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Binderless-PCD as cutting material for micro milling of cemented carbide moulds

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Abstract

The high-precision cutting of cemented carbide with geometrical defined cutting edge is due to high tool wear restricted. A new promising diamond based cutting material for machining cemented carbide has been developed by SUMITOMO ELECTRIC HARDMETAL CORPORATION, Itami, Japan. In this paper, detailed information about the properties of the developed binderless-PCD are given. Furthermore, results of experimental studies with binderless-PCD as cutting material while milling cemented carbide are shown. As the result of this work the successful application of binderless-PCD as cutting material for machining cemented carbide could be shown. An arithmetical mean deviation Ra = 28 nm could be achieved by using a spindle speed n = 50 000 1/min and a feed per tooth f_t = 0.5 µm.

Keywords: micro milling, cemented carbide and PCD

1. Introduction

For serial production of low priced plastic parts with high requirements regarding geometrical accuracy and surface roughness micro injection moulding and hot embossing are key technologies. For pilot run and preproduction run non-ferrous materials like aluminium and brass alloys are often used as material for injection moulds and hot embossing tools. Injection moulds and hot embossing punches for serial production require high wear resistance and long tool operating life. Cemented carbide offers a high potential to improve the tool life of micro injection moulds due to the high hardness 10 GPa ≤ HV ≤ 20 GPa. Based on the high hardness HV the machining of cemented carbide is restricted at present.

2. Cutting materials for machining cemented carbide

For machining cemented carbide different research activities were done. One approach is the use of cemented carbide micro milling tools with of diamond coating. These tools suffer from chipping and delamination of the coating [1]. Cutting materials based on cubic boron nitride (cBN) with binder phase and polycrystalline diamond (PCD) with binder phase suffer from the elution of the binder phase and chipping of the cutting edge during the machining of cemented carbide. The hardness of PCD with binder phase is limited to HV ≤ 60 GPa [2]. Due to the anisotropic hardness HV of the single crystal diamond the diamond suffer from cleavage during the machining of cemented carbide [3]. Furthermore, the hardness H of single crystal diamonds varies in a range of 60 GPa ≤ HV ≤ 120 GPa dependent on crystal orientation. These wear phenomena lead to poor surface quality and geometrical inaccuracy. Figure 1. illustrates the wear of a single crystal diamond milling tool after machining cemented carbide for a path length l_c = 5 m. The shell-shaped propagation of the crack has grown parallel to the crystal orientation <100>. The visible lines of rest give a hint to the major wear mechanism surface fatigue.

Process:	**Workpiece material:**
Micro milling	Cemented carbide GXF
Process parameter:	**Tool:**
v_c = 50 m/min	Single crystal diamond
f_t = 5 µm	One flute end mill
a_p = 5 µm	D = 0.5 mm
a_e = 5 µm	

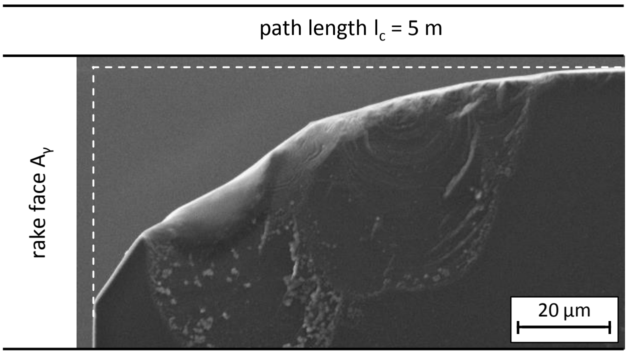

Figure 1. Rake face A_γ of a single crystal diamond milling tool after a path length l_c = 5 m

3. Binderless polycrystalline diamond (Binderless PCD)

To overcome these limitations SUMITOMO ELECTRIC HARDMETAL CORPORATION, Itami, Japan developed a new binderless polycrystalline diamond (binderless-PCD) cutting material for machining brittle materials like cemented carbide, silicon, ceramics and glass. The binderless-PCD was sintered without any binder phase. For sintering the binderless-PCD a new developed process management with a pressure p ≥ 15 GPa and a temperature T ≥ 2 200 °C was used to convert graphite directly to diamond [1]. The developed binderless-PCD has a hardness HV ≤ 150 GPa with a grain size d_g = 30 nm [2].

4. Experimental set up and results

The investigations were carried out on a high-precision machine tool Wissner Gamma 303 HP from WISSNER GESELLSCHAFT FÜR MASCHINENBAU MBH, Göttingen, Germany with ball bearing guideways and spindle was used. The piezoelectric dynamometer Kistler MiniDyn 9256C2 from KISTLER INSTRUMENTE AG, Winterthur, Schweiz was used for the cutting force acquisition. First cutting tests were carried out with one flute ball end mills with a tool radius r = 0.5 mm and a negative rake angle γ = -45 °. The binderless-PCD was brazed on the front side of a cemented carbide shank. Cemented carbide GXF with a grain size d_g = 1.5 µm was used as workpiece material. A study on the influence of spindle speed n and feed per tooth f_t on the arithmetical mean deviation Ra was carried out with six different spindle speeds n in a range of 5 000 rpm ≤ n ≤ 50 000 rpm. For each spindle speed n the feed per tooth f_t was varied in the range of 0.5 µm ≤ f_t ≤ 5 µm. The arithmetical mean deviation Ra was measured with a tactile contour and roughness measurement device HOMMEL-ETAMIC Nanoscan 855 from the company JENOPTIK AG, Jena, Germany.

Figure 2. illustrates the results of the cutting tests with the binderless-PCD micro milling tools. Each cutting experiment was repeated three times. Furthermore, the standard deviation is given as an error bar of three measurements for every cutting experiment. The spindle speeds in a range of 5 000 1/min ≤ n ≤ 20 000 1/min show a smooth progression of the arithmetical mean deviation 30 nm ≤ Ra ≤ 66 nm. An increase of the spindle speed n > 20 000 1/min leads to a different progression of the arithmetical mean deviation 28 nm ≤ Ra ≤ 199 nm. A feed per tooth f_t > 1 µm causes a significant increase of the surface roughness compared to spindle speeds n ≤ 20 000 1/min. The results of the cutting tests represent the dependency of the spindle speed n and the feed per tooth f_t on the surface roughness for machining cemented carbide GXF with micro milling tools made of binderless-PCD. Lowest arithmetical mean deviation Ra = 28 nm could be achieved with a spindle speed n = 50,000 1/min and a feed per tooth f_t = 0.5 µm.

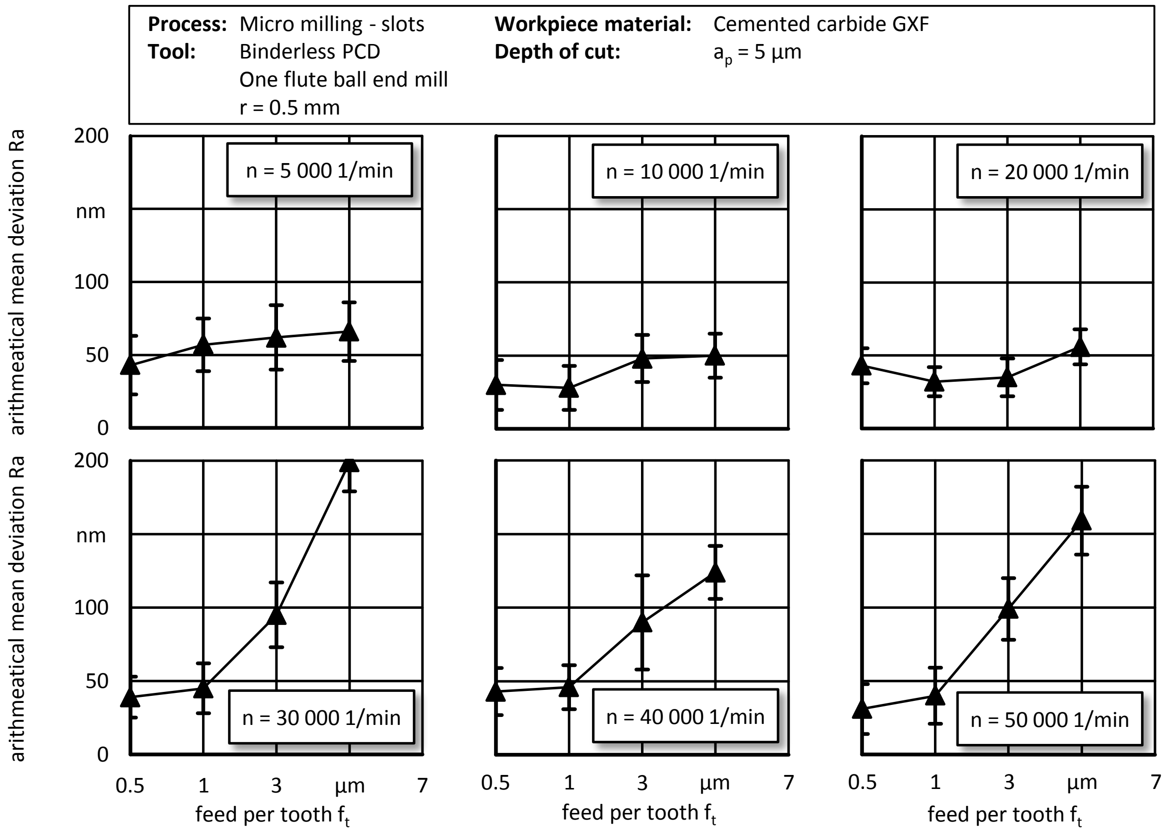

Figure 2. Results of the cutting tests

5. Conclusion and Outlook

As a result of this work the successful application of binderless-PCD as cutting material for machining cemented carbide could be shown. The findings indicate the critical interaction between spindle speed n and the feed per tooth f_t for machining cemented carbide. Spindle speeds n ≤ 20 000 1/min lead to lower surface roughness for feed per tooth f_t > 1 µm. Nevertheless, an arithmetical mean deviation Ra = 28 nm could be achieved with a spindle speed n = 50 000 1/min and a feed per tooth f_t = 0.5 µm using a high-precision machine tool with ball bearing guideways and spindle. First cutting tests regarding wear behaviour showed a width of flank wear land VBmax = 9 µm after a path length l_c = 5 m. The used spindle speed was n = 50 000 1/min with a feed per tooth f_t = 0.5 µm. In the next step of this ongoing work the wear behaviour of binderless-PCD for machining cemented carbide and the machining of different hard to machine materials will be investigated.

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