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Study on effect of lead and tilt angle of tool on cutting force and tool wear in turn milling

Koji Utsumi[1], Shoki Shichiri[2], Shinji Kayama[3], Hiroyuki Sasahara[2]

[1]*Process Research Department, Hitachi, Ltd., Japan*
[2]*Department of Mechanical Engineering, Tokyo University of Agriculture and Technology, Japan*
[3]*Machining Engineering Group, Hitachi Metals, Ltd., Japan*

koji.utsumi.pk@hitachi.com

Abstract

Turn milling method is one of the key technic to achieve high efficiency machining and improvement of tool life for difficult-to-cut materials. It is because the depth of cut can be increased compared with common turning method. In addition, tool wear distributes on the several cutting edges of milling tool. However, a contact condition between rotating tool and cylindrical workpiece varies significantly depending on the tool posture such as tool lead angle and tilt angle. Then, it is important to evaluate the effect of lead angle and tilt angle of tool on cutting force and tool wear in turn-milling in order to estimate the optimal tool posture. In this report, a simulation model which can calculate the removal area and contact area geometrically for 5-axis controlled turn milling is proposed to estimate cutting force and behaviour of contact area between tool and workpiece regarding tool posture. The workpiece was modelled as a point-group model and the points were removed when tool edge passed the workpiece surface. Cutting force was obtained as a function of the removal area in this simulation. The simulated cutting forces are experimentally verified for round insert cutter. Furthermore, the tool wear on each tool posture was also tested, and the relationship between tool wear and tool posture was evaluated by using the simulation. It was found that the experimental cutting force increased with an increase of tilt angle, and it was also verified that the simulation showed same tendency. Moreover, from the results of the simulation, it was clarified that the experimental tool wear, especially boundary wear, changed depending on tool posture, because boundary shape and length between tool edge and workpiece surface changed with tool lead angle and tilt angle.

Key Words: turn-milling, tool wear, analytical model

1. Introduction

High-efficiency cutting of difficult-to-cut materials such as Ti alloys and Ni-base super heat resistant alloys become more important in the field of aircraft [1]. Recently, turn milling method which is one of the new milling method to improve machining efficacy for above materials is commonly used in actual production line, since temperature rising on tool edge is suppressed due to dispersing cutting heat along cutting tool edge. A few preliminary studies on turn milling regarding simulation and experiment were reported. Karaguzel et al. developed simulation model of cutting force in turn milling with the tool and workpiece vertically intersecting, and investigated the influence of each parameter on such as cutting force, surface quality and tool wear [2][3][4]. Comak et al. proposed mechanics of turn-milling operations with five-axis machining to predict cutting forces, torque and power [5]. Zhu et al. reported another side of view which is that the analytical models of 3D chips shape are proposed based on the orthogonal turn-milling principle [6].

Many simulation models were verified in the case of orthogonal turn milling test which considered only tilt or lead angle, however there were a few reports discussing the influence of turn milling parameters such as tilt and lead angle on cutting force and tool wear in the case of five axis turn milling model. Turn milling has complicated contact between the tool and the workpiece, and its cutting mechanism is often unclear. In this report, a simulation model which can consider tilt and lead angle simultaneously are proposed. This simulation can predict not only cutting force but also boundary area shape between tool edge and workpiece surface. Furthermore, machining test evaluating an effect of tilt and lead angle on cutting force and tool wear are implemented, and these results are compared with simulation results. Then, an effect of changing tilt and lead angle simultaneously on tool wear and cutting force are investigated.

2. Simulation methodology for turn milling

Fig.1 shows a geometrical schematic view of the turn milling. In turn milling, many parameters such as work material rotation speed Sw[min^{-1}], tool rotation speed St[min^{-1}], tool lead angle α [deg], tool tilt angle β [deg], tool axial movement feed Fa[mm/min], and tool axial feed ratio FRz[mm/min] affect the cutting force and tool wear.

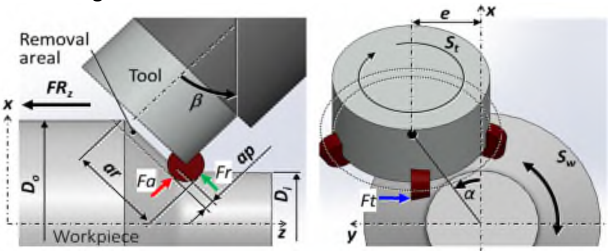

Figure 1. Schematic view of 5-axis turn-milling(CW)

Tool axial feed ratio FRz is $FRz = ap / \sin\beta$. Since the workpiece has a cylindrical shape, ap changes during the period from engagement to disengagement in one rotation. The tool lead angle α cannot set directly in actual machine tool, so it can control by setting y-axis offset *e* in operation. The tangential cutting force *Ft*, the radial forces as *Fr*, and the tool axial forces *Fa* is rotate with tool rotation as shown in the figure.

2.1. Cutting force calculation model

Fig.2(a) shows the proposed simulation model of turn milling as shown in Fig.1. In this model, the workpiece is expressed as a point group surface, and insert with the cutting edge has a volume which can detect interference with the workpiece point group. Fig. 2(b) shows the overview of calculation method of the interference region between the insert volume and the workpiece surface. The rake face of the cutting edge is divided into differential axial elements dz_i, and contact with the workpiece point group is judged on each element. A distance from the cutting edge to the workpiece surface point (dfo_i) determined in each region is defined. Then, chip thickness is determined as $df_i = dfo_i/\sin\kappa$. Cutting forces are simulated as flowing equation.

$$F_j = \sum_i (K_{jc} df_i + K_{je}) dz_i \quad (j = t,a,r) \qquad (1)$$

Where F_j is tangential(*Ft*), radial(*Fr*) and axial force(*Fa*) respectively. K_{jc} and K_{je} are the cutting and edge force coefficients which are determined by cutting force measurement on full immersion milling tests. A block materia of stainless steel (SUS304) was machined using a rounded indexable tool of 5 mm radius with changing cutting conditions such as speed, feed rate and depth of cut.

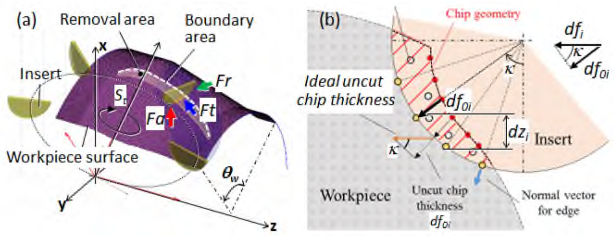

Figure 2. Simulation model for turn milling(a) and chip thickness(b)

2.2. Boundary wear changing

Fig.3 shows the contact area between tool and workpiece as shown in Fig.2. Boundary area is also changes during tool rotation, and affect to boundary tool wear. In this report, boundary movement ratio L_{br} and contact ratio γ_{br} are proposed as flowing equations.

$$L_{br} = L_b / L_t, \quad \gamma_{br} = \gamma / \pi \qquad (2)$$

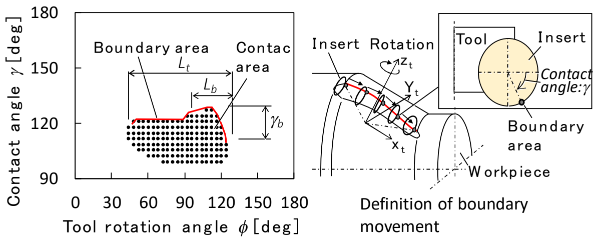

Figure 3. Evaluation method of boundenly area

Where L_b is movement length of boundary area, L_t is contact length, γ_b is contact angle of tool edge to workpiece. Both L_{br} and γ_{br} are one of the expression of boundary movement during tool rotation.

3. Experimental verification test

Fig.4 shows the experimental setup for evaluation of cutting force and tool wear in turn milling. Cutting force was measured by using rotating dynamometer on each condition as shown in Table.1. Tool wear was also tested with *V*=200m/min, *fr*=0.1mm/tooth, α=30deg, β=15,30 deg, number of tooth *Nt*=1.

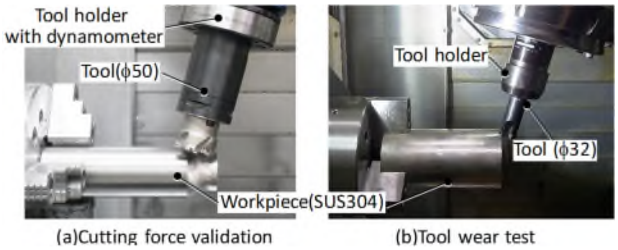

Figure 4. Experimental setup for turn milling test

Table 1 Experimetnal conditions (*Nt*=1, non-coated insert)

V[m/min]	*fr*[mm/tooth]	*ap*[mm]	*ar*[mm]	*a*[deg]	*b* [deg]
200	0.1	0.5	16	35	15, 30, 45, 60

4. Test results of cutting force and tool wear

Fig.5(a) shows comparison between simulated cutting force and experimental data with α=35deg, β=15deg . Fig.5(b)shows the maximum cutting force on x_t-y_t coordinate system which rotated with tool. Although tool vibration affected on experimental data, simulation results by proposed method are good agreement with experimental data. Fig.6 is the results of boundary wear test which is compared with simulated boundary movement. From the evaluation of tool wear and boundary movement, result in Fig.6(b) is bigger boundary wear due to boundary movement is smaller than the result of Fig.6(a).

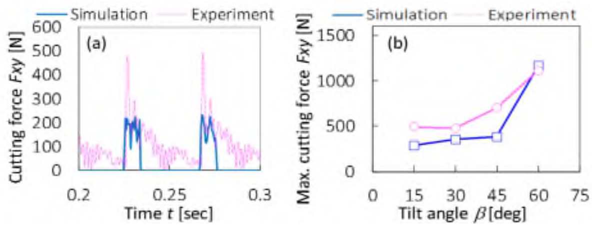

Figure 5. Simulated and measured cutting forces in turn-milling

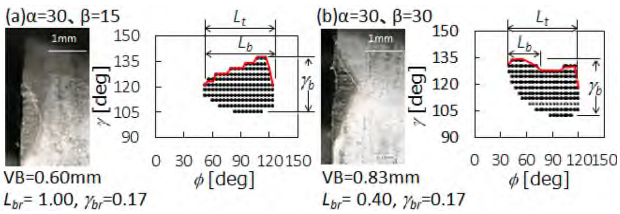

Figure 6. Effect of lead and tilt angle on boundary wear

5. Conclusion

Turn milling simulation method which can consider lead and tilt angle by using the point group model is proposed. This model is also verified experimentally and has good agreement with measured cutting force. Furthermore, boundary wear is affected by tool posture such as lead and tilt angle. From comparison of boundary movement and tool wear, tool wear becomes small in the case of big boundary movement.

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