Influence of Adhesion to Cutting Edge on Surface Roughness in Ultra-Precision Cutting of Stainless Steels with Coated-Cemented-Carbide Tool

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1. Introduction
The ultra-precision cutting technique of difficult-to-cut materials such as stainless steels, titanium alloys and so on has been strongly required. However the life of diamond tool which is generally used for ultra-precision cutting of soft metals such as aluminum alloys, copper alloys and so on is short for cutting of difficult-to-cut and as the results, the formed surface roughness is not enough for ultra-precision cutting. In our previous researches, the coated-cemented-carbide tool is found useful for ultra-precision cutting of difficult-to-cut materials[1, 2]. Until long cutting length, the surface roughness formed using water-immiscible type cutting fluid is below 100 nm(P-V) [2]. The adhesion of stainless steel, however, is found on the cutting edge. The research aims to clarify the influence of adhesion to cutting edge on surface roughness and tool wear in the ultra-precision of stainless steels.

2. Experimental procedure
The experiments are executed by face-turning two kinds of stainless steels which are the SUS316 and the SUS304 (in JIS) with a commercial coated-cemented-carbide tool set on the ultra-precision lathe. The main experimental conditions are listed in Table 1. The cutting fluids used are water-immiscible type and two soluble types of cutting fluids. The surfaces of stainless steels and cutting tools are examined by observing with Nomarski differential interference microscope and scanning electron microscope (SEM). The surface smoothness of face-turned stainless steels is measured with surface interferometer (WYKO).

<table>
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<tr>
<th>Table 1 Experimental conditions</th>
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<tr>
<td>Cutting tool: Coated cemented carbide tool</td>
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<td>Nose radius: 0.4 mm</td>
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<td>Rake angle: 0 deg</td>
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<td>Relief angle: 7 deg</td>
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<tr>
<td>Workpiece materials: SUS316(18Cr-12Ni-2Mo) SUS304(18Cr-8Ni)</td>
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<tr>
<td>Cutting fluids: Water-immiscible type Soluble types</td>
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<td>Cutting conditions Feed rate: $f = 2 \mu m/rev$, Depth of cut: $d = 5\mu m$ Cutting speed : $V = 95-125 \text{ m/min}$</td>
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</tbody>
</table>

3. Results and Discussions
Figure 1 shows the SUS316 surfaces face-turned using water-immiscible type and soluble type “A” of cutting fluids. The irregular cutting grooves are observed on the surface formed using water-immiscible type of cutting fluid. The regular cutting grooves, on the other hand, are clearly
observed on the surface formed using soluble type “A” of cutting fluid. The surface roughnesses formed using water-immiscible type and soluble type “A” of cutting fluid are about 137 nm ($R_z$) and 41 nm ($R_z$) in three dimensional measurement or 92 nm ($R_z$) and 24 nm ($R_z$) in two dimensional measurement, respectively. Compared with water-immiscible type of cutting fluid, soluble type “A” of cutting fluid is referred much more useful for ultra-precision turning of the SUS316. Figure 2 shows the cutting edges after face-turning the SUS316 using water-immiscible type and soluble type “A” of cutting fluid. The cutting length executed is $L=275m$. It is found clearly that the cutting edge wear formed using soluble type “A” of cutting fluid is much smaller than that using water-immiscible type of cutting fluid. The wear land formed using water-immiscible type of cutting fluid appears to be cloudily white colored by adhesion. The wear land formed using soluble type “A” of cutting fluid, on the other hand, displays the ground color of tool. Figure 3 shows the change of cutting edge before and after corroding. The cutting edge is formed by the cutting length of 3,015m using water-immiscible type of cutting fluid. After corroding, the flank wear surface on the cutting edge changes clearly from cloudily smooth unevenness to clear unevenness because of the remove of the adhesion. In case of soluble type
“A” of cutting fluid, according to the separate experiments, the change can not be found. Accordingly the soluble type “A” of cutting fluid is considered to act an important role for repressing the adhesion to cutting edge, and improve the surface smoothness.

Using soluble type “B” of cutting fluid, the surface roughness of workpiece and the wear land of cutting edge formed after ultra-precision turning of the SUS316 are shown in Fig.4. The surface roughness becomes about 125 nm ($R_z$) in three dimensional measurement. Compared with soluble type “A”, it is rough. The adhesion to cutting edge is observed on the wear land.

The phenomenon for using soluble type “B” differs from that for using soluble type “A”. Therefore, it is considered that the additives including in the soluble type of cutting fluid act an important role for repressing the adhesion to cutting edge.

Figure 5 shows the surface roughness of the SUS316 formed using three kinds of cutting fluids. It is clear from figure that the surface roughness formed using soluble type “A” is much better than using others and becomes below 30nm ($R_z$) in two dimensional measurement.

The change of the surface roughness with cutting length using soluble type “A” is shown in Fig.6. The surface roughness is below 50nm ($R_z$) in two dimensional measurement until the cutting length of about 1,200m. From the cutting length of about 1,200m to about 2,000m, the surface roughness increases steeply and afterwards keeps almost the same constant value until cutting length near 3,000m. The constant surface roughness is below 100nm ($R_z$) in two
dimensional measurement which is almost the same as the surface roughness formed in the initial cutting process using water-immiscible type. Figure 7 shows the SUS304 surface formed using soluble type “A” of cutting fluid. The regular cutting grooves are clearly observed on the SUS304 surface. The smooth surface roughness of about 57nm ($R_z$) in three dimensional measurement is formed.

4. Summary

The influence of adhesion to cutting edge on surface roughness in ultra-precision cutting of stainless steels is examined from the point of cutting fluids. The main conclusions obtained are as follows:

1) Compared with water-immiscible type and soluble type “B” of cutting fluid, soluble type “A” of cutting fluid is considerably useful for repressing the adhesion of stainless steel to cutting edge, reducing the tool wear and, as the results, improving the surface roughness.

2) Using the soluble type “A” of cutting fluid, the surface roughness attains about 40nm ($R_z$) in three dimensional measurement or about 20nm ($R_z$) in two dimensional measurement.

3) Using soluble type, “A” of cutting fluid, the surface roughness is kept below 40nm ($R_z$) or 100nm ($R_z$) until the cutting length of about 1,200m or 3,000m, respectively.

4) Using soluble type “A” of cutting fluid, the face-turned SUS304 surface becomes the similarly smooth surface as the SUS316.

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References
