Polishing of V-groove and Fresnel optics using localized vibration-assisted magnetic abrasive method

Jiang Guo[1, a *], Renke Kang[1, b], Zhigang Dong[1, c], Xiaoguang Guo [1, d]

[1] Key Laboratory for Precision and Non-traditional Machining Technology of Ministry of Education, Dalian University of Technology, Dalian 116024, China

[a] guojiang3302@gmail.com

Keywords: Polishing; Vibration; Magnetic field; Surface quality; V-groove; Fresnel optics.

Abstract. This paper presents a new localized vibration-assisted magnetic abrasive polishing (VAMAP) method using loose abrasives for V-groove and Fresnel optics finishing. The purpose is to improve the surface quality while maintaining the form of microfeatures. This method allows abrasives to access the corners of the microfeatures and remove materials locally and uniformly by effectively controlling the magnetic field and vibration. The results show that the surface roughness achieved about 7 nm Ra from the initial value of over 10 nm Ra while the microfeatures of V-groove and Fresnel optics were well maintained. At the same time, the surface defects including voids, scratches as well as tool marks were clearly removed.

Introduction

V-groove and Fresnel optics are key optical components in many optical systems in optical fiber positioning, solar energy focusing system, grating, etc [1-3]. With the dramatic increase in activity of V-groove and Fresnel optics, high precision machining processes were developed in recent years to produce V-groove and Fresnel optics with high accuracy and surface quality. However, in some cases, due to the limitation of the achievable surface quality which is attributed to defects such as burrs, tool marks and surface defects, a post-polishing process is necessary to improve the surface quality.

To date, some methods have been reported for structured and microstructured surfaces finishing such as using conical pin-type and conical wheel-type tools, magnetorheological fluid and dual magnetic roller tool [4-6]. However, these methods have some limitations when it comes to effectively improving surface finish while maintaining the form of microfeatures. To solve the problem, in the previous work, a vibration-assisted magnetic abrasive polishing (VAMAP) method has been proposed which shows the capability to finish microfeatured surfaces [7]. However, it is limited to non-magnetic or slightly magnetic materials with straight microfeatures. It is also difficult to prevent surface defects due to the long scratches caused by the large amplitude of linear vibration. As continuous research is undertaken to tackle this challenge, in this paper, a new localized VAMAP method is proposed. It can be used to polish curved microfeatures and the workpiece material could be ferrous. The paper details the principle, experimental setup and conditions, magnetic flux density distribution analysis, and experimental results in the following sections.

Methodology

As shown in Fig. 1, in this method, a magnet is placed under the microstructured surface of workpiece with a small gap to generate a magnetic field. A pole is set on top of the microstructured surface to constrain the magnetic particles in a small area to achieve localized material removal. From the cross-sectional view, through adjusting the designs of magnet and pole, the magnetic particles are attracted to the magnet and therefore contact the microstructured surface closely by the magnetic force. As a result, the magnetic particles are able to conform to the form of the microfeatures and access the corners of microfeatures. Then by introducing vibration, a relative movement is generated between the magnetic particles and microstructured surface, causing material to be removed by the abrasives. As the vibration direction traces along the path of the microfeatures, the form of the microfeatures will be maintained.

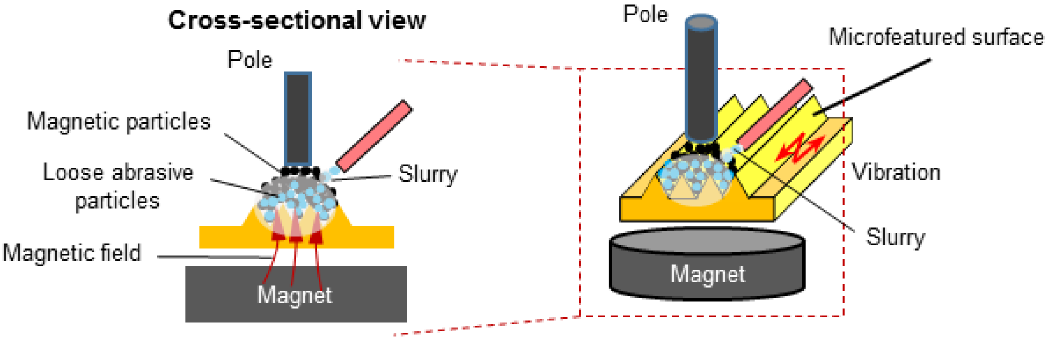
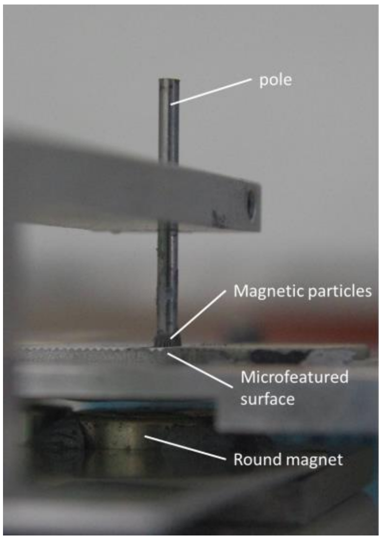


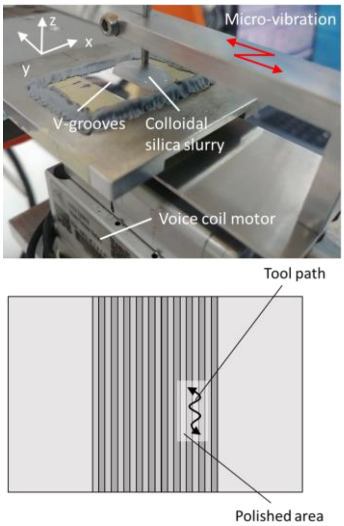
Figure 1. Schematic illustration of the VAMAP method.

Experimental setup

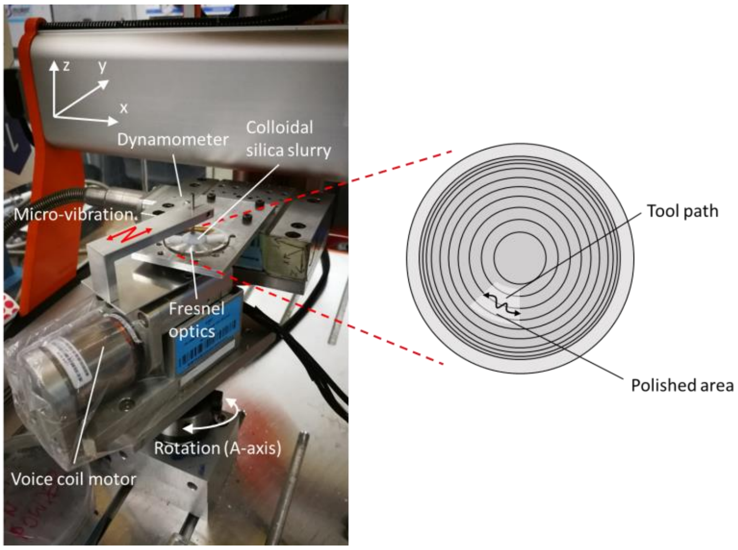
A polishing system was developed to verify the feasibility of the localized VAMAP method. Fig. 2(a), (b) and (c) shows the experimental setups for pole-magnet positioning, V-groove and Fresnel optics polishing, respectively. The V-groove and Fresnel optics samples were made of rapidly solidified aluminium RSA905. The vibration frequency was set to 50 Hz with an amplitude of 150 μm. The magnetic particles were made of iron powder with major size of 3 μm, and the loose abrasive slurry was made of colloidal silica with the average particle size of 50 nm in diameter. The iron powder plays as the carrier of the abrasives while colloidal silica performs material removal function. During polishing, the pole vibrated and scanned a S-curve on the microstructured surfaces. For V-grooves, the vibration direction is parallel to V-grooves to remove waviness and tool marks while for Fresnel optics, the vibration direction is perpendicular to the facets to reduce the tool mark effect caused by diamond turning.



(a)



(b)



(c)

Figure 2. Experimental setups for (a) pole-magnet positioning, (b) V-groove and (c) Fresnel optics polishing.

Results and discussions

Fig. 3(a) and (b) shows the surface roughness profiles of V-groove structures before and after polishing, respectively. 25% diluted colloidal silica slurry was used and the polishing time lasted about 2 h. The surface roughness decreased from 14.2 nm Ra to 6.6 nm Ra, a reduction of over 50%. For Fresnel-type structures, the polishing was also conducted using 25% diluted colloidal silica slurry for 1.5 h. As shown in Fig. 4(a) and (b), the surface roughness was reduced from the initial value of 10.4 nm Ra to 7.7 nm Ra.

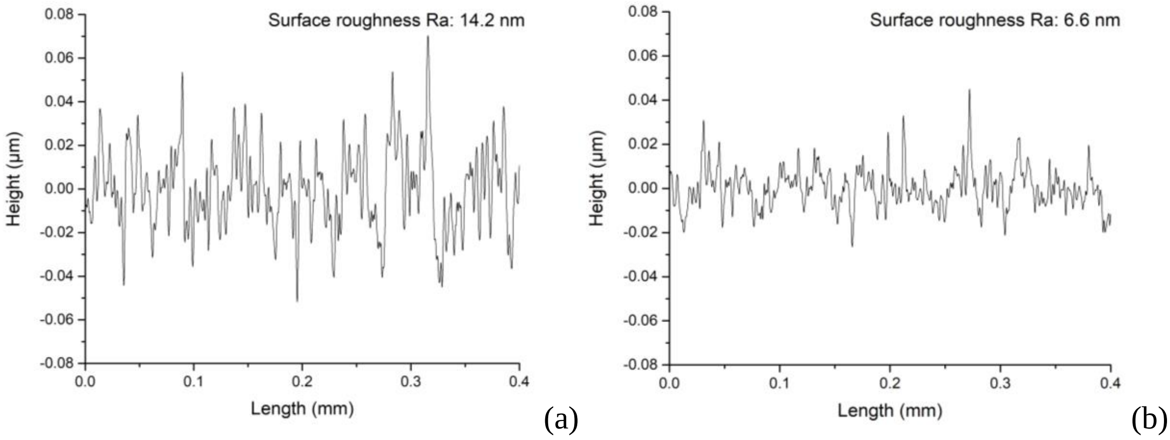


Figure 3. Surface roughness of V-groove structures (a) before and (b) after polishing.

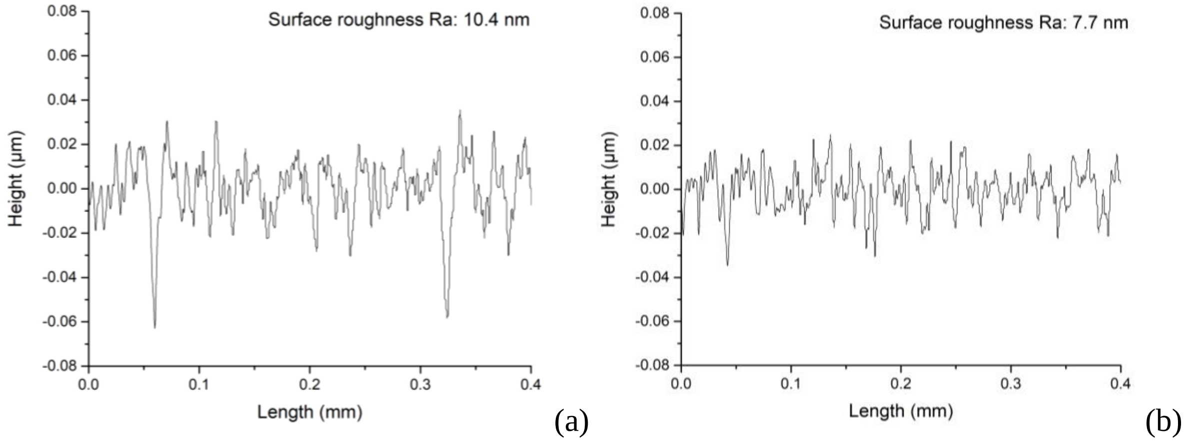


Figure 4. Surface roughness of Fresnel-type structures (a) before and (b) after polishing.

As shown in Fig. 5(a), the form difference between initial and polished microfeatures of V-grooves was quite small in the range of a few micrometers. The change on side surface of microfeatures was less than 1 μm. It was relatively large at the peak and valley of microfeatures, indicating that the sharp corners became round after polishing, but the difference was still less than 5 μm. For the microfeatures of Fresnel optics as shown in Fig. 5(b), similar results were obtained that the form change was quite limited on the facets. As the vibration direction was perpendicular to the microstructures, the forms at the peak and valley corners were changed more than those of V-grooves, but still less than 50 μm. It should be pointed out that as the diamond stylus has a radius of 2 μm at the tip, the form at valley and peak may not be precisely evaluated so it will be further confirmed by SEM observation.

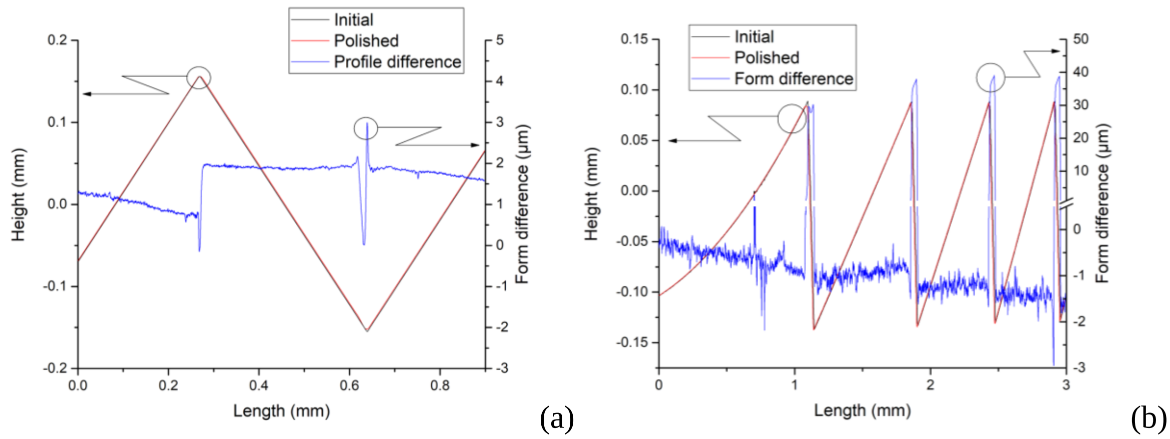


Figure 5. Form change of (a) V-groove and (b) Fresnel-type structures before and after polishing.

The surface defects were further examined by SEM. As shown in Fig. 6(a), before polishing voids and scratches can be found on top, side and bottom of V-groove structures. The voids were caused by the loss of higher hardness grains due to the relatively higher stresses during V-grooving process. After polishing, from Fig. 6(b) it can be seen that these defects were clearly removed and a smooth surface was obtained. The form was well maintained although the valley became slightly rounder.

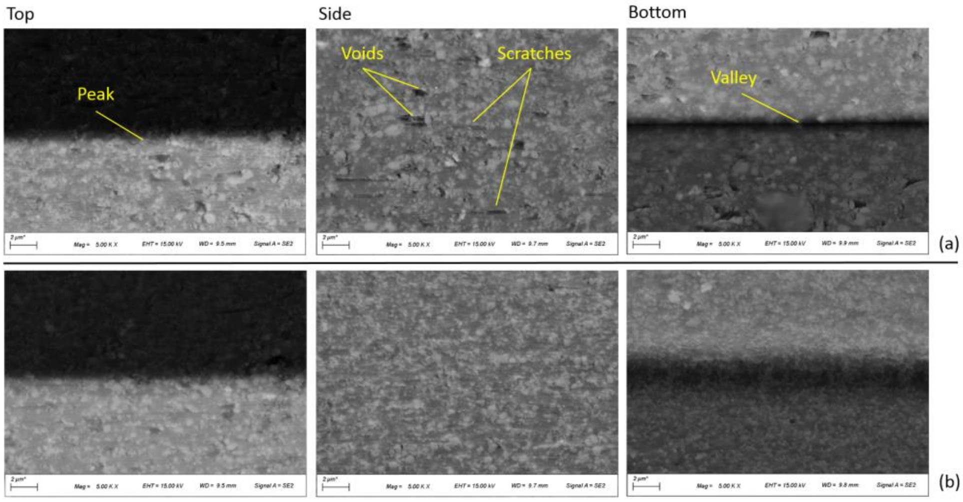


Figure 6. Secondary electron images of surface morphologies on top, side and bottom of V-groove structures (a) before and (b) after polishing.

Summary

The VAMAP method is capable of improving surface quality and maintaining the form of microfeatures of V-groove and Fresnel optics. By using loose abrasives, nanometric surface roughness was achieved and the surface defects were removed which will improve the optical performance.

References

[1] M. Brass, J. M. Enoch, E. W. Van Stryland, and W. L. Wolfe, Handbook of Optics (Volume III), in: Vision and Vision Optics, McGraw-Hill Education, 2010.

[2] F. Z. Fang, X. D. Zhang, A. Weckenmann, G. X. Zhang, and C. Evans, Manufacturing and measurement of freeform optics, CIRP Ann. 62 (2013) 823–846.

[3] W. T. Xie, Y. J. Dai, R. Z. Wang, and K. Sumathy, Concentrated solar energy applications using Fresnel lenses: A review, Renew. Sust. Energ. Rev. 15.6 (2011) 2588-2606.

[4] W. B. Kim, S. H. Lee, and B. K. Min, Surface finishing and evaluation of three-dimensional silicon microchannel using magnetorheological fluid, Journal of manufacturing science and engineering. 126.4 (2004) 772-778.

[5] E. Brinksmeier, O. Riemer, and A. Gessenharter, Finishing of structured surfaces by abrasive polishing, Precision Engineering. 30.3 (2006) 325-336.

[6] J. Guo, K. Liu, Z. Wang, and G. L. Tnay, Magnetic field-assisted finishing of a mold insert with curved microstructures for injection molding of microfluidic chips, Tribology International. 114 (2017) 306–314.

[7] J. Guo, C. W. Kum, K. H. Au, Z. E. E. Tan, H. Wu, and K. Liu, New vibration-assisted magnetic abrasive polishing (VAMAP) method for microstructured surface finishing, Opt. Express. 24.12 (2016) 13542-13554.