EFFECT OF TOOL POSTURE FOR TOOL WEAR ON TURN-MILLING

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ABSTRACT
For turn-milling process using multi-tasking machine, some process parameters such as depth of cut, feed rate, rotational speed of workpiece, spindle speed, relative angle between tool axis and workpiece, and offset of cutting position influence on cutting force variation and tool wear. However, there exist little investigations for the effect on cutting state by those machining parameters. In this paper, the combination of machining parameters and cutting process is defined for the turn-milling process with bullnose mill. Furthermore, this paper proposed a method to calculate the effect of tool posture for turn-milling by analyzing contact area between workpiece and tool modeled as point-cloud.

1. INTRODUCTION
Machining difficult-to-machine workpieces such as alloys used in aerospace, nuclear and medical industries are usually accompanied with low productivity, poor surface quality and short tool life [1]. Then, new cutting method to mill workpiece rounding continuously or intermittently is remarked and that is called ‘turn-milling’. In this method, various cutting edges contact to workpiece, so less tool wear occurs on each cutting edge. Furthermore, clogging is prevented because of interrupted cutting. Using this method, not only cylinder geometry but also adjustable surface can be processed. Moreover, tool posture can be changed flexibly by inclination of tool axis and offset for Y axis direction, and the flexibility makes depth of cut deeper than that of conventional turning.

Karaguzel [2] et al. developed cutting force simulation of vertical turn-milling, and investigated the effect of cutting parameters for cutting force and surface quality. In turn-milling process, the variation of contact area between tool and workpiece is complicated, and the cutting mechanism is not defined perfectly. There are some studies on analysis of cutting process that has complicated cutting mechanism. For example, Iwabe [3] et al. analyzed the cutting mechanism of inclined surface processing with ball mill, and investigated the effect of degree of inclined surface and feed direction. In the preceding studies above, the behavior of complex cutting mechanisms under simple processing conditions were focused. The subject of this research is analysis under more complicated processing conditions.

In this paper, the combination of machining parameters and cutting process is defined for the turn-milling process with bullnose mill. Adding to this, this paper proposed a simulation model to calculate the variation of contact area between tool and workpiece, and defined the effect of tool posture and other cutting parameters for tool wear on turn-milling.

2. OUTLINE OF TURN-MILLING
Fig.1 shows schematic image of turn-milling and the cutting parameters. In turn-milling, there are many parameters such as rotational speed of workpiece \( S_w \), rotational speed of tool \( S_t \), tool lead angle \( \alpha \), tool tilt angle \( \beta \), feed rate in the Z-axis \( FR_z \), and cutting direction, and they have an effect on cutting state. Axial depth of cut \( a_p \) and radial depth of cut \( a_r \) are defined as shown in Fig.1. When tool tilt angle is given for \( \beta \) in turn-milling, tool travel for Z axis per workpiece rotation is formulated as \( FR_z = a_p / \sin(\beta) \). Also, since the workpiece has a cylindrical shape, the tool radius cut changes during the period
from the moment of cutting edge’s engagement to
disengagement. The direction of feed rate \( f_r \) is determined by
the composite speed of the peripheral speed by the rotation of
the workpiece and the tool feed speed in the Z-axis direction. In
the XY plane, the angle formed by the straight line connecting
the tool tip center point and the workpiece center and the X-axis
is defined as the lead angle. Regarding the direction of rotation,
CW is defined as clockwise when viewed from the end face side
of the workpiece, and CCW is defined as counterclockwise.

### 3. EXPERIMENTAL SETUP

Table 1 shows the experimental conditions for the tool
wear experiment. For the experiment, a 5-axis compound
processing machine (Yamazaki Mazak INTEGREX i-200) was
used. Tool is a bull nose end mill fitted with a round insert and
workpiece is a round bar material of SUS 304. The subject is
the distribution of flank wear width of the tool after turn-
milling. The effect of the tool lead and tilt angle on the flank
wear was observed by changing the tool tilt angle.

<table>
<thead>
<tr>
<th>Table 1 Cutting condition</th>
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<tr>
<td>Cutting method</td>
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<tr>
<td>Workpiece material</td>
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<td>Tool material</td>
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<tr>
<td>Number of flute</td>
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<tr>
<td>Tool diameter [mm]</td>
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<tr>
<td>Corner radius [mm]</td>
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<td>Cutting speed ( V ) [m/min]</td>
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<td>Axial depth of cut ( a_p ) [mm]</td>
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<td>Tool lead angle ( \alpha ) [°]</td>
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<td>Tool tilt angle ( \beta ) [°]</td>
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<td>Cutting direction</td>
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In turn-milling, cutting length is defined as the contacting
length between cutting edges and the workpiece. Cutting
length is calculated from the angle between tool and
workpiece drawn from geometrical analysis on CAD, tool
diameter, and tool rotation number. Also in this experiment, to
observe tool wear emerged in steady state cutting, turn-milling
was performed on the workpieces in advance.

### 4. OBSERVATION OF FLANK WEAR

Fig. 2 shows the flank wear profile curve. As can be seen
from Fig. 2, as the tool tilt angle increases, the flank wear
tends to decrease. When we finally cut 250 m, the decrease of
30 \( \mu m \) in the tool wear width was observed when \( \beta = 15^\circ \) and
\( \beta = 45^\circ \) were compared. This is probably because the
boundary of the contact area between the tool and the
workpiece moves as the tilt angle increases, the portion
contributing to the cutting of the cutting edge increases, and
the wear is dispersed.

Fig. 3 shows the distribution of flank wear due to the
cutting position. It can be seen that the wear progresses mostly
in the cutting position \( \theta = 123^\circ \) under both conditions. Fig. 4
shows the state of the tool flank after 250 m cutting. When
comparing the two conditions, adhesion occurred at the tool
tilt angle \( \beta = 45^\circ \).
5. WEAR DISTRIBUTION SIMULATION

Fig. 5 shows the schematic image of the simulation of the area where the workpiece is removed by the tool during turn-milling. Judging the interference between the workpiece and tool that are expressed by point-cloud, geometrically the removal region is calculated, and the instantaneous cutting force is calculated based on the cutout thickness. It is also possible to show the time course of the contact part between the cutting edge and the workpiece.

Fig. 6 shows the change of the position $\theta$ [$^\circ$] in contact with the workpiece on the cutting edge with respect to the tool rotation angle $\Phi$ [$^\circ$]. The end of the portion in contact with the workpiece on the cutting edge is indicated by a black solid line and this is defined as a boundary. In case of the face milling, the boundary is fixed at a constant position from the blade bottom where boundary wear develops. However, in case of turn-milling the boundary portion moves on the cutting edge. In addition, it can be seen that the trajectory greatly changes at the boundary depending on processing conditions. Therefore, at the boundary, supposing that the wear rate increases due to oxidation and the work hardening layer in addition to the wear mechanism due to rubbing against the workpiece on the flank surface, the state of boundary during the period from the moment of cutting edge’s engagement to disengagement was evaluated quantitatively. As a result of the analysis, it was found that the time at which the boundary remains at the cutting edge position $\theta = 118^\circ$ and $128^\circ$ at the tool tilt angle $\beta = 15^\circ$ and $45^\circ$ respectively is long. This agrees well with the edge position $\theta = 123^\circ$ where wear has progressed most in the wear experiment. In the range of this evaluation, it can be seen that the movement of the boundary becomes remarkable with the change of the tool tilt angle.

Fig. 7 shows the change in the time when each blade edge comes into contact with the workpiece during one rotation of the tool, which is obtained from the analysis result. Referring to Fig. 7, the time during which the specific portion of the cutting edge position is in contact is shorter as the tool tilt angle is larger. Consequently, the increase of tool tilt angle results in the increase of contact portion between cutting edge and workpiece, and that leads to prevention of tool wear on actual process.
CONCLUSIONS

When the tool lead angle $\alpha = 30^\circ$, the result that the flank wear width decreases as the tool tilt angle increases was obtained. This is probably because the boundary of the contact area between the tool and the workpiece moves as the tilt angle increases, the portion contributing to the cutting of the cutting edge increases, and the wear is dispersed.

As a result of the analysis, it was found that the position where the boundary portion stays on the cutting edge coincides with the position on the cutting edge where the flank wear width is the maximum.

REFERENCES

