Study on Characteristic of EDM for Permanent Magnets with Different Initial Magnetizing Ratio

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Abstract. It is difficult to machine permanent magnets by traditional machining because of brittle-material and magnetic force, but EDM can machine permanent magnets easily. However, because magnets have a Curie point, the reduction in the magnetic flux density may occur in EDM where the machined surface becomes high temperature. In previous studies, when 1mm removal machining was performed for the cylindrical neodymium magnet under rough machining condition, the magnetic flux density decreased in the region of several millimeters directly below the machined surface. Therefore, it is considered that the machining progresses in the state that is different from the initial magnetic flux density. In this study, EDM was performed for the magnet with different initial magnetizing ratio before machining, and it was made efforts in EDM characteristic of the machining. In particular, change in the magnet internal temperature during machining and the magnetic flux density distribution after machining were measured, and it was considered about influence of both. As a result, in spite of the same discharge conditions, it was found that the magnet internal temperature during machining varies greatly due to the difference in initial magnetizing ratio. And, it was inferred that the thermal conductivity of the magnet changes.

Introduction

Neodymium magnets, which are rare earth magnets, are used for various industrial products as highly functional materials and are indispensable for precision instrument and electronic device. In recent years, permanent magnets having complicated shapes and various magnetic characteristics have been demanded with the reduction in size and weight of equipment. However, it is difficult to machine permanent magnets by traditional machining such as cutting and grinding, because of brittle-material and magnetic force. This is because most of cutting and grinding tools are made of ferromagnetic material. Generally, permanent magnets are shaped by grinding before the magnetizing, and then are magnetized. Dedicated coils and magnetizing yokes are required for magnetizing, and there is also a problem that it is difficult to manufacture magnets with complicated magnetizing patterns and shapes. If shape machining is possible for the magnet after magnetizing, the application range will be expanded, for example, it is possible to machine commercially available magnets. Electrical discharge machining (EDM), which is a non-contact thermal machining method, can machine permanent magnets easily. In the EDM process, non-magnetic materials such as copper or graphite are typically used for electrode. Therefore, it is not to receive influence of magnetic force in EDM. Also, EDM progresses with continuous pulse discharge and the discharge point reaches above the melting point of the material. Magnets have a Curie point and magnetic force disappears when they exceed its temperature. Even less than Curie point, they have a temperature dependence that the magnetic force weakens at 100°C or higher. Thus, using this characteristic, the authors have been studying to change the magnet shape and the magnetic characteristic at the same time and/or individually[1].

In this study, EDM was conducted by changing initial magnetizing ratio before machining, and it was made efforts in EDM characteristic of the machining. In particular, change in the magnet internal temperature during machining and the magnetic flux density distribution after machining were measured, and it was considered about influence of both.

Change in magnetic flux density and internal temperature due to discharge condition

We have investigated change in the magnetic flux density due to the difference of the discharge condition. A Neodymium magnet (N40, recommended temperature below 80°C) 10mm in diameter, and 10mm in height (actual value before machining : 520mT) was used for the experiment. The magnet was removed 1mm height by EDM (Sodic Co. AM3L). The electrode material was copper. The electrode diameter was 11mm. The electrode polarity was positive, and an electrode jump up motion was applied twice per second for all machining. Each jump up motion time was 0.2 seconds. The machining was performed under finishing condition (5A, 32μs, D.F.50%) and rough machining condition (20A, 128μs, D.F.50%). After each machining, the surface magnetic flux density was measured using a Tesla meter (KANETEC Co. TM-701). The surface magnetic flux density was used the value of the magnet central portion. Fig. 1 shows difference between the magnetic flux density before and after machining. When 1mm removal machining was performed for the cylindrical neodymium magnet under finishing condition, the magnetic flux density decreased by the reduction in the magnet height. On the other hand, under rough machining condition, the magnetic flux density decreased due to the temperature rise in addition to the reduction in the magnet height. After that, in order to experimentally measure change in the internal magnetic flux density, removal machining was repeated every 1mm under finishing condition, and the measurement of the surface magnetic flux density was repeated each time. Fig. 2 shows change in the magnetic flux density in each magnet height due to the difference of the discharge condition. As shown in Fig. 2, when removal machining is performed under finishing condition (Fig. 2 ①), it shows the same value as commercially available magnets of each height, and there is almost no reduction in the magnetic flux density due to the temperature rise. On the other hand, under rough machining condition, the magnetic flux density decreased to 270mT (Fig. 2 ②). After that, by continuing the removal machining in the depth direction under finishing condition, the rise in the magnetic flux density from the magnet height of 9mm to 6mm was confirmed, so that it is inferred that the reduction in the magnetic flux density due to the temperature rise occurred in this region.

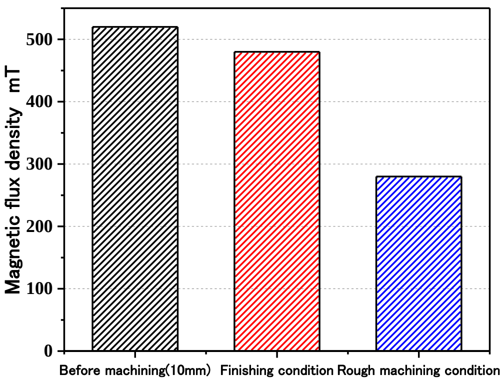

Fig. 1 Difference between the magnetic flux density before and after machining

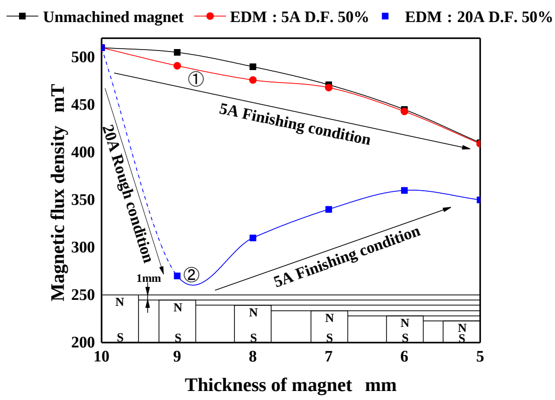

Fig. 2 Change in the magnetic flux density in each magnet height due to the difference of the discharge condition

Therefore, the magnet internal temperature during the 1mm removal machining was simultaneously measured at multiple point and compared. A K type thermocouple with a tip diameter of about 0.25mm was used for the magnet internal temperature measurement. A hole 1mm in diameter and 5mm in depth was machined into the sidewall of the magnet by EDM and the K type thermocouple was embedded. The inside of the hole was filled with silicone for heat radiation (thermal conductivity : 0.84W/mK). Internal temperature was simultaneously measured in each position of 2, 4, 6mm from the top of magnet, as indicated in Fig. 3. Here, 1mm removal machining was performed. Thus, the distance between the thermocouple and the machined surface approach 1mm at the end of machining. The output from the thermocouple was acquired at a sampling interval of 0.1s using a data logger (T&D Co. MCR-4TC) until the end of machining. The experimental results are shown below. The machining time was about 50 minutes under finishing condition and about 6 minutes under rough machining condition. The magnet internal temperature at the measurement position 2mm (1mm below the machined surface at the end of machining) under finishing condition was about 80°C and it was not over 100°C at which the magnetic force reduction begins. On the other hand, under rough machining condition, the magnet internal temperature was about 170°C at the measurement position 2mm (1mm below the machined surface at the end of machining), was about 125°C at the measurement position 4mm (3mm below the machined surface at the end of machining) and was about 95°C at the measurement position 6mm (5mm below the machined surface at the end of machining). It was over 100°C at which the magnetic force reduction begins at the measurement position 4mm and this corresponded to the region where the reduction in the magnetic flux density seems to be occurring[2], [3].

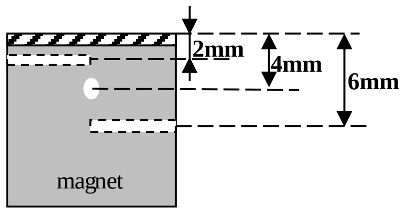

Fig. 3 Measurement position of internal temperature at simultaneous measurement

Change in the magnetic flux density and internal temperature due to difference in initial magnetizing ratio

From the experiments described above, when the 1mm removal machining under rough machining condition was performed for the cylindrical neodymium magnet, the magnetic flux density decreased largely due to the magnet internal temperature rise in addition to the reduction in the magnet height, and it is known that the magnetic flux density reduction occurs in the region of approximately 3mm. When EDM is performed, the magnet internal temperature rises. The magnet internal temperature is higher as it is directly under the machined surface and becomes lower as it goes farther from the machined surface. Therefore, the reduction in the magnetic flux density also increases as it is directly under the machined surface and decreases as it goes further from the machined surface. That is, the magnetic flux density decreases like a gradation. After this, as machining is performed, the place where the magnetic flux density gradually decreases is machined, so that the experiment object becomes complicated. Therefore, to simplify the experiment object, a part of portion where the magnetic flux density decreased was picked up and the magnet with height of 10mm imitating that state was made. As the method of making the magnet, the method of changing initial magnetizing ratio was used. EDM was performed for the magnet with different initial magnetizing ratio before machining, and it was made efforts in EDM characteristic of the machining. In particular, the experiment was performed focusing whether the reduction ratio of the magnetic flux density changes and whether the magnet internal temperature during machining changes.

A Neodymium magnet (10mm in diameter, 10mm in height) was used for the experiment. When the magnet with the magnetic flux density of 520mT magnetized to the saturation state was regarded as initial magnetizing ratio of 100%, samples aiming at initial magnetizing ratio of 30% (156mT), 50% (260mT), and 80% (416mT) were made using a magnetizer and a total of four types including 100% (520mT) was used for machining. Experiments similar to those described above were performed on these magnets. Fig. 4 shows difference between the magnetic flux density before and after machining in different initial magnetizing ratio after 1mm removal machining under rough machining condition. The machining times were 5 to 6 minutes in four kinds of magnets. As initial magnetizing ratio is lower, the amount of reduction in the magnetic flux density was lower. In initial magnetizing rate of 100%, the amount of reduction in the magnetic flux density was 200mT or more, whereas in initial magnetizing rate of 30%, the amount of reduction in the magnetic flux density was about 20mT. However, when expressed in terms of the reduction ratio, the reduction ratio decreases to 48%, 37%, 24%, 13% in order from initial magnetizing rate of 100%. This is probably because initial magnetic flux density is small, so that the influence of the reduction in the magnetic flux density due to the reduction in the magnet height is reduced.

Next, the magnet internal temperature during machining under rough machining condition was measured. Magnets used in the experiment were five types of magnets with the above four types and initial magnetizing ratio of 0% (0mT). Temperature measurements similar to those described above were performed on these magnets. Fig. 5 shows the magnet internal temperature of each height in initial magnetizing ratio of 100% during machining under rough machining condition. The machining time was more than 6 minutes. The numerical values shown in the figure show the average value after the temperature is stabilized. The magnet internal temperature was about 180°C at the measurement position 2mm (1mm below the machined surface at the end of machining), was about 130°C at the measurement position 4mm (3mm below the machined surface at the end of machining) and was about 95°C at the measurement position 6mm (5mm below the machined surface at the end of machining). This was similar to the conventional measurement result. Next, Fig. 6 shows the magnet internal temperature of each height in initial magnetizing ratio of 30% during machining under rough machining condition. The machining time was slightly shorter than initial magnetizing ratio of 100% and more than 5 minutes. The magnet internal temperature was about 100°C at the measurement position 2mm (1mm below the machined surface at the end of machining), was about 70°C at the measurement position 4mm (3mm below the machined surface at the end of machining) and was about 60°C at the measurement position 6mm (5mm below the machined surface at the end of machining). Despite the fact that the materials of the magnets themselves are the same, even if the same removal machining is performed under the same discharge condition due to the difference in initial magnetizing ratio, the magnet internal temperature changes. The magnet internal temperature of initial magnetizing ratio of 80%, 50% and 0% at the measurement position 2mm (1mm below the machined surface at the end of machining) were about 150°C, about 120°C and 110°C, and as initial magnetizing ratio is lower, the magnet internal temperature tended to be lower. Also, the machining time tended to be shorter as initial magnetizing ratio is lower.

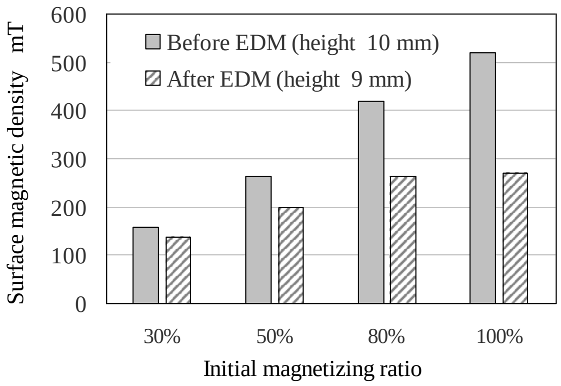

Fig. 4 Difference between the magnetic flux density before and after machining in different initial magnetizing ratio

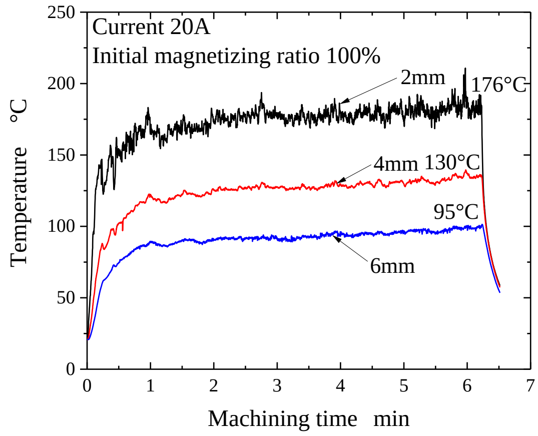

Fig. 5 The magnet internal temperature of each height in initial magnetizing ratio of 100% during machining under rough machining condition

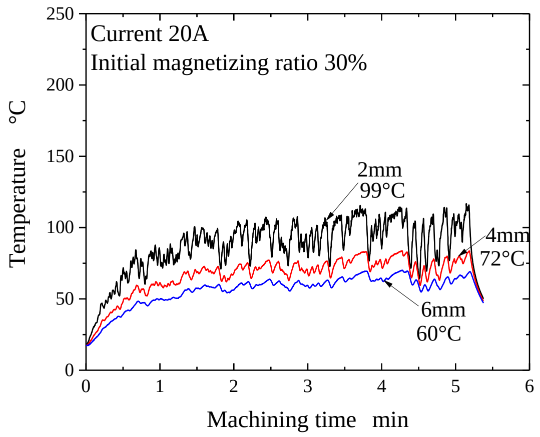

Fig. 6 The magnet internal temperature of each height in initial magnetizing ratio of 30% during machining under rough machining condition

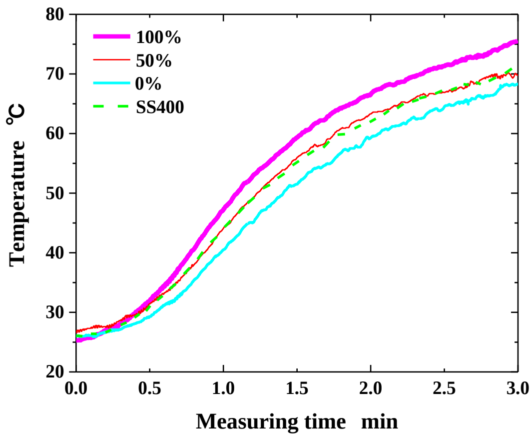

Fig. 7 Change in temperature rise in each initial magnetizing ratio and SS400

Change in thermal conduction due to the difference in initial magnetizing ratio

From the machining results, it was found that the machining speed is faster as initial magnetizing ratio is lower. It is estimated that the discharge frequency increases as machining speed is faster. Also, it is inferred that the internal temperature also is higher, as the discharge frequency increases. However, in the result of actual temperature measurement, the internal temperature was lower as the initial magnetizing ratio was lower. The reason why the internal temperature decreases as initial magnetizing ratio is smaller is considered, and it was thought that the thermal conductivity or the specific heat may change due to the difference in initial magnetizing ratio. In particular, it was estimated that the thermal conductivity is higher as initial magnetizing ratio is lower, the heat conduction become better, and the internal temperature decreased due to heat dissipation from the side surface. Therefore, it was experimentally confirmed whether there is the difference in thermal conductivity.

In the comparison of the apparent thermal conductivity, SS400 (10mm in diameter, 10mm in height, thermal conductivity 51.6W/mK) with a known thermal conductivity was used in addition to initial magnetizing ratio of 5 types of magnets (initial magnetizing ratio of 100% : thermal conductivity 8.95W/mK). These were placed on the center of the hot plate (AS ONE Co. CHP-250D), heated from room temperature to preset temperature of 100°C at the same time, and the temperature of the magnet central top surface was measured in the same method described above. Fig. 7 shows change in temperature rise in each initial magnetizing ratio and SS400. The temperature rise was faster as initial magnetizing ratio is higher and the temperature rise of SS400 showed a slow rise similar to initial magnetizing ratio of 30% and 50%. It is thought that Fast temperature rise means that the thermal conductivity is large, but the value of the thermal conductivity of SS400 is more than 5 times greater than initial magnetizing ratio of 100%. From this, it was inferred that SS400 and magnets with low initial magnetizing ratio have a high thermal conductivity, so that the heat dissipation from the side surface occurred, and the temperature rise of the top surface was slow. That is, it can be estimated that the thermal conductivity of a magnet with a small initial magnetizing ratio is larger than initial magnetizing ratio of 100%. Even when removal machining is performed under the same discharge condition, the magnet internal temperature varies due to the difference in initial magnetizing ratio. It was inferred that this is due to the difference in thermal conductivity.

Summary

In EDM of the neodymium magnet, the relationship between change in the magnetic flux density and the internal temperature due to the difference in initial magnetizing ratio was investigated, and the following was clarified.

1) There was a difference in the magnet internal temperature during machining due to the difference in initial magnetizing ratio. This is estimated to be due to change in thermal conductivity.

2) Although it have been thought that the magnet internal temperature during machining can be calculated from the machined surface temperature, it can be inferred that the thermal conductivity changes during machining and the internal temperature calculation becomes more complicated.

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