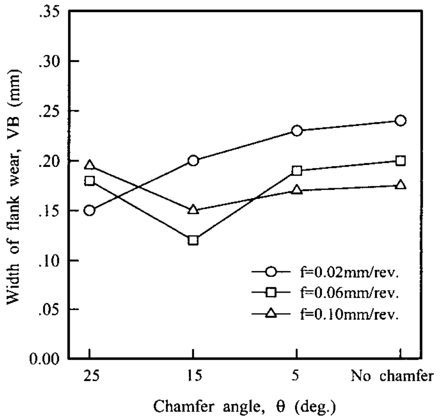


Fig. 8 Effect of the chamfer angle of tool edge on flank wear width
V=90m/min, t=0.2mm, L=500m

of depth of cut on flank wear. It is expected that the tool wear would be smaller by means of selecting properly both the feed and depth of cut for the purpose of forming the large lump type chips. However, when both the feed and depth of cut are high, the tool wear becomes severe because of higher cutting temperature and impact energy.

The effect of feed on surface roughness at different depths of cut is shown in Fig. 7. The increasing rate of the surface roughness with increasing feed is similar in all depths of cut, and the surface roughness increases largely by increasing feed. The surface finishes produced are seen to be more strongly dependent on the feed than the depth of cut. This fact reveals that the surface roughness is more remarkably affected by the uncut region due to subsurface fracture than by the feed mark.

Fig. 8 exhibits the effect of the chamfer angle of tool edge on the flank wear at various feeds. The flank wear decreases with the increase of chamfer angle at the lowest feed, but the tool wear in the case of the chamfer angle of 15°is the smallest at the feeds of 0.06 and 0.10mm/rev. Thus, at the depth of cut of 0.02mm, it is thought that the difference in chamfer angle causes the variation of rake angle. Since the fracture during cutting with the tool of smaller chamfer angle occurs on the smaller scale, the

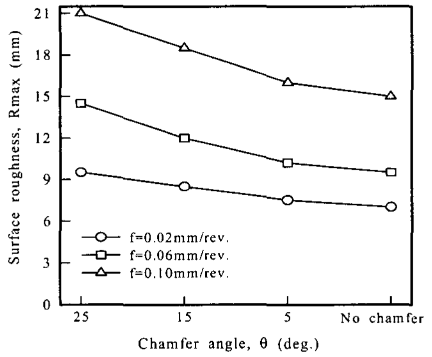


Fig. 9 Effect of the chamfer angle of tool edge on surface roughness
V=90m/min, t=0.2mm, L=300m

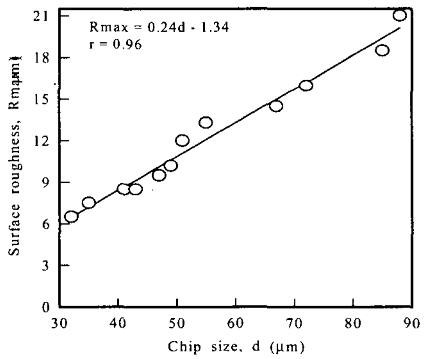


Fig. 10 Relation between chip size and surface roughness
V=90m/min, f=0.02, 0.06, 0.10mm/rev., t=0.2mm, θ=25, 15, 5(deg.), L=300m

removal of small chips becomes difficult and the real contact area between the tool-work interface is increased, consequently increasing flank wear. When cutting at the feeds of 0.06mm/rev or higher, the flank wear with the chamfer angle of 25°becomes larger than that in the case of 15°. It is believed that this is because cracks which nucleate into workpiece in the vicinity of the cutting edge grow more deeply at the feeds, consequently requiring larger cutting energy owing to larger fracture scale.

Fig. 9 shows the relation between the chamfer angle of tool edge and the surface roughness at various feeds is shown in Fig. 9. When the chamfer angle increases, the surface roughness becomes larger due to the increase of fracture scale for chip formation, and this effect tends to increase with the increase of feed.

Fig. 10 shows the relation between the chip size and the surface roughness in cutting with different feeds and chamfer angles at the constant cutting speed and depth of cut. The surface roughness is seen to be linear approximately with respect to chip size(d) as the empirical relationship of $R_{max} = 0.24d - 1.34$. The fact that the chip size increases suggests the increase of fracture scale during chip formation. Therefore, the surface roughness can be estimated by knowing the chip size.

4. Conclusions

From the results concerning the turning of $CuFe_2O_4$ ferrite, the following conclusions were obtained.

1) The tool wear becomes the smallest at the cutting speed of 90m/min, and the roughness of the machined surface increases with the increase of cutting speed.
2) The tool wear is the smallest at the depth of cut of 0.2mm. The tool wear reduces with increasing feed at the depth of cut not more than 0.2mm, however, showing a reverse tendency with the increase of feed at the depth of cut of 0.3mm.
3) The tool wear in the case of the chamfer angle of 15° is the smallest at the feeds not more than 0.06mm/rev, but the surface roughness decreases with decreasing the chamfer angle at all the feeds tested.
4) The surface roughness decreases almost proportionally with the decrease in chip size.

References

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