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A chemical consideration of binderless-cBN as cutting material for ultra-precision turning

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Abstract

Ultra-precision cutting of stainless steel with diamond as cutting material needs modification of the workpiece material or special equipment for vibration assisted machining. In this paper detailed information about the chemical reaction for direct cutting of stainless steel with binderless-cBN while turning is given. The effect of lubricant on the wear of binderless-cBN is shown and confocal Raman spectroscopy with confocal imaging was done on the cutting tools.

Keywords: Ultra-precision turning, stainless steel and cBN

1. Introduction

Hardened steel moulds with high requirements regarding accuracy in shape and an optical surface finish are needed. Precision cutting of ferrous materials requires special equipment because of the diamonds wear behaviour [3]. To avoid the utilization of expensive equipment several investigations have been done [3]. One of them is the application of binderless-cBN as cutting material. To achieve the direct cutting of hardened steel fundamental investigations of binderless-cBN have been carried out [5, 7]. Afterwards the behaviour of binderless-cBN while cutting will be investigated.

2. Chemical fundamentals

The covalent and heteropolar bond between the element boron (B) and nitride (N_2) is well known as boron nitride (BN). BN is an allotrope material which can appear in different modifications in the same aggregate phase [6]. The technical relevant configurations are the hexagonal boron nitride (hBN) and the cubic boron nitride (cBN). For cutting process only the sp^3-hybridization as cBN with a band gap $g_B = (6.3 \pm 0.2)$ eV is relevant [2, 8]. Furthermore, the sp^3-hybridization of BN is chemically inert against molten metals, but not against materials which have the ability to build nitrides or borides [2, 8].

Oxidation of cBN starts at a temperature T = 400 °C, but a protective layer made of boron oxide (B_2O_3) prevents the material against further oxidation up to a temperature T = 1 200 °C [2, 8]. The equation 1 shows the chemical reaction between BN and oxygen (O_2) [8].

$$4\ BN + 3\ O_2 \rightarrow 2\ B_2O_3 + 2\ N_2 \tag{1}$$

cBN shows a great resistance against oxidation, nevertheless metal oxides are able to remove the layer during the cutting process. This process leads to an ongoing reaction between BN and O_2. In addition metal oxides have the ability to react with the protective layer composed of B_2O_3 to borides [1]. To clarify the wear characteristics of the investigated cutting material binderless-cBN cutting test and confocal Raman spectroscopy with confocal imaging were done.

3. Cutting test

3.1. Wear behaviour

For face turning cutting tests with binderless-cBN stainless steel Stavax ESR (1.2083) of the company BÖHLER-UDDEHOLM Deutschland GmbH, Düsseldorf with a Rockwell-hardness H = 52 HRC was used as workpiece material. The cBN was sintered without any binder phase by SUMITOMO CORPORATION, Itami, Japan and machined by the company Mössner GmbH, Pforzheim. Investigations were carried out on a Moore 350 FG machine tool of the company Moore Nanotechnology Systems, LLC, Swanzey, USA. Figure 1 shows a comparison of cutting tools with a corner radius $r_\varepsilon = 50$ µm after a path length $l_c = 50$ m. These tools were used with a cutting speed $v_c = 150$ m/min, a depth of cut $a_p = 5$ µm and a feed f = 1,4 µm. Due to the use of the lubricant W200SL of the company OPORTET®, Duisburg the width of flank wear land VB_{max} was reduced from $VB_{max} = 44$ µm to $VB_{max} = 10$ µm.

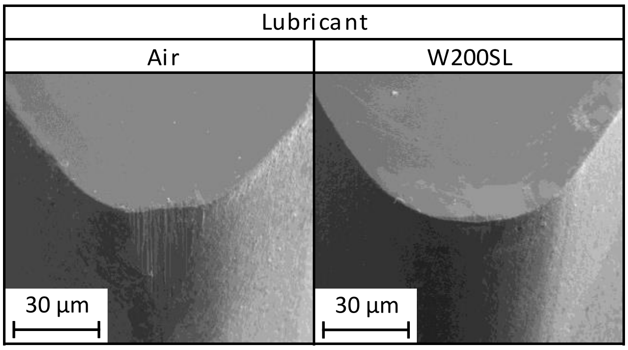
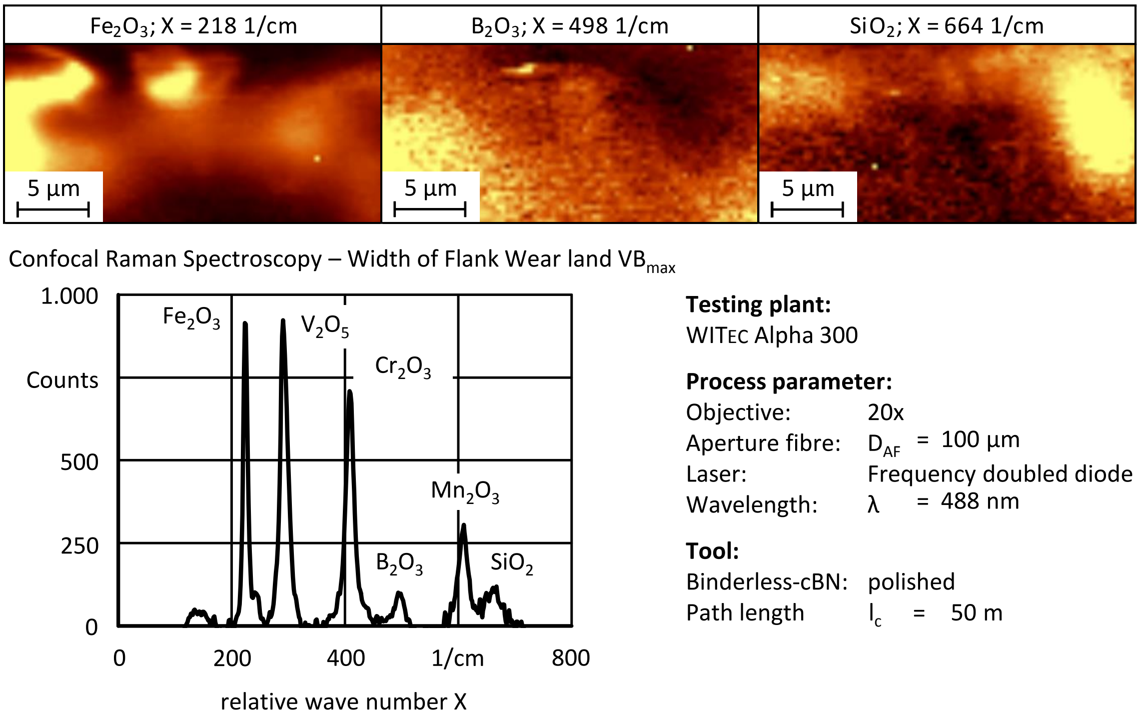


Figure 1. Flank wear on binderless-cBN-tools

3.2. Raman spectroscopy

After the cutting tests confocal Raman spectroscopy and confocal imaging with a Raman microscope of the company WITEC WISSENSCHAFTLICHE INSTRUMENTE UND TECHNOLOGIE GMBH, Ulm were done. In the focus of the consideration was the investigation of the flank wear on not cleaned PcBNoB-tools. The spectral peaks could be identified by comparison with the data base of the S.T. JAPAN-EUROPE GMBH, Köln. Figure 2 shows the normalised spectrum of confocal Raman spectroscopy of a binderless-cBN-tool after a path length $l_c = 50$ m. The spectrum illustrates the presence of ferrous(III)-oxide (Fe_2O_3) at a relative wave number X = 218 1/cm, it also shows a spectral peak at X = 281 1/cm which indicates the presence of vanadium(V)-oxide (V_2O_5). In addition boron oxide (B_2O_3) which can be identified by a spectral peak at X = 498 1/cm was detected. The mentioned bonds were also found after model test regarding wear mechanisms of binderless-cBN [5]. Furthermore chrome(III)-oxide (Cr_2O_3), manganese(III)-oxide (Mn_3O_4) and silicon oxide (SiO_2) could be identified. Base of the oxides are materials which are ingredients of the workpiece material STAVAX ESR. The intensity distribution of B_2O_3 shows a relatively smooth spread, that indicates the formation of a layer. The hardness H of B_2O_3 is about $H \leq 16$ GPa whereas the hardness H of Cr_2O_3 is about $H \leq 29$ GPa [4]. The metal oxides are formed as particle, this leads to an abrasive effect on the B_2O_3-layer which covers the binderless-cBN-tool. The dominant abrasive effect is visible in terms of grooves on the flank face A_α. Application adapted lubricant can reduce this mechanism, e.g. figure 1. For the range of the relative wave number 800 1/cm ≤ X ≤ 1 600 1/cm no additional bonds between boron (B) and metals like iron boride (FeB) could be observed. Furthermore, no change in the lattice structure from cubic (cBN) to hexagonal (hBN) could be found. Therefore it can be assumed that the wear of binderless-cBN is chemically induced and not by the change of the lattice.



Testing plant:
WITEC Alpha 300

Process parameter:
Objective: 20x
Aperture fibre: D_{AF} = 100 µm
Laser: Frequency doubled diode
Wavelength: λ = 488 nm

Tool:
Binderless-cBN: polished
Path length l_c = 50 m

Figure 2. Raman spectrum after cutting test with binderless-cBN and STAVAX ESR

4. Conclusion and outlook

The findings of this ongoing research display that the wear of binderless-cBN could be reduced by using W200SL as lubricant. The Raman spectroscopy of binderless-cBN-tools after cutting tests shows the presence of metal oxides and B_2O_3. The formation of Cr_2O_3 particle leads to a dominant abrasive wear. Due to the use of the application adapted lubricant and the lowered cutting temperature T_C the formation of metal oxides could be reduced. Within the scope of this paper no reaction between B_2O_3 and metal oxides could be observed. Further research activities address the influence of the volume V as well as the concentration of the water-based lubricant.

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