Precision Engineering 47 (2017) 191–196

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

# Investigation on the burr formation mechanism in micro cutting

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ARTICLE INFO

*Article history:*
Received 10 June 2016
Received in revised form 18 August 2016
Accepted 23 August 2016
Available online 24 August 2016

*Keywords:*
Micro cutting
Burr formation
Stress distribution
Cutting edge radius

ABSTRACT

It is desirable to minimize burr formation for improving part quality. This paper presents an investigation on the burr formation mechanism in micro cutting by taking into consideration the stress distribution around the cutting edge arc. The influences of the uncut chip thickness and the cutting edge radius on burr formation were investigated. Poisson burr is attributed to the side flow of the stagnation material at the bottom of the cutting edge arc. The stress distribution at the cutting edge arc has great influence on Poisson burr formation. The burr height decreases to the minimum value and then increases with reducing the uncut chip thickness due to the change of the maximum stress distribution. An optimum machining strategy also is suggested in micro milling of snake-shaped groove microstructure.



## 1. Introduction

Micro cutting is capable of fabricating micro parts with complex features in various materials. It is widely used for producing aerospace and optics devices [1]. Burr formation in micro cutting affects the part quality by dimensional distortion at the edge, damage to the subsurface and challenge during assembling [2]. The common approach to solve the burr formation issue is the subsequent deburring step or the optimization of machining process. In macro cutting burr removal is a necessary step for the finishing of most parts [3,4]. The deburring method has also been studied a lot in micro cutting. George [5] experimentally evaluated abrasive assisted brush deburring of micro milled grooves on tool steel and copper. Jang [6] proposed the magnetorheological fluid deburring method and applied it for producing micro molds. Gillespie [7] pointed out that the cost of burr removal may reach 30% of the total manufacturing cost in precision miniature parts and be more if the part is smaller. Burr removal in micro cutting cannot be easily accomplished with conventional deburring method due to the small size of micro part. Furthermore, the deburring process may introduce dimensional error or residual stress to the miniature parts. Hence, burr minimization by optimizing the machining process is the most desirable approach [8,9]. Burr formation is affected by many factors including workpiece material ductility, tool geometry and machining parameters. Schaller [10] suggested that the materials with higher ductility usually produce larger burr size. Filiz [11] found that the top burr size on the down milling side is larger than on the up milling side. Nakayama [12] reported that the side burr size could be reduced by decreasing the uncut chip thickness. Fang [13] reported that once the workpiece material and other machining parameters are specified, burr size is determined by the uncut chip thickness.

In micro cutting the uncut chip thickness is comparable to the cutting edge radius. The size effect and the minimum chip thickness phenomenon have great influence on the cutting process. Burr formation is more complicated when compared to macro cutting. Bissacco [14] and Schueler [15] reported that the top burr size is large in micro milling due to the size effect. Chen [16] studied the modeling of burr formation in micro ball end milling. They found that a low ratio of the axial depth to the milling cutter radius is conducive to suppress top burr formation. Zhang [17] also pointed out that the ratio of the uncut chip thickness to the cutting edge radius has great influence on burr size. However, further study of the various mechanisms is necessary to minimize burr formation. This paper presents an investigation on the burr formation mechanism by taking into consideration the stress distribution around the cutting edge arc. The influences of the uncut chip thickness and the cutting edge radius on burr formation were investigated and an optimum machining strategy is suggested for micro milling of snake-shaped groove microstructure.

## 2. Burr formation mechanism in micro cutting

### 2.1. Poisson burr formation

Based on the causes of formation, four basic types of burrs are defined: Poisson, tear, rollover and cut-off burr [15]. The side flow of workpiece material results in Poisson burr. In micro cutting the

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http://dx.doi.org/10.1016/j.precisioneng.2016.08.004
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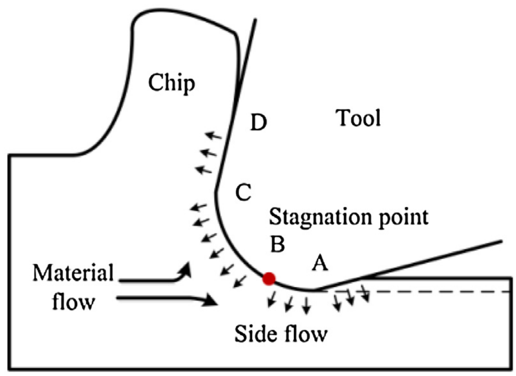


**Fig. 1.** Poisson burr formation.

cutting edge radius of used tool cannot be ignored. The tip of cutting edge can be divided into two parts, the straight rake face and the cutting edge arc, i.e. the straight line CD and the arc AC, as shown in Fig. 1. When the tool contacts the workpiece, both the straight rake face and the cutting edge arc act on the workpiece and extrude it in the cutting direction. There is considerable interacting stress on the contact area between the workpiece and the tool. The workpiece begins plastic deformation when the stress value is higher than the yield strength of workpiece material. Material always flows along the minimum resistance direction under high stress. On the straight rake face, plastic deformation is constrained in the forward and the downward directions by bulk material. In the upward and the side directions the constraint is small. Material primarily flows along the upward direction, forming a chip. Little material bulges to the side, leading to the rugged side surface of chips [18]. Under the cutting edge arc, the flow of material in the upward direction also is constrained by the tool to some extent. This leads to very high interacting stress on the workpiece. However, it is a free surface in the side direction and has low constraint. A certain amount of material may flow to the side surface. The effective rake angle at the cutting edge arc is actually negative. When the cutting process is performed with negative rake angle the flow of material in front of the tool is in two directions, some up the rake face to form a chip, and some through the flank face to the machined surface, with a stagnation point [19,20]. The material that has flowed to the side surface above the stagnation point subsequently flows up the rake face, becoming a part of chips. However, the material that has flowed to the side surface under the stagnation point subsequently flows to the machined surface, resulting in a Poisson burr, as shown in Fig. 1. Furthermore the material that has flowed to the machined surface suffers elastic recovery. The elastic recovery leads to severe extrusion between the machined surface and the flank face. There is very high interacting stress at the machined surface. If the tool is imperfectly manufactured or has worn at the flank face the interacting stress becomes higher. The high stress may result in some material also flows to the side surface of machined surface, and Poisson burr will be formed as well. It is concluded that Poisson burr mainly is attributed to the side flow of the stagnation material that lies at the bottom segment of the cutting edge arc.

When this burr is formed in orthogonal cutting it is called side burr. It is top burr when formed on the top edge of milled groove. When the ductility of workpiece material is higher, the thickness of the stagnation material layer is larger as well. More material will flow through the flank face to the machined surface. It is accompanied with more material under the stagnation point first flowing to the side surface and then flowing to the machined surface. At the same time, more material occurs side flow at the machined surface as well. This explains why the materials with higher ductility produce larger burr size. Poisson burr is one of the most common burr types in metal cutting. It has detrimental influence on part quality, such as the dimensional accuracy and the surface quality. The detrimental influence becomes stronger when the part feature size is in micro scale. However, as the cutting edge radius always exist, the formation of Poisson burr is inevitable. Hence, it is desirable to minimize the burr size with optimizing the machining process. From indentation experiment it is well known that when the loading pressure on specimen is higher more material suffers plastic flow. Since Poisson burr is caused by the plastic side flow of the stagnation material at the bottom segment of the cutting edge arc, it is implied that the interacting stress at the bottom segment of the cutting edge arc has a positive correlation with the burr formation. The higher the interacting stress, the more the stagnation material may occur side flow, the larger the burr formation as well. The stress concentration at the cutting edge arc has great influence on Poisson burr formation. Hence, the analysis of stress distribution around the cutting edge arc is necessary to reveal the stress at the bottom segment of the cutting edge arc varying with the cutting edge radius. The burr size variation can be indirectly revealed from the stress variation.

**Table 1**
Simulation parameters.

| | |
|---|---|
| Cutting speed $v$ (mm/s) | 300 |
| Cutting width $a_w$ (μm) | 100 |
| Uncut chip thickness $a_0$ (μm) | 2 |
| Cutting edge radius $r_n$ (μm) | 0, 1, 2, 5 |

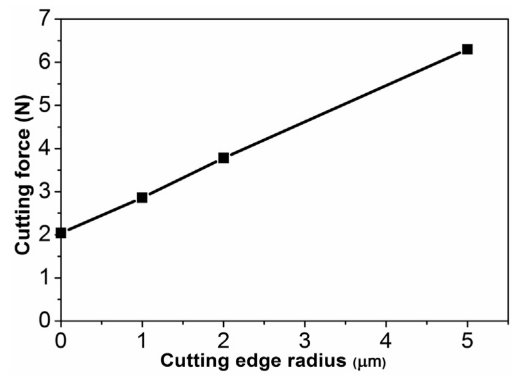


**Fig. 2.** Cutting force for different cutting edge radii.

### 2.2. Stress distribution in micro cutting

Cutting force and stress distribution in micro cutting was analyzed utilizing DEFORM software. The workpiece material was oxygen free copper, and the J-C constitutive material model was used. The tool material was diamond. The rake and flank angles were 10° and 5°, respectively. The shear friction model based on constant shear assumption was used, and the friction factor was fixed at 0.6. The uncut chip thickness was set as a fixed value. The cutting edge radius was a variable, in order to investigate the stress distribution under different relationships between the uncut chip thickness and the cutting edge radius. Four different values were selected for the cutting edge radius, including smaller and larger than the uncut chip thickness. The cutting edge radius of zero also was considered. All the cutting parameters are listed in Table 1.

The variation of cutting force with the cutting edge radius is shown in Fig. 2. It is seen that the cutting force almost linearly rises with the cutting edge radius. Micro cutting force is composed of shearing force and ploughing force components. The ploughing force is caused by the ploughing and scratching on the cutting edge arc. With larger cutting edge radius more material is machined by