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cBN-micro-milling tools for machining hardened steel moulds

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Abstract
High-precision cutting of hardened steel with geometrical defined cutting edge is restricted due to excessive and random tool wear. For serial production of precision plastic parts hot embossing tools and micro injection moulding tools with high requirements regarding geometrical accuracy and surface roughness are needed. Cutting materials based on cubic Boron Nitride (cBN) are successfully used in macro-machining of hardened steel. In this paper, detailed information about machining hardened steel with micro-milling tools with cutting edges made of cBN are given. An arithmetical mean deviation Ra = 19 nm could be achieved using a high-precision micro-milling machine tool with ball bearing guideways and spindle.

Keywords: micro-milling, hardened steel, cBN

1. Introduction

Micro-injection moulding and hot embossing are key technologies for producing precision plastic parts with high requirements regarding geometrical accuracy and surface roughness. For serial production high wear resistance and long operating tool life of the hot embossing punches and the micro-injection moulding tools are needed. Therefore, micro-injection moulding tools and hot embossing punches made of steel with a Rockwell-hardness $H \geq 50$ HRC are commonly used. In general the direct machining by micro-cutting as well as the indirect machining by die-sinking EDM for manufacturing of the replication tools can be distinguished in industry.

2. Cemented carbide micro-milling tools

Regarding the current state-of-the-art cemented carbide micro-milling tools suffer from fast tool wear and random tool breakage while machining replication tools made of hardened steel. Therefore, the achievable surface roughness and geometrical accuracy are restricted. For micro-milling of steel different research activities were done. A promising approach to improve the tool life of micro-milling tools is the defined cutting edge preparation. For this, different technologies exist. Uhlmann et al. [1] successfully applied immersed tumbling for cutting edge preparation of micro-milling tools made of cemented carbide. In comparative cutting tests of micro-milling tools with a defined cutting edge preparation and ground micro-milling tools it could be shown that the maximum width of flank wear land VB_{max} could be reduced by 14 %. The variance of the results was reduced by 92 %. As workpiece material steel with a Rockwell-hardness $H \sim 24$ HRC was applied.

The coating of micro-milling tools made of cemented carbide is the most commonly used approach to improve the tool life. Amongst other scientists Aramcharoen et al. [2], Uhlmann et al. [3], Twardy [4] as well as Krebs and Kersting [5] investigated coated micro-milling tools made of cemented carbide for machining steel. Delamination of the coatings and chipping of the cutting edges could be detected. Figure 1 illustrates the wear of a TiAlN-coated micro-milling tool after machining hardened steel for a path length $l_c = 4$ m. As workpiece material STAVAX ESR from the company BÖHLER-UDDEHOLM Deutschland GmbH, Düsseldorf, Germany, with a Rockwell-hardness H = 52 HRC was used.

Process:	**Workpiece material:**
Micro-milling	STAVAX ESR (H = 52 HRC)
Process parameter:	**Tool:**
v_c = 100 m/min	Cemented carbide
f_t = 4 µm	TiAlN-coated
a_p = 50 µm	Two flute end mill
a_e = 50 µm	r = 0.5 mm

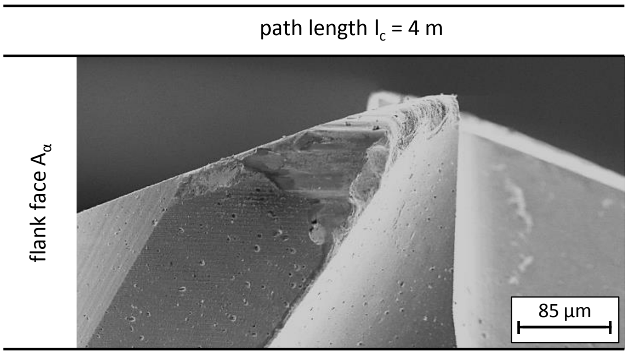

Figure 1. TiAlN-coated micro-milling tool made of cemented carbide after a path length l_c = 4 m.

3. Experimental setup and machining results

The shown investigations were carried out on the high-precision machine tool Wissner Gamma 303 HP from Wissner Gesellschaft für Maschinenbau mbH, Göttingen, Germany, with ball bearing guideways and spindle. A piezoelectric dynamometer Kistler Mini Dyn 92562 C from the company Kistler Instrumente AG, Winterthur, Switzerland, was used for the cutting force acquisition. To overcome the mentioned limitations cBN offers a great potential for micro-milling hardened steel moulds with improved geometrical accuracy and reduced surface roughness. The cutting tests were carried out with one-flute end mills with a radius r = 0.5 mm, a rake angle γ = 0 ° and a cutting edge radius r_β = 6 µm. The used cutting material made of cBN has a Vickers-hardness H ≤ 5,000 HV, a grain size $d_g \leq 2$ µm and was radial brazed on a shank made of cemented carbide. The micro-milling tools were manufactured by DIXI POLYTOOL GmbH, Birkenfeld, Germany.

As workpiece material the mould steel STAVAX ESR with a Rockwell-hardness H = 52 HRC was applied. Comprehensive cutting tests were carried out to investigate the influence of cutting speed v_c and feed per tooth f_t on the surface roughness. For the four different cutting speeds in a range of 25 m/min ≤ n ≤ 150 m/min the feed per tooth was varied in a range of 1 µm ≤ f_t ≤ 4 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 findings of the cutting tests with the manufactured cBN-micro-milling tools. The feed per tooth in the field of 0.5 µm ≤ f_t ≤ 4.0 µm shows a smooth progression of the arithmetical mean deviation in the range of 19 nm ≤ Ra ≤ 46 nm. In general, the arithmetical mean deviation Ra increased with an increase of the feed per tooth f_t for the investigated set of parameters. The lowest arithmetical mean deviation Ra = 19 nm could be achieved with a cutting speed v_c = 100 m/min and a feed per tooth f_t = 2 µm. Thus, an optimal ratio of the feed per tooth to the cutting edge radius $f_t/r_\beta \sim 1/3$ could be identified for cutting the hardened steel STAVAX ESR with cBN-micro-milling tools. The dependency of the cutting speed v_c, the feed per tooth f_t, and the cutting edge radius r_β could be shown. Within the investigations process forces $f_p \leq 24$ N were measured. First cutting tests concerning the wear behaviour have shown a high potential for cBN as cutting material for micro-milling of hardened steel moulds.

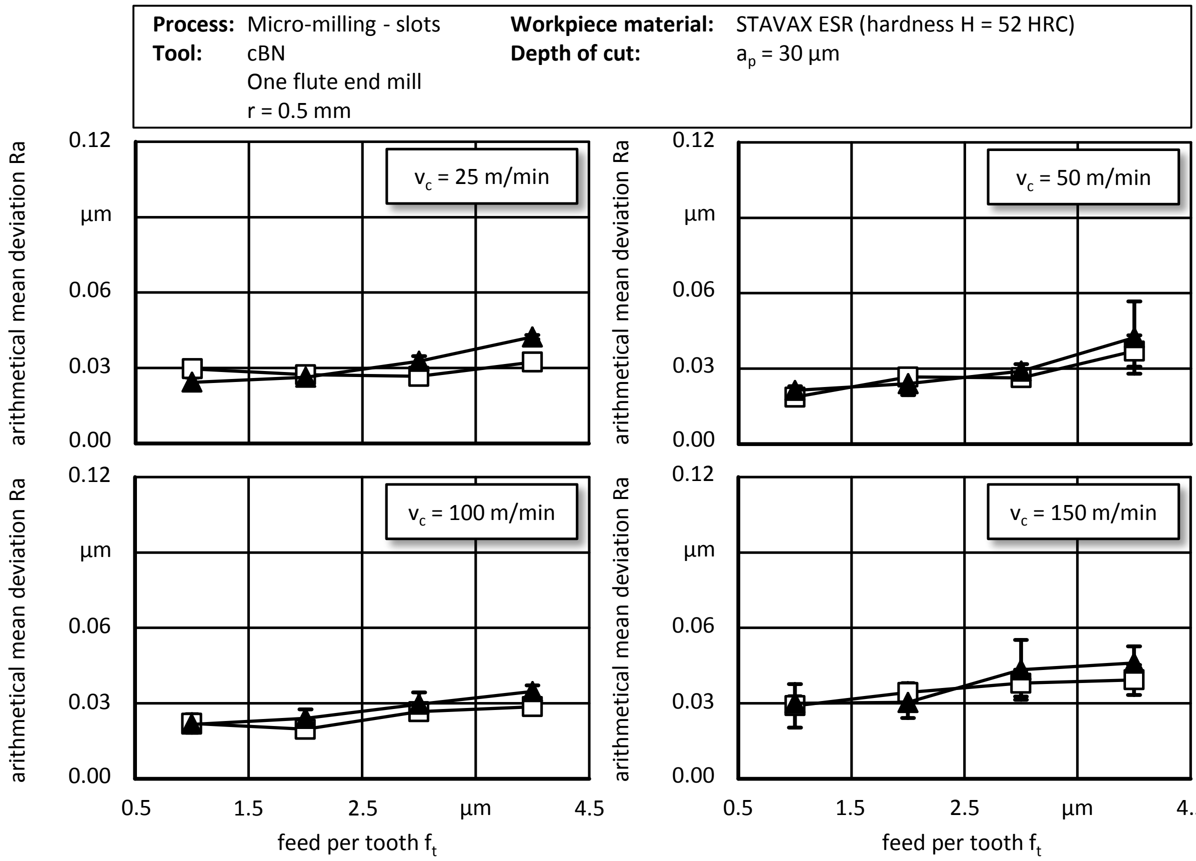

Figure 2. Results of the cutting tests.

5. Conclusion and Outlook

The results indicate the dependency of the cutting speed v_c, the feed per tooth f_t, and the cutting edge radius r_β on the arithmetical mean deviation Ra. Lowest arithmetical mean deviation Ra = 19 nm could be achieved with a cutting speed v_c = 100 m/min and a feed per tooth f_t = 2 µm. In the next step of this ongoing work the wear behaviour of the cBN-micro-milling tools for machining hardened steel will be investigated. This work is funded by the German Research Foundation (DFG).

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