AN INVESTIGATION OF MAGNETIC FIELD ASSISTED MASS POLISHING FOR PRECISION MANUFACTURING OF OPTICAL FREEFORM SURFACES

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INTRODUCTIONS

Freeform surfaces have been widely used in various industrial applications, such as imaging, illumination, aerospace, biomedical engineering, green energy, etc. [1,2] The polishing process usually takes most of the time during the manufacturing process of precision freeform surfaces, which imposes a lot of challenges for meeting the increasing market demand. Hence, several kinds of mass finishing processes were developed to implement mass finishing of freeform surfaces, such as vibratory finishing, centrifugal barrel finishing, rotary barrel finishing, centrifugal disc finishing and spindle finishing [3]. However, those mass finishing methods cannot achieve high surface form accuracy and nanometric surface finish.

The magnetic field-assisted polishing method has been used for polishing various kinds of surfaces for decades due to its high adaptability to curved surfaces [4]. Shinmura et al. [5] conducted research on the finishing of roller surface based on magnetic field assisted finishing for the first time, and the surface roughness was reduced from 0.45 μm to 0.04 μm. Yamaguchi et al. [6-8] further developed this technology and used a rotational magnetic field for the finishing of internal surfaces. Jain, et al. [9] and Chang, et al. [10] also conducted magnetic field assisted polishing of roller surface, and the polished surface roughness was smaller than 0.1 μm. However, most of the current applications of magnetic field-assisted polishing only polish one workpiece in one setup which makes the polishing process time-consuming. Hence, this paper presents the development of a magnetic field assisted mass polishing (MAMP) process, which not only implements mass polishing for precision manufacturing, but also be able to obtain nanometric surface roughness for a batch of optical freeform surfaces.

Magnetic field assisted mass polishing (MAMP)

Figure 1 shows the working principle and the design of a prototype of MAMP system [11]. A magnetic field is set up outside the annular chamber of MAMP process to drive the magnetic brush to impinge on and remove materials from the workpiece mounted inside the chamber. The magnetic brush is generated by the magnetic abrasives under the effect of the magnetic field. The permanent magnet pairs are mounted on a rotary table, and the rotary table is driven by one servo motor, resulting in the generation of the rotating magnetic field, leading to the rotation of the magnetic brush accordingly. Bonded magnetic abrasives and loose magnetic abrasives could be used for rough polishing and fine polishing. The bonded magnetic abrasive is the ferromagnetic particle bonded with different kinds of polishing abrasives, while the loose magnetic abrasive is the ferromagnetic particle mixing with the polishing abrasive.

Experiments

In this study, an experimental prototype has been built up as shown in Fig. 1(a). Two pairs of N52 Neodymium permanent magnet (size: 25.4mm×25.4mm×50.8 mm) were mounted on the rotary table as shown in Fig. 1(c). Two magnetic brush can be generated as shown in Fig. 1(d). The workpiece with a cylindrical surface is designed for the polishing test in this study, and detail dimension of the workpiece has been shown in Fig. 2(a). Six workpieces can be polished simultaneously according to the fixture design in Fig. 1(e). Moreover, the number of the workpiece can be further increased through changing the design of the fixture. The target surface is clamped facing the outer wall of the chamber. Two kinds of magnetic abrasives were adopted for the rough polishing and fine polishing, which are bonded magnetic abrasive and loose abrasive, respectively. Table 1 shows the three groups of polishing conditions.

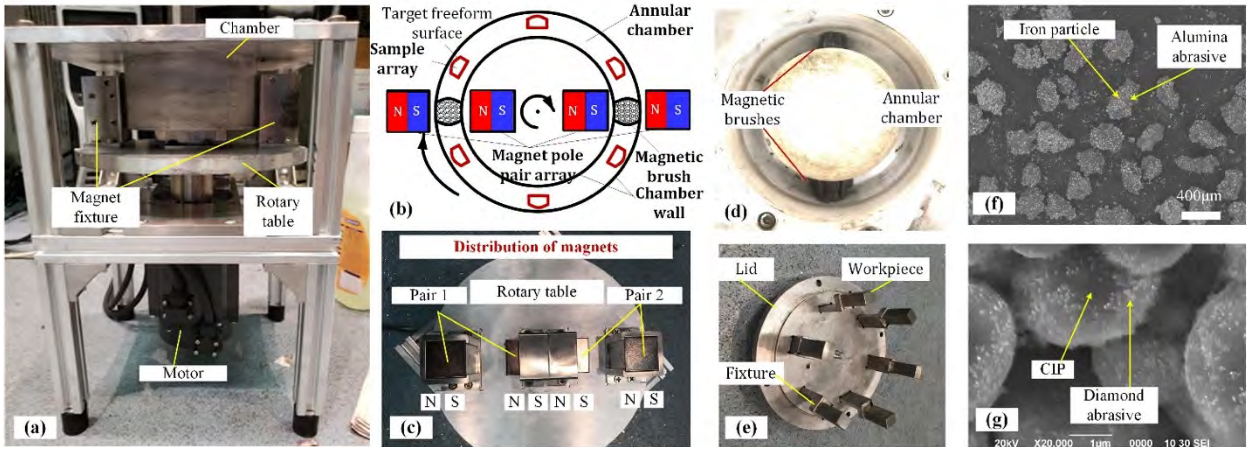

FIGURE 1. Principle and design of a MAMP system. (a) Snapshot of the MAMP device, (b) schematic diagram of the MAMP method, (c) distribution of the permanent magnet pairs, (d) generated two magnetic brushes under the effect of the magnetic field, (e) demonstration of workpiece clamping, (f) SEM photo of the bonded magnetic abrasive for rough polishing, and (g) SEM photo of the loose magnetic abrasive for fine polishing.

TABLE 1. Polishing conditions

Conditions	Group 1	Group 2	Group 3
Workpiece type	Cylindrical surface	Freeform surface	Cylindrical surface
Workpiece material	304 stainless steel	304 stainless steel	304 stainless steel
Average initial surface arithmetic roughness (Ra)	455.4 nm	261 nm	74nm
Rotation speed	1500 rpm	1500 rpm	1500 rpm
Magnetic abrasive for rough polishing	Bonded type magnetic abrasive	Boded type magnetic abrasive	N/A
Magnetic abrasive for fine polishing	Loose type magnetic abrasive. Weight percentage of the polishing slurry is 23.3%.	Loose type magnetic abrasive. Weight percentage of the polishing slurry is 23.3%.	Loose type magnetic abrasive. Weight percentage of the polishing slurry varies from 0, 10%, 20%, 30%, 40% and 50%
Polishing time	30 min rough polishing and 20 min fine polishing	30 min rough polishing and 20 min fine polishing	20 min fine polishing

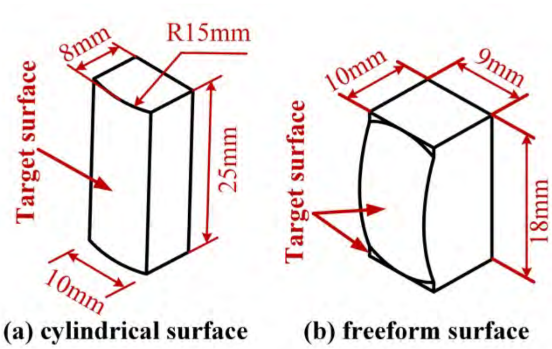

FIGURE 2. Sample design for the polishing test. (a) Cylindrical surface, and (b) freeform surface.

The bonded magnetic abrasive is iron particle (i.e. 100−200 μm, 80 wt.%) bonding with alumina abrasive (i.e. ~2 μm in average, 20 wt.%), as shown in Fig. 1(f). The loose magnetic abrasive is a mixture of carbonyl iron powder (CIP) and nanometer scale alumina abrasive (~150 nm) as shown in Fig. 1(g).

Three groups of polishing experiments were conducted in this study. The first one is the rough polishing and fine polishing of the cylindrical surface. Polishing test was then conducted on the freeform surface as shown in Fig. 2(b), which is a compound surface including one aspheric surface and 4 flat surfaces. An investigation on the effect of the polishing abrasive concentration was conducted during the fine polishing process. The percentage of the solid in the polishing slurry used in this experiment is 19~22%.

The surface roughness before and after polishing was measured on ZYGO NEXVIEW 3D optical profilometer. And the surface profile was measured on Talysurf PGI1240. The micro surface topography before and after polishing was also measured on Hitachi Electron Microscope TM3000.

RESULTS AND DISCUSSIONS

Figure 3 shows the snapshots of the cylindrical samples before polishing, after rough polishing and fine polishing, respectively. It can be seen that the surface finish of the workpiece has been largely improved after polishing, and mirror-like surface was obtained after fine polishing. According to the results from Zygo interferometer showed in Fig. 4, the surface roughness was reduced to Sa 49.8 nm after rough polishing, and further reduced to Sa 13.8nm after fine polishing.

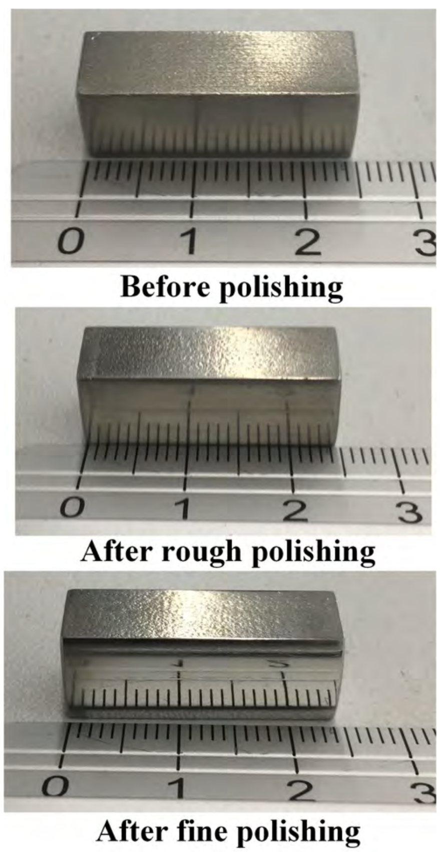

FIGURE 3. Snapshots of the cylindrical surface at three different stages.

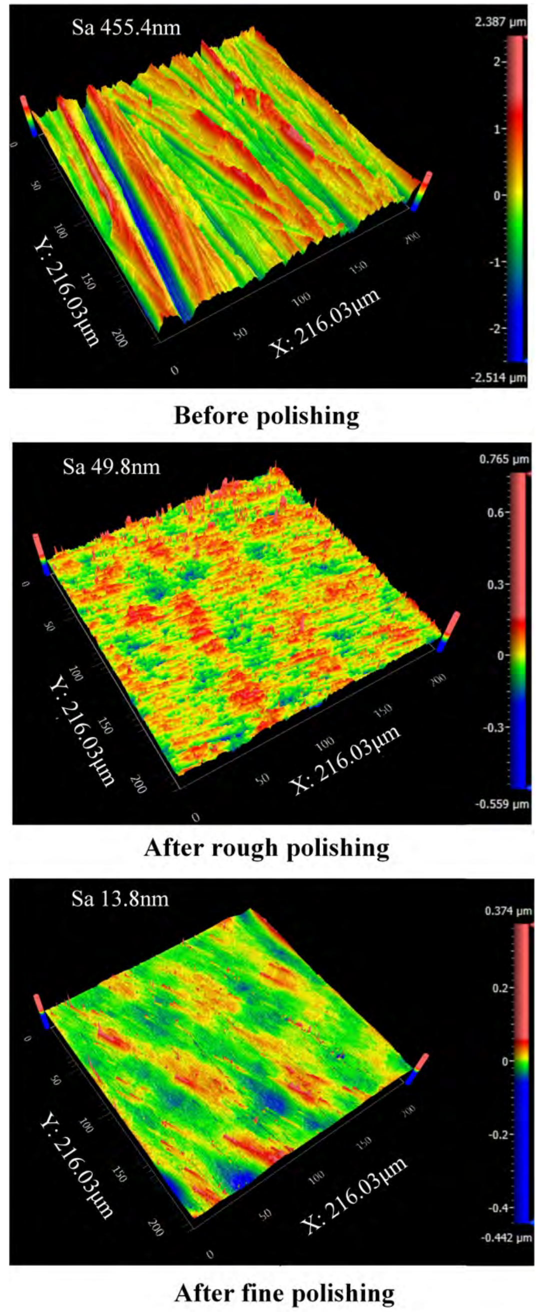

FIGURE 4. Surface roughness measurement of the surface before and after polishing

In order to observe the change of micro-scale topography of the surface before and after polishing, the photos taken under the scan electron microscope (SEM) were also provided in Fig. 5. Two photos with different magnifications were presented for each stage. These results indicate that the initial rough surface has been successfully smoothened after rough polishing and fine polishing.

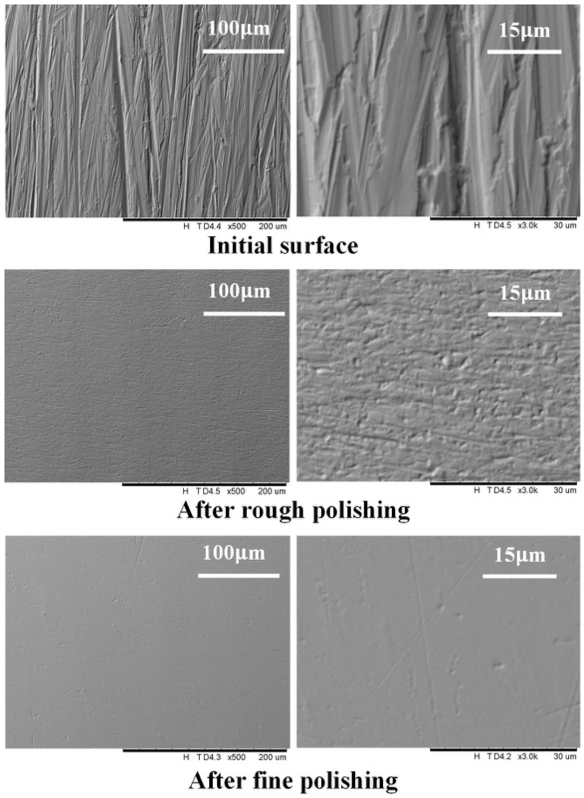

FIGURE 5. SEM measurement results of the surface before and after polishing

Polishing performance test of MAMP on free form surface, which is a compound surface was also conducted. Figure 6 shows the surface before and after polishing. Mirror-like freeform surface was also obtained after MAMP. The surface roughness was reduced from Ra 261nm to Ra 15nm， which proves the feasibility of MAMP for freeform surface.

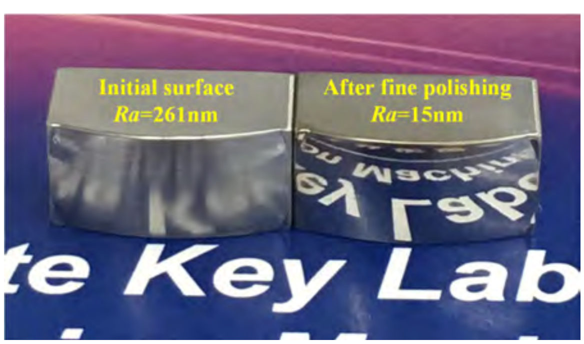

FIGURE 6. Snapshots of the freeform surface before and after MAMP

CONCLUSIONS

In this paper, a novel magnetic field-assisted mass polishing (MAMP) method is presented to implement mass finishing technology for precision manufacturing optical freeform surfaces with nanometric surface finish. A prototype MAMP system has been designed and built. A series of experiments were also carried out to demonstrate the technical feasibility of this novel mass finishing process. The results show that the MAMP process are effective for mass polishing a number of optical freeform workpiece concurrently with nanometric surface finish. The success of this research work will provide a novel and high efficient precision manufacturing technology for optical freeform surfaces.

FUTURE PLAN

The MAMP process is a newly developed process for the mass finishing of freeform surface targeting on implementing nanometric surface roughness. In order to make this process more robust and stable, further investigations on various aspects are still undergoing, such as the optimal concentration of the polishing slurry, multi-scale material removal mechanism, optimal clamping orientation for samples with different geometry, etc.

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