
Available from: http://dx.doi.org/10.1016/S0304-8853(02)01497-X

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Effect of magnetic cluster and magnetic field on polishing using magnetic compound fluid (MCF)

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Abstract

Using the magnetic compound fluid (MCF) developed by one of the authors in this paper, we performed polishing under various intensities of steady and fluctuating magnetic fields. We determined the optimal intensity of both types of magnetic field in order to produce the most effective polishing effect. The optimal intensity is related to the produced magnetic clusters in the MCF.

1. Introduction

Magnetic fluid (MF) is more stable in its dispersion of the particles than is example magneto-rheological fluid (MRF). After a long period at rest, the particles of MRF becomes sedimented. Therefore, MRF can be appropriately dealt with as a kind of powder rather than a fluid. Contrary to the MRF, the engineering applications of MCF require larger magnetic pressure and increment of apparent viscosity by applying a magnetic field, and more stable particle distribution with maintaining the fluid's behavior such as MF. Shimada has developed a MF, compounded by nm-size magnetite and \textmu m-size iron particles in a solvent, as a new magnetic intelligent or smart fluid \cite{1}. This fluid is named magnetic compound fluid (MCF).

The application of intelligent fluids, for example MRF and MF, to the finishing process has been the subject of much study \cite{2-4}. Shimada has also applied MCF to microscopic polishing. It has been shown that MCF is a more effective polishing agent than are MRF and MF \cite{5} under the same concentration of the included iron and magnetite. However, a detailed investigation focusing on the relation between the effect of magnetic field intensity and the polished material has not been performed.

In the present paper, we investigated the relation and used microscopic observation to investigate the effect of magnetic field on micro-polishing using MCF.
2. Experimental procedure

Fig. 1 shows the experimental apparatus of microscopic polishing using MCF. We used three materials-SUS304, SKD61, and SKH51-as materials for polishing, each with a diameter of 8 mm. Under room temperature, the fluid was compounded using MF (W35(20wt%)) at 6 g, carbo-nyl iron (HQ) at 6 g, \( \text{Al}_2\text{O}_3 \) at 2 g and kerosene at 0.4 g, inserted between the polishing pad and polishing specimen on each rotating magnetic pole. The abrasive particles of \( \text{Al}_2\text{O}_3 \) is one of ordinary material in the polishing. HQ has a mean value of diameter of 1.2 \( \mu \text{m} \) and \( \text{Al}_2\text{O}_3 \) has that of 0.05 \( \mu \text{m} \). The MF used is water-based containing 10 nm magnetite Fe\(_3\)O\(_4\) particles. Two rotating magnetic poles of 15 mm in diameter are attached to the upper and lower AC servo motor, respectively, as shown in Fig. 1. Beforehand, a load cell was inserted between the rotating magnetic poles for measuring the force to the specimen. The magnetic pole jointed to the polishing pad was rotated at a constant speed of 800 rpm counterclockwise, and the one pole attached to the polished specimen was rotated at 300 rpm, while a force of 20 N was applied to the specimen. Each polishing test lasted 15 min. The surface roughness of the specimen was measured five times using a surface profile meter by varying the magnetic field amplitude at a frequency of 1 Hz.

3. Results and discussion

3.1. Surface roughness

Figs. 2 and 3 show the results of the surface roughness of \( R_a \) and \( R_y \). \( R_a \) and \( R_y \) are ordinary surface roughness: the mean value, and the difference between the maximum and minimum height of the roughness, respectively. Each material has a discrete optimal value of the magnetic field strength for both the steady and fluctuating magnetic fields. Thus, the optimal value of the magnetic field strength is not related to the type of magnetic field. This tendency does not dependent.
on the kind of material of the polishing specimen. Regarding to the optimal value for the fluctuating magnetic field, titanium showed its optimal value at almost the same fluctuating magnetic field strength as shown in a previous work [5]. The optimal value is considered to be independent on the material of the polishing specimen. We address the cause of the existing optimal value in the next section.

3.2. Microscopic investigation

Fig. 4 shows SEM images of the MCF without abrasive particles of Al₂O₃. The upper figure of Fig. 4 is the image that the MCF is dried on a material surface under a steady magnetic field of 3000 G without vibration. The needle-or necklacelike clusters of the MCF are made of iron particles surrounded by magnetite or surfactant of oleic acid, and the clusters are aligned to the direction of the application of the magnetic field. The aggregated iron particles model of the cluster in the MCF without abrasive particles has been shown in a previous investigation as shown in Fig. 8 in the appendix [5]. The lower part of Fig. 4 shows the image of the aggregated iron particles in the cluster, and the figure is according to the Fig. 8.

Fig. 5 shows a microscopic photograph of the extracted cluster of aggregated MCF particles with abrasive particles of 3 μm Al₂O₃. The figure shows the case without any vibration. The cluster without any abrasive particles has been successfully extracted from colloidal suspensions of MCF and MR. These details of the process have been described in another report [6]. The clusters of
Fig. 5 were extracted by the same method. In the Fig. 5, only HQ iron and abrasive particles can be seen in the images. It is guessed that the magnetite particles and surfactant joint among the iron and abrasive particles. The investigation in the report [6] has also shown that MCF composed of any elements all have the same needle- or necklace-shaped clusters, and that the clusters can be formed as the same aggregated particles model of Fig. 8. Therefore, the cluster with abrasive particles of Al₂O₃ has also the same formation of the aggregated particles model of Fig. 8. That tendency can be shown by Fig. 6. As shown in Fig. 6, the abrasive particles can be included in the clusters.

As mentioned above, from the result of the investigation in the report [6] that MCF composed of any elements of iron and abrasive particles all have the same needle-or necklace-shaped clusters as shown in Fig. 8, the MCF with abrasive particles of 0.05 μmAl₂O₃ of differing components from those used Figs. 5 and 6 has also the same formation of the aggregated particles model of Fig. 8.

Using these photographic results, we can propose the polishing model as shown in Fig. 7. The behavior of the clusters including abrasive particles is very important factor on the polishing. At the lowest magnetic field strength, the probability of the abrasive particles touching the material surface is small because few clusters exist according to the applied magnetic field strength. As the magnetic field strength increases, the probability of the abrasive particles touching the material surface increases because the number of clusters on the material surface increases, as shown by the upper part of Fig. 7. At the largest magnetic field strength, the probability of the abrasive particles touching the material surface decreases because of the number of clusters on the material surface which cannot collide or rotate, as shown in the lower part of Fig. 7. Thus, this demonstrates...
Fig. 7. Schematic diagrams of the polishing micro-mechanism of polishing in the case of a lower magnetic field strength (upper figure) and in the case of a larger magnetic field strength (lower figure).

the determination of the optimal value of the strength of the magnetic field on the polishing effect.

On the other hand, as the distance between the polishing pad and the polished material's surface is very small, the shear flow speed is not different from the rotational speed of the polishing pad and the polished material. The motion of the cluster depends exactly on the rotational speed of the polishing pad and the polished material, and does not depend on shear flow. As a result, the fluctuation of the clusters influenced by the fluctuating magnetic field is small, and the behavior on the material surface under the fluctuating magnetic field is almost the same as that under a steady magnetic field. Thus, the optimal value of the magnetic field strength on the polishing effect has been determined not to depend on the type of magnetic field.

4. Conclusions

We determined the optimal intensity of both types of steady and fluctuating magnetic fields in order to produce the most effective polishing effect. The optimal value of the magnetic field strength on the polishing effect has been determined not to depend on the type of magnetic field. The optimal intensity is related to the produced magnetic clusters in the MCF.
Acknowledgements

We thank for Prof. Fujita, Mr. Miyazaki, Dr. Shibayama and Dr. K. Saito in Akita University for collaboration of the operating SEM in the optical investigation.

Appendix

The aggregated particles model of MCF without abrasive particles has been shown in a previous investigation in Fig. 8 [5].

References