Feasibility study on fluid jet polishing of structured surfaces

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Abstract. A generic, cost-effective and high accuracy structured surface polishing process is needed to meet the increasing demand of precision components with structured surface. Low pressure fluid jet polishing (FJP) was innovatively proposed to polish the structured surface. Feasibility study were carried out on the polishing of sinusoidal structure surface made of S136 mold steel, which was pre-machined by wire electrical discharge machining. The surface topography, surface roughness, and surface form before and after polishing were compared. Highly smooth surface was obtained after polishing, and the surface roughness was improved by over 96%, while the form deviation before and after polishing was only ~3.7%, which proves the feasibility of the FJP on structured surface.

Introduction

Structured surface here refers to a surface that has a regular periodic structure array in micrometer or millimeter scale, which can perform specific functions in optics, physics, biology, etc.[1] These kinds of surface could be Fresnel lens structure [2], optical microlens array [3], bionic optical compound eye structure [4], V-shaped or cylindrical groove structure array [5,6], reflective prism array [7], etc. Due to the rapid development of optical fiber communication in recent years, imaging technology and other industries, components with functional structured surfaces have been widely used in micro-optoelectronic and communication products, biomedicine, automotive lighting and other fields.

Driven by a large number of demand and expensive processing costs of a single component, high-precision molds are currently used for mass production. Structured surface on the mold can be machined using precision milling, electrical discharge machining (EDM), precision grinding or cutting. However, most of the processed mold surfaces cannot meet the practical accuracy requirements, and subsequent polishing is required, especially for difficult-to-machine materials [8,9]. Hence, several kinds of polishing process were developed, targeting on improving the surface roughness of the structured surface. The utilization of a profiling tool is a commonly used method for the polishing of structured surfaces, in which the shape of the polishing tool is similar to the structure [10-12]. But each kind of tool can only be used for the polishing of one kind of surface, and tool wear is also a problem of this method. Moreover, matching between the tool and the small structure is usually very difficult. Other polishing methods, such as magnetic assisted polishing method [13-15], vibration assisted polishing [16-18], and laser polishing [11,19] were also proposed for the application of structured surface polishing, but there still exist various problems of them, including low polishing efficiency, low form maintainability, low surface accuracy, etc. Hence, a generic, cost effective and high accuracy polishing process is needed for the polishing of structured surfaces.

With this in view, low pressure (smaller than 20 bar) fluid jet polishing (FJP) [20,21] process was tried for the first time in this paper, to polish the structured surfaces. In FJP, the pressurized slurry is ejected from the nozzle at a high speed and impact the surface to implement material removal as shown in Fig. 1 [22]. Different with the abrasive water jet machining method reported by Matsumura et al. [23], in which a relatively high pressure (150 bar) was adopted, no mask will be needed in FJP benefiting from the low fluid pressure, which makes it more applicable and cost effective. Moreover, the FJP has the advantages of no tool wear, high adaptability to complicated surfaces, no temperature raise, wide material applicability [24]. Hence, it will have broad application and market prospects if it is proved to be feasible. Feasibility study of the fluid jet polishing on structured surface was carried out in this paper. Polishing experiments were conducted on the sinusoidal structure surface. The surface topography, surface roughness and surface form were analyzed before and after polishing.

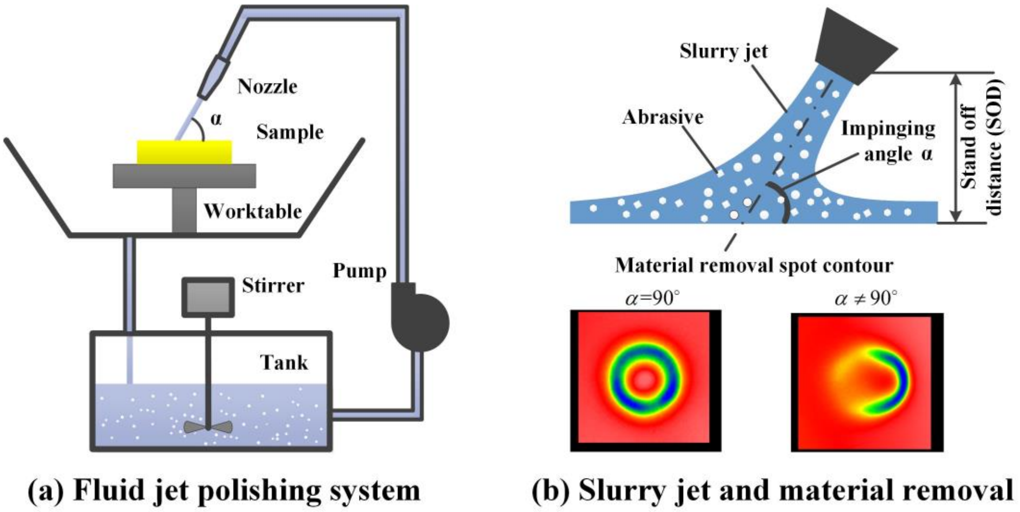


Fig.1 Schematic diagram of the fluid jet polishing process.

Experimental Design

The polishing experiment was conducted on Zeeko *IRP200* polishing machine as shown in Fig.2. The sinusoidal structure surface made of S136 mold steel was used target structured surface, which is used for the flood lighting components, implementing the function of transforming surface source to line source. The diameter of the sapphire nozzle is 0.5mm. The function of the sinusoidal profile has also been demonstrated in Fig. 2. The size of the surface is 16×20 mm^2. The initial sinusoidal surface was machined by wire EDM. Other polishing conditions are summarized in Table 1.

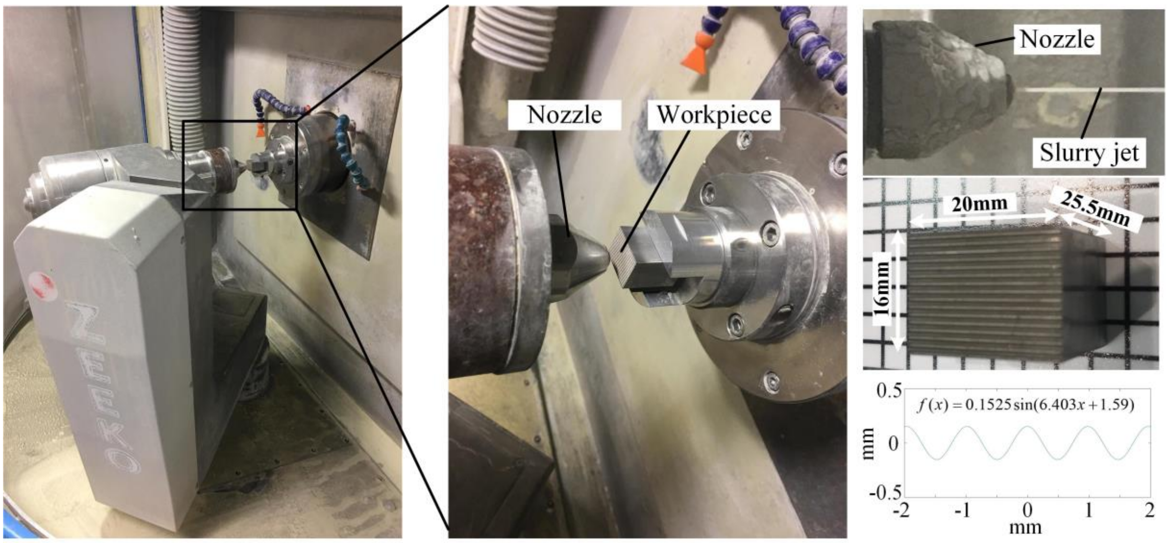


Fig. 2 Snapshots of the experimental setup

Table 1 Conditions for the structured surface polishing

Conditions	Value
Polishing slurry	wt.10% of 1000# SiC mixing with water
Fluid pressure	10 bar
Impinging angle	90 degree
Stand off distance (SOD)	2mm
Feed rate	50mm/min
Polishing path	Raster path with 0.2 mm scanning interval
Polishing time	3 passes of polishing, 32.4 min for each pass

The surface topography before and after polishing were characterized by *Hitachi* Electron Microscope *TM3000*. The surface roughness was measured on the *Zygo Nexview* white light 3D interferometer. And the 3D surface form was measured on *Alicona IFM G4* optical measuring system.

Results and Discussions

Surface Topography Analysis. Fig.3 shows the snapshots of the sinusoidal surface before and after polishing. The surface after polishing becomes much more shining as compared to the initial surface. The SEM measurement results on the top, side and bottom surface of the sinusoidal surface are presented in Fig. 4 under three different magnifications. As shown in Fig. 4, typical discharge craters after EDM [25] can be easily found on the initial surface. These defects were thoroughly removed after polishing, only leaving tiny abrasive erosion marks. The SEM photos on the edge were also compared as presented in Fig. 5. It is noted that the surface after polishing is much smoother the initial surface. Meanwhile, the form at the sharp edge was also maintained well.

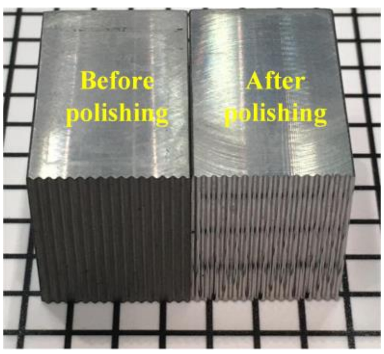
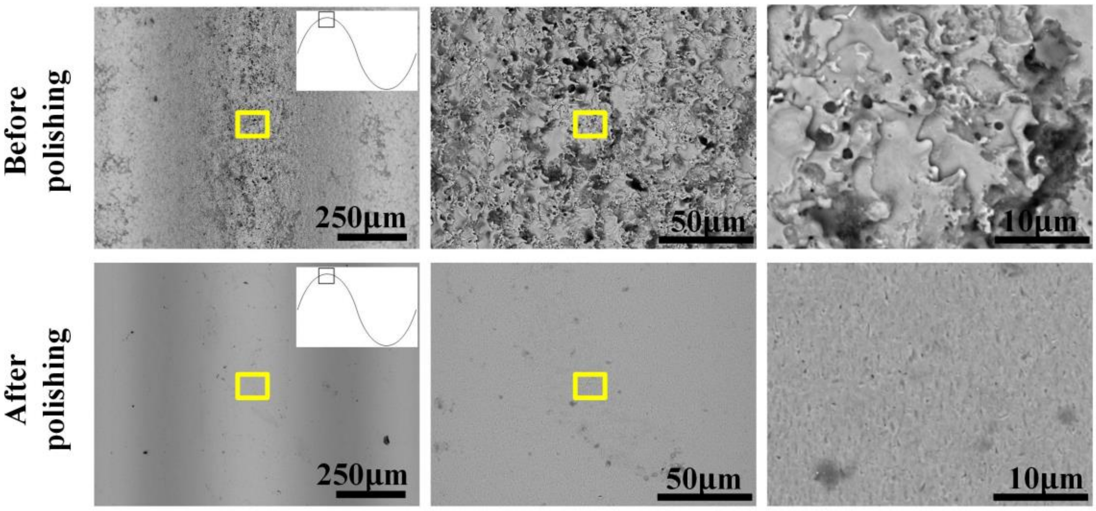
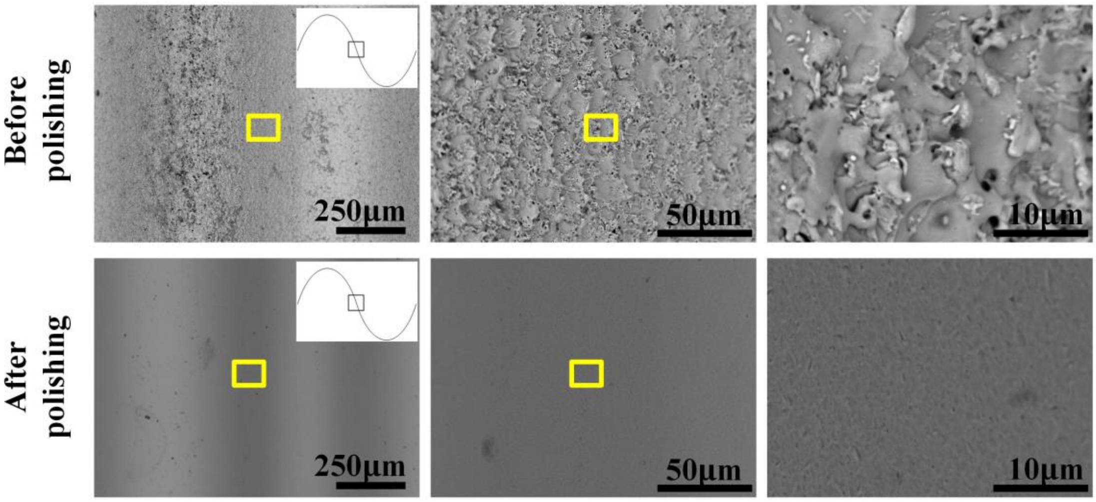


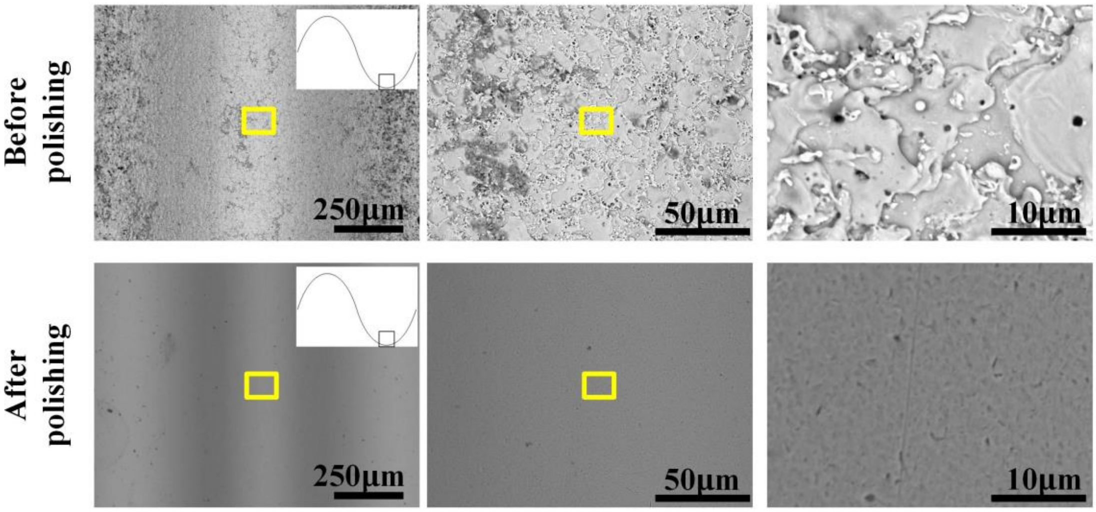
Fig. 3 Snapshots of the sinusoidal surface before and after polishing



(a) Top surface before and after polishing



(b) Side surface before and after polishing



(c) Bottom surface before and after polishing

Fig. 4 SEM photos of the surface before and after polishing under three different magnifications

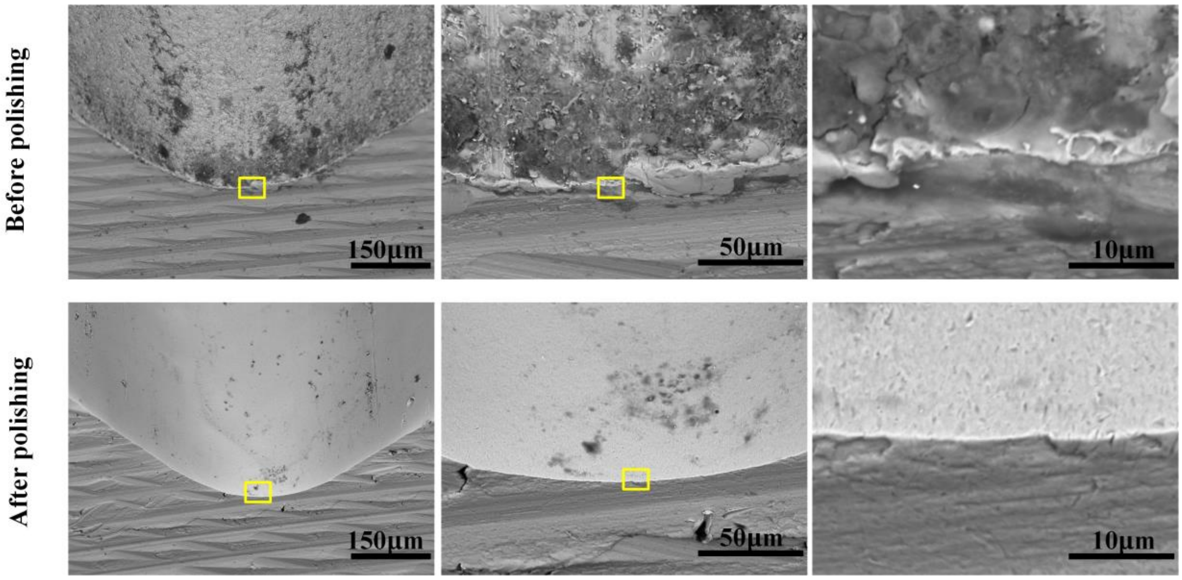


Fig. 5 SEM photos of the edge surface before and after polishing

Surface Roughness Analysis. The surface roughness measurement results are presented in Fig. 6. The surface arithmetic average roughness (Sa) on top and bottom surface before polishing are 642.1nm and 458.9nm, respectively. After polishing, the Sa of the top and bottom surface reduced to be 18.8nm and 14.4nm, respectively. The convergence ratio of the surface roughness reaches more than 96% as compared to the initial surface roughness, which proves that FJP is effective to reduce the surface roughness of structured surface. Moreover, the surface roughness could be further improved through adopting smaller abrasives.

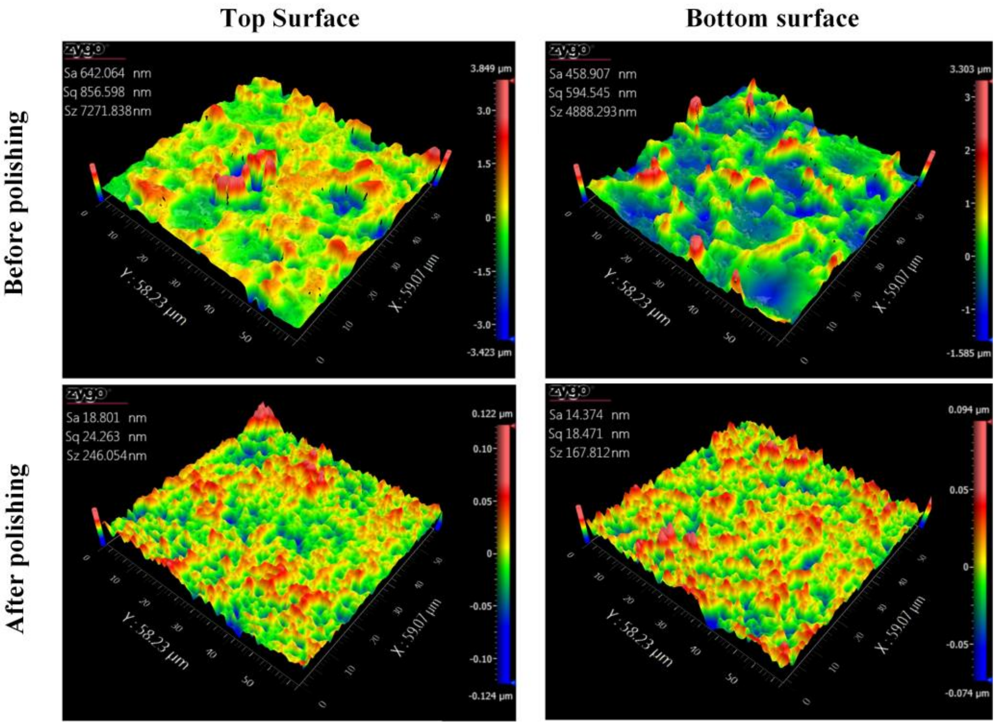


Fig. 6 Surface roughness comparison before and after polishing

Surface Form Maintainability Analysis. Except for the surface roughness, the surface form maintainability is also an important evaluation index in structured surface polishing. Since the polished sinusoidal surface is highly reflective after polishing, the surface form can hardly be measured directly by *Alicona* optical measuring system. The structured surfaces before and after polishing were imprinted to the plastic materials, and the surface form can be measured on the imprinted surface indirectly. Fig. 7 shows the measured surface form. The surface profiles before and after polishing were matched based on anyDOF registration algorithm [26]. It is found that the surface form maintains well as shown in the sectional profile comparison results. The maximum deviation as compared the peak value of the profile is only ~3.7%, which indicates the high form maintainability in FJP of sinusoidal surfaces.

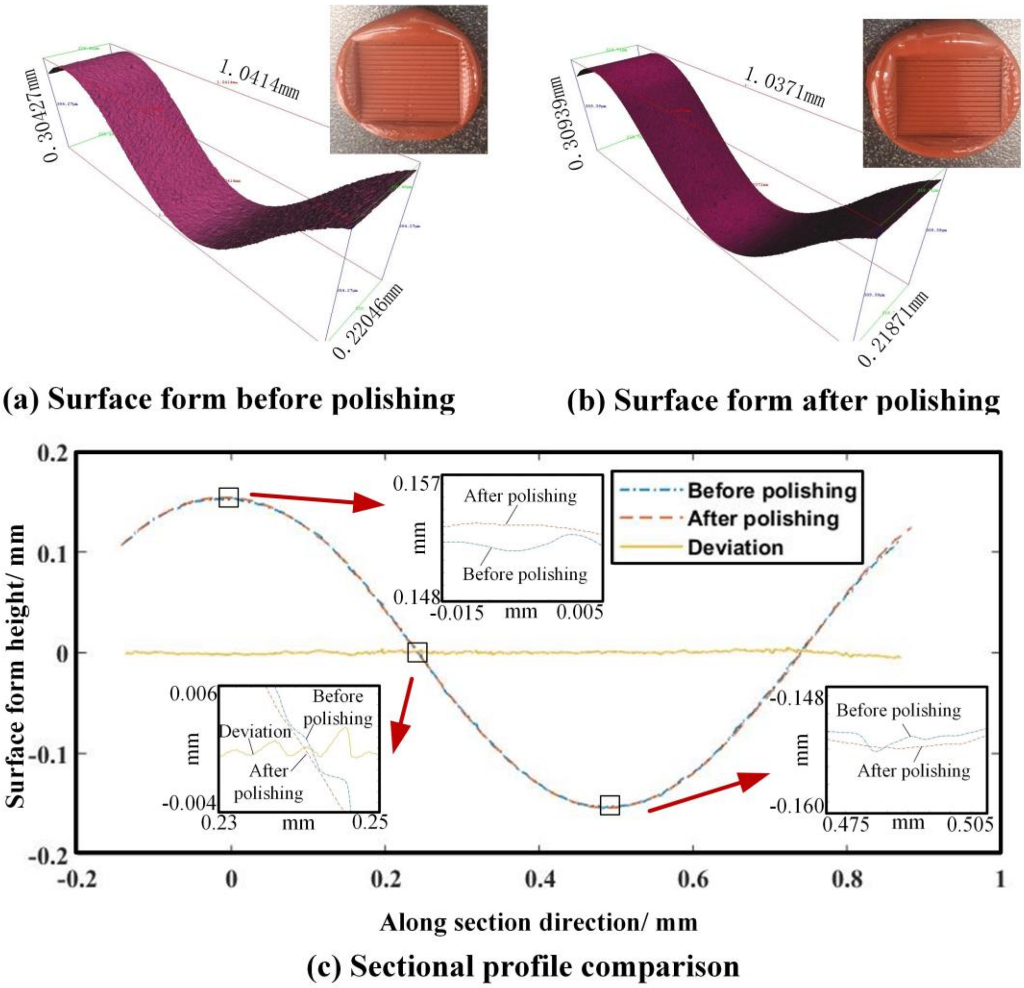


Fig. 7 Surface form comparison before and after polishing

Conclusions

Feasibility study of fluid jet polishing (FJP) on structured surface was carried out in this paper. The surface defects on the sinusoidal structure surface generated by wire EDM machining were thoroughly diminished by FJP, obtaining a highly smooth surface. The surface roughness on the top and bottom position was reduced from 642.1nm and 458.9nm to 18.8nm and 14.4nm, respectively. Meanwhile, the surface form deviation is only ~3.7%, which indicates high form maintainability. Hence, FJP may be an effective way for structured surface polishing. And the polishing efficiency could be largely boosted through adopting the multi-jet polishing method [27-31]. Hence, FJP would become a competitive method for the structured surface polishing based on the unique advantages of the FJP method.

However, the sinusoidal structured surface in this paper cannot represent all kinds of structured surface. As for structured surface with sharp edges (i.e., V-groove structure, Fresnel lens, etc.), the form maintainability may be not easy to maintain, which will be tested in the near future. At the meantime, polishing performance test on different kinds of materials needs to be conducted, including metals, ceramics and glasses. Moreover, the effect of the polishing parameters to the surface quality, so as to the material removal mechanism, need to be investigated to further optimize the polishing process.

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