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ROTARY ULTRASONIC MACHINING OF POLY-CRYSTALLINE CUBIC BORON NITRIDE

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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.

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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* [6]

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).

CHEMICAL COMPOSITION OF PCBN Table 1

B [wt. %]	N [wt. %]	Al [wt. %]	O [wt. %]	Co [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.

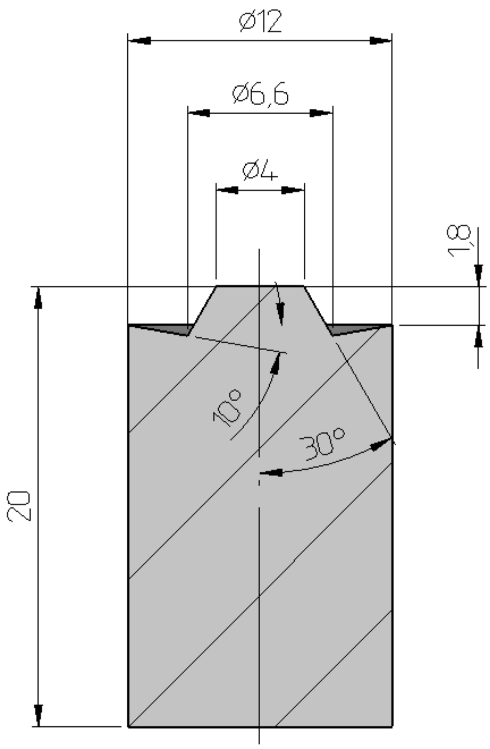

Fig. 2 *Tool for friction stir welding*

Following machining parameters have been used: spindle speed 8000 rpm, feed rate 300 $mm.min^{-1}$, 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 *Ra* and maximum height of the assessed profile *Rz*. Machined surface after RUM achieve value Ra 0.24 μm and Rz 2.834 μm (14).

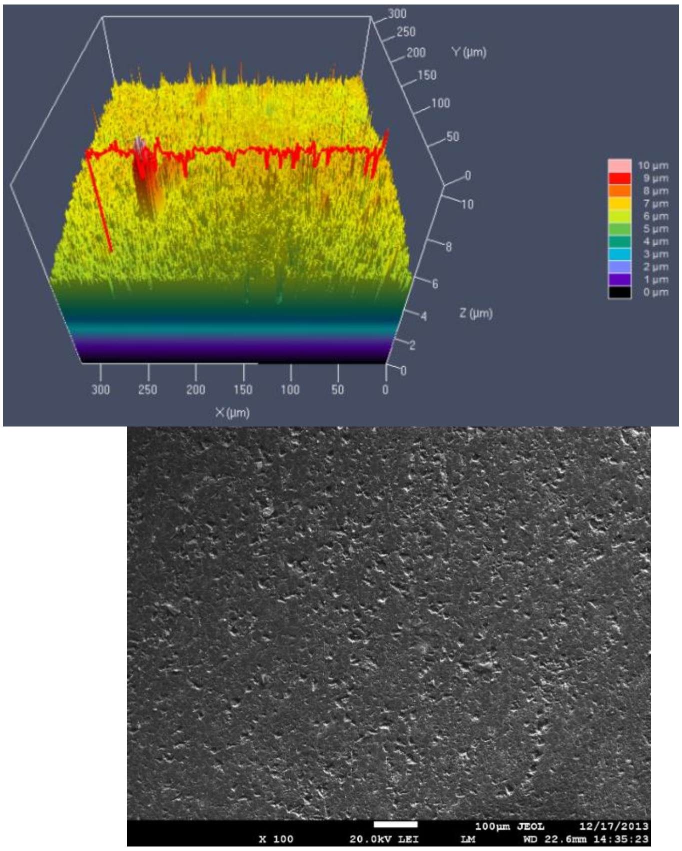

Fig. 3 *Topography of machined surface after RUM*

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 [wt. %]	**N** [wt. %]	**Al** [wt. %]	**O** [wt. %]	**Co** [wt. %]
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.

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