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233 Study on Particle-Brush in Magnetic Field Assisted Machining —Finishing Characteristics of Grooves—

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Summary

Magnetic field assisted machining method uses flexible particle-brushes that consist of ferromagnetic particles. It is processed using particle-brush and abrasives slurry. Ferromagnetic particles are connected along the line of magnetic force, and form a particle-brush. In magnetic field assisted machining, basic research associated with the particle-brush is crucial for expansion and development of magnetic polishing. However, many items relating to details of machining characteristics are still unknown.

In this study, smaller diameter ferromagnetic particles are mixed with larger diameter ferromagnetic particles to form the particle-brush to be used for polishing. It has been clarified that the particle-brush containing smaller diameter ferromagnetic particles is effective in machining the workpiece with a groove.

Keywords: Magnetic Field Assisted Machining, Particle-Brush, Grain, Surface Roughness, Edge

1. Introduction

Magnetic field assisted machining method is a processing using a flexible brush formed by magnetically combined particles (the particle-brush) as the polishing tool, and its application to surface polishing and edge finishing of parts with complicated shapes is highly expected [(1)]. Many papers have dealt with polishing of workpieces having curvatures and stepwise surfaces [(2)~(5)], and high efficiency magnetic polishing using slurry as the abrasives has been studied by several researchers [(6)~(9)]. With magnetic polishing method using abrasives slurry, ferromagnetic particles and abrasive grain are supplied separately to the machining area. In this case, the particle-brush is composed solely of ferromagnetic particles. Since abrasive grains are non-magnetic and are therefore not retained metallurgically in the ferromagnetic particles, minute cutting is made on the workpiece when these are caught between the workpiece surface and the particle-brush. Fig.1 shows principle of processing.

In magnetic field assisted machining, basic research associated with the particle-brush is crucial for expansion and development of magnetic polishing. However, many items relating to details of machining characteristics are still unknown. Focusing attention on the particle-brush, studies on polishing characteristics of the workpiece with a groove have been made [(10)]. Relationship between diameter of ferromagnetic particles used to form the particle-brush, and machining characteristics is as follows: (1) Removal efficiency is higher with larger particle diameters. (2) Good finish surface roughness is obtained with smaller particle diameters. (3) Larger particle diameters are more suited for polishing of the groove bottom. In summary, there are two approaches. In some cases, larger diameter ferromagnetic materials are preferable while smaller diameters are preferable in other cases. The authors consider that the range of magnetic field assisted machining will be expanded by combining advantages of both approaches.

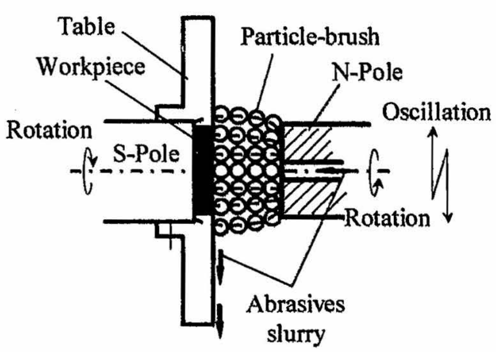


Fig.1 Principle of magnetic field assisted machining using abrasives slurry

In this study, smaller diameter ferromagnetic particles are mixed with larger diameter ferromagnetic particles to form the particle-brush to be used for polishing. It has been clarified that the particle-brush containing smaller diameter ferromagnetic particles is effective in machining the workpiece with a groove.

2. Experimental method and experimental conditions

2.1 Experimental apparatus

Fig.2 shows the magnetic field assisted machining apparatus using spindle through type magnetic pole. In this apparatus, two rotating poles are arranged opposite each other, one a rotating N-pole being inserted into the magnetic coil and the other a rotating S-pole forming a closed magnetic circuit through the yoke. Rotation and oscillation are given to the N-pole simultaneously. The workpiece is mounted to the nose of S-pole and rotational motion is given to it.

Fig.3 shows relative motion between the N-pole and the workpiece (S-pole). Ferromagnetic particles form a particle-brush along with the line of magnetic force when they are placed between the workpiece and N-pole. This brush then generates a polishing pressure on the surface of the workpiece by magnetic attraction force. Abrasives slurry is supplied from the nose of the magnetic pole to the nose of the particle brush, and is then discharged from the machining area, and is recovered into a tank from a receiving pan placed under the table to be supplied again.

2.2 Experimental conditions and evaluation method

Table 1 shows the experimental conditions. Steel balls for shot peening were used as the ferromagnetic particles and their diameters were 260 μ m (SP-260) and 420 μ m (SP-420). Fig.4 shows SEM photographs. The workpiece was processed by the wire-cut electric discharge machine to the shape shown in Fig.5 while initial surface roughness was 6 μ m*Rz*.

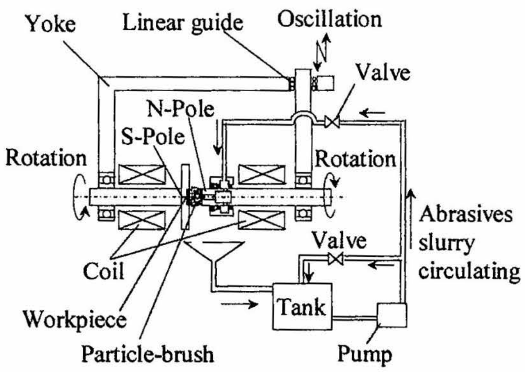


Fig.2 Schematic diagram of experimental apparatus

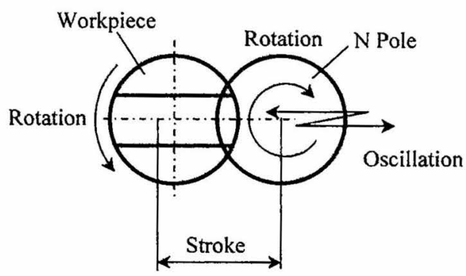
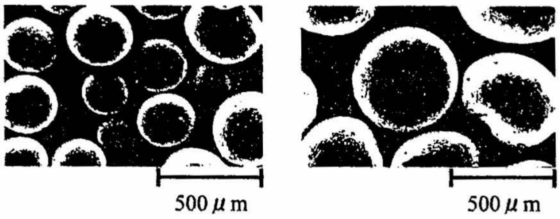


Fig.3 Relative motion between workpiece and N pole

Table 1 Experimental conditions

Rotation	N-pole : 1300 min^{-1},CW S-pole : 200 min^{-1},CCW
Oscillation	Stroke : 20mm, Frequency : 1Hz
Magnetomotive force	3.0×3000 A turn
Clearance	3 mm
Flow rate of slurry	300 mL / min
Workpiece	SUS304 (ϕ20×2 t mm)
Pre-processed	Wire-cut EDM
Initial roughness	6 μ m*Rz*
Groove	Width : 8 mm, Depth : 1.5 mm
Ferromagnetic particle	Steel ball for shot peening
Particle size	SP-260 : Mean dia.260 μ m, SP-420 : Mean dia.420 μ m
Grains	WA#2000, 10 wt%
Grinding fluid	Soluble type



(a) SP-260 (b) SP-420
Fig.4 SEM photograph of the ferromagnetic particles

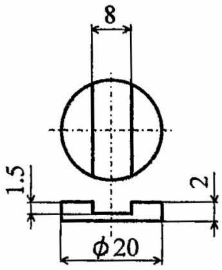


Fig.5 Shapes of workpiece with groove

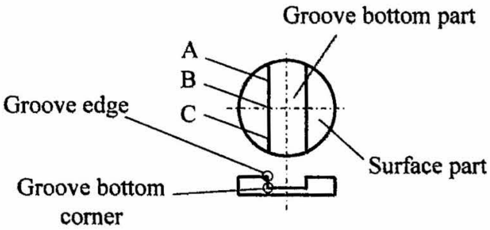
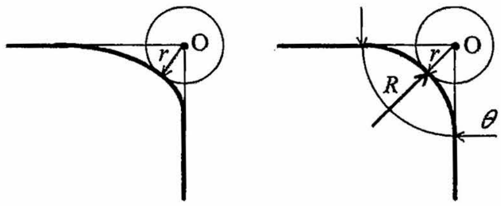


Fig.6 Evaluation points of the workpiece



(a) Actual shape (b) Ideal shape
Fig. 7 Roundness radius of the edge part

Fig.6 shows the points of evaluation of surface roughness and of edge part. Surface roughness was measured at two places: one the surface part and the other the groove bottom part. Evaluation points of the edge shape were defined on two places: one the groove edge and the other the groove bottom corner. Measurements were taken at points A, B, and C. The evaluation method for groove edge and groove bottom corner will be explained hereafter. The roundness radius R was defined as shown in Fig.7 referring to the groove edge. First distance r was measured, and the roundness radius R was calculated using Eq. (1).

$$R = \frac{r}{\operatorname{cosec}\frac{\theta}{2} - 1} \qquad (1)$$

The roundness radius R on the groove bottom corner was measured by a similar method.

3. Machining characteristics of particle brush formed by mono-size ferromagnetic particles

Polishing characteristics of the particle-brush formed by mono-size ferromagnetic particles were examined. The following description deals with comparison of the particle-brush formed by SP-260 only and the that formed by SP-420 only. Fig.8 shows the relationship between the size of ferromagnetic particles and surface roughness of the groove bottom and the surface part finished simultaneously. In the case of the particle-brush formed by SP-420, it was possible to finish both the surface part and the groove bottom part to the same level. On the other hand, with the particle-brush formed by SP-260, surface roughness of the groove bottom was not improved.

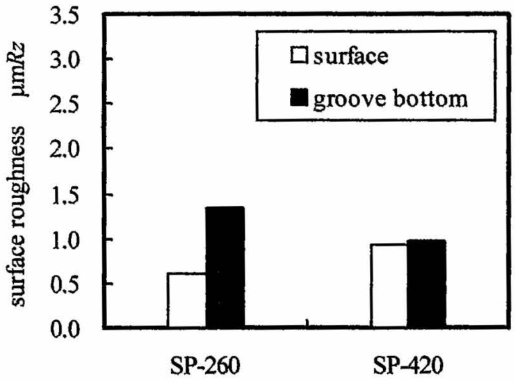


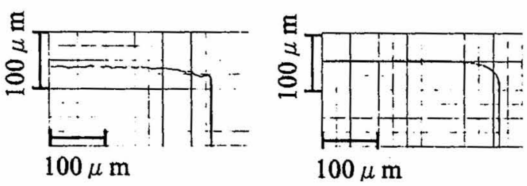
Fig.8 Relationship between the size of ferromagnetic particles and surface roughness

These events can be explained as follows:

According to visual observation, when the particle-brush was passed the groove part, it was cut at two locations: one in N-pole side and the other in the groove bottom side. At the step of the groove, cutting of the particle-brush due to the step and re-forming due to gathering of ferromagnetic particles along the line of magnetic force take place repeatedly. Since binding capability of ferromagnetic particles is proportional to the particle diameter, smaller diameters result in reduced reformation capability of the particle-brush. It is considered that as a result, relative motion of the particle-brush at the groove bottom is reduced and surface roughness is not improved. From above discussions, it may be said that larger diameter ferromagnetic materials are more suited for polishing of the groove bottom.

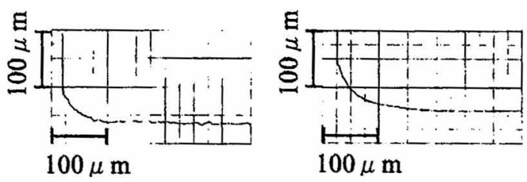
Machining characteristics of the groove edge part is investigated. Since polishing of the groove bottom is not possible, SP-260 case is omitted. Fig.9 shows shape of the groove edge. The roundness radius *R* of the edge part before machining was about 24 μ m which changed to about 60 μ m after machining for the case SP-420 was used. It is evident from this that the edge part is removed excessively.

Next, finishing of the corner part is investigated. Fig.10 shows shape of the groove bottom corner. The roundness radius *R* of the corner part before machining was about 90 μ m which changed to about 120 μ m after machining for the case SP-420 was used. It is evident from this that corner shape is collapsed for the case where larger diameters are used. This event can be explained as follows: As shown in Fig.11, when particle diameter of the ferromagnetic material is large, particles can not enter into groove bottom corner part. It is therefore considered that polishing while maintaining the initial shape of the corner *R* is not possible. Machining characteristics of the particle-brush formed by mono-size ferromagnetic materials as discussed above can be summarized as follows: (1) With smaller diameter ferromagnetic particles, groove bottom is not polished. (2) The groove edge part is removed excessively. (3) Shape of groove bottom corner is collapsed.



(a) before polishing (b) after polishing

Fig.9 Shape of the groove edge



(a) before polishing (b) after polishing

Fig.10 Shape of the groove bottom corner

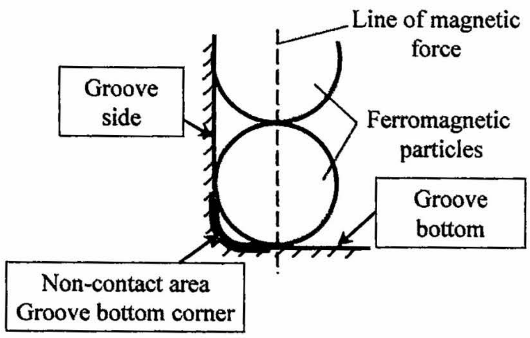


Fig.11 Contact situation between the ferromagnetic particles and the groove bottom corner

4. Effect of mixing ratio of smaller diameter ferromagnetic particles to particle-brush on machining characteristics

The purpose of groove polishing is to improve surface roughness of the groove bottom while maintaining the shape of the edge part. However, this purpose can not be accomplished fully by the particle-brush formed by mono-size ferromagnetic materials. Then the authors attempted to form a particle-brush by mixing smaller diameter ferromagnetic particles with larger diameter ferromagnetic particles.

4.1 Effect on surface roughness

Effect of mixing ratio of SP-260 and SP-420 on the surface roughness was investigated. Fig.12 shows relationship between surface roughness of the groove bottom part and workpiece surface part, and mixing ratio of SP-260. In the case SP-260 = 0% for example, the particle-brush is formed by SP-420 only while in the case of SP-260 = 100%, the brush is formed by SP-260 only.

In the case mixing ratio of SP-260 is less than 50%, simultaneous polishing of the surface part and the groove bottom part was possible. As the mixing ratio increases, the surface roughness was improved from about 1.1 μ m*Rz* to about 0.9 μ m*Rz*. However, with the mixing ratio more than 50%, improvement of the surface roughness of the groove bottom part was not observed. It is considered this is attributable to that relative motion at the groove bottom was reduced due to increased smaller diameter ferromagnetic particles.

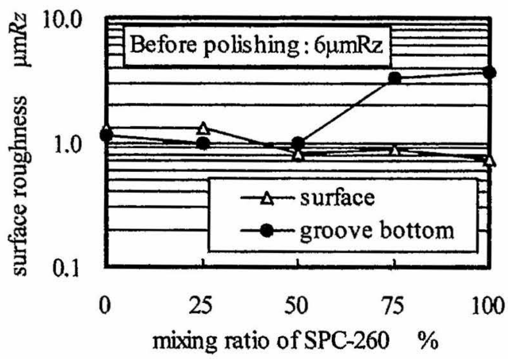


Fig.12 Relationship between surface roughness of the groove bottom part and workpiece surface part, and mixing ratio of SP-260.

4.2 Shape of groove edge part and groove bottom corner part

Shape of the edge part and corner part was examined. Fig.13 shows relationship between roundness radius *R* at edge part and mixing ratio of SP-260. Measurement of the roundness radius *R* was omitted since, as evident from experimental results shown in Fig.12, the groove bottom part is not polished for the cases where SP-260 mixing ratio is more than 50%. The roundness radius at measurement point B was larger than that of points A and C. It is considered the reason for this is that polishing pressure at point B which is closer to the magnetic pole center is higher than that of points A and C. As long as the mixing ratio of SP-260 is less than 50%, the roundness radius tended to become smaller as the mixing ratio of SP-260 became higher. This event demonstrates that excessive removal of the edge part is well prevented.

Fig.14 shows the relationship between roundness radius *R* at groove bottom corner and mixing ratio of SP-260. Measurement of the roundness radius *R* was omitted since similar to Fig.13, the groove bottom part is not polished for the case where SP-260 mixing ratio is more than 50%. As long as the mixing ratio of SP-260 is less than 50%, the roundness radius decreased as the mixing ratio was increased. It is noteworthy that the roundness radius *R* with the mixing ratio of 50% was identical with that of before machining. This event can be explained as follows: As shown in Fig.15, small diameter ferromagnetic particles (SP-260) in the particle-brush can make contact with the groove bottom corner part. Abrasive grains in the abrasives slurry are then caught between the corner and SP-260, and are used for finishing. It is considered that as a results, the particle-brush in which small diameter ferromagnetic particles are mixed carried out polishing successfully without losing the shape of the corner part. Fig.16 shows the shape of the groove bottom corner part.

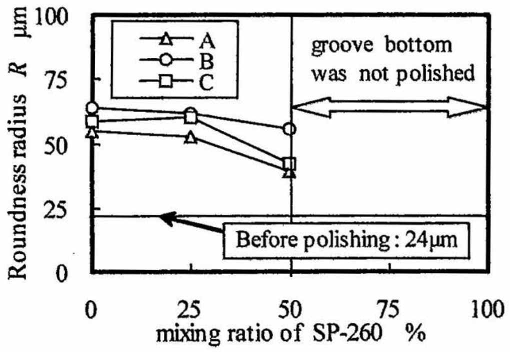


Fig.13 Relationship between roundness radius *R* at edge part and mixing ratio of SP-260

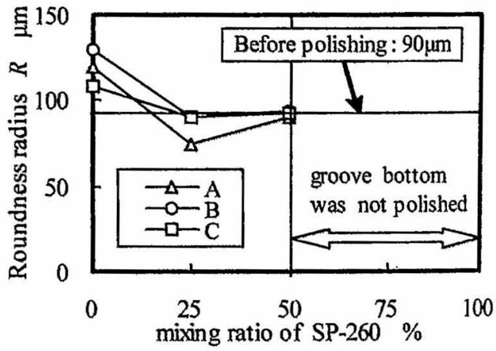


Fig.14 Relationship between roundness radius *R* at groove bottom corner and mixing ratio of SP-260

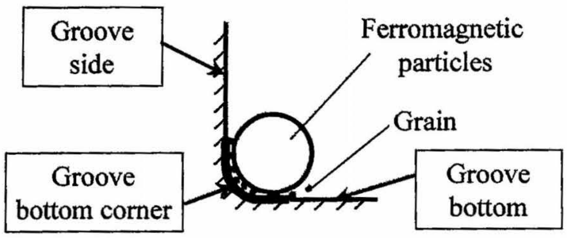


Fig.15 Polishing mechanism on the groove bottom corner by the mixing effect of SP-260

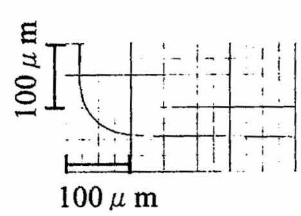


Fig.16 Groove bottom corner after machining in the case of the mixing ratio is 50%

5. Conclusions

Effects of the brush formed by magnetically combined particles on polishing of the groove and on edge machining are examined by experiments. Results obtained are summarized as follows:

(1) For polishing of the workpiece with a groove, the particle-brush in which small diameter ferromagnetic particles are mixed is effective.

(2) With mixing ratio of small diameter ferromagnetic materials less than 50%, the surface part and the groove bottom part can be polished simultaneously. As the mixing ratio increases, the surface roughness is improved from about 1.1 μ m*Rz* to about 0.9 μ m*Rz*.

(3) With mixing ratio of small diameter ferromagnetic particles less than 50%, the roundness radius tends to become smaller as the mixing ratio becomes higher thereby preventing excessive removal of the edge part.

(4) With mixing ratio of small diameter ferromagnetic particles of 50%, polishing can be made successfully without losing the shape of the groove bottom corner part.

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