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3차원 절삭에서 발생하는 측면버에 관한 실험적 연구

Experimental Investigations of Sideward Burr Formation in 3-Dimensional Cutting

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ABSTRACT

Burrs can be formed on the feed marks ridges as well as on the edges of the machined parts in machining operations. These burrs are undesirable in terms of the surface quality, the precise dimensioning of machined parts and the safety of operators. This paper experimentally investigates the sideward burr formation in 3-dimensional cutting. In particular, the experimental relationships between the size of sideward burr and the cutting parameters are established and suggestions are made for minimizing sideward burr formation.

국 문 요 약

버(burr)는 절삭공정중 공작물의 표면상의 피드마크 뿐만 아니라 측면에도 발생할 수 있다. 이는 공작물의 정밀도와 작업자의 안전의 측면에서 바람직하지 않다. 본 연구에서는 3차원 절삭에서 발생하는 측면버에 관한 실험적 연구를 수행한다. 특히, 측면버의 크기와 절삭 파라메터 사이의 실험적 관계가 설정되며, 이를 통하여 버의 크기를 최소화할 수 있는 방법이 제안된다.

1. Introduction

Burrs produced on the surfaces or on the edges of machined parts are undesirable in terms of the surface quality, the effective functioning and the precise dimensioning of machined parts, and the safety of operators. In some cases, burrs can cause the rubbing wear

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of the tool during the machining[1]. These burrs must be completely removed in most cases. One way of removing burrs left on the machined surface is the polishing operation. Burrs left on the edges of the machined parts can be removed by deburring operation. However, these approaches are highly costly, e.g., considerable amount of time and effort are needed as the production increases. Formation of burrs in machining can also be minimized by properly selecting the cutting parameters and work materials. However, this causes some limitations on the productivity and the automation of the production.

The main purpose of this study is to experimentally investigate the sideward burr formation in 3-dimensional cutting. Apparently, very little attention has been paid to the investigation of the sideward burr formation and its removal in 3-dimensional cutting. In particular, the experimental relationships between the size of sideward burr and the cutting parameters are established and suggestions are made for minimizing sideward burr formation.

2. Burr Formation in 3-Dimensional Cutting

Burrs can be conveniently classified into four types depending on the location where they develop[2]: backward (entrance) burr by backward flow of materials, sideward burr by sideward flow, forward (exit) burr by forward flow and leaned burr by leaning to the feed direction. Fig. 1 shows the typical sideward burr formed in orthogonal cutting, respectively. Depending on the mechanism of formation, there are four basic types of burrs[3]: Poisson burr, rollover burr, tear burr and cut-off burr. Although some burrs can be a combination of these burrs, one mode of formation usually predominates. The Poisson burr is the result of a material's tendency to bulge at the sides when it is compressed. The rollover burr is essentially a chip which is pushed out of the cutter's path rather than sheared. It is usually found at the end of cut. We consider both Poisson burr and rollover burr in this study.

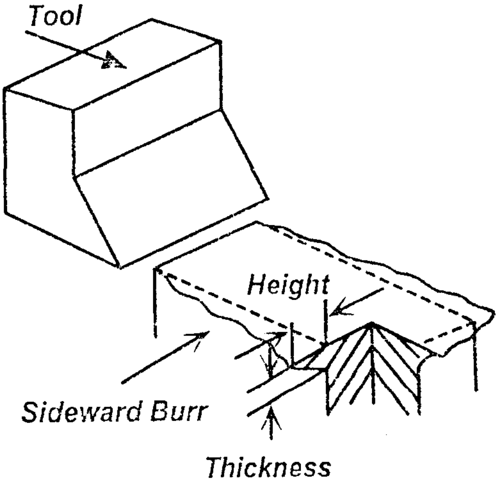

Fig. 1 Typical sideward burr formed in orthogonal cutting.

It has been well known for some years that burrs formed on the feed marks ridges are caused by the material side flow, e.g., the displacement of work material opposite to the feed direction or movement of material in a direction perpendicular to the direction of cutting. The material side flow is known to be caused by the squeezing effect that the material is pressed sideways where it could escape. Such effect is due to the local pressure between the flank surface of the tool and the workpiece surface being generated. One supporting evidence for this hypothesis is that the squeezing effect is more pronounced with a worn tool than with a fresh tool[1]. Consequently, pressure distribution around the tool tip which depends on both the chip formation process and the tool condition appears to be a key factor in minimizing the material side flow. In 3-dimensional cutting, the level of pressure around the tool tip can be controlled simply by adjusting the oblique angle i_F..

As for burrs on the edge, a unique relationship between the normalized burr height (burr height divided by the depth of cut) and the shear strain was observed while cutting 65-35 brass[2), Fig. 2. In that study, burr size was found to depend on the shear strain only. In general, the shear strain (γ) is related to the normal shear angle (ϕ_n) by :

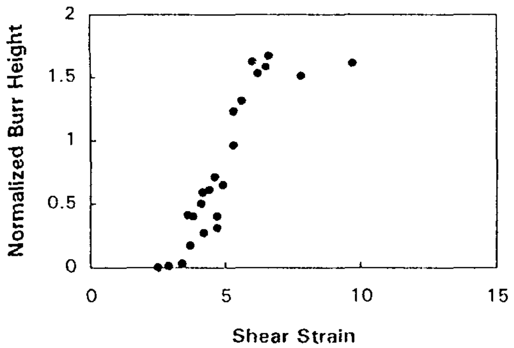

Fig. 2 Experimental relation between the normalized burr height (burr height/depth of cut) and the shear atrain obtained in cutting 35-65 brass, [2].

$$\gamma = \cot\phi_n + \tan(\phi_n - \alpha_n) \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Then, ϕ_n is a key factor controlling the size of burr in this case. In general, the oblique angle i_F in 3-dimensional cutting influences the normal shear angle by a relationship[4) :

$$\frac{\tan\eta_c}{\tan i_F} = \frac{\cos(\phi_n - \alpha_n)}{\sin\phi_n} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

and Stabler's chip flow rule[5) states that :

$$\eta_c \approx i_F \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

3. Experiments

A series of tests were conducted at low cutting speed on a Bridgeport vertical milling machine to cut flat workpieces that have 6.35 mm width of cut and 45.7mm length. Detailed description of experimental setup used is given elsewhere[6). Fig. 3 depicts the ideal 3-dimensional cutting where angles and velocities are designated. The size of burr was measured using a microscope after the initial transient period of burr formation stabilized to the steady state condition. This typically happened after the tool traveled approximately 3cm from its initial contact with the workpiece.

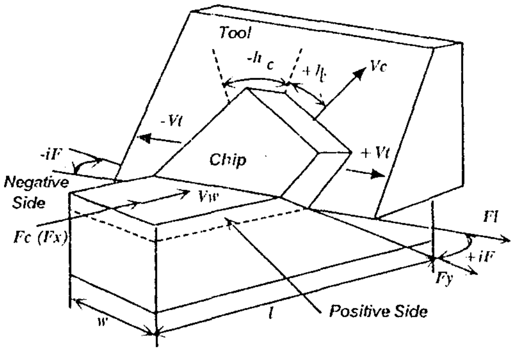

Fig. 3 Designation of angles and velocities in three dimensional cutting

4. Results and Discussions

Since the thickness of burr in Fig. 1 for varying cutting parameters exhibits a similar trend as the height[2), only the height of sideward burr is considered in this study. It was observed during the experiments that linear relationships between the height of Poisson burr (H_P) and the depth of cut hold for the work materials and i_F tested. Note that the cutting force component along the tool cutting edge (F_l) is negligible and the cutting force component in the cutting speed direction ($F_x = F_c$) is proportional to depth of cut in orthogonal cutting, i.e.,

$$F_x = K_1 t_1 + K_2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where K_1 is the proportionality constant. K_2 is the intercept value obtained from the force-depth of cut plot. Then, a linear relationship between F_x and H_P can be assumed as :

$$H_P = C_1F_x + C_2 \qquad (5)$$

Experimental data in Fig. 4 confirms such a linear relationship. It may also be stated from the results in the figure that the ductility of Al1100 is mostly responsible for the larger size of Poisson burr since the ductile materials can sustain larger plastic deformation, whereas the brittle materials such as Al2024-T3 have very little capacity for plastic deformation[6,7]. Fig. 5 shows the variation of the height of sideward burr (H_S) with the oblique angle i_F for workpieces and cutting conditions indicated. The negative values of burr height represent the burrs on the negative side of the workpiece. The experimental results revealed a trend that the larger size of burr is formed on the positive side of the workpiece than on the negative side.

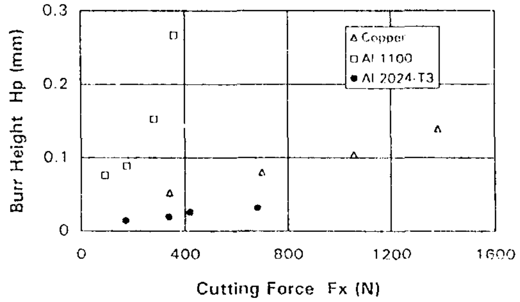

Fig. 4 Variation of H_P with F_x in orthogonal cutting. Cutting conditions are : V_w = 0.3m/min, t_1=0.051~0.203mm, α_n=10°.

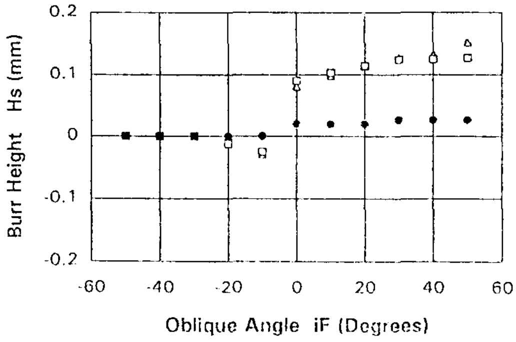

Fig. 5 Variation of H_S with i_F. Workpiece : Copper, (a) Al1100, (b) Al2024-T3, (c) Cutting conditions are same as in Fig. 4.

These observations strongly suggest that :

1) there exists a correlation between the chip flow angle and the size of burr. In general, two principles can be deduced: a larger burr is developed on the side over which the chip flows and the larger size of burr results from the larger chip flow angle on that side.
2) control of sideward burr formation is possible simply by adjusting the chip flow direction in 3-dimensional cutting.

Since the non-zero chip flow angle in 3-dimensional cutting brings about the force component in y direction (F_i) in Fig. 3, it is interesting to see how the size of burr is correlated with the force components. For example, Fig. 6 shows the experimental relationship between F_y and H_S obtained for various combinations of depth of cut and i_F. Again, a linear relationship can be established between the two variables such that :

$$H_S = C_3F_y + C_4 \qquad (6)$$

For small depth of cut, Poisson burr is produced by the high pressure between the tool flank and the workpiece extruding material along the cutting edge axis[3]. Then, in order to investigate the pure effect of F_y on the sideward burr formation (denoted as H_{yo}), it is necessary to decompose the size of Poisson burr from H_S. Since a linear relationship between the size of Poisson burr and F_x was established in Eq.(5), one can assume that :

$$\begin{aligned} H_{yo} &= H_S - H_P \\ &= C_3F_y - C_1F_x + C_4 - C_2 \\ &= C_5F_{yo} + C_6 \qquad (7) \end{aligned}$$

where

$$F_{yo} = \frac{C_3F_y - C_1F_x}{C_5}$$

$$C_6 = C_4 - C_2 \quad \cdots\cdots\cdots\cdots (8)$$

and C_i, $i=1$, 6 are constants.

The variation of H_{yo} with F_{yo} is seen in Fig. 7. Comparing Fig. 7 with Fig. 6, one can notice that formation of rollover burr was predominant in the experiments performed. One thing to note at this point is that the intercept value K_2 in Eq.(4), which is usually neglected for investigation of chip formation process, was not subtracted from Eq.(7) since it represents the plowing force at the tool flank face. The main squeezing effect in sideward burr formation is performed at the tool flank face[1].

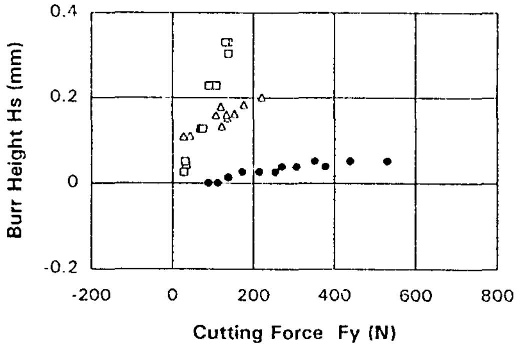

Fig. 6 Variation of H_S with F_y. Cutting conditions are same as in Fig. 4.

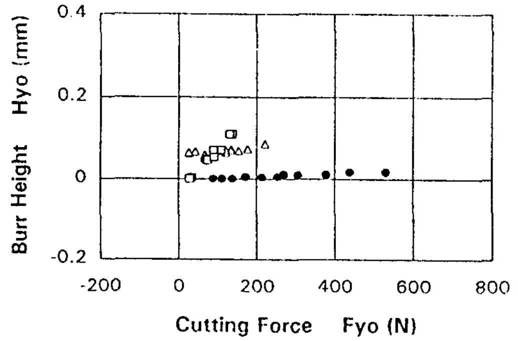

Fig. 7 Variation of H_{yo} with F_{yo}. Cutting conditions are same as in Fig. 4.

5. Conclusions

Based on the experimental observations made in this study, the following conclusions can be drawn:

1) Most significant factors that characterize the formation of sideward burr are the cutting force component in y direction and the direction of chip flow. These factors were found to have strong correlations with the size of burr (H_S).
2) Minimization of this force component and proper control of chip flow can, therefore, lead to a minimum size of burr. This can be achieved by properly selecting i_F in conjunction with other cutting parameters for given work material.

NOMENCLATURE

F_c : Cutting force component in the cutting speed direction
F_i : Cutting force component along the cutting edge
F_x, F_y : Cutting force components in x and y directions, respectively
H_P : Height of Poisson burr
H_S : Height of sideward burr
i_F : Oblique angle
i : Length of workpiece
t_1 : Depth of cut
V_w : Cutting velocity (speed)
w : Width of cut
α_n : Normal rake angle
α_g : Geometric rake angle
ϕ_n : Normal shear angle
η_c : Chip flow angle

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