Observations on Ductile Laser Assisted Diamond Turning of Tungsten Carbide

Di Kang, Jayesh Navare, Yang Su, Dmytro Zaytsev, Deepak Ravindra, Hossein Shahinian
Micro-LAM, Inc., 5960 S Sprinkle Rd., Portage, Michigan, 49002
Author e-mail address: hossein.shahinian@micro-lam.com

Abstract: X-ray diffraction and scanning electron microscopy were used to assess the subsurface integrity of tungsten carbide samples processed by micro laser assisted machining. The effects of laser power and tool condition were evaluated.
OCIS codes: (220.1920) Diamond machining; (220.4610) Optical fabrication.

1. Introduction

Tungsten carbide (WC) is an emerging material in precision glass molding to fabricate optical components used in consumer electronics. WC molds can be finished by traditional processes such as grinding and polishing, which are usually lengthy. Single point diamond turning (SPDT) of WC is uncommon, as its high hardness tends to induce brittle fracture zones on the work piece and rapid tool wear [1]. The ductile cutting depth of WC could be improved by optimizing process parameters such as coolant and tool radius, although it was still limited to about 1 μm [2].

The micro laser assisted machining (μ-LAM) process provides a viable enhancement to SPDT, which facilitates ductile mode material removal by locally heating the cutting region with laser [3, 4]. A more detailed description of how the μ-LAM technology is incorporated into SPDT can be found in [5]. This paper examines the subsurface integrity of WC samples with different test conditions using μ-LAM.

2. Samples and method

Three cylindrical, binderless WC samples with dimensions of roughly 15 mm (length) × 3 mm (diameter) were tested. One planar surface on each sample was machined with a 2000 rpm spindle speed, 2 mm/min feed rate, 1 μm depth of cut, and a tool with 0.5 mm nose radius and -35º rake angle. Table 1 lists the laser power and total number of passes used during μ-LAM of the samples.

Table 1 Machining parameters for WC samples

Test No.	Laser power	Total passes
1	3 W	5
2	6 W	12
3	6 W	5

After machining, a JEOL IT-500HR scanning electron microscope (SEM) was used to image the surfaces. For each sample, a micrograph was taken between the center and edge with an accelerating voltage of 15 kV. XRD was done on a Siemens D5000 diffractometer, with Cu Kα radiation at 40 kV and 30 mA. A Bragg-Brentano scan range of 46-51º was used to profile the strongest (101) peak, at a speed of 17 mrad/min. Grazing incidence scans were performed at 3º and 5º, corresponding to a penetration depth of about 240 nm and 400 nm, respectively. The beam size is about 2 mm (width) × 12 mm (height).

3. Results and discussion

Fig. 1 shows secondary electron images of the WC samples after SPDT. Test 1 exhibits the highest density of defects with some large ones, while test 2 has fewer and smaller defects and test 3 is the best among the three. This suggests that higher laser power and a newer tool yield the best surface, and laser power is more influential than tool condition on surface finish. Even for test 1, much of the surface region is free of brittle fracture, suggesting that the laser promoted ductile mode material removal. The average grain size is estimated to be about 300 nm, and energy dispersive X-ray spectroscopy (EDS) confirms that the samples have no binder material.

Grazing incidence XRD enables characterization of a shallower surface layer. The data can be compared with regular Bragg-Brentano scans to identify differences between the surface and subsurface. Fig. 2 shows the grazing incidence results at 5º for the samples, in which test 1 has the widest peak and test 3 has the narrowest (the wider a peak, the more residual stress/less perfect crystal). Peak width can be quantified using full width at half maximum

(FWHM) calculated from Gaussian curve fitting in MATLAB. The results from regular and grazing incidence scans are shown in Fig. 3.

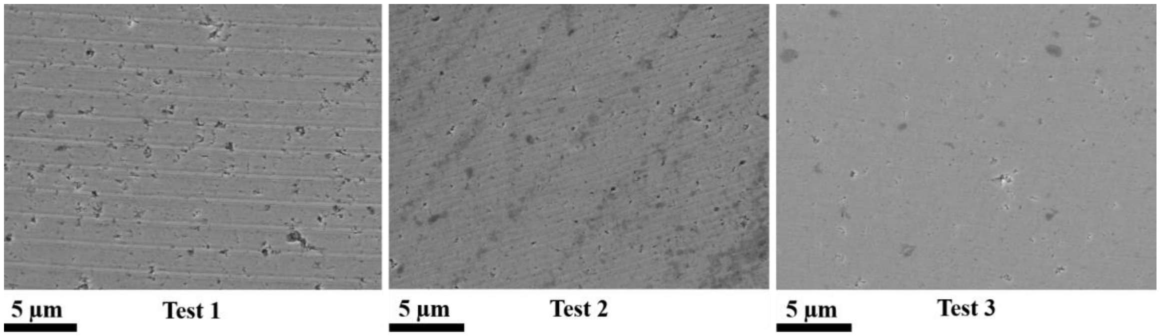

Fig. 1 Secondary electron images of the WC samples after µ-LAM

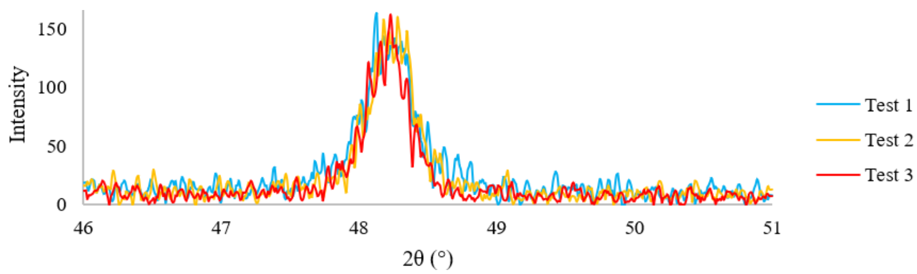

Fig. 2 Grazing incidence (5º) XRD line profiles of the WC samples after µ-LAM

Fig. 3 FWHM of (101) peaks from grazing incidence and regular scans of the WC samples after µ-LAM

In all cases, the FWHMs are smallest for test 3 and largest for test 1, consistent with the implications from SEM that test 3 has the best surface finish. Furthermore, the difference is more significant at smaller incident angles (3º), indicating that the material near the surface is more affected by SPDT. The FWHMs are almost equal for regular scans (about 1.9 µm penetration depth), suggesting that the deformation layer is minimal (around 1 µm) and the sub-surface remains intact.

4. Conclusions

SEM and XRD analyses of three µ-LAM WC samples suggest that high laser power and a new cutting tool yield the best surface and that the deformation layer is shallow, at about 1 µm.

5. References

1. Nath, C., M. Rahman, and K. Neo, *A study on ultrasonic elliptical vibration cutting of tungsten carbide.* Journal of Materials Processing Technology, 2009. **209**(9): p. 4459-4464.
2. Doetz, M., et al. *Ductile mode single point diamond turning (SPDT) of binderless tungsten carbide molds*. in *Optical Manufacturing and Testing XII*. 2018. International Society for Optics and Photonics.
3. Ravindra, D., *Ductile mode material removal of ceramics and semiconductors.* 2011.
4. Ravindra, D., M.K. Ghantasala, and J. Patten, *Ductile mode material removal and high-pressure phase transformation in silicon during micro-laser assisted machining.* Precision engineering, 2012. **36**(2): p. 364-367.
5. Shahinian, H., et al., *Micro Laser Assisted Machining (µ-LAM) of Precision Optics.* to be published in Optical Design and Fabrication 2019 (Freeform, IODC, OFT), OSA Technical Digest (online) (Optical Society of America, 2019). 2019.