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Study on tool wear characteristic of precision cutting in the ductile iron FCD600

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Abstract. In recent years, the importance of environmental problems has increased in aircraft industry and automobile industry. FCD600 which is named ductile cast iron has spherical graphite. As a result of the organization of spherical graphite, FCD600 has excellent tensile strength and elongation. It has great toughness and has been selected for use in applications such as automobile chassis parts and body parts. For example, it has always been selected for the materials of automobile exhaust manifolds and suspensions. However, for difficult-to-cut materials such as FCD600 with extremely high strength of 600 N/mm^2 or more there are many problems such as low cutting stock removal rates, tool fractures, and difficulties in securing processing accuracy. To reduce the impact on the environment and its associated costs, the minimum quantity lubrication (MQL) cutting method, which uses a very small amount of cutting fluid, has been found to be preferable for cutting difficult-to-cut materials. However, this method has drawbacks such as the cutting stock removal rate and the wear on cemented carbide tools. Consequently, we examined the wear of a cemented carbide tool in cylindrical cutting of FCD600. In this paper, we experimentally examined the relationship between the tool materials, cutting speed, cutting condition, and tool wear characteristics. Results showed that there are slight differences between high-pressure coolant cutting and near-dry cutting. With MQL cutting, the criteria for surface roughness and tool life were able to be satisfied.

1. Introduction

Ductile cast iron (FCD600) which is a difficult-to-cut material, is normally selected for the material of automobile exhaust manifolds and suspensions (Figure 1) [1].

(a) Exhaust manifold

(b) Automobile chassis parts and body parts

Figure 1. Photographs of automobile parts

As shown in Figure 2, ductile cast iron has an organization of spherical graphite which makes it have excellent tensile strength and elongation. As a result of these material characteristics there are many problems in precision cutting of FCD600 [2]. As described above, high-pressure coolant processing has attracted attention as a standard method to improve the cutting efficiency of high-strength material with highly difficult-to-cut properties. In high-pressure coolant processing, it is expected that the cooling of the tool affects the frictional heat suppression and the chip cutting. These effects are expected to reduce tool wear, improve the surface roughness, and extend the tool life [3-5]. However, since high-pressure coolant processing uses a large amount of cutting fluid there are problems such as the processing cost of the cutting fluid, increased energy consumption, and environmental burdens [6,7]. In order to reduce the environmental impact, the minimum quantity lubrication (MQL) cutting method has been found to be preferable for precision cutting of difficult-to-cut materials [8-10]. In this study, we examined the relationship between the tool materials, cutting speed, cutting condition, and tool wear characteristics.

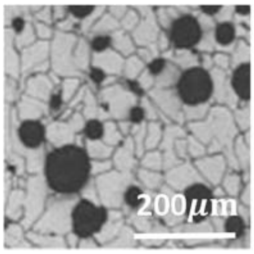


Figure 2. Photograph of spherical graphite cast iron

2. Experimental Equipment and Conditions

The experimental equipment used in this study and details of the cutting and lubricating activities are summarized in Table 1. Figure 3 shows the experimental setup. We used both wet cutting and near-dry cutting and the high-pressure coolant and MQL tool holder are shown in Figures 4 and 5. The high-pressure coolant supply system supplies the cutting fluid to the tool rake face at a maximum coolant pressure of 7 MPa. The MQL oil supply system supplies the cutting fluid to the tool from the rake face and end clearance.

Table 1. Experimental equipment and details

Machine tool	NC turning: Cincom RL21(Citizen Machinery Miyano)
Work piece	FCD600, HV281, ϕ20 × 30 mm
Measurement equipment	Cutting tool dynamometer: 9251A (KISTLER)
Cutting tool	Cemented carbide: S05, S05 TiAlN coating, K01 Rake angle: α = 7°, Nose R: 0.2 mm
Cutting conditions	Cutting speed V = 25~450 m/min Feed rate f = 0.05~0.2 mm/rev Depth of cut t = 0.125~0.416 mm Cutting length L = ~576 m
Measurement	Cutting force: Dynamometer 9251A (KISTLER) Surface roughness: Form Talysurf 5.04 (Taylor Hobson) Tool wear: OPTEICS H1200(LASERTEC)
Lubricating methods	Wet: Blasomil 22 (Blaser Swisslube) Coolant pressure: 7 MPa, Flow rate: 1134 L/h
	MQL equipment: MS-1（Kyouritu Gokin） MQL oil: Unicut Jinen MQL（JX Holdings） Air pressure: 0.3 MPa, Flow rate: 76 mL/h

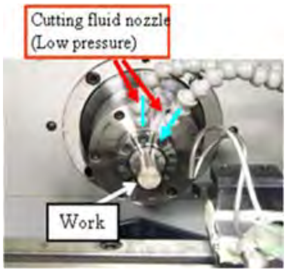


Figure 3. Photograph of the experimental setup

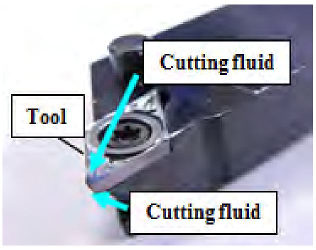


Figure 4. Photograph of the MQL tool holder

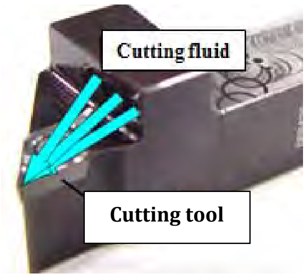
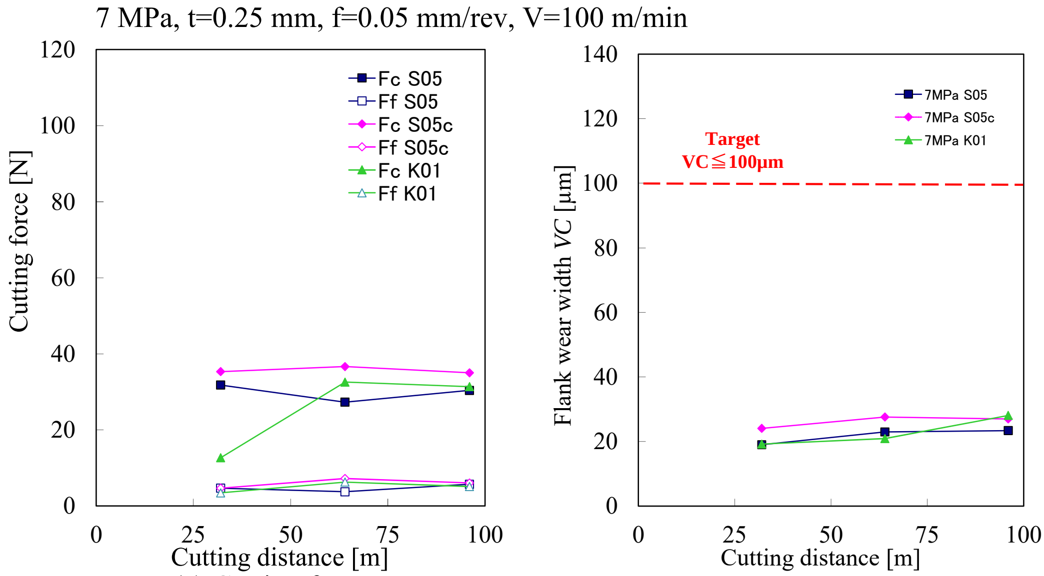


Figure 5. Photograph of the high pressure coolant holder

3. Result of the Experiment

3.1. *Relationship between tool wear characteristics and cutting tool materials*

First, we performed an experiment on cutting tool materials to examine the relationship between tool wear and tool materials using wet cutting and MQL cutting. In this experiment, we used cemented carbide tool S05, S05 TiAlN coatings and K01 as the cutting tool. Figure 6 shows the relationship between cutting distance, cutting force, and flank wear width *VC* with wet cutting.



(a) Cutting force (b) Flank wear width *VC*

Figure 6. Relationship between cutting distance, cutting force, and flank wear width *VC* (7 MPa)

Figure 6(a) shows that the principal force F_c was nearly constant when we used S05 and S05 TiAlN coatings. On the other hand, the feed force F_f was nearly constant regardless of the cutting tool materials. As shown in Fig. 6(b), the flank wear width VC was nearly constant at 36 μm and it was below the target line. From this result, we deduced that using different cutting tool materials has a slight effect on tool wear with wet cutting.

We did the same experiment with MQL cutting with the results shown in Fig. 7. As shown in Fig. 7(a), the principal force F_c and feed force F_f were nearly the same as the result with wet cutting. And because of the found of built-up-edge the cutting force Fc increased over the increase of cutting distance in the case of S05 and S05coating, but remained in the case of K01. From Fig. 7(b), the flank wear width VC was almost constant and nearly the same result as wet cutting. From this result, we deduced that MQL cutting will be preferable for cutting with FCD600.

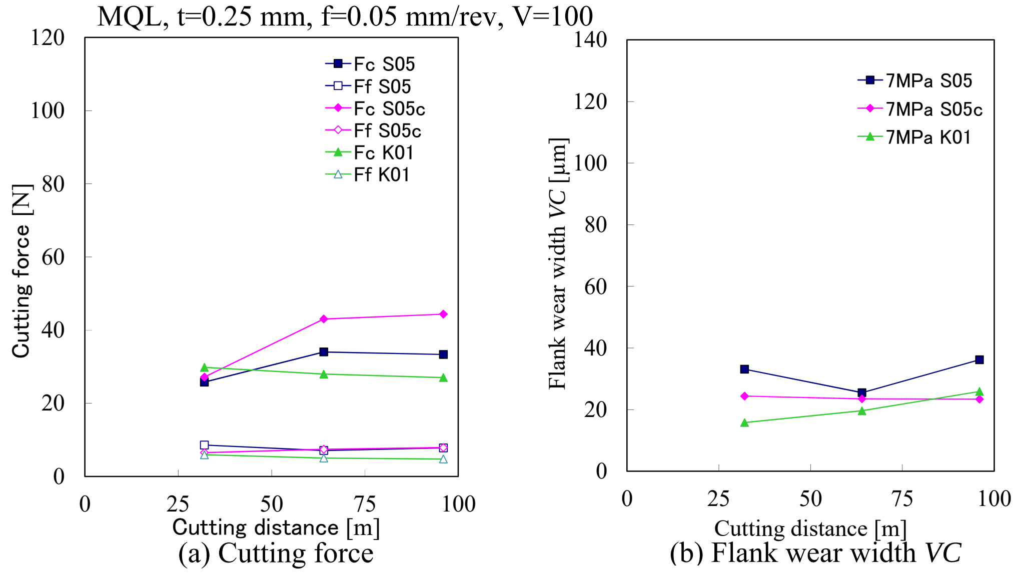


Figure 7. Relationship between cutting distance, cutting force, and flank wear width *VC* (MQL)

3.2. *Relationship between tool wear characteristics and cutting speed*

Next, we used a cemented carbide tool K01 to examine the relationship between tool wear and cutting speed with MQL cutting. In this experiment we selected a cutting condition of t= 0.25 mm and f=0.05 mm/rev. Figure 8 shows the relationship between cutting speed, cutting force, and flank wear width VC. As shown in Fig. 8(a), when the cutting speed was changed from 25 m/min to 450 m/min, the principal force Fc was nearly constant. However, when the cutting speed was 450 m/min the base metal covered the organization of spherical graphite, the principal force increased. As the same reason the flank wear width VC was increased at a very high cutting speed. Figure 8(b) shows that when the cutting speed was between 100 m/min and 350 m/min, the flank wear width *VC* varied from 26 μm to 32 μm. We considered that the tool wear can be reduced by cutting speed V from 100 to 350 m/min.

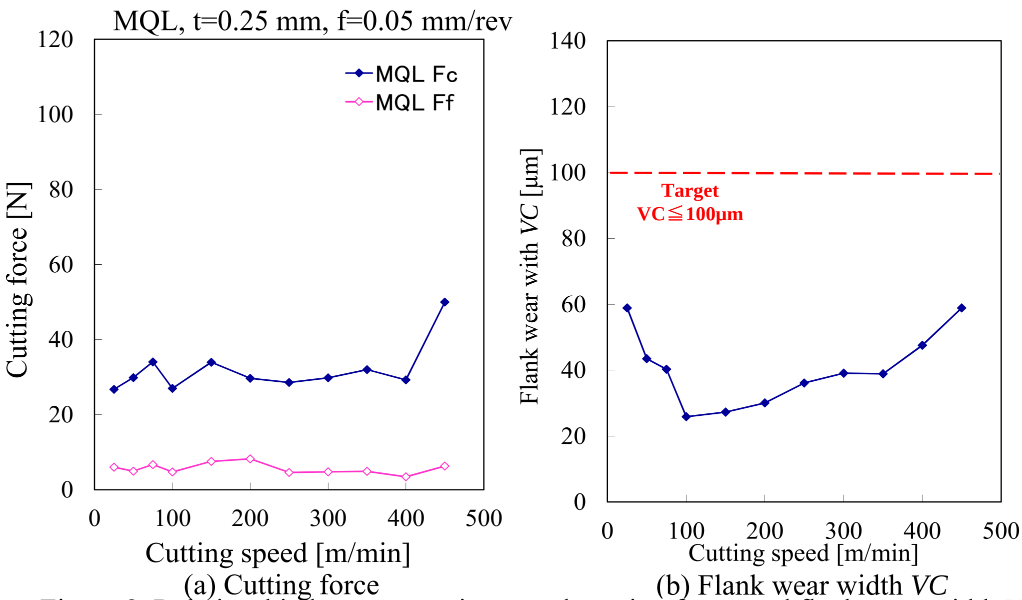
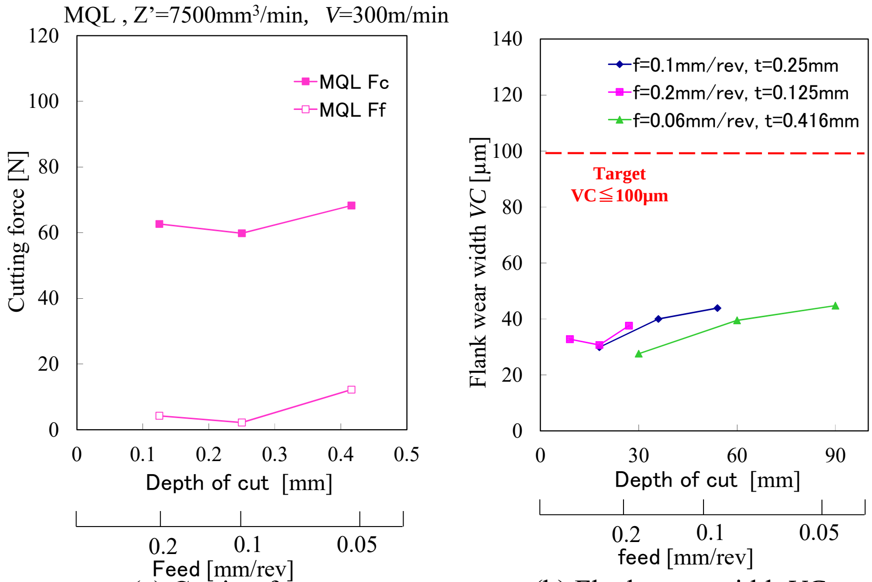


Figure 8. Relationship between cutting speed, cutting force, and flank wear width *VC*

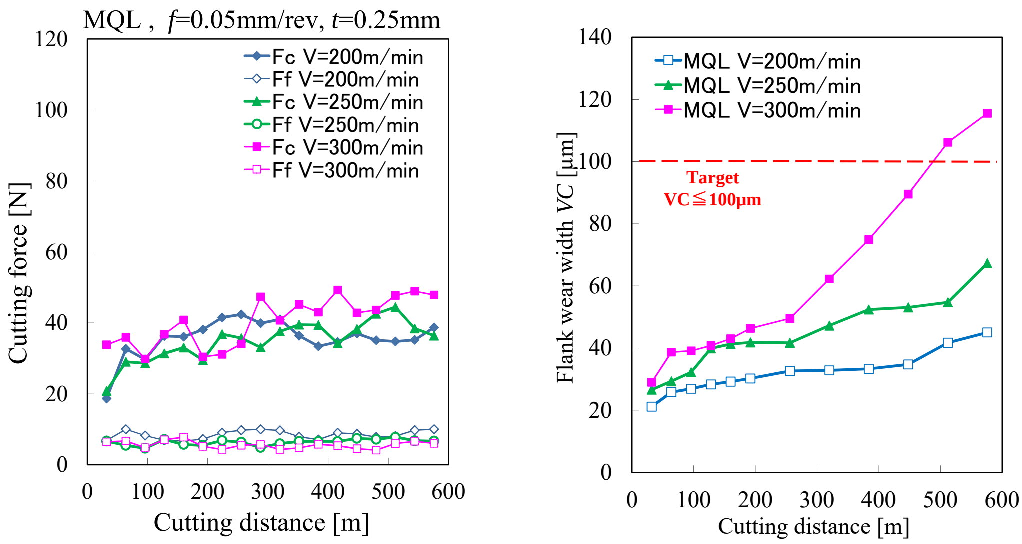
3.3. *Relationship between tool wear characteristics and cutting conditions*

According to the results of the cutting speed experiment, using different cutting speeds has a slight effect on tool wear characteristics. Therefore, we used cemented carbide tool K01 and a cutting speed of V=300 m/min to examine the relationship between tool wear characteristics and cutting speed. Figure 9 shows the relationship between the cutting conditions, cutting force, and flank wear width *VC*. As shown in Fig. 9(a), the principal force F_c was from 60 to 68N and the feed force F_f was from 2 to 12N The cutting force was nearly constant regardless of the cutting conditions. As shown in Fig. 9(b), the flank wear width VC was almost constant at about 40 μm. We deduced that using different cutting conditions has a slight effect on tool wear.



(a) Cutting force (b) Flank wear width *VC*

Figure 9. Relationship between cutting conditions, cutting force, and flank wear width *VC*



(a) Cutting force (b) Flank wear width *VC*

Figure 10. Relationship between continuous cutting, cutting force, and flank wear width *VC*

3.4. *Relationship between tool wear characteristics and cutting continuous*

As a result of cutting conditions having a slight effect on tool wear characteristics, we selected the cutting condition of t=0.25 mm, f=0.05 mm/rev, and high-cutting speed V=200~300 m/min in order to examine the relationship between tool wear characteristics and continuous cutting. Figure 10 shows the relationship between continuous cutting, cutting force, and flank wear width *VC*. As shown in Fig. 10(a), the principal force F_c and feed force F_f were both nearly constant regardless of the cutting distance. As shown in Fig. 10(b), when the cutting distance was 576 m, the tool life criterion was satisfied by cutting speeds of V=200 and 250 m/min. However, when the cutting speed was 300 m/min, the flank wear width VC was 106 μm at a cutting distance of L=512 m. It was over the tool life criterion line. And in this case, there was a very great efforts from cutting temperature, the tool wear progressed very fast after the distance of 250m. From this result, we expect that high-speed cutting will be preferable for cutting FCD600 but that the cutting speed should not be greater than 300 m/min.

4. Conclusion

In this study, experiments were conducted to examine the relationship between cutting characteristics and tool wear. The following conclusions can be drawn from the experimental results.

(a) Tool wear characteristics of initial cutting with FCD600

The flank wear width VC was nearly constant regardless of the cutting tool material and cutting conditions. Additionally, the tool wear can be reduced by reducing the cutting speed from 100 to 350 m/min.

(b) Tool wear characteristics of continuous cutting with FCD600

When the cutting distance was 576 m, the tool life criterion was satisfied by cutting speeds of V=200 and 250 m/min. When the cutting speed was 300 m/min, the flank wear width VC was 106 μm which was larger than with cutting speeds of V=200 and 250 m/min. The flank wear VC was also over the tool life criterion line at cutting speed of 300 m/min. We expect that high-speed cutting will be preferable for cutting FCD600 but that the cutting speed should not be greater than 300 m/min.

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