euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
www.euspen.eu

Study on the effect of milling strategy on machining outcomes during the micro-milling of glow discharge polymer

Ruiyang Guo, Guo Li*, Kai Du

Laser Fusion Research Center, China Academy of Engineering Physics, Mianyang, Sichuan, 621900, China

**ryguo1997@163.com*

Abstract

Glow discharge polymer (GDP) micro-shells with controllable microstructures are taking place as the most commonly used ablator material in confined inertial fusion applications. Machining performance of GDP microstructure is critical to its surface quality and service performance during micro-milling. This study mainly investigates the effect of two typical milling strategies on machining performance and surface morphologies in micro-milling of GDP. A novel trajectory planning approach for GDP micro-milling was first proposed based on the self-developed five-axis ultra-precision machine tool. A series of multi-target micro-pit machining experiments were conducted on GDP surface by a single-edge diamond tool corresponding to two typical milling strategies (case one: B-axis is fixed during machining and case two: B-axis rotates corresponding to the target position during machining, respectively). The machining performances of the aforementioned two milling strategies were analyzed and compared from the perspectives of chip geometry and surface roughness. Experiments demonstrate that the milling strategy of case one shows superior machining performance compared to case two with an reduction in surface roughness of 75.34% This study could provide guidance for machining performance analysis of the common polymers during milling.

Machining performance, milling strategy, glow discharge polymer, micro-milling, single-edge diamond tool

1. Introduction

Glow discharge polymer (GDP) microshell is widely used as an ablator in inerial confinement nuclear fusion (ICF) field[1]. Machining of micro-pits, micro-grooves on the surface of GDP is of great concern to hydrodynamic instability induced by Rayleigh-Taylor effect, which contributes to better absorption of high-power laser energy[2]. However, the effect of the milling strategy on the surface quality during the micro-milling of GDP remained unclear, which need to be studied systematically.

Milling strategy has great influence on the microstructure machining quality, which has attracted the attention of many scholars. Li et al.[3] analysed the effects of down/up milling, as well as the fiber cutting angle, on the cutting force, vibration and surface quality, and then proposed a hybrid (up-down-up) milling strategy. Cui et al.[4] studies the cutting force and surface quality of ultra-precision milling with a single-edged diamond tool under different cutting strategies. It found that under the cutting strategy of down milling, chip residue randomly appears on the machined surface and decreases the surface quality. Patil et al.[5] investigated the helical milling strategy through computer aided tool path as a viable option for Hole production. The results shown that cutting speed and feed/tooth affect the circularity of the hole. It's worth noting that the current studies on machining strategy mainly focus on the optimization of the machining technology, while few studies lay on the milling strategy introduced by the machine structure.

The main contributions of this paper are: (1) A novel trajectory planning approach for GDP micro-milling was first proposed. (2) A series of multi-target micro-pit machining experiments were conducted on GDP surface by a single-edge diamond tool. (3) The machining performances of the typical two milling strategies were analyzed and compared.

2. Experimental details

A ultra-precision five-axis machine tool, equipped with a pneumatic spindle with a maximum speed of 80k rpm and a runout within 30 nm, was developed for the machining of GDP micro-pits (**Figure 1**). The feed motion was provided by three linear motors installed on X/Y/Z hydrostatic guide rails with a resolution of 0.1 µm, a repetitive positioning accuracy of ±0.5 µm, and working strokes of 260×60×260 mm, respectively. While its rotary motion was realized by a hydraulic rotating shaft (B-axis) clamped on Z axis with a resolution of 0.4" and a repetitive positioning accuracy of 1.5". Morever, an arc single-edge diamond tool (SDT) with a radius of 246 µm was attached to the spindle by pneumatic chuck for milling.

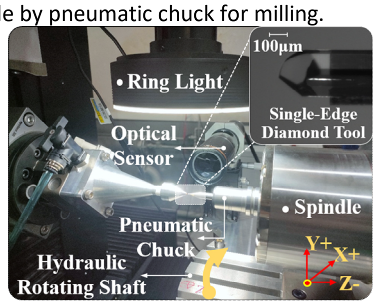

Figure 1. Ultra-precision five-axis machine tool

3. Trajectory planning approach

Aiming at the engineering requirements of evenly distributing several microstructures on the surface of the microshell, a novel point-set distribution and trajectory planning approach was proposed based on based on Fibonacci principle. First, the coordinate system O_w-$X_wY_wZ_w$ was established with the microshell center as the origin. Then divide the microshell into N laters along the O_w-Z_w direction, and the midpoint of layer i was:

(1)

Based on the Fibonacci principle, the *X* and *Y* directions were distributed in an arithmetic sequence, which can be expressed as:

(2)

(3)

Where .

Based on the secondary development software, the milling trajectory of the surface microstructure was obtained, as shown in **Figure 2**.

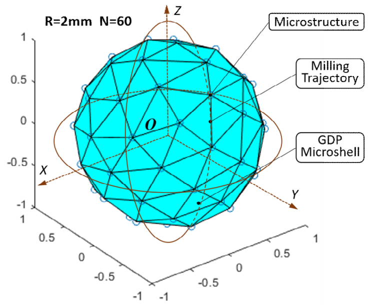

Figure 2. Ultra-precision five-axis machine tool

4. Results and discussion

A series of micro-pits microstructures were machined on surface of the GDP microshell corresponding to two typical milling strategies. Case one: B-axis was fixed during machining and case two: B-axis rotated corresponding to the target position during machining, respectively. Case two introduces B-axis coordinates when programming compared with case one. The deyailed milling parameters were presented in **Table 1.** And the tests were repeated three times for each group of parameters.

Table 1 The milling parameters applied in the micro-milling tests of GDP microshell.

Tool overhang length (mm)	**Spindle speed** ($\times 10^3$rpm)	**Milling depth** (μm)	**Feed rate** (mm/s)
20	25, 35, 45	4	0.02

The surface morphologies of GDP micro-pits at processing parameters of case one and two were illustrated in **Figure 3**. It can be seen that the surface roughness decreases with the increase of the spindle speed, which can be explained that a higher spindle speed forms a larger material removal rate, and the material accumulation is effectively alleviated, improving the machined surface quality.

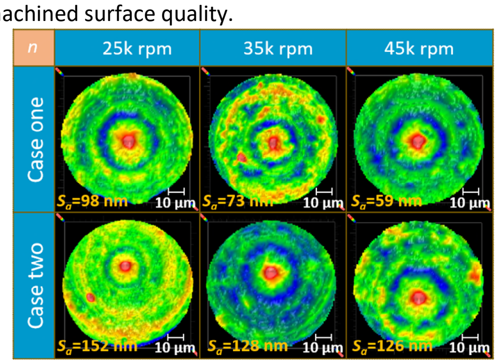

Figure 3. Surface morphologies of GDP micro-pits

It is worth outlining that the surface quality of the micro-structure formed by the B-axis rotary milling strategy is worse than that when the B-axis is fixed. Taking the spindle speed of 35k rpm as an example, the surface roughness corresponding to case two is 128 nm with a standard deviation of 4.04 nm, while the surface roughness of case one is 73 nm with a standard deviation of 3.05 nm, an sharp increase of 75.34%. It can be explained that B-axis rotation error is introduced when B-axis participates in milling, which affects the machining accuracy of machine tool. It indicates that case one (B-axis is fixed) is more conducive to forming perfect surface quality. In addition, it found that further increase in spindle speed has a poor effect on improving the surface quality of the microstructre. It is acceptable considering that the rotation error introduced by B-axis weakens the improvement effect of material removal rate on machining surface quality.

Further, based on milling case one of milling strategy one, the machining parameters were optimized as *n*: 27k rpm and *f*: 0.01mm/s and the optimized machined surface was obtained, as shown in **Figure 4**. The excellent surface roughness achieve is 27 nm with a maximum PV value of 0.24 μm, indicating that the B-axis fixed milling strategy has good machining performance.

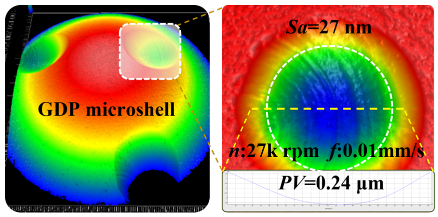

Figure 4. Surface morphology under optimized parameter combination of case one

5. Conclusion

This study investigates the effect of two typical milling strategies on machining performance and surface morphologies in micro-milling of GDP, and proposed a novel trajectory planning approach for GDP micro-milling based on the self-developed five-axis ultra-precision machine tool. Through a series of multi-target micro-pit machining experiments, the machining performances of the aforementioned two milling strategies were analyzed and compared. It found that surface roughness decreases with the increase of the spindle speed, and the surface quality of the micro-structure formed by the B-axis rotary milling strategy is worse than that when the B-axis is fixed. The results show that further increase in spindle speed has a poor effect on improving the surface quality of the microstructure, provide guidance for machining performance analysis of the common polymers during milling.

References

[1] Guo R, Yu T, Zhou X, et al. Chip geometry modeling in micro-milling of glow discharge polymer by a single-edge diamond tool considering tool inclination[J]. Journal of Materials Processing Technology. 2023, **320**: 118109.

[2] Guo R, Yu T, Chen M. Frictional behavior of tool-workpiece on surface quality of glow discharge polymer during micro-milling[J]. Wear. 2023, **522**: 204707.

[3] K Li C, Liu N, Chen L, et al. Analysis of the effects of different milling strategies on helical milling of unidirectional CFRP under minimum quantity lubrication[J]. Journal of Manufacturing Processes. 2024, **132**: 27-37.

[4] Cui Z, Liu H, Wu L, et al. Cutting force and surface quality in ultra-precision milling of oxygen-free copper under different cutting strategies[J]. Journal of Manufacturing Processes. 2024, **131**: 2420-2442.

[5] Patil A S, Sunnapwar V K, Bhole K S. Cumulative effect of Shearing parameters and Ramp angle on Hole surface quality in Ti6Al4V by Helical milling strategy[J]. Materials Today: Proceedings. 2024, **113**: 147-151.