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FLUID DYNAMIC INVESTIGATION OF POLISHING THE INNER WALL OF A TUBE UTILIZING A MAGNETIC COMPOUND FLUID (MCF)

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ABSTRACT

In this study, we investigated the mechanism of polishing the inner wall of a tube utilizing a magnetic compound fluid (MCF) from a hydrodynamic viewpoint. We conducted polishing experiments by filling a tube with a MCF consisting of abrasive grains and applying a rotating magnetic field perpendicular to the tube axis. In addition, in order to clarify the polishing mechanism, we performed visualization experiments by observing the behavior of the abrasive grains and measuring the pressure distribution on the inside surface of the tube using a hydrodynamic technique. This study demonstrated that a magnetic field distribution for effective polishing should exist in the region furthest from the centerline between the magnetic poles in the tube. At this position, the abrasive grains are located on the sides of the walls of the inner tube of the clusters formed along the line of magnetic force and the pressure generated is effective for polishing. The pressure distribution has a flat valley profile. Therefore, the radial force of clusters formed near these locations is considered to impart a processing force to the abrasive grains.

KEY WORDS

Magnetic compound fluid, Polishing, Inner tube wall, Visualization, Pressure distribution

INTRODUCTION

The increasing reduction in the size of products and components is making precision polishing essential for the inner walls of capillaries and microtubes having complex shapes. Since conventional methods for polishing inner tube walls are not effective for polishing such surfaces, it is essential to develop of a new polishing method. Against this background, we have proposed a new polishing method that employs a magnetic compound fluid (MCF), which is a mixture of a magnetic fluid (MF) and iron powder. In this method, an MCF containing nonmagnetic abrasive grains is allowed to pass through a tube and a rotating magnetic field is applied perpendicular to the tube axis [1]. To clarify the polishing mechanism of this method, we investigated the effect of the composition of fluids containing abrasive grains and the magnetic field distribution on polishing of the inner tube wall with no effect from the fluid. Polishing was found to be greatly affected by the magnetic field distribution and it was possible in the midpoint between the electrodes and in the region furthest from the central axis where the magnetic flux density and the rate of decrease of the magnetic flux density are both large [2].

The goals of this study are to observe the behavior of the abrasive grains in this polishing method and to hydrodynamically investigate the polishing mechanism of this method by measuring the pressure distribution on an inner tube wall. Specifically, a visualization experiment is conducted to observe the arrangement and behavior of the abrasive grains, and a pressure measuring experiment is conducted to check the processing pressure of magnetic clusters and to investigate the characteristics of the pressure distribution in polishing.

PRINCIPLE OF THE POLISHING METHOD

Figure 1 shows a schematic diagram of magnetic clusters and abrasive grains in the cross-section of a tube filled with a MCF when a magnetic field is applied perpendicular to the tube axis. The effect of the applied magnetic field on the MCF is to cause magnetic clusters to form that consist of iron particles and magnetite particles along the lines of magnetic force. The magnetic clusters are concentrated near the magnetic poles and their tips on the inner wall side are considered to retain the abrasive grains. Magnetic clusters are formed even in the center of the tube between the electrodes and in the region furthest away from the central axis. In an earlier report describing our experimental results, we conjectured that this polishing method uses abrasive grains retained on the surface of the inner wall of the magnetic clusters in the center of the tube in between the electrodes and in the region furthest away from the central axis, as shown in the figure.

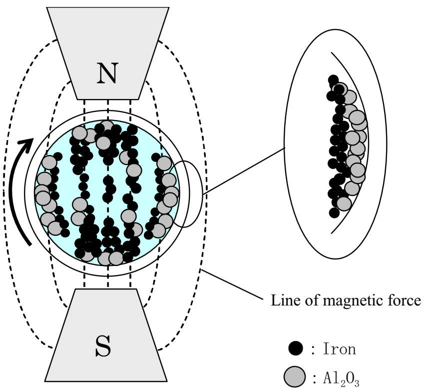

Figure 1 Principle of polishing on an inner capillary wall

ABRASIVE GRAIN VISUALIZATION EXPERIMENT

Figure 2 shows a photograph of the observation system. The system consists of a turntable on which there is an observation tube filled with a MCF and a magnetic field generator for applying a rotating magnetic field. The MCF used for this experiment was prepared by adding carbonyl iron powder (HQ, Yamaishi Metal) that had an average particle diameter of 1.2 μm to a water-based magnetic fluid (W-40, Taiho Industries). Instead of abrasive grains, 0.4-mm-diameter glass beads were mixed into the solution. Table 1 lists the composition of this fluid called WMCF40G30. The fluid-filled observation tube was a short resin pipe (internal diameter *d*: 10 mm, external diameter: 16 mm, length: 2 mm) with glass covers bonded to both ends. To generate the magnetic field, permanent magnets (20×20×10 mm, neodymium magnets, Niroku Seisakusho) were attached to a U-shaped yoke (SS400, cross-section: 20×20 mm) and pole pieces (SS400) having a tip width *w* of 10 mm were attached. The distance between the magnetic poles δ was fixed at 22 mm. In this experiment, a rotating magnetic field was

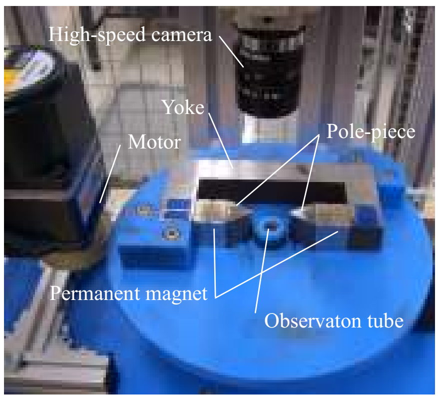

Figure 2 Photograph of the observation system

Table 1 Components of testing fluids

Testing fluids	Volume concentration (Vol.%)		
	Magnetic fluid	Iron	Glass beads
WMCF40G30	62.7	7.3	30.0
WMCF25	94.5	5.5	—

Table 2 Experimental conditions for optical observations

Magnetic flux density at center (*w*=10 mm)	0.182 T
Revolution rate of magnetic field	7.5 rpm

applied perpendicular to the axis of the observation tube and a halogen light was irradiated through an optical fiber from below the central axis. The behavior of the glass beads in the tube was then observed. Table 2 lists the experimental conditions.

RESULTS OF VISUALIZATION EXPERIMENT AND DISCUSSION

Figure 3 shows a visual image of the glass beads. In the figure the glass beads can be seen to form a strip on the inner wall of the tube in the midpoint between the magnetic poles and in the region furthest away from the central axis. In the experiment, this strip of glass beads was found to rotate synchronously with the rotating magnetic field. This strip may be formed by glass beads ejected from the magnetic clusters in the center of the tube between the magnetic poles and in the region furthest away from the central axis and retained on the sides of the inner tube wall of the magnetic clusters. Therefore, the force of magnetic clusters acting on the glass beads may generate pressure on the inner tube wall. No glass beads were observed near the magnetic poles in this experiment. Judging from this, the tube may be polished by abrasive grains that are retained on the inner tube wall sides of magnetic clusters at the midpoint between the magnetic poles and in the region furthest away from the central axis. However, it is important to note that the glass beads may not exhibit the same behavior as fine abrasive grains since the glass beads are considerably larger than fine abrasive grains.

EXPERIMENT TO MEASURE THE INNER TUBE WALL PRESSURE

The force of the magnetic clusters acting on the abrasive grains, or the polishing force, is considered to be equal to the inner tube wall pressure. Therefore, the distribution of the processing force generated by the

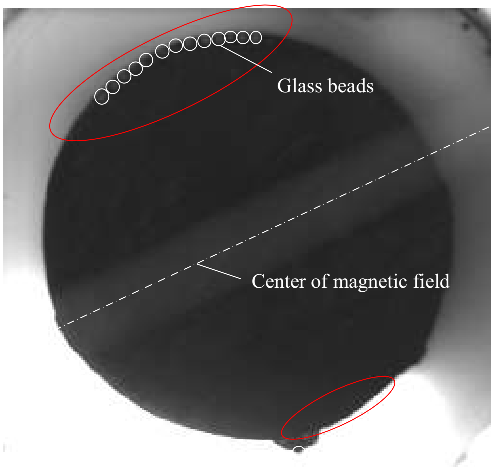

Figure 3 Optical observation of glass beads inner tube

magnetic clusters was investigated by measuring the pressure of the inner tube wall. For this measurement, the observation tube on the observation system was replaced with a circular tube for measuring pressure and a potentiometer makes contact with the turntable to measure the angle of rotation. Figure 4 shows the structure and coordinates of the circular tube for measuring pressure. The circular tube is a cylindrical resin container filled with the test fluid and sealed with a lid (internal diameter d: 10 mm, external diameter: 20 mm, height: 20 mm, internal height: 5 mm). This circular tube had a 0.5-mm-diameter pressure hole. A diaphragm pressure sensor (PSM-1KAB, Kyowa Electronic Instruments) was attached to the pressure chamber. The magnetic field source used was the same as that used for the observation system. The applied magnetic field distribution was varied by installing pole pieces having different tip widths w (=2, 6, 10, and 20 mm). The fluids used in this experiment were W-40 and WMCF25 (see Table 1). A rotating magnetic field was applied perpendicular to the central axis of the pressure measurement circular tube and the output voltages from the pressure sensor and potentiometer were measured. Table 3 lists the experimental conditions.

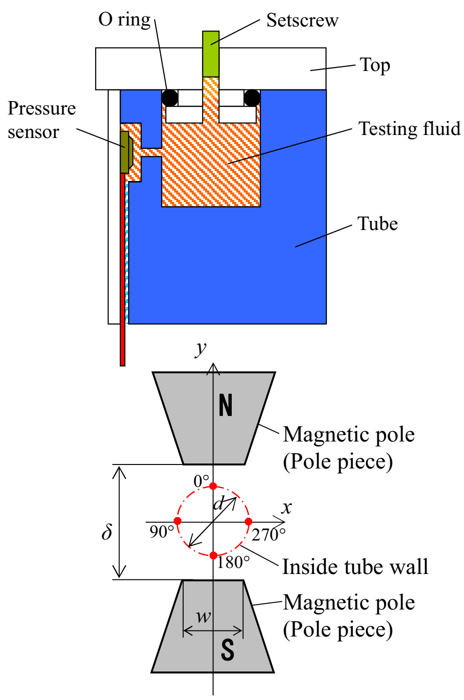

Figure 4 Schematic diagram and co-ordinate system of the experimental apparatus for measuring pressure

Table 3 Experimental conditions for measuring pressure

Magnetic flux density at center (w=2 mm)	0.168 T
Magnetic flux density at center (w=6 mm)	0.180 T
Magnetic flux density at center (w=10 mm)	0.182 T
Magnetic flux density at center (w=20 mm)	0.172 T
Revolution rate of magnetic field	2.5 rpm

PRESSURE MEASUREMENT RESULTS AND DISCUSSION

In the previous report about the results of investigating the influence of magnetic field distribution on polishing, effective polishing was achieved when w = 10 mm [2]. In the current experiment, we investigated the effect of pressure distribution on polishing. Figure 5 shows the results of measuring the inner tube wall pressure distribution about W-40. Theoretically, a magnetic fluid in which the dispersant is dispersed uniformly exhibits a high inner tube wall pressure near the magnetic poles (about 0, 180, and 360°) and becomes zero in the center between the magnetic poles and in the region furthest away from the central axis (about 90 and 270°). According to the experimental results, the inner tube wall pressure is high near the magnetic poles and is low near 90° and 270° being close to zero except when w = 10 mm. When w = 10 mm, the pressure is positive probably because the dispersant aggregates near 90° and 270° and the aggregate generates pressure by acting on the inner tube wall. In the magnetic field distribution when w = 10 mm, the magnetic flux density and the rate of decrease of the magnetic flux density are larger than those for the magnetic poles having different tip widths, so that aggregation occurs easily.

Figure 6 shows the results of measuring inner tube wall pressure with WMCF25 as the MCF. Except when w = 6 mm, the inner wall pressure is higher than with a magnetic fluid. The pressure is high near 90° and 270° when w is 2 and 10 mm. This pressure is attributable to the known anisotropy of the magnetic force generated by nearby magnetic clusters. Compared with the pressure distribution near 90° and 270°, the pressure distribution when w = 2 mm has an almost V-shaped trough. In this case, polishing does not progress because abrasive grains concentrate in confined regions near 90° and 270° where the pressure is low. When w = 10 mm, the pressure distribution shows a trough with a flat bottom. In this case, polishing proceeds because abrasive grains are scattered around 90° and 270°.

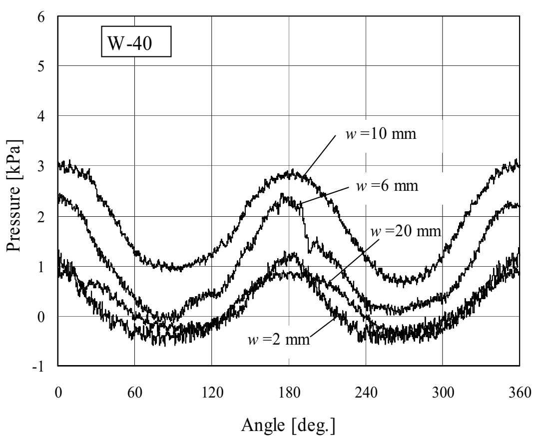

Figure 5 Pressure distribution inner tube wall (W-40)

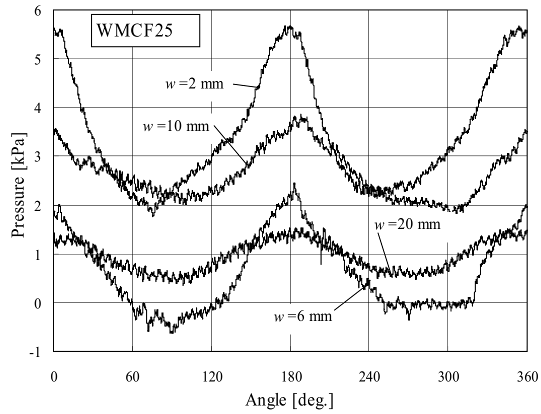

Figure 6 Pressure distribution inner tube wall (WMCF25)

In other words, a polishing effect is obtained when the pressure distribution is flat for the required polishing force near 90° and 270°. This is attributable to the radial force of magnetic cluster strips formed on the inner tube wall near 90° and 270°. Thus, the radial force of magnetic clusters acting on the abrasive grains is considered to produce the force for this polishing.

CONCLUSION

In this study, we clarified the mechanism of inner tube wall polishing using an MCF by observing the behavior of abrasive grains and measuring the pressure distribution on the inner tube wall. The results of this study can be summarized as follows:

(1) Abrasive grains (glass beads) form strips along the tube wall in the center between the magnetic pole and in the region furthest away from the central axis (on the inner tube wall near 90° and 270°).
(2) If the magnetic flux density and the rate of decrease of the magnetic flux density are large on the inner tube wall near 90° and 270°, the pressure distribution exhibits a flat trough in the required polishing force in these regions.
(3) The radial force of magnetic clusters formed near 90° and 270° act on abrasive grains to produce the force for this polishing.

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