IMPROVING ANTI-ADHESIVE PROPERTIES OF CUTTING TOOL SURFACE BY NANO/MICRO TEXTURES -CONSIDERING THE TEXTURE PATTERNS-

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INTRODUCTION
Such advantages as a high ratio of strength to mass and good corrosion resistance have rapidly raised for lightweight aluminum alloy composites, especially in the transport industry. Their low hardness compared to steel makes aluminum alloys easy to cut, but this can be outweighed in certain applications by their low melting point and high ductility, which make aluminum chips adhere strongly to the cutting edges of tools, leading to tool breakage. Then many cutting tool technologies such as cutting tool geometry, and cutting tool surface coating and finishing have been developed. In particular, diamond-like carbon (DLC) coated tools with extremely low friction are being applied in the dry or near dry cutting of aluminum alloys, but adherence of aluminum chips to DLC coated tools still requires a flooded cutting fluid in practical use [1]. Furthermore, tool breakage occurs frequently in cutting processes such as deep hole drilling, milling and tapping, in which it is difficult to directly supply cutting fluid to the cutting point.

To solve these problems, we used a surface engineering approach, namely, a highly functionalization of tool surfaces by textures to determine the role of textured surfaces in: (i) retaining cutting fluid and (ii) reducing actual contact area between the tool and chips. Effective application is expected to increase lubricity and promote anti-adhesive properties at tool chip interface. As shown in Fig. 1, a DLC-coated cutting tool with nano/micro-textured surface using femto-second laser technology was developed. A series of aluminum alloy face-milling experiments showed that the nano/micro-textured surface promoted anti-adhesiveness at the tool chip interface [2] and, however, the adhesion problem still remained.

In this paper, the ways to improve the anti-adhesive properties using nano/micro-textures were studied in order to overcome the above-mentioned problem. Based on this, a cutting tool with a banded nano/micro-textured surface was newly proposed to ensure excellent anti-adhesive properties.

PROBLEMS ASSOCIATED WITH CUTTING TOOL WITH NANO/MICRO-TEXTURED SURFACE

Cutting Tool with Nano/Micro-Textured Surface
Femto-second laser technology was adopted to generate nano/micro-grooves [3] on the rake face of cemented carbide cutting tool. Precise regular grooves are produced using liner polarized femto-second laser energy near the ablation threshold, and spacing of regular structures about the same as the laser wavelength. Applying this technology, the regular nano/micro-grooves 100-150 nm deep and spaced at 700 nm were produced on the rake face of the cemented carbide cutting tool using a laser (Canon Machinery Inc., Model Surfbeat R; peak wavelength 800 nm, pulse duration 150 fs, cyclic frequency 1 kHz, pulse energy 300 µJ). Before laser irradiation, the tool surface was polished with diamond slurry to a surface roughness of P-V 40 nm. After grooving, the plasma-CVD DLC film was coated on the textured surface to improve anti-
FIGURE 2. Experimental setup of face milling test.

TABLE 1. Cutting conditions.

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>Tool (Insert)</th>
<th>Tool geometries</th>
<th>Cutting speed</th>
<th>Depth of cut</th>
<th>Feed rate</th>
<th>Cutting fluid</th>
<th>Supply rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5052 W 75 mm - L 210 mm</td>
<td>Cemented carbide K10 SEKN42M, Sumitomo Electric Hardmetal</td>
<td>Axial rake angle $\theta_A$ 20° Radial rake angle $\theta_R$ -3° True rake angle $\alpha$ 12.4° Corner angle $\gamma$ 45° Cutter diameter $D$ 80 mm</td>
<td>380 m/min (1500 rpm)</td>
<td>3 mm</td>
<td>0.12 mm/rev.</td>
<td>Emulsion type (JIS A1)</td>
<td>Finecut CFS-100, NEOS</td>
</tr>
</tbody>
</table>

adhesiveness. The coating decreased grooves depth 10-20 nm.

Cutting Experiment Procedures and Performance
Cutting experiments were conducted on aluminum alloys A5052 using a vertical machining center (Yamazaki Mazak Corp., AJV-18), as illustrated in Fig. 2. The center of the cutter was set on the center line of the workpiece. Table 1 lists the cutting conditions. Emulsion type cutting fluid (NEOS Co., Ltd., Finecut CFS-100) was supplied at a flow rate of 12.6 L/min.

In cutting performance, the rake face of the cutting tool was observed after 1800 m cutting to evaluate tool surface adhesion. Scanning electron microscope (SEM) (Hitachi High-Technologies Corp., S-3400NX) and energy dispersive X-ray spectrometry (EDX) analysis of the rake face aluminum (Fig. 3) confirmed large adhesion to the rake face of a conventional DLC-coated, namely polished tool. In contrast to this, it was found that the nano/micro-textured surface, particularly, nano/micro-grooves parallel to the main cutting edge, improved anti-adhesion, but not sufficiently on the cutting tool surface (Fig. 3(b)).

Then the enlarged SEM observation was done to determine adhesion to the tool surface in detail (Fig. 4). Although it was confirmed that nano/micro-grooves were not buried by adhesion after cutting for 1800 m, as SEM image showed, aluminum adhered slightly as EDX-Al imaging showed. Concern arose that adhesion could become worse with increasing cutting distance, eventually leading to tool breakage, making it vital to increase anti-adhesive properties.

Anti-Adhesive Properties with Nano/Micro-Texture in Dry Cutting
As stated, the nano/micro-textured surface plays two roles, namely: (i) retaining cutting fluid and (ii) reducing actual contact between the tool and chip. To evaluate these two roles individually, dry cutting experiments were conducted using basically the
same cutting conditions as in Table 1.
In addition to SEM and EDX analysis of the aluminum on the rake face after dry cutting for 1800 m (Fig. 5), the aluminum atom concentration on the tool rake face in EDX-Al imaging was measured to quantitatively evaluate aluminum adhesion (Fig. 6). Compared to wet cutting, aluminum adhesion in dry cutting increased in the tool with a nano/micro-texture and, in contrast, aluminum decreased in the tool with a polished surface.
This is thought to be due to the tool surface making strongly solid contact with chips in dry cutting. The tool with a polished surface had such a large contact area between tool and chips that high cutting heat was generated, decreasing adhesion and suppressing the build-up edge. On the other hand, in the tool with a nano/micro-texture, cutting temperature did not become high due to the small contact area, making adhesion greater than that in the tool with a polished surface. Moreover, chip material also entered easily into nano/micro-grooves under solid contact, i.e., nonlubrication.
It was found that wet cutting with the tool having a nano/micro-texture was superior to the tool having a polished surface in decreasing tool surface adhesion in all types of cutting tool and cutting conditions.
From the above-mentioned consideration, it was found that the retention of cutting fluid on the tool surface was essential for achieving good anti-adhesive properties. Nano/micro-texture ensured that cutting fluid was well retained and that, as a result, anti-adhesion was high under wet cutting conditions.

PROPOSED CUTTING TOOL WITH BANDED NANO/MICRO-TEXTURE

Cutting Tool Development
Two types of texture pattern on the cutting tool surface thought to be effective in retaining cutting fluid are patterns that (1) prevent retained fluid leaking from grooves and (2) increase the amount of retained fluid. Then the DLC-coated cutting tool with a banded nano/micro-textured surface was newly developed, as shown in Fig. 7. Nano/micro-grooves in a direction parallel to the main cutting edge were generated in bands 50 µm wide on the polished tool surface.
The nano/micro-texture is sandwiched between polished surfaces, preventing fluid retained in the textured area from leaking. The banded nano/micro-texture surface is 100-200 nm deep, increasing the amount of fluid retained.

Evaluation of Anti-Adhesive Properties
The result of cutting experiments with the newly developed tool (Table 1) were analyzed using SEM and EDX analysis of the aluminum on the rake face after wet cutting for 1800 m (Fig. 8) and the aluminum atom concentration on rake faces of several tools was measured, including the newly developed one (Fig. 9). From these results, it was found that the banded nano/micro-textured surface provided excellent anti-adhesive properties reducing adhesion less than half compared to the tool having nano/micro-grooves overall.
FIGURE 7. Newly developed cutting tool with banded nano/micro-textured surface.

The observation of the tool surface with optical scope (Keyence Corp., VF-7500) was carried out each 180 m in cutting distance to evaluate changes adhesion as cutting progressed. Fig. 10 shows the changes of the aluminum adhesion area, which was calculated with the image analysis from the microphotograph. Increased adhesion areas were very few in the newly developed tool – 1/15 compared to that of the polished tool and 1/2 compared to that of the tool with grooves overall.

CONCLUSIONS
A cutting tool with a nano/micro-textured surface was developed to improve anti-adhesive properties in aluminum alloy cutting, with the following findings:
- Nano/micro-textured surface increased adhesion of aluminum chips to the surface in dry cutting, but decreased adhesion in wet cutting.
- Improve cutting fluid retention on the tool surface is essential for achieving a good anti-adhesive properties in aluminum alloy cutting.
- The banded nano/micro-textured cutting tool surface significantly improves anti-adhesive properties.

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