A study of burr mechanism in micro grooving

Duy Le*, Jong-Min Lee*, Su-Jin Kim*

Abstract

Burr formation in micro cutting is a serious problem in precision engineering nowadays. It affects a lot on product's quality, besides deburring techniques on micro patterns are almost impossible or too complicated and high-cost. Predicting and minimizing burr size in correlation with cutting conditions is more appropriate. Previous researches about micro burr problems are still not enough to deal with the requirements of the manufacturing industry. For the purpose of exploring the burr phenomenon in micro metal cutting, two cases of burr formation in turning micro patterns are introduced in the paper. The burr happens along the cutting direction - side burr - with prism pattern and rectangular pattern. And the analytical solution for predicting the burr size of prism pattern is also proposed.

Key Words: Burr formation, Micro grooving, Plastic deformation, Slip line theory.

1. Introduction

The motivation for micro mechanical cutting arises from the translation of the knowledge obtained from the macro-machining domain to micro-domain. However, there are challenges and limitations to micro-machining, and simple scaling cannot be used to model the phenomena of micro machining operations [1]. High-accuracy miniaturized components are increasingly in demand for various industries, such as aerospace, biomedical, electronics, environmental, communications, and automotive. This miniaturization will provide micro systems that promise to enhance health care, quality of life and economic growth in such applications as micro channels for lab-on-chips, shape memory alloy 'stent', fluidic graphite channels for fuel cell applications, sub-miniature actuators and sensors, and medical devices [2-5].

Burr formation in micro cutting causes serious problems in precision engineering. It affects a lot on product's quality. Deburring techniques on micro cutting are almost impossible or too specific, complicated and high-cost [6]. Predicting and minimizing burr size in correlation with cutting conditions is more appropriate [7]. Previous researches about micro burr problems are still not enough to deal with the requirements of the manufacturing industry. For the purpose of exploring the burr phenomenon in micro metal cutting, two cases of burr formation in turning micro patterns are introduced in the paper. The burr happens along the cutting direction - side burr - with prism pattern and rectangular pattern. Base on the previous research about predicting micro cutting forces [8] the authors go further with predicting the burr. The analytical solution for predicting the burr size of prism pattern is also proposed.

2. Burr modeling

The model is applied to a ductile work material on which the burr is fully formed without fracture. The cutting direction is parallel to the exit face, as shown in Fig. 1. As a tool with a lead angel φ moves along the feed direction.

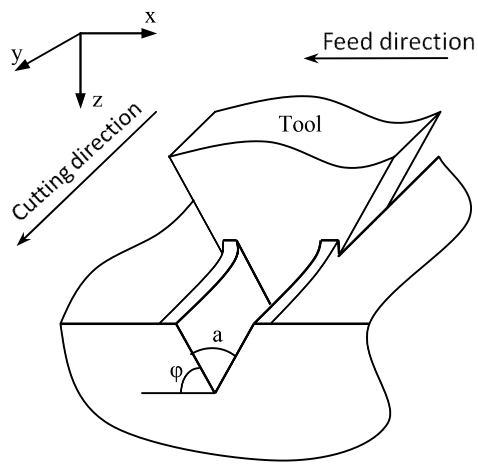

Fig. 1. Cutting model

Burr happens at each cutting depths of the turning schedule according to the cutting condition. It would be better to take care of the burr caused by the last cutting depth because the others can be removed at the next step. At the final depth of cut (d) in turning micro pattern, obviously there exists a critical thickness t_{cr} , at which the cutting is not possible. It causes plowing on the pattern-side surface along with the deformed chip removing upon it. In case of the remained thickness of workpiece is reach to t_{cr} value (prism pattern) then the top part of the allowance begins to deform plastically following the feed direction otherwise it will deform upward the side tool edge (rectangular pattern). This idea is leaded by the comparison and evaluation between burr in macro-machining [9] and micro metal cutting theory [1].

To determine the critical thickness t_{cr} , the cutting of an infinite plate is considered, as shown in Fig. 2, provided there is uniform stress distribution along its unit width. This scheme

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obtained from the normal cross section of the side tool edge in Fig. 1. The experiments [7,10] have shown that burr formation in the feed direction during turning operation is caused by the stresses in shear plane AD (see Fig. 2). In this study the shear τ_s and normal σ_s stresses in shear plane are considered uniform and estimated from cutting forces F_u and F_v. Those forces can be estimated from F_y and F_z which are already found in [8]. Due to these stresses, tension is expected in the plate when the critical thickness is t_{cr}. Slip lines AD and BC are the boundaries of the tensile area. Since the exit surface is free from external stresses, the slip lines are inclined to the exit surface at 45^0, according to the theory of plasticity [11,12]. Besides, this theory implies that the normal and shear stresses on these lines are equal to the value of plasticity k which is determined from Mises criterion [13] as

$$k = \frac{\sigma_y}{\sqrt{3}} \qquad (1)$$

where σ_y is the yield strength of the roll mold material which can be estimated from hardness HV [14].

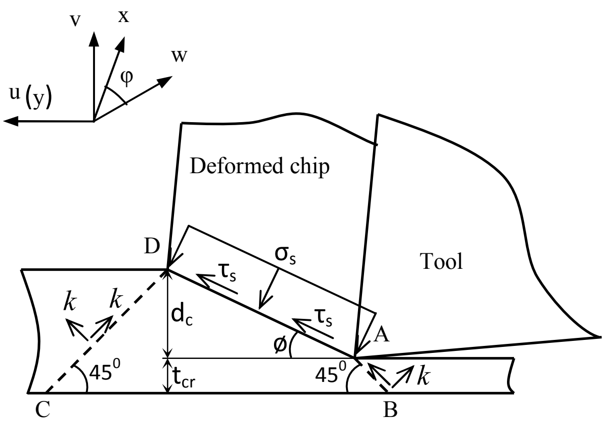

Fig. 2. Determination of the critical thickness t_{cr}

The equation of the force balance of element ABCD with respect to the x-axis yields

$$\left(\tau_s \sin\phi - \sigma_s \cos\phi\right)\frac{a}{\sin\phi} + 4kt_{cr} + 2kd_c = 0 \qquad (2)$$

where d_c is the undeformed chip thickness, and ϕ is the shear angle. According the Merchant's cutting theory [15] ϕ can be calculate by

$$\phi = \frac{\pi}{2} + \frac{\alpha}{2} - \frac{\beta}{2} \qquad (3)$$

with α is rake angle, β is friction angle which is easily estimated by applying Merchant's circle.

$$\beta = \arctan\left(\frac{F_v + F_u \tan\alpha}{F_u - F_v \tan\alpha}\right) \qquad (4)$$

Eq. (2) results in searching limit thickness t_{cr} :

$$t_{cr} = \frac{d_c(\sigma_s \cos\phi - \tau_s - 2k)}{4k} \qquad (5)$$

which can be called burr thickness.

3. Prism pattern

When the side tool edge reaches the thickness t_{cr} , the subsequence movement of the tool in the feed direction causes the plastic deformation of the workpiece material, which is transform in to burr, as shown in Fig. 3. Based on the experimental observations of burr formation in the feed direction [7,10], it is assumed that the deformation of the work material occurs perpendicular to the machined surface during burr formation (see Fig. 3). It is also assumed that burr thickness keeps the same value t_{cr}, and that the prism top of the burr that is being formed remains rigid throughout burr formation. 115The burr height is geometrically obtained as

$$b = \frac{\left(d \sin\frac{a}{2} + t_{cr}\right)}{\tan(a)} \qquad (6)$$

where a is pattern angle, d is final cutting depth.

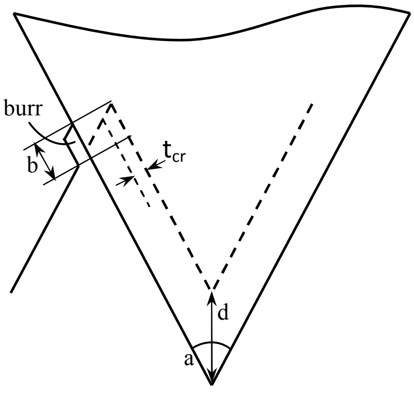

Fig. 3. Burr deformation of prism pattern

4. Conclusion

This paper proposed an acceptable method of predicting the burr size in turning with micro prism pattern. Algorithm (5) shows the critical thickness where the cutting is impossible, (6) gives the burr height in prism pattern. The method is based on theoretical understanding about plastic deformation in micro metal cutting and experiences of observation experiments results about burr in metal cutting. This project is still under construction. In the next stage the authors want to find the analytical method for estimating the burr size of rectangular pattern. After that some experiment works will be setup in order to evaluate the aforementioned analytical methods.

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