Burr and Shape Distortion in Micro-Grooving of Non-Ferrous Metals Using a Diamond Tool

Jung-Hwan Ahn*
Professor, School of Mechanical Engineering, Pusan National Univversity,
Han-Seok Lim
Pusan National University, RIMT
Seong-Min Son
Graduate School, Pusan National University

Burr and shape distortion are two main problems in micro-grooving. In this study, a simplified model is proposed based on large thrust force due to the tool edge radius. Experiments are conducted with a single crystal diamond tool on a 3-axis shaper-like machine varying the depth of cuts, and groove angles on brass, aluminum and OFHC. Experiments have shown that the thrust force becomes a dominant variable in burr generation compared to the principal force when the depth of cut is less than 2 μm. And fewer burrs develop on more brittle materials. Shape distortion is significant only when the groove angle is small and the depth of cut is larger than 30 μm.

Key Words : Micro-Grooving, Burr, Shape Distortion, Diamond Tool

Nomenclature

Bh	: Burr height
Bt	: Burr thickness
Bp	: Total projected depth of cut
D_ϕ	: Shape distortion
Fx	: Principal force
Fy	: y-directional component of thrust
Fz	: z-directional component of thrust
Fn	: Normal force to groove surface
OFHC	: Oxygen Free High Conductivity Copper

1. Introduction

A micro-groove, ranging in size from a few microns to several tens of microns, is the basic geometric shape of miniaturized/thinned optical components such as fresnel lenses, lenticular lenses, reflectors, etc. For optical parts to function as designed, they require a high precision shape/surface quality produced by an ultra-precision machining with a single point diamond tool. Ultra-precision machining also has a unique advantage in that various grooves can be made only by changing the tool geometry or the machining program.

However, problems such as shape distortion and burr, which might be caused by highly specific cutting forces and ductile mold materials, are very undesirable because they degrade the performance of optical components. Many studies have been conducted about the burr generation mechanism in conventional machining. (Gillespie and Blotter, 1976; Ko and Dornfeld, 1994; Choi, 1997) Mostly burrs in a single groove, which swell up at both sides of a groove, have been investigated. (Ueda and Sumiya, 1986; Tamura et al., 1991)

In this study, a simplified model of the burr/shape distortion in grooving multiple micro-grooves is proposed and the effects of cutting parameters such as depth of cut, groove angle, etc.

* Corresponding Author,
E-mail : jhwahn@hyowon.pusan.ac.kr
TEL : +82-51-510-2333 ; **FAX** : +82-51-514-0685
School of Mechanical Engineering, Pusan National University, san 30, Jangjeon-dong, Keumjeong-ku, Pusan 609-735, Korea. (Manuscript **Received** May 25, 2000; **Revised** August 7, 2000)

are investigated.

2. Model of Burr and Shape Distortion in Micro-Grooving

The term "burr", as used here, is limited to the burr which is generated at the summit of the groove tooth, and thus equivalent to the side burr in milling and grinding. Figure 1 shows the geometrical shape of an array of micro-grooves and a tool. Figure 2(a) shows a simplified model

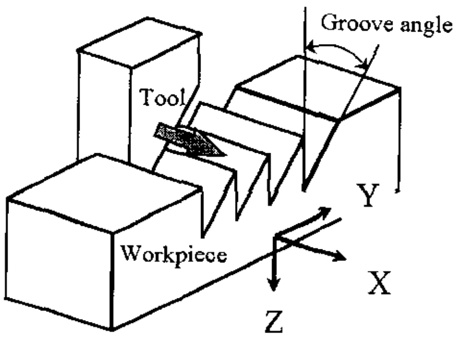
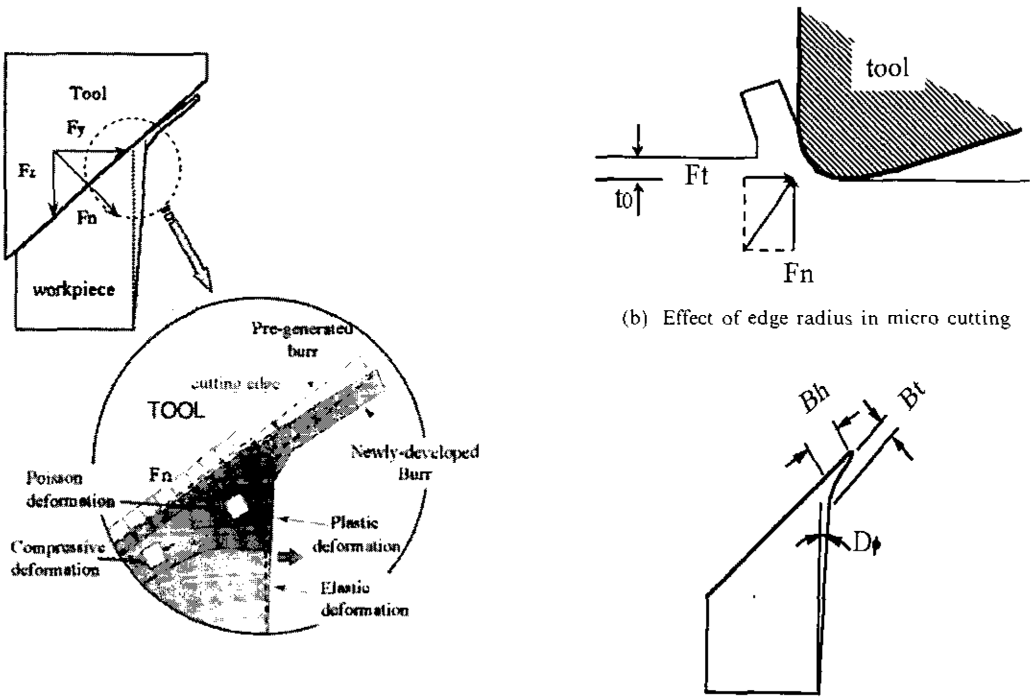


Fig. 1 Array of micro-grooves and tool

of burr generation and shape distortion in micro-grooving where the thrust force normal to the machined surface becomes much more significant due to a comparatively large ratio of the tool edge radius to the depth of cut as shown in Fig. 2(b). (Yang and Cha, 1992; Lim and Ahn, 1992) Figure 2(c) shows designations for burr height (Bh), burr thickness (Bt) and shape distortion (DΦ).

When the tool begins cutting, the groove tooth is elastically/plastically deformed by the thrust force normal to the groove surface during chip separation. The pre-generated burr hanging on the tooth edge rotates away the cutting edge so that only a part of the burr is cut away by the tool. The rest of the burr remains accumulated on the newly-generated burr. This is the formation process for burrs in multi-groove operations. That is, a combination of bending, shear and Poisson deformation due to both thrust force and the geometrically-weakened-tooth is assumed to cause the burr and shape distortion in multi-grooving. (Lim and Ahn, 1992; Nakayame and



(a) A model of burr and shape distortion

(b) Effect of edge radius in micro cutting

(c) Designation of burr and shape distortion

Fig. 2 A model of burr/shape distortion in grooving

Arai, 1987)

3. Experimental Method

Figure 3 shows the schematic diagram of the experimental setup. The machine has, developed for this experiment, a micro-stepping motor driven z-axis with a resolution of 0.2 μm and an AC servo motor driven XY table with a resolution of 1 μm which are mounted on a granite plate with vibration-absorbing air springs. Cutting forces are measured with a tool dynamometer and recorded while grooving for data analysis.

The cutting parameters are depth of cut, groove angle, and workpiece material. Cutting speed, cutting edge radius, rake angle and tool setting angle are to be kept constant at 5 mm/s, 0.8 μm, 0 deg and 0 deg, respectively. The experiments were conducted in two ways. One is, for the convenience of measuring cutting force and burr shape, orthogonal cutting with 0.5 mm thick workpiece, so called single-grooving, and the other is multi-grooving to measure shape distortion. Every experiment under a given condition is conducted repeatedly up to the total accumulated depth of 100 m and the total amount of burr and shape distortion is compared. Cutting conditions are summarized in Table 1.

Table 1 Experimental cutting conditions

Scheme	Speed	Pitch	Groove angle	Depth of cut	Work piece
Single	5 mm/s		20°-80°	1-12 μm	brass Al7075 OFHC*
Multiple		50 μm	50°	1-50 μm	

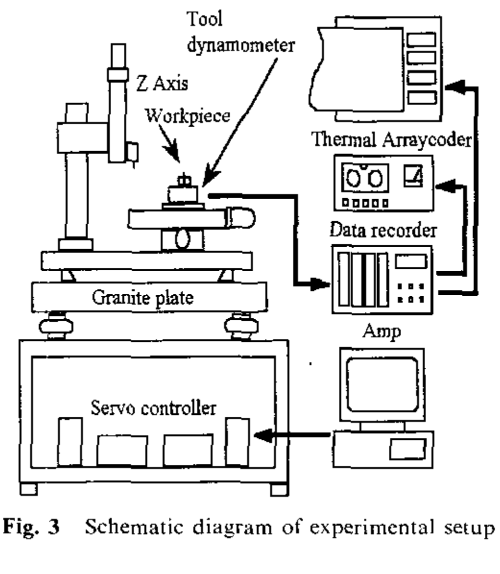


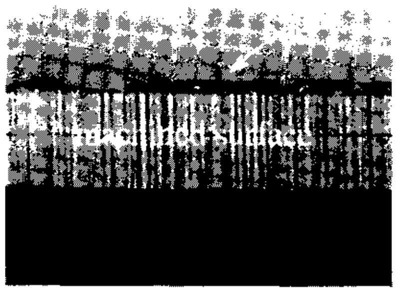
Fig. 3 Schematic diagram of experimental setup

4. Experimental Results and Discussion

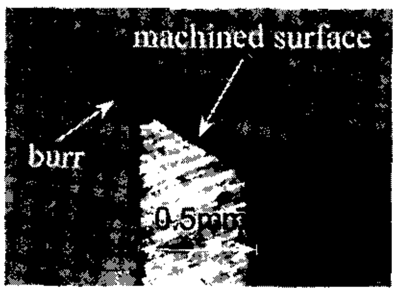
4.1 Topography of burr and distorted groove

Figure 4 shows a top view (a) and a side view (b) of a machined surface. Burr develops outwards at the sharper side of the groove surface while nothing happens at the blunt side. This implies that the burr produced by micro-grooving is generated in different ways than by milling or grinding.

Figure 5 is a microscopic photograph showing the cross-sectional view of distorted gooves. Grooves are deformed opposite from the tool feeding direction, because the stiffness of the groove tooth is not enough to sustain the thrust cutting force. Therefore, proper cutting conditions should be selected to keep burr/shape distortion to a tolerable level.



(a) Top view



(b) Side view

Fig. 4 Machined surface and burr

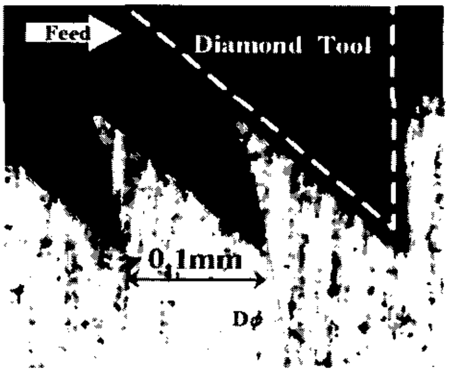
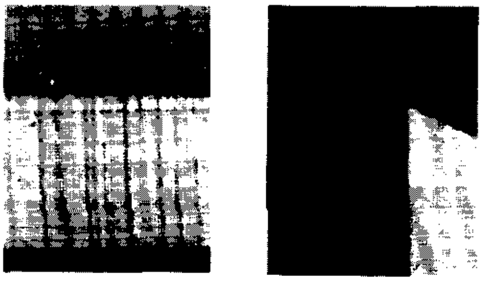
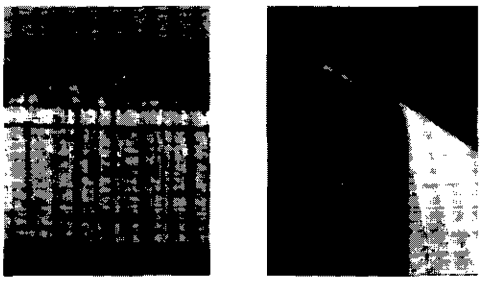


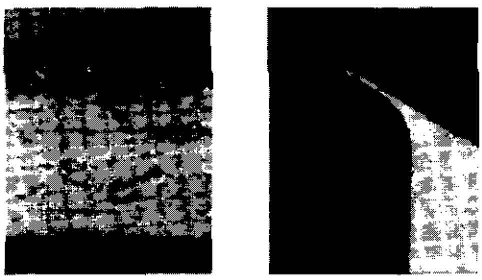
Fig. 5 Shape-distorted groove



(a) Depth of cut 4 μm



(a) Depth of cut 8 μm



(c) Depth of cut 12 μm

Top view Side view

Fig. 6 Comparison of burr/shape (brass)

4.2 Effects of depth of cut and groove angle

Figure 6 shows the effects of the depth of cut to the burr status by comparing the top and side view of burrs generated for various depths of cut on a brass plate. It is shown that burr thickness increases and the root thickens. The burr becomes more rigid when depth of cut increases.

In cuts deeper than 6 μm, burr becomes uniform. Meanwhile, in more shallow cuts, burrs become thinner and more nonuniform with parts of burr torn out probably by the shear force and with small cracks in the boundary between burr and workpiece appearing.

Figure 7 shows the accumulated burr height for a 100 μm groove with the depth of cut and groove angle varied for brass. As the depth of cut increases, the burr becomes thicker and larger. The burr height is nearly proportional to the depth of cut.

Smaller groove angles result in larger burr heights. As the groove angle becomes smaller, the stiffness of tooth lowers and it causes a larger bending deformation which results in a larger burr. This clearly supports the suggested model of burr in grooving.

6 μm may be a critical depth of cut where burr characteristics in the view of uniformity and possibility of removal changes rapidly. The accumulated burr height at a depth of cut of 6 m is nearly equivalent to the projection (Bp) of an accumulated depth of 100 μm on the machined surface. The dotted line indicates Bp for each

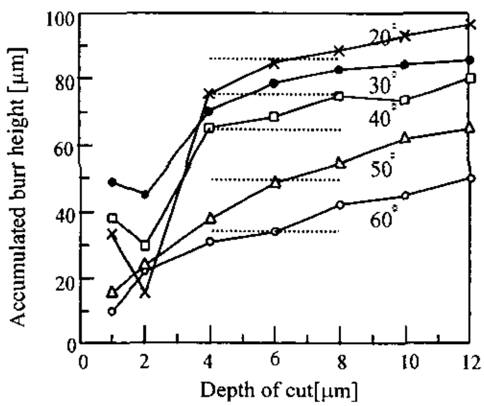
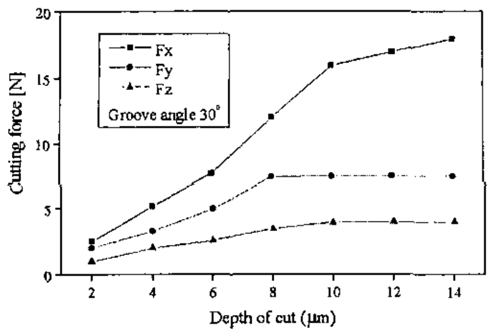
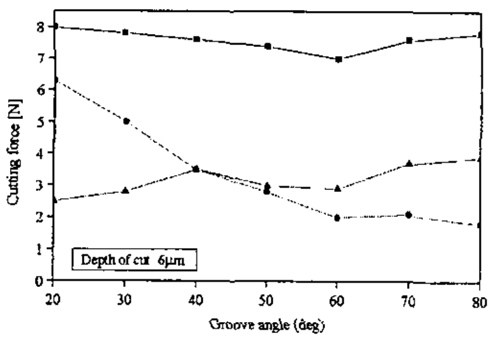


Fig. 7 Accumulated burr height for the total depth of 100 μm (brass) (Dotted line : Bp)

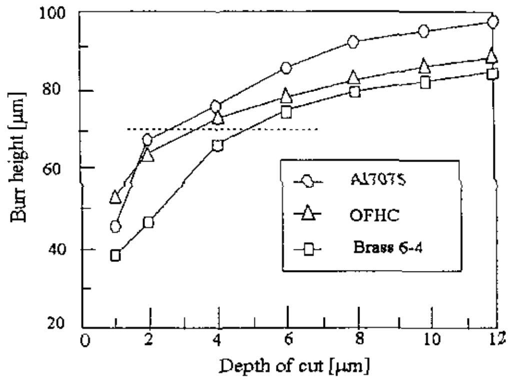


(a) With depth of cut

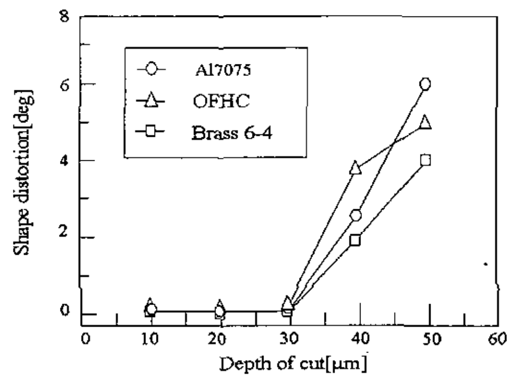


(b) With groove angle

Fig. 8 Variations of cutting force



(a) Burr height



(b) Shape distortion

Fig. 9 Accumulated burr height and shape distortion of multi-grooving (Dotted line : Bp)

groove angle. Cutting conditions which results in burrs with projected depth of cut less than Bp would be recommended to help deburring following grooving.

Figure 8 shows cutting forces with varied depths of cut and groove angles. As the depth of cut decreases, the two components of the thrust force, Fy and Fz, decrease slightly, whereas the principal force decreases almost linearly. It verifies that the thrust force plays a significant role in burr generation in micro machining. As the groove angle decreases, Fy, the y-directional component of the thrust force increases rapidly, whereas the principal force is almost constant. It is due to the increase of force on the groove tooth which is largely elastically deformed. This also explains why the burr is dominant at the sharp side in a single-groove cut.

4.3 Effects of workpiece material

Figure 9 shows the effect of workpiece material to the burr height (a) and shape distortion (b) in multi-grooving. In Fig. 9(a), the burr height increases with the depth of cut like Fig. 7. Aluminium and OFHC seem to generate larger burr than brass because they are more ductile. As shown in Fig. 9(b), shape distortion does not occur when the depth of cut is less than 30 μm because the strength of the tooth can sustain the thrust force. At depths of cut over 30 μm shape distortion occurs nearly proportionally to depth of cut. The shape is less distorted in brass than in other materials because the strength of brass is higher. Therefore, shape distortion is less significant once Bp is considered when selecting the depth of cut.

Figure 10 shows the measurements of burr thickness for the three kinds of workpiece materials. It is thicker for OFHC than for aluminium. In case of brass, it is thinner than that of aluminum. It corresponds to the order of large ductility

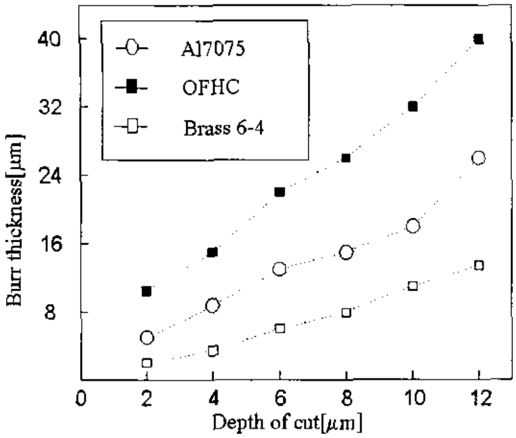


Fig. 10 Burr thickness versus depth of cut

which is nearly proportional to yield strength. The yield strengths of the materials used in this study are 44.3 kgf/mm^2 for brass, 28.1 kgf/mm^2 for OFHC and 15 kgf/mm^2 for aluminum. Therefore, materials with some brittleness, like brass are thought to be more suitable for micro-grooving from the viewpoint of burr.

5. Conclusion

The results of this study can be summarized as follows:

(1) Thrust force in micro-grooving plays a significant role in burr generation and shape distortion.

(2) The burr of a micro-groove grows, mainly, due to bending deformation caused by a large groove angle and large depth of cut.

(3) A critical depth of cut, where an accumulated burr height is less than the projection (Bp) of the accumulated depth of cut, is recommended for better deburring after grooving.

(4) Shape distortion is less significant when depth of cut is selected which yields less burr.

(5) Burr thickness is propertional to the ductility of materials.

Acknowledgements

This research was financially supported by the Korea Science and Engineering Foundation (KOSEF) through the Engineering Research Center for Net Shape and Die Manufacturing at Pusan National University.

References

Choi, G.H. 1997, "Experimental Investigations of Sideward Burr Formation in Rotary Machining," *KSME Int'l Journal*, Vol. 11, No. 1, pp. 20 ~28.

Gillespie, L.K. and Blotter, P.T., 1976, "The Formation and Propeties of Machining Burrs," *J. of Eng. for Ind., Trans. of ASME*, pp. 66~74.

Ko, S.L. and Dornfeld, D. A., 1991, "A Sutdy on Burr Formation Mechanism," *J. of Eng. Mat. and Tech., Trans. of ASME*, Vol. 113, pp. 75 ~87.

Lim, H.S. and Ahn, J.H., 1997, "A Study of Burr Formation on Microgrooving for Fresnel Lens Mould," *J. of KSPE*, Vol. 14, No. 3., pp. 28~34. (in Korean)

Nakayame, K. and Arai, M., 1987, "Burr Formation in Metal Cutting," *Annals of the CIRP*, Vol. 36, No. 1, pp. 33~36.

Tamura, T., Arakawa, N. and Masuda, M., 1991, "Generation Phenomena of Burrs in Micro Grooving of Single Crystal Ferrite," *J. of JSPE*, Vol. 57, No. 5, pp. 155~160. (in Japanese)

Ueda, K. and Sumiya, M., 1986, "Ultra High Precise Micro Grooving," *J. of JSPE*, Vol. 52, No. 12, pp. 22~25. (in Japanese)

Yang, G.E. and Cha, I. C., 1992, "Effect of Polar Organic Substance on Burr Formation in Orthogonal Cutting," *KSME Int'l Journal*, Vol. 6, No. 1, pp. 63~69.