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Study on ultra-precision magnetic abrasive finishing process using low frequency alternating magnetic field

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ABSTRACT

We proposed a new ultra-precision magnetic abrasive finishing (MAF) process using low frequency alternating magnetic field in this paper. Magnetic cluster themselves may produce the up and down movement change under alternating magnetic force. The movement may not only promote the dispersion of micro-magnetic particles, but also improve stirring effect and cross-cutting effects of the abrasives, achieving circulation and update to ensure the stability of grinding tools. This process is considered to be able to efficiently apply in ultra-precision finishing of plane and complicated micro-surfaces. In this study, we investigated the effects of alternating magnetic field on magnetic field distribution, finishing force and abrasive behavior. Furthermore, a set of experimental devices have been designed for finishing SUS304 stainless steel plate. The present work is aimed at understanding finishing particularity of this process and studying impacts of important process parameters namely grinding fluid, rotational speed of magnetic pole, current frequency on change in finish surface and material removal. Experimental results indicate that the process can realize ultra-precision finishing of plane by using oily grinding fluid. In the present research, the surface roughness of SUS304 stainless steel plate was improved from 240.24 nm to 4.38 nm by this process.

1. Introduction

With the development of semiconductor and optical high technology industry, the ultra-precision finishing technology of complex micro-shaped components in high surface quality and high efficiency is strictly demanded. Magnetic abrasive finishing (MAF) process is a magnetic field-assisted finishing technology, which utilizing the action at a distance between magnetic pole and magnetic abrasive to finish workpiece by introducing the magnetic field [1]. This process is considered to be a promising precision finishing technique for flat surfaces [2,3], complex curve surface [4] and inner surfaces of tube [5,6] because polishing tools (magnetic brush) composed of fine magnetic particles is flexible and easy to closely follow the finished surface [7,8]. The method can not only finish ferromagnetic materials, but can also polish effectively nonferromagnetic materials such as stainless steel [9–11], glass [12], ceramic [13,14] and brass [15]. Nowadays, magnetic field-assisted finishing processes are becoming developed for a wide variety of applications including the manufacturing of medical components [16,17] and optics parts [12,18]. Some researches related to plane MAF process are reported in this paper.

Shinmura et al. studied the basic processing principle and abrasive characteristics of plane MAF and verified that the MAF have the ability to achieve precision finishing of flat surface [19,20].

Jain et al. have studied the MAF process on non-magnetic stainless steel workpiece and concluded that the working gap and circumferential speed are the parameters which significantly influence the surface roughness value, proved forces and change in surface roughness (ΔRa) increase with increase in current to the electromagnet and decrease in the working gap [21–23]. Joshi et al.'s analysis of MAF of plane surfaces concluded that the surface finishing may improve significantly with an increase in the grain size, feed rate and current [24].

Yin et al. developed three modes (horizontal vibration, vertical vibration and compound vibration) of vibration-assisted MAF process for polished flat surface and 3D micro-curved surface. It is observed that the combination of the vibrations leaded to a higher polishing efficiency as well as a smoother surface [4,25]. Pandey et al. have studied the mechanism of surface finishing in Ultrasonic-Assisted Magnetic Abrasive Finishing (UAMAF) process and verified that the polishing effectiveness of MAF can be improved significant by add ultrasonic vibrations [26,27].

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The previous researchers have concluded the main parameters affecting the performance of MAF process and found out the methods improving significantly efficiency of MAF. However, to processing quality, the MAF process is still considered to be difficult to obtain effectively few nanometer finish surface, especially in finishing on flat and micro-complex surface workpiece made of hard materials. The key issues are as follows.

In conventional plane MAF process using magnetic brush, in order to obtain high surface quality few microns magnetic particles need to be used in ultra-precision finishing process. However, there are some problems that the fine magnetic particles consist of magnetic brush are easy to agglomerate during finishing process and magnetic brush is difficult to recover its original shape after contact with workpiece surface, which hinder the realization of ultra-precision finishing to some extent. Moreover, in finishing process, non-uniform distribution of abrasives is also indirectly affecting the uniformity of finished surface. On the other hand, magnetic brush itself is still under static magnetic field, resulting abrasives cannot be adequately transported over the magnetic brush in finishing process. Therefore, in complicated micro-curved surface MAF, abrasives are difficult to polish into all machined surfaces. Moreover, continuous use of the same abrasives particles leading to dullness of the cutting edges of the abrasives particles, decreasing finishing efficiency.

In order to overcome these problems, a new MAF process using low frequency alternating magnetic field was proposed in this paper. Firstly, we selected magnetic cluster instead of conventional magnetic brush. The magnetic cluster is made of iron power, abrasive and grinding fluid, which present a liquid state without the action of magnetic force. Magnetic cluster is considered to more applicable to nanometer level surface finishing because it is more flexible than conventional magnetic brush not easy to cause to surface scratches. Secondly, we use alternating current to energize electromagnetic which makes the magnetic field fluctuating. Therefore, the flexible magnetic cluster will generate a fluctuation of up and down under the action of alternating magnetic field. The fluctuating flexible magnetic cluster is not only promote to the scatter of micro-magnetic particles, but also prevent itself deformation after contact with workpiece surface, achieving circulation and update to ensure the stability of grinding tools. Moreover, with the fluctuation of magnetic cluster the abrasive particles can be refreshed and mixed during finishing process without recharging, which improve homogenous of finish surface and enhance finishing efficiency compared to use of static magnetic cluster.

This study investigated the magnetic field distribution in processing region and studied the effects of fluctuating magnetic cluster on finishing force and abrasive behavior. Moreover, we fabricated a set of experimental setup to conduct the comparison finishing experiments under alternating magnetic field and direct magnetic field. The present work is aimed at understanding finishing particularity of this process and studying the effects of important process parameters namely grinding fluid, rotational speed of magnetic pole, current frequency on change in finish surface and material removal.

2. Processing principle

Fig. 1 shows the force analysis of magnetic particles in alternating magnetic field. A magnetic particle along magnetic equipotential line direction generates a force f_x and along magnetic force line direction generates a force f_y, it is calculated by the following formula [28]:

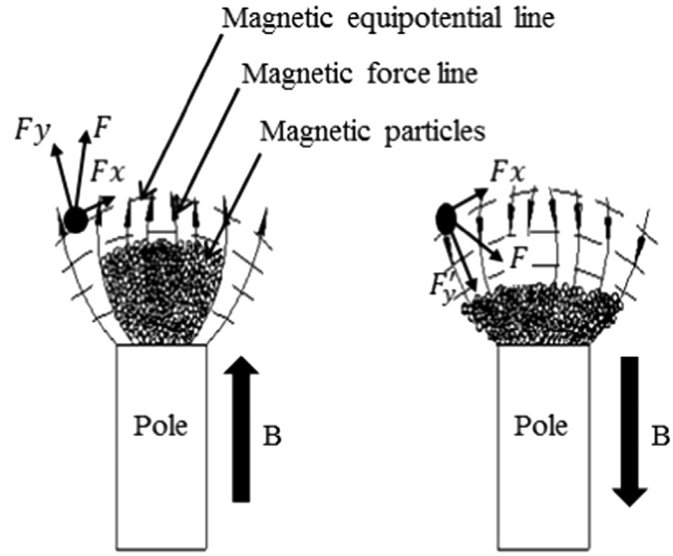

Fig.1. Force analysis of magnetic particles in alternating magnetic field.

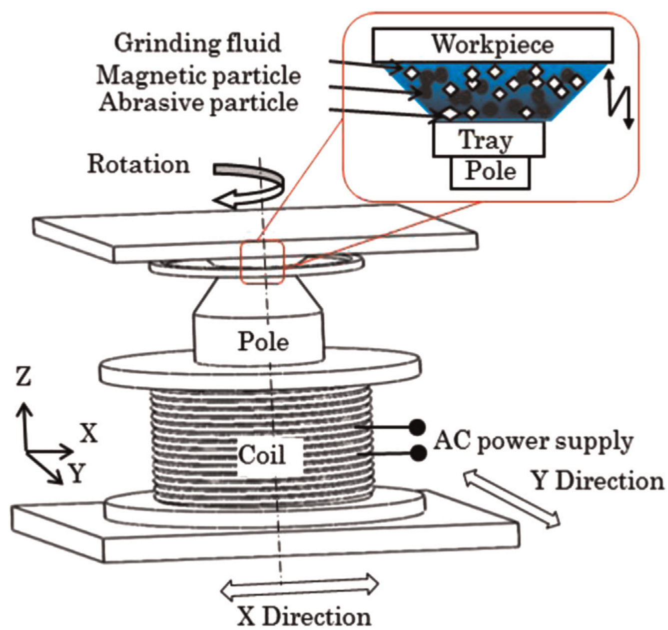

Fig.2. Schematic of processing principle.

$$F_x = V\chi\mu_0 H\left(\frac{\partial H}{\partial x}\right) \quad F_y = V\chi\mu_0 H\left(\frac{\partial H}{\partial y}\right) \tag{1}$$

where V is the volume of magnetic particle, χ is the susceptibility of magnetic particles, μ_0 is the permeability of vacuum, H is the magnetic field intensity, $\partial H/\partial x$ and $\partial H/\partial y$ are gradients of magnetic field intensity in x and y directions, respectively.

Due to the size and direction of alternating current present a cyclical variation over time, the direction of magnetic force f_y is changing under alternating magnetic field. Therefore, when the alternating current is supplied to the electromagnet, the magnetic cluster will generate a fluctuation of up and down with the change of magnetic field direction.

Fig. 2 shows a schematic of the plane MAF process using alternating magnetic field. The tray contains the compound magnetic finishing fluid (grinding fluid, iron powders and abrasives), the lower is the magnetic pole and the upper is the workpiece. After electromagnetic coil entering alternating current, the iron particles are attracted towards each other along the magnetic force