Lapping of EDM Processed Tool Steel Surfaces Using Modified Figure-8 Tool Motion

M. Mizuno, D. Tanaka, T. Iyama, N.Yoshihara, N.Nishikawa
Iwate University, Japan

m.mizuno@iwate-u.ac.jp

Abstract

The authors previously developed a lapping machine, which finishes EDM processed tool steel surfaces by applying figure-8 motions to a lapping tool in the presence of diamond compound. The lapping machine allows producing a surface roughness of about 0.1 μm R_a when using a 3 μm diamond compound. Furthermore, the difference between the surface roughness values measured in parallel and in perpendicular to the work feed direction was reduced to 0.005 μm R_a when the intersection angle of the figure-8 motion was set to 90 degrees. However, the material removal rate is still low. Aiming to improve the material removal rate, the tool motion is modified in this paper so that the sliding length of the lapping tool on the workpiece surface during one cycle of motion may become long. The experimental results show that the material removal rate tends to increase by the modified tool motion.

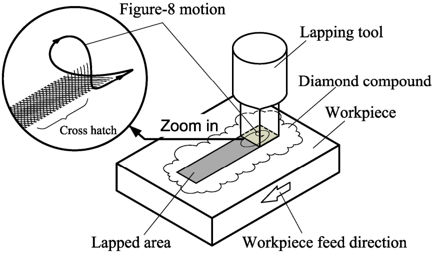


Figure 1: Lapping by a figure-8 tool motion

1 Introduction

The electrical discharge machining (EDM) process is most widely used in the mold-making industries. It can be applied to hard metals that are very difficult to machine with traditional techniques, and produce various shapes that are impossible to do with rotary tools. However, it is well known that the surface produced by EDM is generally rough and heat affected. Aiming to remove the heat affected zone efficiently and reduce the surface roughness with low or no surface roughness anisotropy, the authors previously developed a lapping machine [1], which finishes surfaces by applying figure-8 motions to a lapping tool in the presence of diamond compound as shown in Figure 1. By using a figure-8 tool motion with an intersection angle of 90 degrees, the difference between the surface roughness values measured in parallel and in perpendicular to the work feed direction was reduced to 0.005 μm R_a [2].

However, the material removal rate is still low. In order to improve the material removal rate, the tool motion is modified in this paper so that the sliding length of the lapping tool on the workpiece surface during one cycle of motion may become long. This paper elucidates the effect through some lapping experiments.

2 Outline of lapping machine

The developed lapping machine is shown in Figure 2. To aid the explanation, a right-handed rectangular coordinate system (*X*, *Y*, *Z*) is introduced as shown in Figure 2. The machine was composed of an oscillating tool system, a *Z* axis table which positions the oscillating tool system vertically, an *XY*-table which positions the workpiece horizontally, a force sensor to measure the average lapping force.

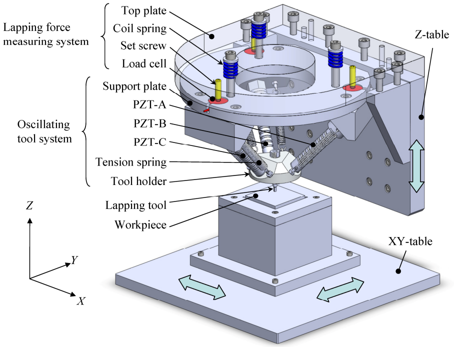


Figure 2: Developed lapping machine

Three multilayer piezoelectric transducers (PZTs) were installed between a PZT support plate and a tool holder with an appropriate preload. The three PZTs were arranged in a rotational symmetry of a 120 degree angle with respect to the centre axis of the tool (*Z* axis). Here, the centre axis of PZT-C lied in the *YZ* plane. Each PZT axis formed a 45 degree angle with the *XY* plane.

3 Modified figure-8 tool motion

For convenience, the position of the tool end centre when each PZT has its nominal length is chosen as the origin of the *XYZ* coordinate system. The *XYZ* coordinates of the moving tool end centre (D_X, D_Y, D_Z) in the previous lapping experiments can be expressed as follows

$$D_X = G_X \sin \omega t \ \cdots (1), \quad D_Y = G_Y \sin 2\omega t \ \cdots (2), \quad D_Z = -G_Z \cos 2\omega t \ \cdots (3)$$

where t (s) is time; ω (rad/s) is frequency; G_X, G_Y and G_Z serve to scale the amplitudes. Equation (3) is modified so that the sliding length of the lapping tool on the workpiece surface during one cycle of motion may become long. The modified equation is as follows

$$D_Z = G_Z (2 \sin^{2n} \omega t - 1) \ \cdots (4)$$

where n is a constant related to the sliding length. When n =1, Eq. (4) becomes the same with Eq. (3).

4 Lapping experiments

4.1 Experimental method

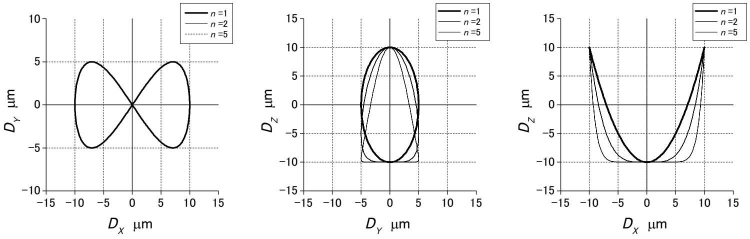
In order to investigate the fundamental lapping performance, lapping experiments were performed on a flat surface parallel to the *XY* plane.

The lapping tool was made of an epoxy resin (ThreeBond Co Ltd., Base: 2023, Hardener: 2105C). The tool end was formed to a square flat end of side length 2 mm.

Oil-based diamond compounds (Engis Co Ltd., Hyprez OS Compound: 1-OS-47, 3-OS-40) were used in the lapping experiments. The compounds had average abrasive grain sizes of 1 μm and 3 μm, respectively.

The workpiece was made from cold worked tool steel (Daido Steel Co. Ltd., DC53). It was heat treated to increase the hardness. The surface to be lapped was EDM-processed. The Vicker's hardness of the EDM-processed surface was 510-520 HV and the average surface roughness (R_a) was 1.3 - 1.5 μm.

The work-feed direction was parallel to the *Y* direction. The work-feed velocity was 4 mm/min and the stroke of the reciprocating workpiece motion was 4 mm. Constant *n*



(a) View in *XY*-plane (b) View in *YZ*-plane (c) View in *XZ*-plane

Figure 3: Tool motions applied in the experiments

in Eq. (4) was changed to 1, 2, 5 while the amplitudes of tool motion in X, Y and Z directions were fixed to 10 μm (=G_X), 5 μm (=G_Y) and 10 μm (=G_Z), respectively. Tool motions used in the following experiments are shown in Figure 3. Lapping was always kept down-mode. Normal lapping force F_Z were set to 4 N, 6 N and 8 N.

4.2 Experimental results

Figure 4 shows the relationship between n and material removal sectional area W_a. For 3 μm diamond compound, W_a increases with the increase of n regardless the lapping force. However, for 1 μm diamond compound, the trend is uncertain. The surfaces lapped with 1 μm diamond compound were covered with a soft thin film. The tool material might transfer to the workpiece surface and the film might act as a protective coat.

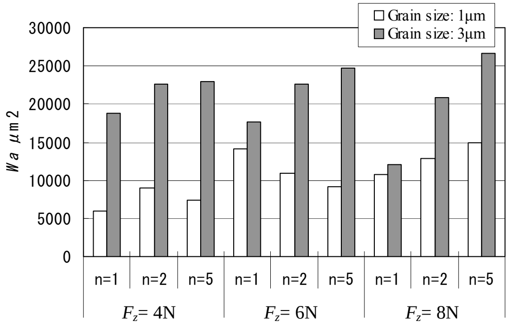


Figure 4: Relationship between n and material removal sectional area W_a

5 Conclusions

This study elucidated the relationship between the sliding length of the lapping tool on the workpiece surface during one cycle of motion and the material removal rate. When using 3 μm diamond compound, the material removal rate increased with the increase of the sliding length.

References:

[1] M. Mizuno, T. Iyama, X. Zhang, N. Nishikawa: Development of a Three-Dimensional Tool Oscillation System for Finishing Metal Molds, Key Engineering Materials, Vols. 389-390, pp.302-307, 2008.

[2] M. Mizuno, T. Iyama, N. Nishikawa, H. Mifune: Lapping of EDM Processed Tool Steel Surfaces Using Three-Dimensional Figure-8 Tool Motion, Proceedings of the euspen International Conference, Vol.1, pp.130-133, 2009.