

Application of magnetic abrasive polishing to composite materials[†]

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Abstract

Magnetic abrasive polishing (MAP) is an advanced machining process that can produce smoother surfaces in many material types. The present study conducted an experimental assessment of MAP for a newly developed, non-ferrous and aluminum-based composite material. A permanent magnet was installed under the workpiece to enhance its magnetic flux density, which had proved insufficient for effective MAP. The success of the permanent magnet in improving the surface roughness of the non-ferrous material was verified.

Keywords: Magnetic abrasive polishing; Magnetic flux density; Non-ferrous material; Permanent magnet; Surface roughness

1. Introduction

These days, composite materials are being used in a wide range of applications for structural and functional products [1, 2]. These materials are very attractive in various industrial areas, owing to their superior specific strength, wear resistance and mechanical property characteristics under high temperatures [3-6]. Non-ferrous composite materials reinforced with ceramic particles have been found to be especially valuable in the manufacture of lighter-weight and higher-hardness products. Despite their advantages, however, composite materials have some serious drawbacks for industrial applications, such as low cost effectiveness and poor machinability. Thus, most of these materials are deemed as difficult-to-cut material [7, 8]. Nevertheless, the demand for precision machining of composite materials increases more and more.

To satisfy the demand for precision machining of composite materials, advanced techniques are necessary [9]. One such, magnetic abrasive polishing (MAP), is a process initially designed to produce highly-finished surfaces by the use of magnetic abrasives in the presence of a magnetic field. Generally, MAP can produce a good surface for many material types, reflecting the great amount of research over many years that has been devoted to the process. However, MAP's suitability for newly developed and wide-application composite materials has not to be determined clearly yet, thus further study is essential [10]. One major problem is that the magnetic flux

density, which is indispensable to machining efficiency in MAP, is prohibitively low for non-ferrous materials such as aluminum-based composites. The task at hand then is to increase the magnetic flux density in MAP for non-ferrous workpieces. With that goal in sight, the present study tested the MAP process with an aluminum-based composite material. Based on the experimental results, this paper proposes a novel means of improving the surface roughness of such material, specifically through increasing the magnetic flux density with an installed permanent magnet.

2. Working principle of MAP

The MAP process is defined as a process by which material is removed, in such a way that the surface finish and deburring is performed with the presence of a magnetic field in the machining zone [11]. The MAP is based on the magnetization property of ferromagnetic iron and the machining property of abrasives, which is made of Al_2O_3 , SiC and Diamond paste. Fig. 1 shows the magnetic abrasives bonded with Al_2O_3 and Fe. Along the magnetic flux density which is performed by the magnetic inductor, the magnetic powders are arranged like brushes. Fig. 2 presents a schematic drawing of the MAP system.

In MAP, the distribution of the magnetic flux density determines the polishing pressure. The magnetic flux density can be represented by Maxwell's equation in terms of the magnetic field intensity. This means that the magnetic force can be controlled by the electric current supplied to the inductor in the MAP system. The magnetic force generated by the electric current plays a dominant role in the formation of a flexible brush of magnetic abrasives [12]. The ferrous particles are

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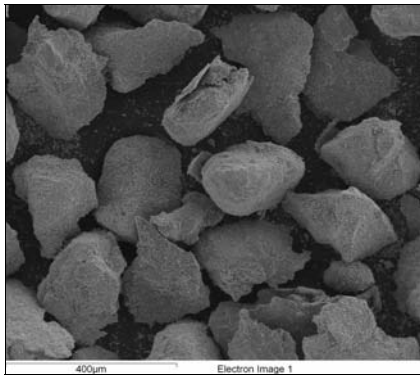


Fig. 1. Bonded magnetic abrasives ($\text{Al}_2\text{O}_3+\text{Fe}$).

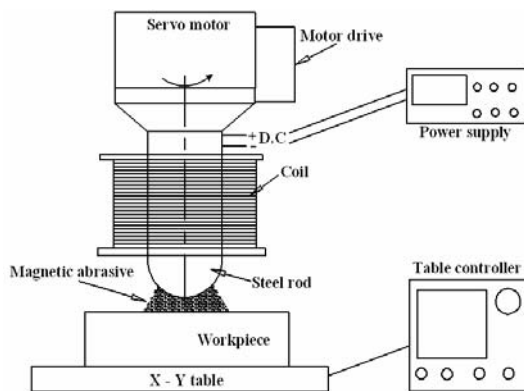


Fig. 2. Schematic drawing of MAP system.

conglomerated by magnetic force in the polishing area and mixed with abrasives. The abrasives are sandwiched between the inductor and the workpiece. If the tangential component of the magnetic force acting on the workpiece is larger than the friction force between the magnetic abrasives and the surface of the workpiece, the magnetic abrasives held in the polishing area exert a smooth relative motion against the surface of the workpiece when the inductor is rotated at high speed. Resultantly, material is removed from the surface by the abrasives.

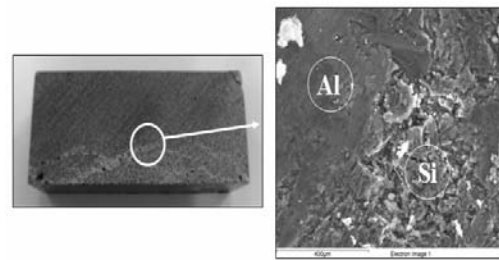
There are some important MAP factors that influence machining results. First of all, the diameter of the inductor affects the formation of the magnetic flux density. The material characteristics of ferrous or nonferrous workpieces machined by the MAP process also are important factors.

According to the applied machining conditions, the obtained MAP results differ significantly. In the present study, the aluminum-based composite material was experimentally evaluated in consideration of the various MAP-related factors.

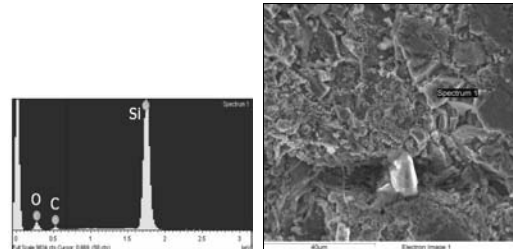
3. Experimental conditions and setup

3.1 Specimen preparation and preliminary analysis

The aluminum-based composite material used in this study consists of about 40% weight ratio of SiC particles. Fig. 3(a) shows the specimen and its SEM image. The boundary layer between the aluminum and the SiC particles is very clear.

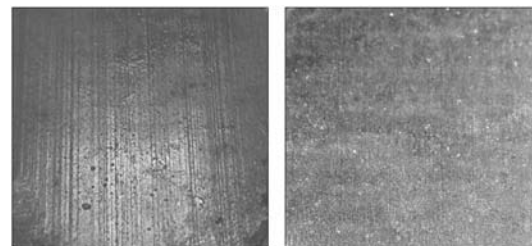


(a)



(b)

Fig. 3. Analysis of specimen surface.



(a) After grinding

(b) After MAP

Fig. 4. Specimen after grinding and after preliminary MAP.

Unfortunately, this gives rise to serious trouble in, for example, the polishing process. Fig. 3(b) shows the chemical components of the specimen on the surface.

These components differ with the measuring point, but as shown in the spectrum data the intensities of the Si and C components are very high.

Prior to the MAP application, grinding was performed on the specimen so as to impart a uniform surface. After the grinding (Fig. 4(a)), the surface of the specimen very quickly produced an oxidized layer owing to the effects of the grinding temperature and the aluminum of the specimen. Thus it can be appreciated that the grinding process is not suitable for finishing composite material. By contrast, there was no oxidized layer after the MAP (Fig. 4(b)), because the machining temperature was very low.

3.2 Experimental conditions

Fig. 5 shows the employed MAP system. An inductor connected to a DC power supply is set on the spindle of the system. The diameter of the ball-end-mill-like inductor is 40mm. The magnetic flux density of 200mT was applied in the work-

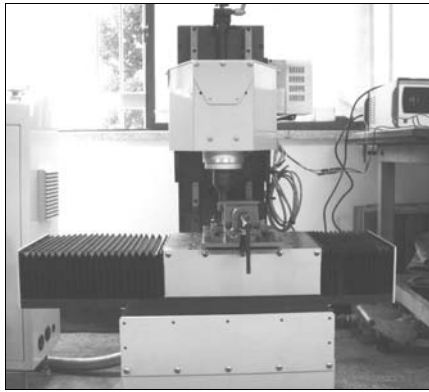


Fig. 5. MAP system used in this study.

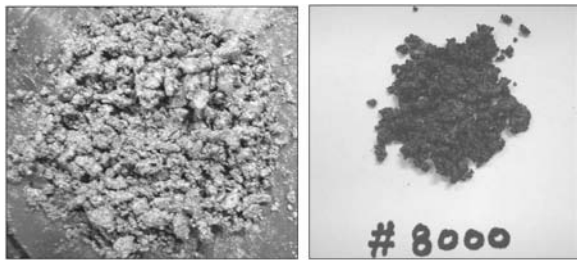


Fig. 6. Diamond paste used in experiments.

ing gap of 1 to 1.5mm. The working gap was kept constant during the experimentation. The amount of current inputted to the inductor was 1.5A. Diamond abrasives, shown in Fig. 6, were selected as the polishing agents in this experiment because the alternative Al_2O_3 and SiC abrasives are the same elements as those found in the aluminum-based composite material to be polished.

The magnetic abrasives were mixed with ferrous iron particles of 100 to 150 μ m and diamond paste (#8000). A small amount of olive oil was utilized for improvement of the cohesiveness between the ferrous iron particles and the diamond paste. The spindle speed was set to 1,720rpm in consideration of the inductor diameter. Coolant was continuously supplied to the surface of the workpiece. Table 1 lists the experimental conditions.

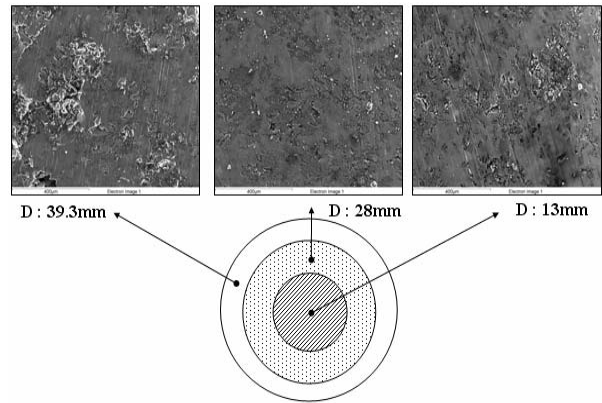
4. Results and discussion

4.1 Machining performance according to distance from center of inductor

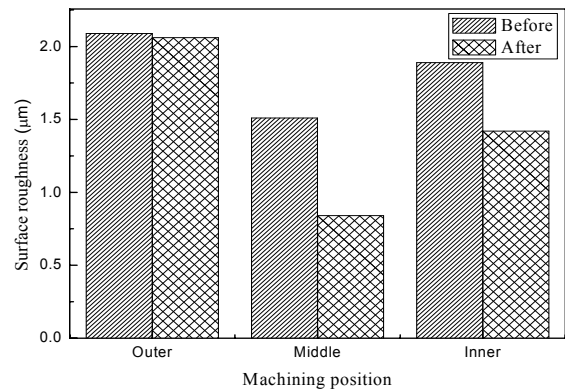
In the results of the preliminary experiment, it was seen that the magnetic force changed along the distance from the center of the inductor, because the magnetic flux density at the center of the inductor is stronger than in the outer regions. This means that the machining performance of the MAP differs in accordance with the radial distance. In addition, it differs according to the material, ferrous or non-ferrous. Thus, in this study, the machining performance of the MAP with the aluminum-based composite, a non-ferrous material, was evaluated along the radial distance. In the experimentation, the feed

Table 1. Experimental conditions.

| Working Parameters | Description |
|--------------------|--|
| Inductor diameter | 40mm (HSS) |
| Supplied current | 1.5A |
| Magnetic abrasive | Diamond paste #8000 (0.4g) + Fe particles (2g) + Oil |
| Working gap | 1~1.5mm |
| Spindle speed | 1,720rpm |
| Coolant | Constant supply |



(a) SEM images after MAP



(b) Surface roughness after MAP

Fig. 7. Polishing performance along radical distance.

of the workpiece was kept constant during the process. The surface roughness was measured after a machining time of ten minutes.

Fig. 7(a) shows SEM images of the aluminum-based composite workpiece surface at three positions along the radial distance after the MAP. Fig. 7(b) shows the surface roughness along the radial distance as measured using a stylus-type tester (Surftester 301, Mitutoyo).

Despite the stronger magnetic flux density at the inner (center) position of the inductor, the middle position of the working area had a better surface roughness than did the inner position, indicating that the efficiency of the MAP at the former

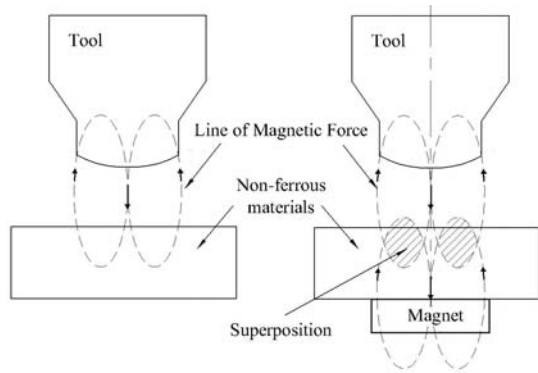
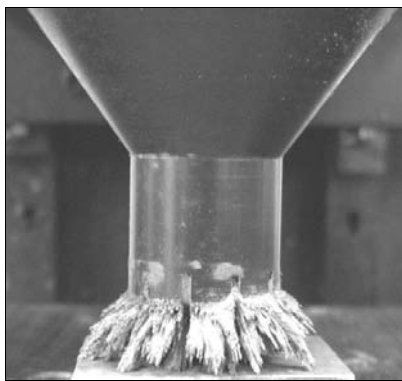
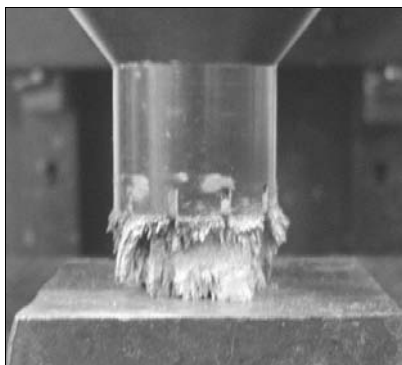


Fig. 8. Schematic of proposed method for improving magnetic force.



(a) Without permanent magnet



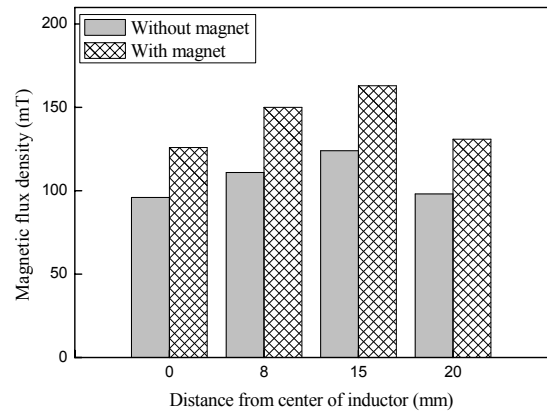
(b) With permanent magnet

Fig. 9. Brush formation in accordance with proposed method.

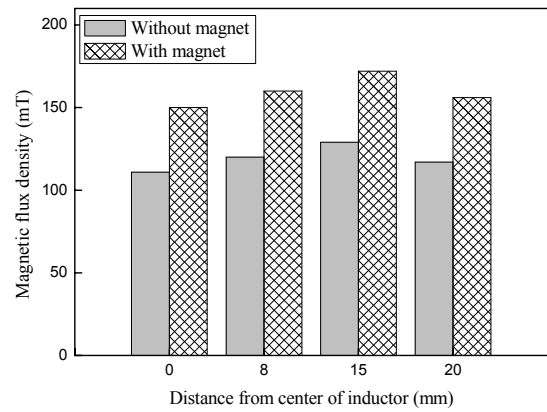
position is higher than at the latter. The reason is that the relative sliding velocity at the inner position is too low, causing ready and abundant scattering of magnetic abrasives at the outer position. Thus, the surface roughness at the outer position after the MAP was the worst.

4.2 Improvement of magnetic force for composite material

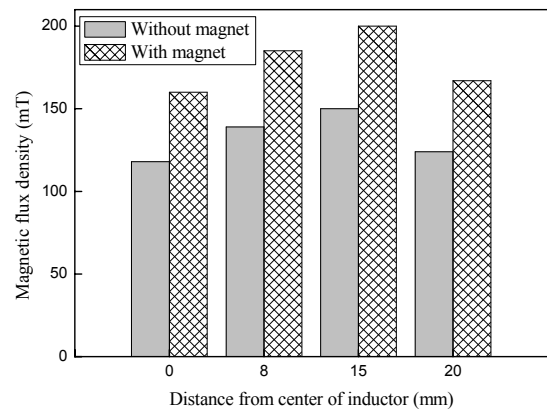
Aluminum-based composite material is non-ferrous. Accordingly then, the magnetic force between a workpiece and the inductor is lower than in the case of ferrous materials such as SM45C.



(a) 0.5A



(b) 1.0A



(c) 1.5A

Fig. 10. Comparison of measured magnetic flux density with and without a magnet.

A lower magnetic force means lower efficiency. To solve this problem for non-ferrous materials, this paper proposes a practical method according to which a permanent magnet is installed under the workpiece. The permanent magnet plays the crucial role of increasing the magnetic force to ferrous-material-like levels.

Fig. 8 is a schematic diagram of the experimental setup. The permanent magnet positioned under the workpiece. The magnetic flux density (magnetic force) in the right Fig. is larger

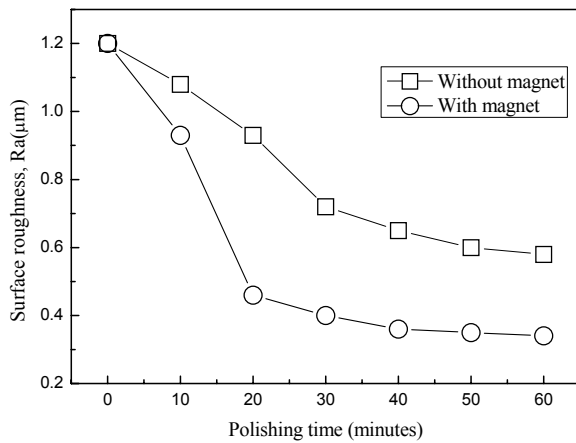


Fig. 11. Surface roughness variation according to the polishing time.

than in left one, due to the increased magnetic force imparted by the permanent magnet. Fig. 9 is a photograph of the inductor during the MAP process, showing the brush formation in the proposed methodology. In Fig. 9(a), the case without the permanent magnet, the severe dispersion of the magnetic abrasives from the inductor would seriously deteriorate the machining efficiency. By clear contrast, in Fig. 9(b), with the permanent magnet, the magnetic abrasives are strongly concentrated around the inductor.

To verify the actual effect of the permanent magnet in the MAP process, the magnetic flux density was measured using a tesla meter (TM-701, KANETEC); the results are tabulated in Fig. 10. As can be seen, the magnetic flux density was increased with the increase of the applied current from 0.5 to 1.5A. In all of the cases with the permanent magnet under the workpiece, the magnetic flux density was about 20% higher.

Fig. 11 plots the surface roughness variation according to the polishing time. The surface roughness was measured at the middle point of the workpiece, since the roughness differs along the machining position and, as shown above in Fig. 7, the middle point typically is the best. The experimental conditions were the same as those listed in Table 1. On the whole, without considering the permanent magnet, the surface roughness was improved by increasing polishing time. Significantly though, the surface roughness of the workpiece with the permanent magnet was better than that without the magnet. The surface roughness of the workpiece, with the permanent magnet, was improved especially rapidly after 20 minutes' polishing. After 60 minutes' polishing moreover, the surface roughness of the aluminum-based composite material was about 0.35μm.

5. Conclusions

This study aimed to optimize machining of difficult-to-cut aluminum-based composite material. To that end, a novel and practical magnetic abrasive polishing methodology was applied and tested in order to strengthen the magnetic force for non-ferrous workpieces. The results obtained in the experi-

mentation, and the conclusions drawn therefrom, are as follows.

- (1) To increase the magnetic force for non-ferrous materials, a practical method entailing the basic concept of a permanent magnet installed under the workpiece was derived. It was seen that the magnetic abrasives were strongly concentrated around the inductor when the permanent magnet was installed.
- (2) The middle position of the inductor imparted a better surface roughness due to the smaller velocity at the inner position and the scattering of magnetic abrasives at the outer position.
- (3) The surface roughness of the workpiece with the permanent magnet was better than that without the magnet when the polishing time was increased. The surface roughness of the aluminum-based composite material after 60 minutes' polishing was about 0.35μm.

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