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Tool Wear Characteristics of Near-Dry Cutting with the High Hardness Materials

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Abstract

Recently, energy saving and global warming gas discharge reduction become the important problem with such as the automobile industry or the aircraft industry. SUJ2(AISI 52100), which has excellent wear resistance, has been selected for use in such as a bearing. However, SUJ2(AISI 52100) is high hardness , so it difficult material to cut. Consequently, wet cutting is generally adopted for the cutting of difficult-to-cut -materals. Wet cutting, which uses a large amount of cutting fluid, is costly and requires considerable energy for maintenance and disposal of the cutting fluid, making this cutting method environmental unfirendly. To reduce the associated cost and environmental load, the near-dry cutting method, which uses a very small amount of cutting fluid, may be preferable for cylindrical cuuting of SUJ2(AISI 52100). However, this method has some drawbacks, such as the cutting stock removal rate and the wear on cemented carbide tools. For example, the cutting stock removal rate is lower than with wet cutting because cutting edge fracture occurs easily in near-dry cutting. In this report, we experimentally examined the relationships among near-dry cutting, the tool materials and the tool fracture. We also examined the relationships between Wet cutting and the cutting chararicteristics with SUJ2(AISI 52100). As a result, with the tool materials S05coating, the tool wear can be reduced. Moreover, when the cutting speed was 100m/min of near-dry cutting, the tool fracture was relatively small.

***Keywords**:* SUJ2(AISI 52100), Near-dry cutting, Wet cutting, Tool wear

1. Introduction

In manufacturing of difficult-to-cut materials such as SUJ2(AISI 52100), for the purpose of reducing a tool wear and improving a machining accuracy, the searching of maching conditions become an important issue [1, 2, 3]. SUJ2(AISI 52100) is high in hardness, so the cutting stock removal rate is low [4, 5, 6]. Consequently, wet cutting is adopted for cutting difficult-to-cut materials [7]. However, wet cutting uses a large amount of cutting fluid, is costly, and requires a considerable energy for maintenance and fluid disposal, making it environmentally unfriendly [8, 9]. To reduce environmental load and its associated cost, the near-dry cutting method [10, 11, 12], which uses a very small amount of cutting fluid, is preferable for cylindrical cutting of SUJ2(AISI 52100) [13, 14]. This report experimentally examines the tool wear characteristics of near-dry cutting and Wet cutting used on difficult-to-cut materials SUJ2(AISI 52100). We adopted a target surface roughness value of $Rz \leqq 3.2\mu m$ and a target tool wear width $VC \leqq 100\mu m/600m$ for this experiment.

2. Experimental Equipment and Conditions

SUJ2(AISI 52100) has high hardness values, so the cutting stock removal rate is low. This report experimentally examines the effect on tool wear with minimum quantity of lubrication (MQL) cutting and Wet cutting. The experimental equipment used in this study and the details of the cutting and lubricating activities are summarized in Table 1. And Figure1 shows the numerical control lathe. Figure2 shows MQL tool holder. Figure 3 shows the high pressure coolant holder. The MQL system provides cutting fluid to the tool rake face and tool end clearance at a pressure of 0.3 MPa. On the other hand, the high pressure coolant system provides cutting fluid to the tool end clearance at a pressure of 7 MPa. The effect on tool wear is first examined by varying cutting speed from V = 25 m/min to V = 200 m/min on S05, K01 and S05 coated with TiAlN as the tool materials.

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Table1 Experimental equipment and conditions

Machine tool	Cincom RL21（Citizen Machinery）
Work piece	SUJ2(AISI 52100) , Φ20×30mm , HRC60
Cutting tool	Cemented carbide S05, K01, S05 TiAlN coating
Cutting conditions	Cutting speed *V*=25, 50, 75, 100, 150, 200m/min Feed *f*=0. 25mm/rev Depth of cut *t*=0.25mm Cutting distance *L*=～576m
Lubricating methods	MQL Equipment：MS-1（Kyouritu Gokin） MQL oil ： Unicut Jinen MQL （ JX Holdings）, Flow rate：76mL/h Air pressure：0.3MPa
	Wet：Blasomil 22 （Blaser Swisslube） Coolant pressure：7MPa, Flow rate：1134L/h

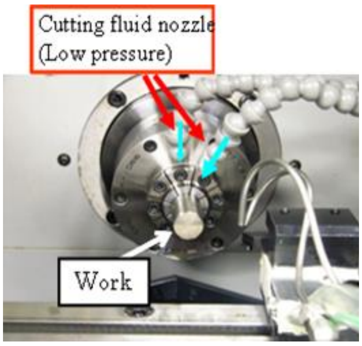


Fig. 1 Photograph of numerical control lathe

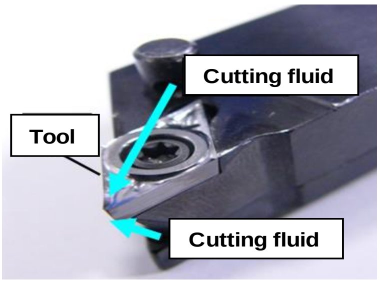


Fig. 2 Photograph of MQL tool holder

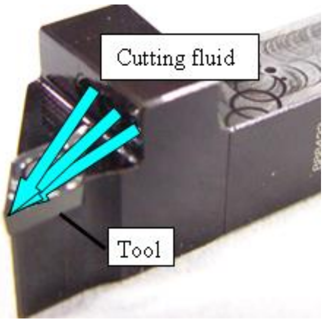
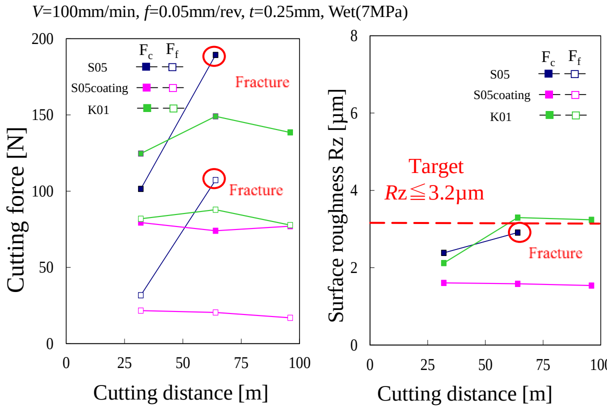


Fig. 3 Photograph of High pressure coolant tool holder

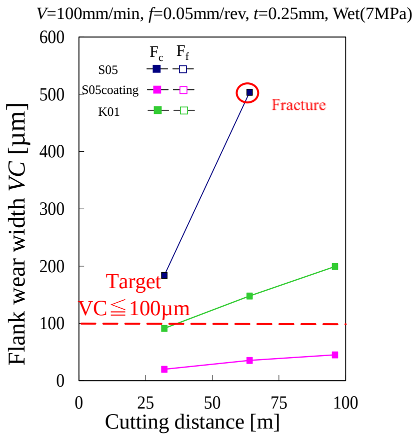
3. Relationships between tool materials and cutting characteristics

The relationship between tool materials and cutting characteristics was first examined for the purpose of select the tool which can make small tool fracture by Wet cutting. The results of the experiments are shown in Fig 4, 5. Figure 4 (a) shows the relationship between the cutting distance and cutting force, while fig. 4 (b) shows the relationship between cutting distance and surface roughness *Rz*. As Fig. 4 (a) shows, the principal force F_c varies from 125 N to 149 N, and the feed force varies from 78 N to 88 N by using cemented carbide tool K01. When we used S05 coated with TiAlN, the principal force F_c varies from 74 N to 80 N, and the feed force F_f varies from 17 N to 22 N. In addition, when the cutting distance L = 64 m, fracture occurred by using S05. As Fig. 4 (b) shows that the surface roughness *Rz* = 2.1 ～3.3 μm, by using cemented carbide tool K01. When the cutting tool is S05 coated with TiAlN, the surface roughness *Rz* = 1.5 ～1.6 μm. This results indicate that if cylindrical is performed with SUJ2(AISI 52100) by using S05 coated with TiAlN, the surface roughness criterion can be satisfied. Figure 5 shows the relationship between the cutting distance and flank wear width *VC*. As Fig. 5 shows, the flank wear width *VC* = 199 μm by using cemented carbide tool K01 at cutting distance *L* = 96 m. On the other hand, when used S05 coated with TiAlN, the flank wear width *VC* = 45μm at cutting distance *L* = 96 m. And when we do the cylindrical cutting with S05, fracture can occurs.



(a) Cutting force (b)Surface roughness Rz

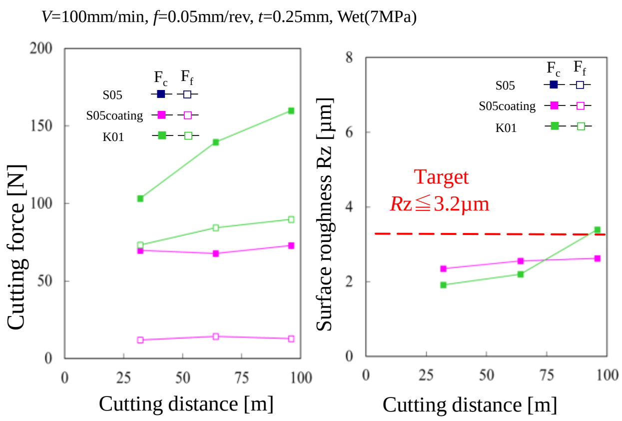
Fig. 4 relationship between cutting distance and cutting force and surface roughness (Wet)



(b) Flank wear width *VC*

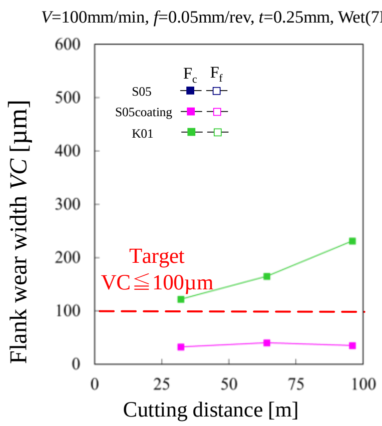
Fig. 5 relationship between cutting distance and flank wear width *VC* (Wet)

Next we experimentally examined the tool wear characteristics of different tool materials by near-dry cutting. The results of the experiments are shown in Fig. 6, 7. Figure 6 (a) shows the relationship between the cutting distance and cutting force, while fig. 6 (b) shows the relationship between cutting distance and surface roughness *Rz*. As Fig. 6 (a) shows, the principal force varies F_c from 107 N to 152 N, and the feed force F_f varies from 75 N to 89 N by using cemented carbide tool K01. When we used S05 coated with TiAlN, the principal force F_c varies from 70 N to 73 N, and the feed force F_f varies from 12 N to 14 N. As Fig. 6 (b) shows that the surface roughness Rz = 2.0 ～3.3 µm, by using cemented carbide tool K01. When the cutting tool is S05 coated with TiAlN, the surface roughness Rz = 2.3 ～2.6 µm. This results indicate that if cylindrical is performed with SUJ2(AISI 52100) by using S05 coated with TiAlN, the surface roughness criterion can be satisfied. Figure 7 shows the relationship between the cutting distance and flank wear width *VC*. As Fig. 7 shows, the flank wear width *VC* = 232 µm by using cemented carbide tool K01 at cutting distance *L* = 96 m. On the other hand, when we used S05 coated with TiAlN, the flank wear width *VC* = 40 µm at cutting distance *L* = 96 m. This results indicate that if cylindrical is performed with SUJ by using S05 coated with TiAlN, the flank wear width VC can be decreased about 80 percent.



(a) Cutting force (b) Surface roughness *Rz*

Fig. 6 relationship between cutting distance and cutting force and surface roughness (MQL)

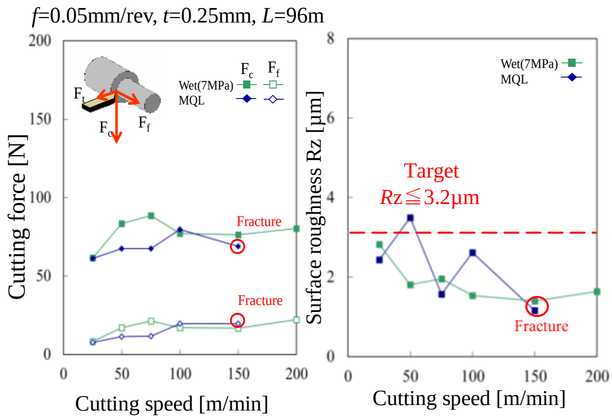


Flank wear width *VC*

Fig. 7 relationship between cutting distance and flank wear width *VC* (MQL)

4. Relationships between cutting speed and cutting characteristics

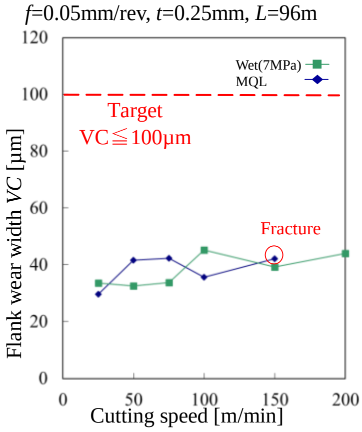
According to the tool materials experiments of Wet cutting and near-dry cutting, it is known that if cylindrical is performed with SUJ2(AISI 52100) by using S05 coated with TiAlN, the surface roughness criterion and flank wear width criterion can be satisfied. Therefore, tool wear characteristics were examined for changing the cutting speed from 25 m/min to 200 m/min by wet cutting and near-dry cutting. The results of the experiments are shown in Fig. 8, 9. Figure 8 (a) shows the relationships between cutting speed and cutting force, Fig. 8 (b) shows the relationships between cutting speed and surface roughness Rz, and Fig. 9 shows the relationships between cutting speed and flank wear width *VC*. As Fig. 8 (a) shows, the principal force F_c varies from 63 N to 89 N, and the feed force F_f varies from 8 N to 19 N with wet cutting. On the other hand, the principal force F_c varies from 61 N to 80 N, and the feed force F_f varies from 8 N to 20 N with near-dry cutting. Principal force F_c and feed force F_f are together regardless of the cutting speed, becomes almost constant. Figure 8 (b) shows that the surface roughness Rz = 1.5 ～1.8 µm with wet cutting. When we use near-dry cutting for the cylindrical cutting of SUJ2(AISI 52100), the surface roughness Rz = 2.6 ～ 3.5 µm. This results indicate that if cylindrical is performed with SUJ2(AISI 52100) by using wet cutting, the surface roughness criterion can be satisfied.



(a) Cutting force (b) Surface roughness *Rz*

Fig. 8 Relationship between cutting speed and cutting force and surface roughness

Figure 9 shows that with wet cutting the flank wear width *VC* varies from 33µm to 45µm. When we use near-dry cutting, the flank wear width *VC* varies from 30 µm to 42µm. There are not much difference between wet cutting and near-dry cutting. However, the fracture occurs when the cutting speed V = 200 m/min with near-dry cutting. Figure 10, 11 show the tool cutting edge. There are not much difference between wet cutting and near-dry cutting.



Flank wear width *VC*

Fig. 9 Relationship between cutting distance and flank wear width *VC*

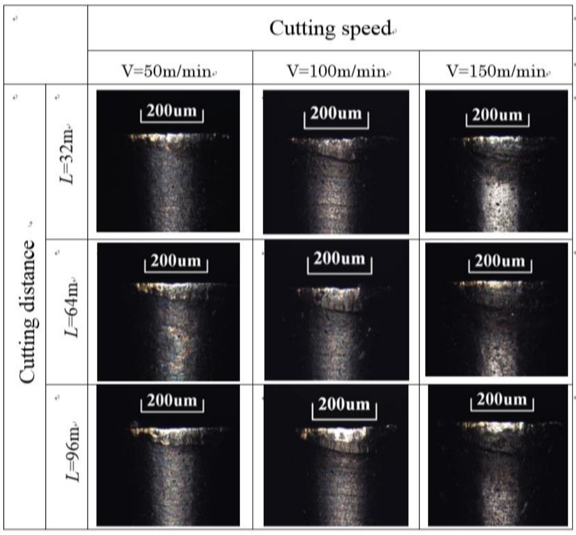


Fig. 10 Photographs of flank wear width *VC* (Wet)

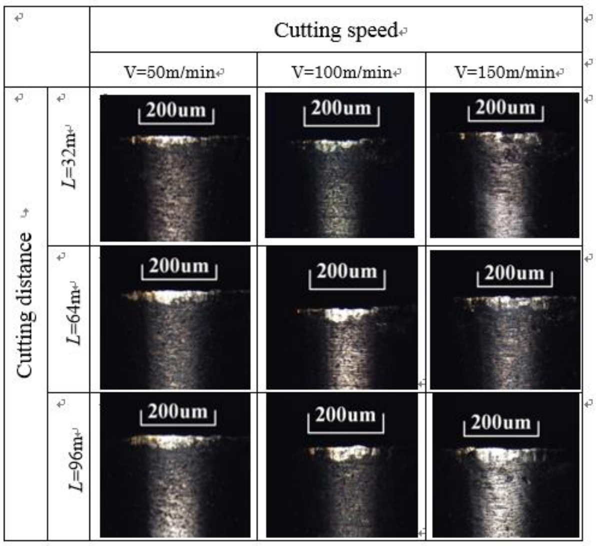
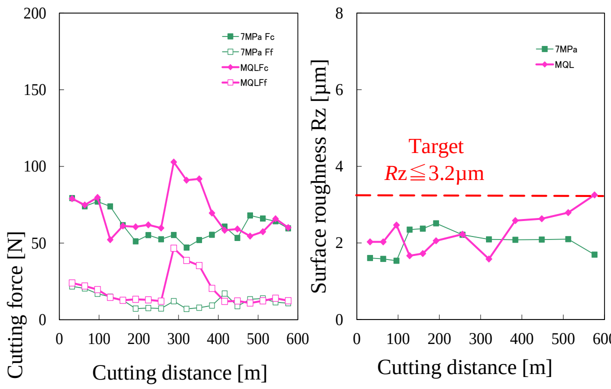


Fig. 11 Photographs of flank wear width *VC* (MQL)

5. Relationships between cutting continuous and cutting characteristics

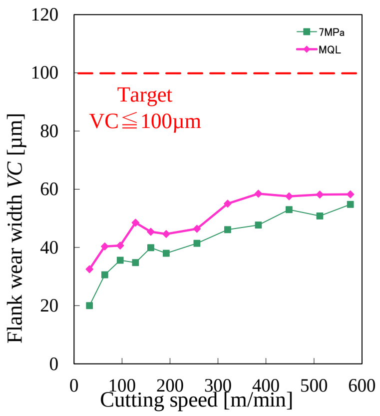
Based on cutting speed experiments with difficult-to-cut materials SUJ2(AISI 52100), we known that the cutting speed is between 50 m/min to 150 m/min, tool wear can be reduced. Therefore, tool wear characteristics were examined for continuous cutting at speed of 100 m/min which is faster and not cause the fracture. Figure 12 shows the relationship between cutting distance and cutting force and surface roughness. Figure 13 shows the relationships between cutting distance and flank wear width. As Fig. 12 (a) shows, according to cutting distance becomes longer, the principal force F_c varies from 47 N to 79 N, and the feed force F_f varies from 7 N to 22 N with wet cutting. On the other hand, the principal force F_c varies from 52 N to 103 N, and the feed force F_f varies from 11 N to 47 N with near-dry cutting. Figure 12 (b) shows that the surface roughness Rz = 1.6 ～2.8 μm with wet cutting. When we use near-dry cutting for the cylindrical cutting of SUJ2(AISI 52100), the surface roughness Rz = 1.6 ～3.3 μm. There are not much difference between wet cutting and near-dry cutting.

Figure 13 shows that with wet cutting the flank wear width *VC* varies from 20 μm to 55μm. When we use near-dry cutting, the flank wear width *VC* varies from 33 μm to 58 μm. There are not much difference between wet cutting and near-dry cutting. Wet cutting and near-dry cutting are together satisfy the flank wear width criterion. As the built-up edge did not occur, the cutting force became lager at cutting distance L = 320 m shown in Fig. 14. The cutting force became smaller at cutting distance L = 448 m by the formation of the built-up edge shown in Fig. 15.



(a) Cutting force (b) Surface roughness *Rz*

Fig. 12 Relationship between cutting speed and cutting force and surface roughness



Flank wear width *VC*

Fig. 13 Relationship between cutting distance and flank wear width *VC*

10pass(L=320m)

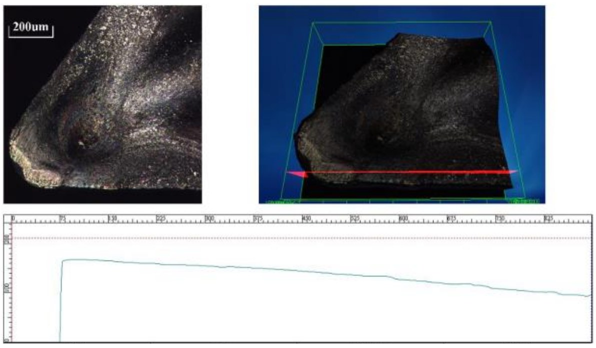


Fig. 14 Cutting edge at cutting distance L = 320 m (MQL)

14pass(L=448m)

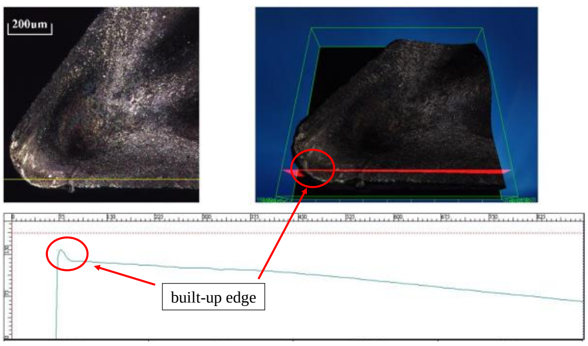


Fig. 15 Cutting edge at cutting distance L = 448 m (Wet)

6. Conclusions

In this study, experiments were conducted to examine the relationships between tool materials, cutting speed, continuous cutting and characteristics on difficult-to-cut material SUJ2(AISI 52100). The following conclusions can be drawn from the experimental results.

(1) Tool materials experiments

When the cutting tool is S05 coated with TiAlN, the surface roughness *Rz* = 1.5 ～1.6 µm by wet cutting. And the surface roughness *Rz* = 2.3 ～2.6 µm with near-dry cutting. Also the flank wear width *VC* is about 45µm at cutting distance *L* = 96 m both on wet cutting and near-dry cutting. This results indicate that if cylindrical is performed with SUJ by using S05 coated with TiAlN, the surface roughness and flank wear width criterion can be satisfied

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(2) Cutting speed experiments

Based on cutting speed experiments with difficult-to-cut materials SUJ2(AISI 52100), we known that the cutting speed is between 50 m/min to 150 m/min, tool wear can be reduced. The flank wear width *VC* varies from 33µm to 45µm with wet cutting. When we use near-dry cutting, the flank wear width *VC* varies from 30 µm to 42µm. There are not much difference between wet cutting and near-dry cutting.

(3) Cutting continuous experiments

Tool wear characteristics were examined for continuous cutting at speed of 100 m/min which is faster and not cause the fracture. The surface roughness *Rz* = 1.6 ～2.8 µm with wet cutting. When we use near-dry cutting for the cylindrical cutting of SUJ2(AISI 52100), the surface roughness *Rz* = 1.6 ～ 3.3 µm. There are not much difference between wet cutting and near-dry cutting. And with wet cutting the flank wear width *VC* varies from 20 µm to 55µm. When we use near-dry cutting, the flank wear width *VC* varies from 33 µm to 58 µm. There are not much difference between wet cutting and near-dry cutting. Wet cutting and near-dry cutting are together satisfy the flank wear width criterion.

7. References

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