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EFFECT OF THE PARTICLE BRUSH ON POLISHING PERFORMANCE OF SURFACE MAGNETIC POLISHING USING SLURRY CIRCULATION SYSTEM

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Abstract Surface magnetic polishing using abrasive slurry was performed, and the effect of particle brushes on polishing performance was examined. In this study, the surfaces of flat workpieces and flat workpieces with grooves were polished. The results are as follows: First, it was clarified that the particle size of the particle brush affected polishing performance. On a flat workpiece, surface roughness was improved from 1 μ mRy to 0.14 μ mRy. Next, the residual stress after polishing was the compression, and the value was 100～200 MPa. Finally, by the selection of particle size, it was possible to smooth the surface part and the groove bottom part at the same time on workpieces with grooves.

Key words Magnetic Polishing, Slurry, Grain, Surface Roughness, Residual Stress, Edge shape

1 INTRODUCTION

Magnetic polishing is an effective finishing method for areas where conventional working methods are difficult, such as the inner surface of a minute circular pipe [1], etc.. Magnetic polishing uses magnetic abrasives which react to a magnetic field as a polishing tool. Magnetic abrasives unite grains with ferromagnetic particles. Various research has been done on magnetic abrasives [2]～[4]. However, there has been a problem that polishing performance lessened when the cutting edge of magnetic abrasives dulled. In order to solve the above-mentioned problem, a method using abrasive slurry and a particle brush composed of iron powder has been studied without using magnetic abrasives [5][6]. There has been an improvement of the polishing efficiency of magnetic polishing using abrasive slurry. However, there are many unclear points about the effect of particle brushes on polishing performance.

In this study, surface magnetic polishing using abrasive slurry was executed, and the effect of particle brushes on polishing performance was examined. Steel balls for shot peening were used for the particle brush. In this paper, magnetic polishing of plane surfaces and plane surfaces with grooves was executed, and the effect of the particle brush on polishing performance was examined. Then, the surface residual stress after polishing was also examined.

2 EXPERIMENTAL METHOD AND CONDITIONS

2.1 Experimental Apparatus

Figure 1 shows the plane magnetic polishing apparatus using a spindle through type magnetic pole. N and S magnetic poles have been placed for the facing, and both magnetic poles form a closed magnetic circuit through the yoke. The N-pole is rotated with the radial oscillation of the workpiece. Simultaneously, the S-pole, which is installed on the workpiece, is also rotated. Between the workpiece and the N-pole, the ferromagnetic particles form the particle brush along the line of magnetic force. Then, polishing pressure is generated by following the surface shape of the workpiece with magnetic attraction. Abrasive slurry is supplied from the N-pole tip using the unit for supplying slurry. In this set up, the relative motion is between the workpiece and the particle brush. Grains in the abrasive slurry are pressurized by the particle brush, and thus give a cutting depth to the workpiece. In the slurry circulation system, the flow rate of abrasive slurry is adjusted by a valve. Discharged abrasive slurry is recovered in a tank. Abrasive slurry is then circulated by pump and supplied to the particle brush again. The diameter of the N-pole is 20mm and the slurry supply hole is 4mm. The experiment was performed without using a filter for chip removal in the slurry circulation system. The experiment was performed, exchanging abrasive slurry every 120 minutes.

2.2 Experimental Conditions

Table 1 shows experimental conditions. The material of the workpiece is SUS304. In the experiment for plane polishing, the thickness was 2mm. In surface polishing of workpieces with grooves, the thickness was 2mm, and the groove width was 8mm. Three types of groove depth were prepared. The surface roughness was 2～3 μ mRy on both the surface part and the bottom part of the groove. For the ferromagnetic particles, steel balls for shot peening were used. Abrasive slurry was produced by mixing of grinding fluid with the grains. The grain concentration of the abrasive slurry was 10wt%.

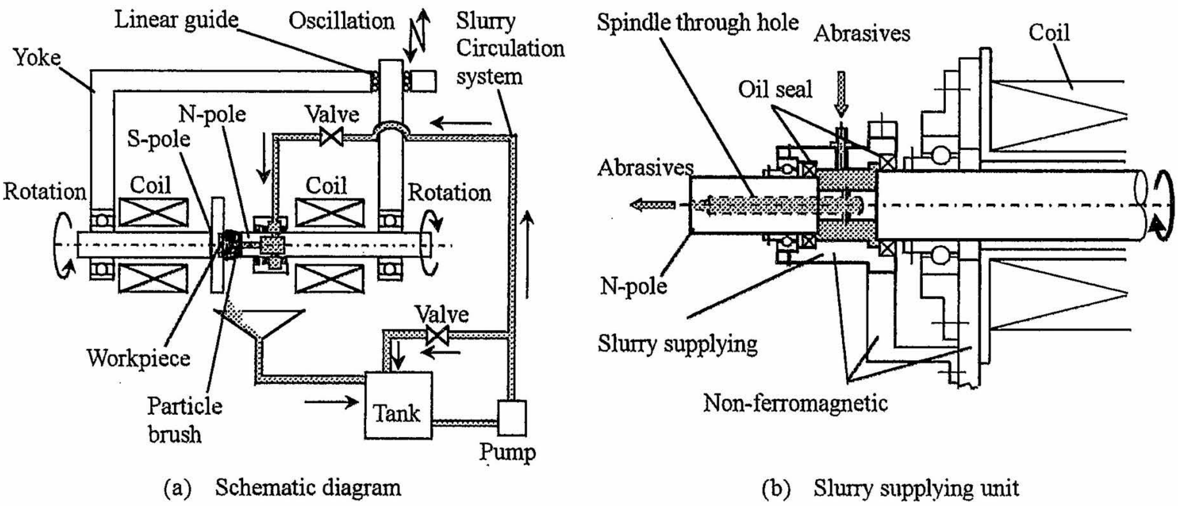


Fig. 1 Experimental apparatus

Table 1 Experimental conditions

N-Pole rotation S-Pole rotation N-Pole oscillation Magnetomotive force Clearance Flow rate of slurry	1300 min^{-1}, CW 200 min^{-1}, CCW Amplitude : 20 mm , Frequency : 1 Hz 3.0×3000 A·turn 3 mm 300 $mL \cdot min^{-1}$
Work-1 (Flat workpiece)	SUS304 (ϕ 20×2t mm), Surface roughness : 1～2 μ mRy
Work-2 (Flat workpiece with grooves)	SUS304 (ϕ 20×2t mm), Initial surface roughness : Surface part : 2～3 μ mRy, Groove bottom part : 2～3 μ mRy Groove width : 8.0 mm, Groove depth : 0.2, 0.5, 1.0 mm
Ferromagnetic particles Grains Grinding fluid	Steel ball for shot peening : (115, 175, 260 μ m) , 4.0 g WA#4000, 10 wt% Soluble type

3 EXPERIMANTAL RESULTS AND CONSIDERATIONS

3.1 Plane Polishing

3.1.1 Effect on Polishing Performance of the Size of Ferromagnetic Particles

Figure 2 shows the relationship between polishing time, stock removal and surface roughness as the size of ferromagnetic particles changes. Stock removal increased with increasing the particles size. In addition, stock removal increases linearly with polishing time for every particle size. In magnetic polishing using conventional magnetic abrasives, there was a problem in which polishing efficiency was lowered by dulling of the grain cutting edge. However, magnetic polishing using the slurry circulation system improved the above-mentioned problem in this study. In order to improve the polishing efficiency, new grains were always supplied by the slurry supplying system for the particle brush and thus it appears that the loading was prevented.

Surface roughness was improved rapidly for 5 minutes, and improved gradually after 5 minutes. Surface roughness became a peculiar value in proportion to the ferromagnetic particle size, though the grain size was equal. Surface roughness improved to 0.14 μ mRy when the ferromagnetic particles were 115 μ m. It appears surface roughness became a peculiar value because the cutting depth of grains changes by the combination of ferromagnetic particle size and grain diameter. Grains receive pressuring force from the ferromagnetic particles, when they are located between the ferromagnetic particle and the workpiece. The principal and thrust forces depends on the size of the ferromagnetic particles and that of grains when the shape of the grains and that of the ferromagnetic particles are assumed to be spherical [4]. Thrust force increases with increasing of the size of the ferromagnetic particles. Therefore, stock removal increases with increasing of the cutting depth of the grains. As a result, surface roughness is not improved since the scratch marks remain. It was clarified that the size of ferromagnetic particles affects the polishing performance.

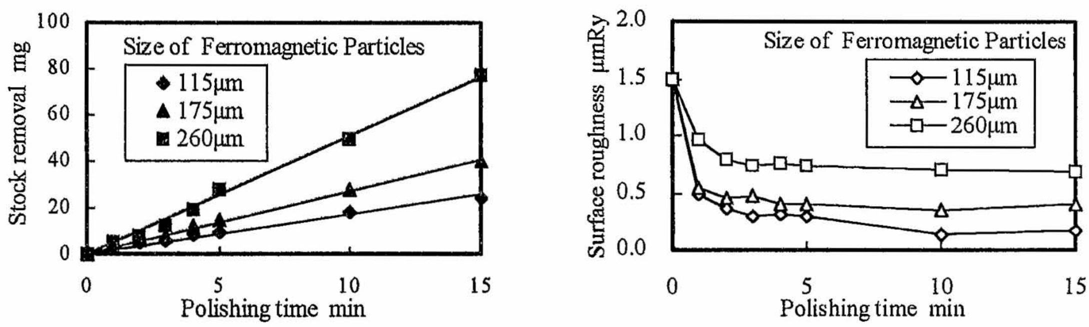
3.1.2 Surface Residual Stress after the Polishing

Figure 3 shows relationship between surface residual stress and polishing time. The residual stress of the surface was measured by the X-ray diffraction method. The residual stress before polishing was the compression, and the value was about 15 MPa. After polishing, residual stress was the compression, and the value changed to 100～200 MPa. As a reason for generating residual stress of the compression, it is considered that the ferromagnetic particles pushed the machined surface like a burnishing. It was clarified that' residual stress of the compression was generated to the magnetic polishing plane.

3.2 Surface Polishing of the Workpiece with Grooves

3.2.1 Effect of the Groove Depth and the Size of Ferromagnetic Particles

Figure 4 shows surface roughness as the groove depth and the size of ferromagnetic particles change. In the case of a groove depth of 0.2mm , the surface roughness of the groove bottom was



(a) Stock removal (b) Surface roughness

Fig. 2 Relations between polishing time and size of ferromagnetic particles (Work-1)

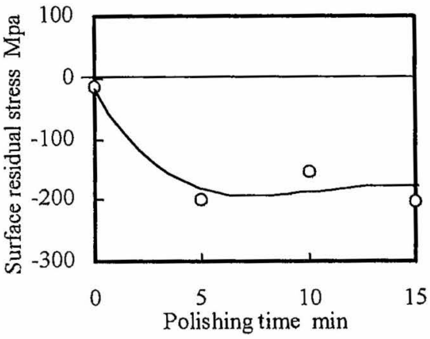


Fig. 3 Relations between polishing time and surface surface residual Stress (Ferromagnetic Particle : 115 μ m, Work-1)

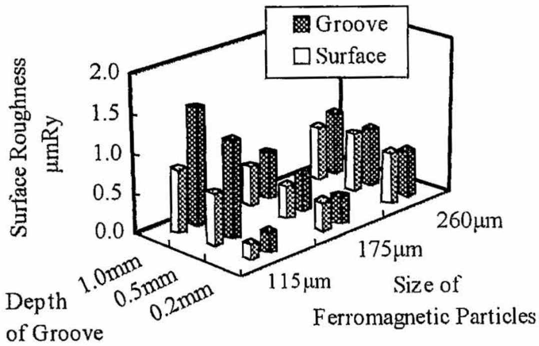
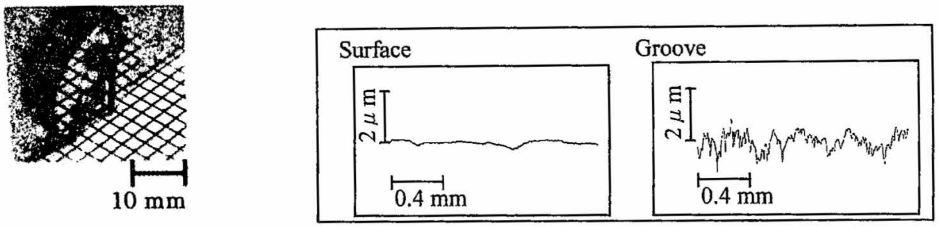


Fig. 4 Relations between depth of groove and surface roughness (Work-2)



(a) Photograph (b) Profile

Fig. 5 Workpiece with the groove (Ferromagnetic Particle:115 μ m, Work-2:Depth of groove 0.5mm)

equivalent to that of the surface part, and it became a peculiar value in proportion to the size of the ferromagnetic particles. However, the groove bottom was not polished with an increase of groove depth when 115 μ m was used. Figure 5 shows a photograph and profile of the workpiece on polishing using 115 μ m. Regardless of changes in groove depth, the surface roughness of the groove bottom was polished as well as that of the surface part when 175 μ m or 260 μ m were used. This phenomenon shows that the particle size of the brush affects polishing performance.

As groove depth increases, the particle brush becomes parted in the grooves. It appears to be because the binding power of the brush changes with ferromagnetic particle size. Binding power increases when the particle size is large in other words, 175 μ m or 260 μ m since the magnetic force of the interparticle is proportional to the size of the ferromagnetic particles [7]. Therefore, it is possible that the particle brush polishes the groove bottom without parting at the groove. On the other hand, when the particle size is small like 115 μ m, since the binding power of the interparticle decreases, the particle brush is parted and remains in the groove. As a result, the relative motion of the particle brush decreases, and the groove bottom part is not polished.

3.2.2 On the Edge Shape of the Groove

The edge shape of the groove was examined. Figure 6 shows the relationship between the groove depth and the roundness radius of the edge portion. Roundness radius R was defined like figure 7 [8]. Actually, the roundness radius of the edge portion is not a perfectly circular arc like figure 7 (a). Then, distance r shown in figure 7 was measured, and R was calculated using equation (1) [8].

$$\mathrm{R} = \frac{r}{sec\frac{\theta}{2} - 1} \tag{1}$$

Here, r is a distance to the nearest contour curve from the ideal edge tip point O. R became almost a constant, when the surface part and the groove bottom part were polished together, as is shown in figure 4. On the other hand, when the groove bottom was not polished, R tends to decrease. This appears to be because the relative motion at the edge portion decreased due to the particle brush remaining in the groove.

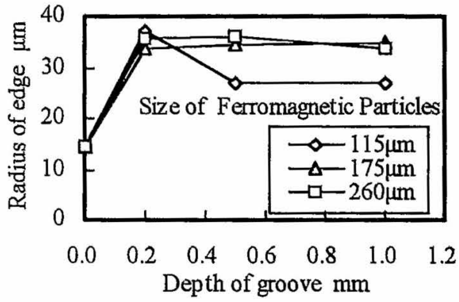
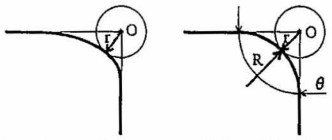


Fig. 6 Relations between depth of groove and roundness radius R (Work-2)



(a) Actual shape (b) Ideal shape
Fig. 7 The definition of the edge shape

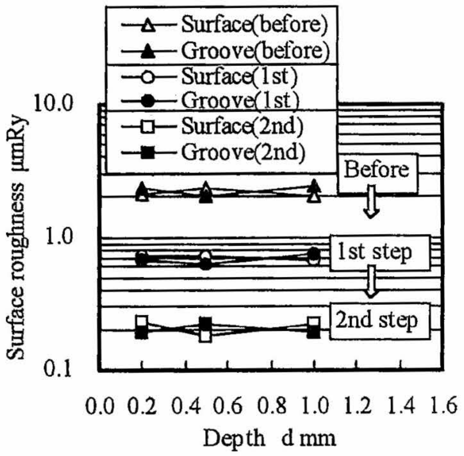
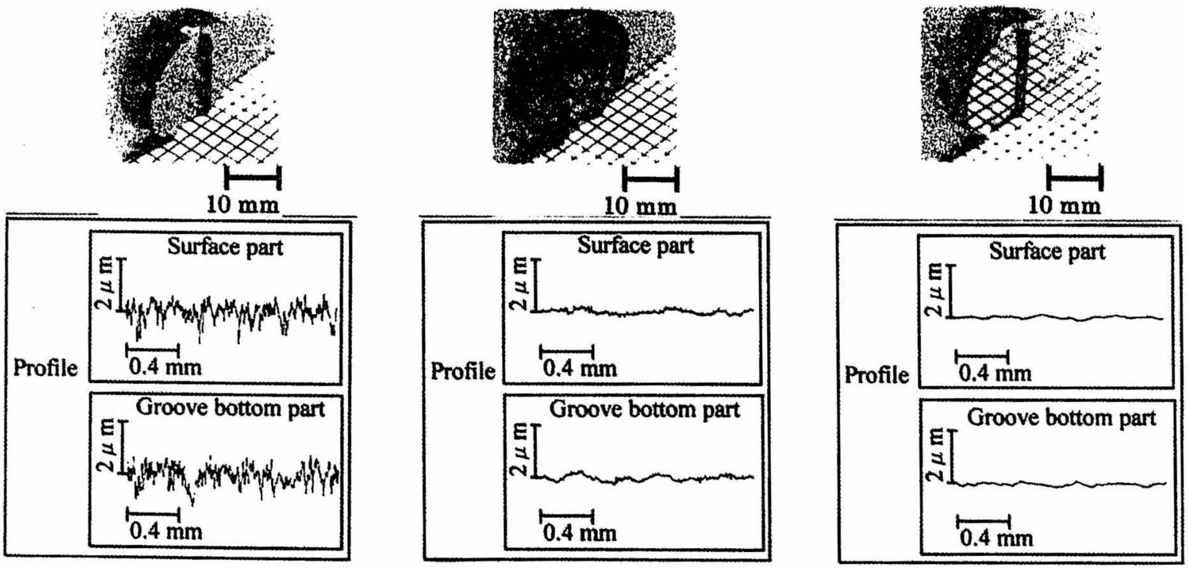


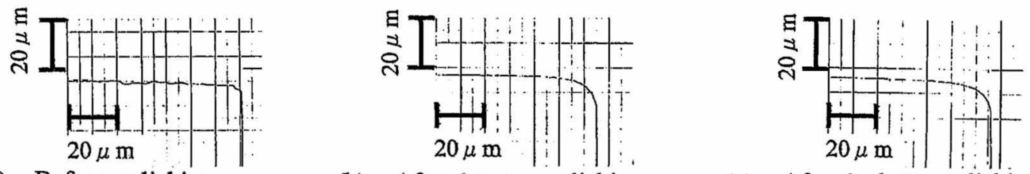
Fig. 8 Relations between depth of groove and surface roughness in two steps polishing method (Work-2)

3.2.3 A Proposal of a Two Step Polishing Method

A two step polishing method was proposed for polishing of workpieces with grooves. In the two step polishing method, the particle size used was 260 μ m in the first step. Then, in the second step, the particle size used was 115 μ m. Figure 8 shows surface roughness as the groove depth changes. After the first step, the roughness of the surface part and the groove bottom were about 0.7 μ mRy. Then, after the second step, the surface roughness was improved to about 0.2 μ mRy. It was possible to smooth the groove bottom and the surface part at the same time in this experimental condition. On the second step of polishing, it appears that smoothing was possible in the groove bottom even if the relative motion is slight, since there remained little ruggedness on the machined surface. Figure 9 shows the photograph and the profile of the workpiece. Figure 10 is the edge shape of the groove. Roundness after the first and the second step of polishing were similar.



(a) Before polishing (b) After 1st step polishing (c) After 2nd step polishing
Fig. 9 Workpiece with grooves



(a) Before polishing (b) After 1st step polishing (c) After 2nd step polishing

Fig. 10 Edge shape of the groove

4 CONCLUTIONS

Results got by the experiments are as follows:

1) It was clarified that the size of ferromagnetic particles affects the polishing performance. Surface roughness became a peculiar value in proportion to the ferromagnetic particle size, though the grain size was equal.

2) The residual stress after polishing was the compression, and the value was 100～200 MPa. As a reason for generating residual stress of the compression, it is considered that the ferromagnetic particles pushed the machined surface like a burnishing.

3) Roundness radius R became almost a constant, when the surface part and the groove bottom part were polished together.

4) A two step polishing method was proposed for polishing of workpieces with grooves. By this technique, it was possible to smooth the groove bottom and the surface part at the same time. Surface roughness was about 0.2 μ mRy after the second step of polishing.

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