euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Sharpening nanotwinned cubic boron nitride (nt-cBN) cutting tool using femtosecond laser ablation

Jinhu Wang[1], Junyun Chen[2], Qingliang Zhao[1], Tianye Jin[3]

[1]*School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, 150001, China*
[2]*College of Vehicles and Energy, Yanshan University, Qinhuangdao, 066004, China*
[3]*College of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, China*

Jhwang86@163.com

Abstract
The novel developed nanotwinned cubic boron nitride (nt-cBN) can potentially be used for direct ultra-precision machining of ferrous materials because of its high hardness and superb chemical stability. In this study, a femtosecond laser micromachining system was applied to sharpen the nt-cBN cutting tool edge. Experiments on laser ablation of points were presented firstly under a serious of laser power to investigate the material removal mechanism. Then various scan strategies were discussed to optimize the quality of rake face and flank surface, and keep the cutting edge as sharp as possible. At last, rounded cutting edge with radius less than 1μm was fabricated by scanning the laser beam parallel to the cutting edge and feeding from the flank surface to the rake face.

Keywords: femtosecond laser, nano-twinned CBN, cutting edge

1. Introduction

CBN has high hardness, superb chemical and thermal stability, so it is potential to be used as tool material for ultra-precision machining of ferrous or carbide-forming hard substances where diamond completely fails. Binderless PcBN (BL-PcBN) is synthesized with no binder materials, possesses finer grain size and better mechanical properties compared to commercial PcBN [1, 2]. Even the BL-PcBN cutting tool has been made as sharp as single diamond cutting tool [3]. However, reports about BL-PcBN cutting tool are less, and the tool manufacturing process has never involved.

Ultra-sharp cutting edge of single-crystal diamond cutting tool is generally formed combining mechanical action with thermochemistry [4, 5]. But BL-PcBN possesses better thermo-chemical stability, which makes the sharp cutting edge difficult to fabricate by using the conventional methods for lapping diamond. In this study, the novel nt-cBN was used as cutting tool material, and femtosecond laser machining was studied as the first step to sharpen the nt-cBN cutting edge.

2. Experiment

2.1. The used material

Nt-CBN is obtained from onion-like BN at high pressure and high temperature, which possesses a Vickers hardness of 95GPa~108GPa, a fracture toughness of 12MPa·m$^{1/2}$, and a high oxidization temperature of 1294°C [6].

2.2. The femtosecond laser system

The experiments were carried out on a self-developed femtosecond laser fabrication system that consisted of Ti: sapphire laser, four-dimensional workbench from PI Company, and accessories including shutter, beam expansion unit, glan-laser polarizer, lens screen et al. Laser beam with a pulsewidth of 50 fs and a central wavelength of 800 nm is directed via multiple bending mirrors and focus on the workpiece by focusing lens (f=50mm).

2.3 Experiment details

Experiments on laser ablation points were carried out under a serious of laser power to investigate the material removal mechanism. Then laser scanning strategies were optimized for the quality of rake face and flank surface, keeping the cutting edge as sharp as possible. At last, sharp cutting tool edge was fabricated by the optimized process.

3. Results and discussion

3.1 material removal mechanisms

According to the laser ablation experiments, nt-CBN is easier to be ablated compared to single-crystal diamond or even SiC. Fig. 1 shows the laser ablated points with 1000 pulses. All craters share a large depth-width ratio and the cumulative effect of laser pulses is noticeable. The reason is that the crystal defects including both of the grain boundary and twin boundary could be expanded under the irradiation of laser pulses. Increasing of defects density reduced the threshold fluence (F_{th}) and the material is ablated by the following pulses. That means less irradiation is beneficial to the sub-surface quality of nt-CBN.

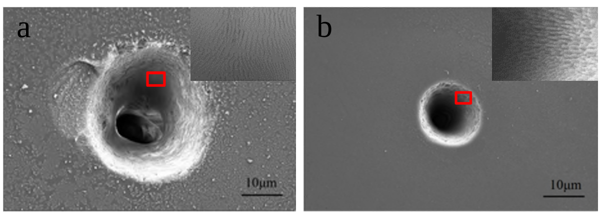

Fig. 1. Laser ablated craters with 1000 pulses. (a) 60mW. (b) 10mW. Insets show the side wall of the corresponding crater

Furthermore, with higher laser power, the side wall of crater was covered by recast layer, shown in Fig. 1(a). As the laser power decrease, periodic micro-structures are more and more regular, shown in Fig. 1(b). These two kinds of ablation surface correspond to different material removal mechanism. The Coulomb explosion predominates under the low laser fluence, while the phase explosion prevails for the high fluence ablation. Therefore, the lower energy should be adopted in sharping process of nt-CBN cutting tool in order to avoid recast.

3.2 forming of rake face

Ablation experiments with the laser beam parallel and perpendicular to the rake face were carried out, respectively. With parallel laser beam, chippings can be removed easily, and secondary adhesion is avoided efficiently. Also, the machined surface was formed by the verge of laser spot where the laser fluence equal to F_{th}. Fig. 2 (a) shows the rake face machined by parallel laser beam. It is flat and covered with uniform periodic microstructures. The machined surface quality is insensitive to process parameters such as scan speed and laser power. As the laser beam perpendicular to the rake face, energy show an uneven distribution and materials under the centre of laser spot will be removed more. So the choice of laser power, scan speed and feed width will affects the surface morphology directly. Moreover, feed depth is difficult to select in multilayer ablation because of the indeterminacy of ablation depth. Accumulated deviation will make the focus position inaccurate and result to efficiency reduction. Fig.2 (b) shows rake face machined by perpendicular laser beam, which are rough and adhered more chippings. The insert shows that the portion under the centre of laser spot is a pit while the portion next to the spot centre is periodic microstructures.

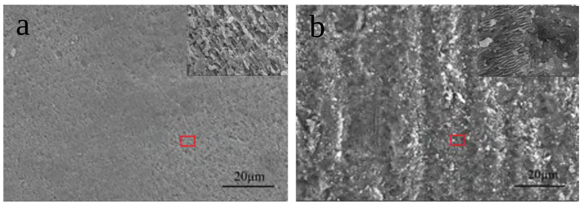

Fig. 2. Laser machined rake face. (a) Laser beam parallel to rake face, 60mW, 0.1mm/s. (b) Laser beam perpendicular to rake face, 10mW, 0.1mm/s. Insets, amplifications corresponding to the position marked with red box.

3.3 forming of sharp cutting edge

Processing of flank surface means cutting edge formation, so surface quality is demanding to meet the requirement of edge roundness and sharpness. When the laser beam perpendicular to flank surface, flatness can't be guaranteed because of uneven distribution of laser energy and high energy in the centre of laser spot will damage the cutting edge. Two scan strategies could be considered if the laser beam parallel to the flank surface, scan perpendicular or parallel to the cutting edge, as is shown in Fig. 3. For the former scanning strategy, the relief angle of cutting tool can be controlled by slope of scan path. However, the process parameters had a great influence on machining quality, because the energy distribution on cutting edge is mainly affected by the laser power and feed width between each scanning, as shown in Fig. 4(a). By the later strategy, laser beam parallel to the cutting edge and feeding from flank surface to rake face. The relief angle can be adjusted by additional device to rotate the cutting tool around x-axis in advance. Both of the flank surface and cutting edge got uniform irradiation and the cutting edge is formed at the verge of laser spot where the laser fluence equal to F_{th}. Uneven energy distribution was avoid but interference between the machined surface and laser beam is inevitable, because the laser beam is focused into cone. So width of machined material along the incident direction of laser beam is restricted and accuracy of relief angle is affected too.

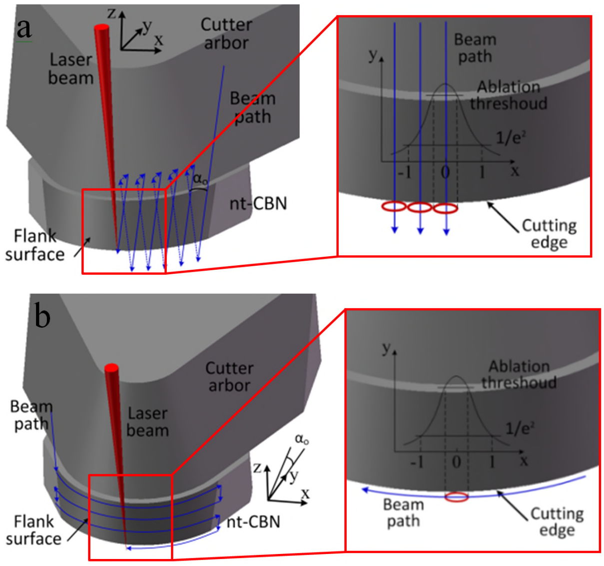

Fig. 3. Laser scan path in forming of flank surface. (a) Perpendicular to the cutting edge. (b) Parallel to the cutting edge**.**

Nt-CBN cutting tools were fabricated by scanning laser beam parallel to the cutting edge and feeding from the flank surface to the rake face. One of the sharpened cutting edges with radius about 1μm is shown in Fig. 4. It is found that times of scan make a greater influence on sharpness of cutting edge compared to laser power.

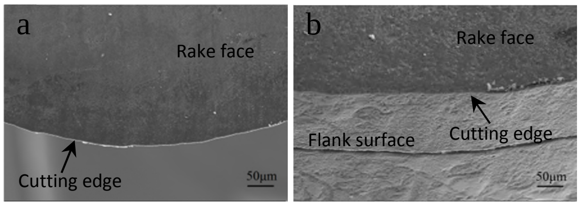

Fig. 4. Laser machined nt-CBN cutting tool with nose radius of 1.2 mm and clearance angle of 7°. (a) The rake face. (b) The cutting edge.

4. Summary

Because of high hardness and fine thermo-chemical stability, forming of nt-CBN cutting edge by mechanical lapping takes several hours. However, crystal defects in nt-CBN make it easily ablated by pulse laser, so the laser beam scan strategy was optimized in this paper. The surface quality is more satisfactory when the laser beam parallel to the machined surface, then cutting edge was fabricated by scanning laser beam parallel to the cutting edge. It is conclude that femtosecond laser is suitable for forming of nt-CBN cutting tool because of high efficiency. Forming of cutting edge takes only several minutes and even can be less by using special fixture. However, the cutting edge quality can hardly meet the requirements of ultra-precision cutting and post-processing is necessary such as ion beam polishing or mechanical lapping.

In future works, a laser beam forming and mechanical lapping process chain will be investigated. Cutting performance of nt-CBN cutting tool for ferrous materials will also be tested.

References

[1] H Sumiya, K Harano, Y Ishida 2014 Diamond Relat. Mater. **41** 14-19
[2] V L Solozhenko, O O Kurakevych, Y L Godec 2012 Adv. Mater. **24** 1540–1544
[3] Fujisaki K, Yokota H, Furushiro N, et al. 2009 J. Mater. Process. Technol. **209** 5646-5652.
[4] W J Zong, D Li, T Sun, et al. 2007 International Journal of Machine Tools & M anufacture **47** 864 – 871.
[5] J A Weima, W R Fahrner, R Job. 2001 J. Solid State Electrochem. **5** 112~118.
[6] Y J Tian, B Xu, D L, Yu, et al. 2013 Nature **493** 385- 388.