

## **ROTARY ULTRASONIC MACHINING OF POLY-CRYSTALLINE CUBIC BORON NITRIDE**

Marcel KURUC<sup>1</sup>, Jozef PETERKA<sup>1</sup>

### **ABSTRACT**

*Poly-crystalline cubic boron nitride (PCBN) is one of the hardest material. Generally, so hard materials could not be machined by conventional machining methods. Therefore, for this purpose, advanced machining methods have been designed. Rotary ultrasonic machining (RUM) is included among them. RUM is based on abrasive removing mechanism of ultrasonic vibrating diamond particles, which are bonded on active part of rotating tool. It is suitable especially for machining hard and brittle materials (such as glass and ceramics). This contribution investigates this advanced machining method during machining of PCBN.*

### **KEY WORDS**

*Rotary ultrasonic machining, cubic boron nitride, very hard materials*

### **INTRODUCTION**

PCBN is very hard material which is manufactured by sintering (at 1500 °C and 5 GPa) and therefore additional treatment usually is not necessary. However, there are some applications, where machining of PCBN is required. One of these application could be tools for friction stir welding (FSW). The principle of FSW consists in application of a rotating tool with specially designed shoulder pin which is impressed to the boundary of welded materials. Mechanical power is transferred to heat during the welding process. Advantages of FSW process include: low heat input, low residual stress, increased mechanical properties, safety, environmentally friendly, welding without spatter and filler metal, etc. (1,2,3,4,5).

Welding tool used in FSW process must be sufficiently tough, robust and wear resistant at welding temperature. Other requirements include: good oxidation resistance and low coefficient of thermal conductivity to minimize the thermal losses. Shoulder profile is usually concave, which prevent an escape of welded volume for the material displaced by the pin. These tools are characterized by different sizes depending on thickness of welded plates, and by different geometry depending on welded material. In experiments, tool for FSW of 2 mm thick steel plates with diameter 12 mm has been created by RUM.

---

Marcel KURUC, Jozef PETERKA

<sup>1</sup> Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, J. Bottu 25, 917 01 Trnava, Slovak Republic, [marcel.kuruc@stuba.sk](mailto:marcel.kuruc@stuba.sk), [jozef.peterka@stuba.sk](mailto:jozef.peterka@stuba.sk)

## MACHINING EQUIPMENT

Rotary ultrasonic machining (RUM) is applied in experiments. RUM utilize rotary tool, which oscillate by ultrasonic frequency (above 20 kHz). Interaction of rotating motion and vibration cause microcracks on surface, which are broken and lead away as microchips. This effect is also enhanced by cavitation effect of coolant. Coolant is feed on tool-workpiece interface and therefore proper properties of coolant are necessary. Due to this principle, very hard and brittle materials can be machined. Advantages of this process include decreasing of cutting force, reduction of generation of heat, increasing of tool life, improving of machined surface (roughness, accuracy), etc. In this experiment, rotary ultrasonic milling machine ULTRASONIC 20 linear (see Fig. 1), made by DMG Mori Seiki has been used. It can work continuously in five axis (6,7,8,9).



*Fig. 1 ULTRASONIC 20 linear*<sup>6</sup>

There has been used ultrasonic milling cutter with diameter 24 mm. NC program for machining has been generated by CAM software PowerMill designed by Delcam company. This software has been supported by CAD software PowerShape, designed by the same company (10).

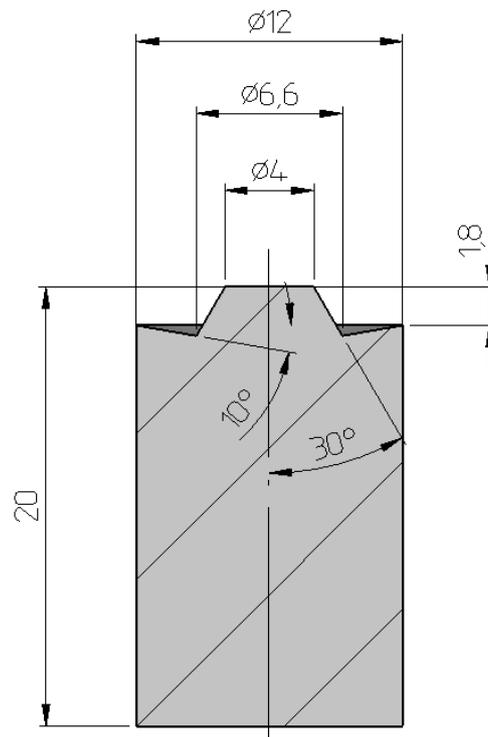
## DESCRIPTION OF EXPERIMENT

Poly-crystalline cubic boron nitride (PCBN) has been used as machined material. This material provides for experiments Welding Research Institute – Industrial Institute of Slovak Republic in Bratislava (VÚZ – PI SR), which also demand creation tool for FSW.

PCBN consists of grains of cubic boron nitride in alumina matrix with alloying of cobalt. EDX microanalysis has been used on this specimen. Analysis has been made in Laboratory of structural analysis in Faculty of Materials Science and Technology in Trnava, Slovak University of Technology in Bratislava (MTF STU). EDX analysis provides chemical composition, which is shown in Tab. 1. PCBN is characterized by very high hardness. Its value is usually over 8000 HV, (over 80 GPa). It is usually utilized as cutting material for machining of ferrous materials, such as hardened steels, etc. (11,12,13).

| <b>B</b><br>[wt. %] | <b>N</b><br>[wt. %] | <b>Al</b><br>[wt. %] | <b>O</b><br>[wt. %] | <b>Co</b><br>[wt. %] |
|---------------------|---------------------|----------------------|---------------------|----------------------|
| 46.99               | 40.58               | 6.26                 | 4.68                | 1.49                 |

Cylinder made of PCBN with diameter 12 mm and length 20 mm have been used for experiments. Specimen has been machined to shape of above mentioned tool for FSW. Dimensioned longitudinal section of this tool is shown in Fig. 2. Surface quality of machined area has been evaluated: by roughness obtained by confocal microscope; and by structure and chemical changes of machined area obtained by EDX microanalysis.

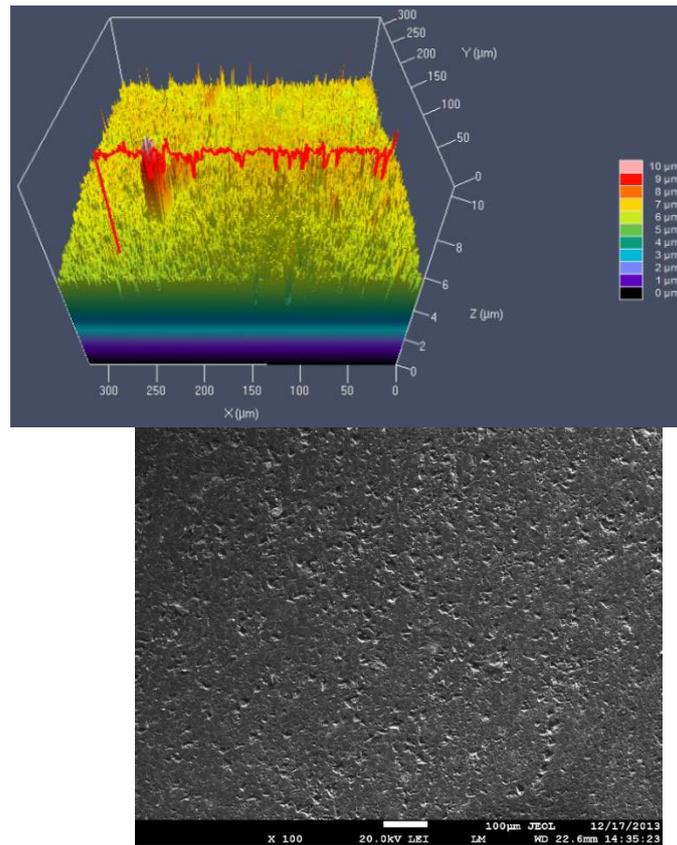


**Fig. 2** Tool for friction stir welding

Following machining parameters have been used: spindle speed 8000 rpm, feed rate 300 mm.min<sup>-1</sup>, depth of cut 0.003 mm, frequency of vibration 21.6 kHz, amplitude 6 μm.

## RESULTS

After RUM of FSW tool, specimen has been send to confocal microscope and EDX microanalysis for obtaining surface topography. Resultant topography of surface after RUM is shown in Fig. 3. On left image is shown 3D representation of machined surface. On the right side is 100 times magnified machined surface, which has been evaluated. There was measured many surface parameters. One of the most important surface parameters are arithmetic mean deviation of the assessed profile  $R_a$  and maximum height of the assessed profile  $R_z$ . Machined surface after RUM achieve value  $R_a$  0.24 μm and  $R_z$  2.834 μm (14).



**Fig. 3** Topography of machined surface after RUM

EDX microanalysis has been used also for determination of specimen's chemical composition of surface layer. Tab. 2 shown chemical composition of machined surface after RUM. There was not been obtained any significant changes in chemical composition. Existence of differences could be caused by not totally homogenous structure (14).

**CHEMICAL COMPOSITION OF SURFACE LAYER AFTER RUM PROCESS**

Table 2

| <b>B [wt. %]</b> | <b>N [wt. %]</b> | <b>Al [wt. %]</b> | <b>O [wt. %]</b> | <b>Co [wt. %]</b> |
|------------------|------------------|-------------------|------------------|-------------------|
| 41.96            | 41.94            | 6                 | 8.41             | 1.7               |

Evaluation of residual stresses and hardness changes is planned in further experiments, as well as comparison of reached results with else machining method proper for this purpose, such as laser beam machining (LBM).

**CONCLUSION**

RUM can achieve low roughness during machining of PCBN (Ra 0.24 μm). However, due requested shape (negative inverted cone), five axis machining is needed. In some cases, there could be problem to achieve proper shape, because angle value of cone is limited by diameter of used tool. However, surface after RUM show absence of ledges. It is caused by fact, that depth of cut was lower than amplitude of tool vibration. Also, RUM does not affect chemical composition of machined area. Generally, tool for RUM is characterized by long tool life, however, during machining so hard material, such as PCBN, tool wear is more significant in comparison with machining of materials more typical for RUM, such as glass and ceramics.

Therefore, RUM should be suitable especially for finishing of surface. Then machined area maintains advantages of machined surface created by RUM (such as low roughness, no chemical affection, etc.). Influence of surface roughness on FSW process will be objective of further research. This research could be performed in Welding Research Institute – Industrial Institute in Bratislava. There could be also investigate possibility to create this tool for FSW process by laser beam machining (LBM) or high speed cutting (HSC) in workplace of Centre of Excellence of 5-axis machining in MTF STU.

## ACKNOWLEDGMENT

Authors want to thank to Ing. Marek Zvončan, PhD. for technical support, to Ing. Tomáš Kupec for ensure of cooperation with Welding Research Institute – Industrial Institute in SR, to Ing. Peter Zifčák PhD. for acquisition of material, to Ing. Kristián Šalgó for results from confocal microscope, to Ing. Martin Sahul, PhD. for EDX microanalysis, and to other people who help with this contribution.

This contribution is a part of the GA VEGA project of Ministry of Education, Science, Research and Sport of the Slovak Republic, No. 1/0477/14 “Research of influence of selected characteristics of machining process on achieved quality of machined surface and problem free assembly using high Technologies”.

This contribution is also elaborated by the support of Operational Project Research and Development of Centre of excellence of five axis machining, ITMS 26220120013, co-financed by European Funds for Regional Development.

*This contribution is elaborated by support  
of Operational Project Research and Development  
of Centre of Excellence of Five Axis Machining,  
ITMS 26220120013, co-financed  
by European Funds for Regional Development.*



We are supporting of research activities in Slovakia/  
Project is co-financed by sources of ES

## REFERENCES

1. Friction Stir Welding. Technical Handbook. ESAB 2011.
2. TWI – Friction Stir Welding. [online], [cit. 2014-03-01]. Available on the Internet: <http://www.twi.co.uk/technologies/welding-coating-and-material-processing/friction-stir-welding/>.
3. TURŇA, M. 1989. *Špeciálne metódy zvarania (Special welding methods)*. Bratislava: Alfa.
4. Friction Stir Welding. [online], [cit. 2013-11-20]. Available on the Internet: [http://med.iaun.ac.ir/site/files/iaun\\_staff\\_498.pdf](http://med.iaun.ac.ir/site/files/iaun_staff_498.pdf).
5. HRIVŇÁK, I. 2009. *Zváranie a zvariteľnosť materiálov (Welding and Weldability of Materials)*. Bratislava. Vydavateľstvo STU. ISBN 978-80-227-3167-6
6. Ultrasonic 20 linear. [online], [cit. 2013-12-12]. Available on the Internet: <http://en.dmgmori.com/products/ultrasonic/ultrasonic-linear/ultrasonic-20-linear>.

7. GERULOVÁ, K. 2012. *Metalworking Fluids Biodegradability and Ecotoxicity Assessment*. - 1st ed. - (Scientific monographs). Dresden: IFW, pp. 72. ISBN 978-3-9808314-7-5
8. GERULOVÁ, K. et al. 2013. Preliminary Study of Utilizing Ozone in Treatment of Operationally Exhausted Metalworking Fluids. In: *Advanced Materials Research*, Vol. **690-693**, pp. 1117-1121. ISSN 1022-6680(P), ISSN 1662-8985(E)
9. BEŇO, M., ZVONČAN, M. KOVÁČ, M. PETERKA, J. 2013. Circular interpolation and positioning accuracy deviation measurement on five axis machine tools with different structures. *Tehnicki Vjesnik - Technical Gazette*, **20**(3), pp. 479-484. ISSN 1330-3651
10. PowerMILL. [online], [cit. 2014-02-14]. Available on the Internet: <http://www.powermill.com/> .
11. Jiaqian Qin, Norimasa Nishiyama, Hiroaki Ohfuji, Toru Shinmei, Li Lei, Duanwei He, Tetsuo Irifune. 2012. *Polycrystalline  $\gamma$ -boron: As hard as polycrystalline cubic boron nitride*. Japan, 13 p. Available on Internet: <http://arxiv.org/ftp/arxiv/papers/1203/1203.1748.pdf> .
12. Changsha 3 Better Ultra-hard Materials Co. [online], [cit. 2013-10-23]. Available on the Internet: <http://3bdiamond.com/> .
13. Nanodiamond & Superhard Thin-films. [online], [cit. 2014-01-30] Available on the Internet: [http://www.cityu.edu.hk/cosdaf/cbn\\_property.htm](http://www.cityu.edu.hk/cosdaf/cbn_property.htm) .
14. ČAPLOVIČ, Ľubomír, SAHUL, Martin. 2011. Application of the EBSD technique for the evaluation of material properties. - ITMS 26220120048. In: *Vákuum a progresívne materiály. Vacuum and Advanced Materials. Škola vákuovej techniky*. Bratislava: Slovenská vákuová spoločnosť, s.10-13. ISBN 978-80-969435-9-3