Study on Surface Roughness of Modified Silicon Carbide Mirrors polished by Magnetorheological Finishing

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Abstract. In order to obtain high precision and high surface quality silicon carbide mirrors, the silicon carbide mirror substrate is subjected to surface modification treatment. In this paper, the problem of Silicon Carbide (SiC) mirror surface roughness deterioration by MRF is studied. The reasons of surface flaws of "Comet tail" are analyzed. Influence principle of MRF polishing depth and the surface roughness of modified SiC mirrors is obtained by experiments. On this basis, the united process of modified SiC mirrors is proposed which is combined MRF with the small grinding head CCOS. The united process makes improvement in the surface accuracy and surface roughness of modified SiC mirrors.

1. Introduction

Silicon carbide materials possess good characteristics of great stiffness, small thermal deformation coefficient, and good thermal conductivity and so on, which is considered as the first choice of body material for space telescope mirror [1]. However, the two-phase structure of the silicon carbide material causes the surface to be less dense than the glass material, and the high hardness leads to poor workability. Therefore, the silicon carbide mirror surface must be modified if it is to obtain a high quality optical surface. Internationally, the surface of silicon carbide is usually plated with a layer of dense silicon carbide or silicon to achieve the purpose of surface modification [2]. Then, the precise polishing is further proposed to get better surface precision and surface roughness.

The deterministic magnetorheological finishing (MRF) technology is a new type of optical component polishing technology proposed by the University of Rochester in the mid-1990s [3]. As an advanced optical processing method, MRF has a good stability of removal function, high surface precision and the good sub-surface quality. However, for the silicon modified layer of silicon carbide mirrors, there is a surface defect that differs from the conventional polishing technique, as shown in figure 1. The surface defects showed slender scratches, whose depth gradually shallowed until disappeared. That is "comet tail" phenomenon. "Comet tail" affect the surface roughness of silicon carbide mirrors seriously, which makes the MRF cannot be effectively used on the figuring process of silicon carbide mirror modification layer.

In this paper, the research on the MRF of silicon carbide modified layer is presented and the reason of "comet tail" phenomenon is analyzed. The relationship between the depth of MRF polishing and the surface roughness is explored through experiments. On this basis, the combined process is proposed to restrain the "comet tail". So that the surface precision and roughness of modified silicon carbide mirror can be improved at the same time.
2. Material Removal Mechanism of MRF

The MRF fluid is mainly composed of micron-sized carbonyl iron powder, cerium oxide abrasive and based carrier liquid. Carbonyl iron powder surface is smooth evenly distributed, whose particle size is mainly distributed in 3-5μm. Ceria oxide abrasive and carbonyl iron powder are uniformly mixed with no agglomeration and other phenomena after high shear rate of mechanical dispersion and ultrasonic dispersion [4]. The MRF fluid will form a bulge ribbon under the action of high gradient magnetic field as shown in figure 2. A chain-like microstructure is formed inside the ribbon. The high-intensity magnetic field has a buoyancy effect on the non-magnetic polishing powder according to the theory of ferrohydro dynamics. Therefore, non-magnetic polishing powder is separated out from the MRF fluid and floating in the surface of ribbon in the high-intensity magnetic field area, which forms a flexible polishing membrane to achieve the material removal.

3. Mechanism of Comet Tail on Modified Silicon Carbide Mirror

Studies have shown that a median or radial crack is created as long as the normal stress on a single abrasive grain exceeds a critical value and a damaged layer is formed on the surface or subsurface of the material. The lateral cracks are induced when the abrasive particles are unloaded resulting in brittle removal of material. There will be only elastic or plastic contact between the abrasive and the workpiece when the abrasive particles are stressed below this critical value, which will not produce surface or subsurface cracks. That is the plastic removal mode. A single polishing particle in MRF fluid is in force of about 10-7N [5], which is far less than the general optical material critical force [6] (about 10-2N). Therefore, the material removal of MRF is the plastic removal mode [5, 7].
In this paper, the modified layer material of silicon carbide is polycrystalline silicon. The anisotropy of the polycrystalline leads to different micro-hardness on different regions. The low hardness area has loose crystal structure, which leads to high activity of silicon atom. It is easy to produce loose Si-O-Si molecules, which is stripped by MRF fluid quickly [7]. While the MRF fluid fills in and expand the contact area of MRF fluid and the low hardness area. The material removal is different in the same time, resulting in the "comet tail" phenomenon.

According to the characteristics of walking robot, the control strategy of two-stage pressure system is proposed, as shown in figure 4.

4. MRF Experiment of Modified Silicon Carbide
As the "comet tail" is due to the difference material removed in the microscopic region, it is necessary to study the modified silicon carbide mirrors by MRF. The experimental method is to polish the surface of the modified layer of the silicon carbide mirror by MRF uniformly. The change of surface roughness before and after the polishing is obtained to quantitatively obtain the relationship between the MRF removal depth and the surface roughness. The CCOS was used to recover deteriorating roughness in the case of the deterioration of surface roughness. The relationship between CCOS removal depth and roughness was quantitatively obtained.

Experimental data: The surfaces of silicon mirrors were uniformly polished by MRF. The depths of material were removed by 100nm, 200nm, 300nm, 400nm, 500nm and 600nm respectively. The average roughness is shown in Figure 3.

![Figure 3. The relationship between surface roughness and polishing depth](image-url)

Through the experimental results in figure 3, we can draw the following conclusions:

(1) When the depth of removal is less than 200nm, the roughness decreases with the increase of removal depth.

(2) When the removal depth is greater than 200nm, the roughness increases with the increase of the removal depth, which is almost linear.

(3) According to the trend of roughness evolution and the roughness profile distribution shown in figure 4, it is considered that the depth and distribution density of "comet tail" generated in MRF processing cause the deterioration of roughness.

On this basis, the silicon carbide mirror modified layer polished by MRF is subjected to the CCOS process of a polyurethane disk to recover the roughness ruptured by MRF. According to the experimental results, the surface roughness polished by MRF of 600nm can be restored to 1.5nm after 150nm polishing by CCOS. The surface roughness polished by MRF of 1200nm can be restored to 1.5nm after 350nm polishing by CCOS.
From the above experimental results, it can be considered that when the surface roughness is recovered, the material removal of CCOS polishing is one-fourth of MRF. The removal amount is basically linear.

5. Combined Polishing Process

According to the experimental results, it is considered that there is a linear relationship between the MRF removal depth and the roughness. The CCOS removal depth also has a linear relationship with the roughness. Thus, the combination of MRF and polyurethane CCOS polishing process is formed. The errors are distributed according to the error ratio. As shown in figure 5, the polyurethane CCOS and MRF should be polished full aperture. MRF is responsible for correcting the surface error and the polyurethane CCOS will recover the surface roughness. After iterative processing, the silicon carbide modified layer is improved in both the surface accuracy and the surface roughness.

6. Conclusion

In this paper, the problem of the surface roughness deterioration of the modified silicon carbide mirrors with MRF was studied. The reasons of the surface defects such as "comet tail" were analyzed. Combining with the experiment of MRF, the influence discipline on MRF depth and surface roughness of MRF is obtained. On this basis, combined process is proposed to make the improvement of surface accuracy and surface roughness of modified silicon carbide mirror.
7. Acknowledgments
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8. References
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