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MACHINING OF POLY-CRYSTALLINE CUBIC BORON NITRIDE BY LASER BEAM MACHINING IN TERMS OF SURFACE ROUGHNESS

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Abstract: Poly-crystalline cubic boron nitride (PCBN) is the hardest material beside diamonds. Generally, so hard materials could not be machined by conventional machining technologies. For this purpose, advanced machining methods have been designed. Laser beam machining (LBM) is included among them. LBM is based on ablation removing mechanism of focused and concentrated light beam. This contribution investigate quality of machined surface achieved by this advanced method during machining of PCBN.

Key words: laser beam machining, poly-crystalline cubic boron nitride, surface roughness

1. INTRODUCTION

PCBN is material which is usually utilized as cutting material. It is manufactured by sintering 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 this technology consists in application of a rotating tool with specially designed shoulder pin which is impressed to the boundary of welded materials. The tool proceeds in weld line direction. Heating occurs owing to friction and plastic strain of welded metals. Mechanical power is transferred to heat during the welding process. Temperature generated in welding zone usually attains 80 to 90 % of melting point temperature of the welded metal. Advantages of FSW process include: low heat input, low residual stress allowing fabrication of precise weldments without any additional operation, then formation of fine-grained microstructure in the welded zone leading to increased mechanical properties of fabricated welds. Welding operation takes place without spatter, harmful radiation and without filler metal. Welding by FSW process guarantees a high measure of safety and is also environmentally friendly [1-5].

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 of majority of tools is usually concave, which acts as an escape volume for the material displaced by the pin. The tool prevents material expulsion from the side of pin shoulder and maintains the desired effect and thus the desirable material forging below the tool. These tools are characterized by different sizes depending on thickness of welded plates, and by different geometry depending on welded material. Therefore, tool for FSW of 2 mm thick steel plates has been created in experiments by LBM.

2. MACHINED MATERIAL AND MACHINING TECHNOLOGIES

2.1 Machining material

Basic As machined material, PCBN has been used. This material provides Welding Research Institute – Industrial Institute of Slovak Republic in Bratislava (VÚZ – PI SR), which also demand creation tool for FSW. They bought this material from its manufacturer–Changsha 3 Better Ultra-hard Materials Co., Ltd (3b diamonds), which is based in China. PCBN consists of grains of cubic boron nitride in alumina matrix doped by cobalt, as shown Fig. 1. Dark areas are grains of CBN, light areas are Al₂O₃ matrix. This image has been created by EDX microanalysis and it is approx. 800 times magnified. This 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). Beside magnified image of structure, EDX analysis also provides chemical composition, which is shown in Tab. 1. PCBN is characterized by very high hardness. Its value is usually in range 7000 to 8000 HV, or above (around 75 GPa). Other modifications of boron nitride
are usually softer. PCBN has high thermal stability. It is usually utilized as cutting material for machining of ferrous materials, such as hardened steels, etc [6-8].

Fig. 1. Microstructure of PCBN

<table>
<thead>
<tr>
<th>B [wt. %]</th>
<th>N [wt. %]</th>
<th>Al [wt. %]</th>
<th>O [wt. %]</th>
<th>Co [wt. %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.99</td>
<td>40.58</td>
<td>6.26</td>
<td>4.68</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of PCBN

2.2 Machining technology

As machining technology, LBM has been used. This method is suitable for machining of hard-machinable materials. Also, it allow to machining some free-form surfaces. Machine tool, which utilize laser to machining is available in Centre of excellence of five axis machining (CE5AM) in MTF STU [9].

LBM utilize ablation effect of concentrated and focused monochromatic and coherent light. There is no tool to wearing and there is no cutting force. Energy of light is so focused, that there is very low heat affected zone (HAZ). No cooling of workplace is needed. Due to no cutting force, clamping of workpiece could be performed by adhesive tape. In this experiment, fiber laser machine LASERTEC 80 Shape, made by DMG Mori Seiki has been used. This machine tool is shown in Fig. 2. It can continuously control five axis during machining. Its fiber is made of ytterbium and can provide laser beam with wave length 1.065 µm. It work only in pulse regime and frequency of pulses could be controlled in range 10 to 100 kHz. Feed rate of laser beam could be adjusted in range 100 to 4000 mm.s⁻¹. Maximum power of laser generator is 100 W. Diameter of laser beam is approx. 1 µm.

During experiment, following parameters have been used: frequency 30 kHz, feed rate 1000 mm.s⁻¹, depth of cut 2 µm, laser power 12.3 %. Adjusted parameters required power approx. 4 W. NC program has been generated by software Lasersoft 3D, desiged by company DMG, which is part of machine tool [10].

3. DESCRIPTION OF THE EXPERIMENT

For experiment, PCBN cylinder with diameter 12mm and length 20 mm has been used. Specimen has been machined on Lasertec 80 Shape. This specimen has been machined to shape of above mentioned tool for FSW. Dimensioned longitudinal section of this tool is shown in Fig. 3. This tool has been created by LBM. Surface quality has been evaluated by roughness obtained by confocal microscope. Machining parameters has been adjusted by recommended values based on catalogue and experience. Depth of cut for LBM could by higher, but it should cause worse surface roughness. Therefore, depth of cut has been suggested accordingly to reach approx. the best time-to-roughness ratio. Machining time could be shorter at the costs of higher roughness and vice versa.

Fig. 2. Used machine tool LASERTEC 80 Shape [11]

Fig. 3. Tool for friction stir welding

4. RESULT OF EXPERIMENT

Machining of FSW tool by LBM method spend approx. 4 hours at adjusted parameters. After machining, specimen has been send to confocal microscope for obtaining surface topography. Resultant topography of surface after laser machining is shown in Fig. 4. On upper image is shown 3D representation of machined surface. There is also red line of section, which is shown on down image. There have been measured many kinds of roughness of machined surface after LBM. Specific values of different roughness are shown in Tab. 2 [12].
5. CONCLUSION

For machining of PCBN, LBM can achieve acceptable roughness (Ra 3 µm). LBM is able to create recommended shape by utilizing of only three axis (in comparison with mechanical machining methods, which required five continuously controlled axes [16]). LBM has also potential to rapidly reduce machining time. It would also cause rapidly rise of surface roughness. In that cause, roughness would be less acceptable. However, if LBM will be used only for roughing, and else method only for finishing, resultant surface will be created at relatively short time (even less than one hour), and surface could keep low roughness. For finishing could be the most suitable some mechanical machining process (such as rotary ultrasonic machining), because resultant roughness after these kind of machining methods do not so depend on previous processing – in comparison, beam machining method cannot improve surface roughness due copping of surface. Influence of surface roughness on FSW process will be objective of further research. There could be also comparison of LBM with rotary ultrasonic machining (RUM), as well as investigation of possibility to create this object by high speed cutting (HSC).

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Table 2. Surface roughness of PCBN after LBM

<table>
<thead>
<tr>
<th>3D roughness</th>
<th>2D roughness</th>
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<tbody>
<tr>
<td>RSc 20.925 µm</td>
<td>Rc 7.781 µm</td>
</tr>
<tr>
<td>RSa 3.934 µm</td>
<td>Ra 3.006 µm</td>
</tr>
<tr>
<td>RSq 4.977 µm</td>
<td>Rq 3.589 µm</td>
</tr>
<tr>
<td>RSk 0.059</td>
<td>Rsk 0.588</td>
</tr>
<tr>
<td>RSpu 20.087 µm</td>
<td>Rp 8.780 µm</td>
</tr>
<tr>
<td>Rsv 16.504 µm</td>
<td>Rv 5.564 µm</td>
</tr>
<tr>
<td>RSt 36.591 µm</td>
<td>Rt 14.344 µm</td>
</tr>
<tr>
<td>RSz 27.045 µm</td>
<td>Rz 13.195 µm</td>
</tr>
</tbody>
</table>

Where [13-15]:
Rc is mean height of the roughness profile elements (µm)
Ra is arithmetic average height (µm)
Rq is root mean square roughness (µm)
Rsk is skewness (–)
Rku is Kurtosis (–)
Rp is maximum height of peaks (µm)
Rv is maximum depth of valleys (µm)
Rt is total height of the profile (µm)
Rz is maximum height of the roughness profile (µm)
RSc (Sc) is mean height of the profile in space (µm)
RSA (Sa) is arithmetic mean height in space (µm)
RSq (Sq) is root mean squared height in space (µm)
RSkk (Ssk) is root mean squared height in space (µm)
RSpu (Spu) is skewness in space (–)
RSku (Sku) is kurtosis in space (–)
RSpu (Sp) is maximum peak height in space (µm)
RSv (Sv) is maximum valley depth in space (µm)
RSt (St) is total height of the profile in space (µm)
RSz (Sz) is maximum height in space (µm)
7. REFERENCES


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