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TiAlN coated ultra-small micro end mills

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Abstract
In milling processes, the cutting operation causes wear of the cutting edge, resulting in rising cutting forces until abrupt tool failure. This is the reason why tools are coated with hard material layers as a countermeasure to improve tool-life. This approach leads to an increased wear resistance and a constant cutting capability over a longer period of time. The size of micro end mills makes coating deposition challenging, mainly regarding the formation of droplets and the achievable cutting edge radius r_β.
Previous studies were performed with tools > 381 µm in diameter. The research presented in this paper shows the coating investigation and the machining results in polymethyl methacrylate (PMMA) of diameter D = 48 µm TiAlN coated ultra-small micro end mills (USM mills). Despite tool dimension the coating technology appears promising, since first coating tests were successful and machining results are similar to uncoated tools.

Keywords: coating, milling, micromachining

1. Introduction

The functionality of surfaces can be improved by microstructures. A suitable process for manufacturing these structures is micro milling due to its high geometrical flexibility and for micro machining relatively high material removal rate. Tools for micro milling are typically made of tungsten carbide because of its high bending strength. However, the ultra-small micro end mills (USM mills) with diameters under 50 µm have a severe wear of the cutting edges as a consequence of the ploughing effect [1]. Thus, the cutting ability and edge-holding property of carbide tools is limited by wear-related behavior. Tool wear is critical since it influences component quality, machining time, and costs. Thus, coating is applied to the milling tool to increase wear resistance. The advantages of coated tools with a coating layer thickness of 1.4 – 1.7 µm have already been shown when machining with tools D = 500 µm [2] and D = 381 µm [3]. When machining with USM mills (diameter < 50 µm), only uncoated tools are used so far although coating is promising [4]. The coating of USM mills and machining with them becomes challenging because of the tool size. Cleaning the tools reliably and generating an extremely thin and evenly distributed coating with a high adhesion strength are steps with the need for research. Normally the cutting edge radius increases while coating and so does the cutting force when machining. This could lead to tool breakage and declined cutting performance.

Initial test results presented in this paper focus on coating feasibility and geometric changes while coating the USM mills and the necessary adjustments of the parameters when machining with the coated USM mills.

2. Coating investigation

The main requirements of tools are increased hardness, high toughness, a low friction coefficient, and wear resistance. In micro milling with coated USM mills these requirements are accentuated by a necessary fine and dense layer because this layer should increase the cutting edge radius as little as possible.

The chosen coating for the USM mill in this research was titanium aluminum nitride (TiAlN). With TiAlN forming thin layers is possible, it is suitable for dry processing and it is widely used for coating micro end mills [2]. The coating was applied by physical vapor deposition (PVD) with a Domino Mini coating system by Oerlikon Metco.

Before coating the cleaning process was tested (see Fig.1). Cleaning is a critical stage in PVD coating processes, since it is not possible to remove macroscopic contaminants during in-chamber etching without adversely affecting the subsequent coating. To remove hydrocarbon materials and adhered contaminants, the USM mills were cleaned with different procedures in order to cover a wide spectrum of contaminants.

Always combined with ultrasonic agitation, the tools were cleaned by acetone, isopropyl alcohol, and a coating standard subsequent chemical detergent cleaning line for rinsing. The purpose of rinsing is to remove cleaning materials and particulate contaminants so that they are not transferred into subsequent tanks. Final rinsing consisted of an agitated immersion in clean water (deionized). After rinsing the components were blown off thoroughly with nitrogen. As it can be seen in the Fig. 1 the number of hydrocarbon materials and adhered contaminants per area becomes significantly smaller, but the micro end mill is not free of contamination.

In the coating chamber, after achieving the base vacuum pressure of 40E-06 mbar, the coating process began with an argon plasma glow discharge ion cleaning, to guarantee better coating adhesion. This step was followed by the application of the titanium bonding layer, and the introduction of the reactive nitrogen gas plus aluminum to form a metal nitride layer.

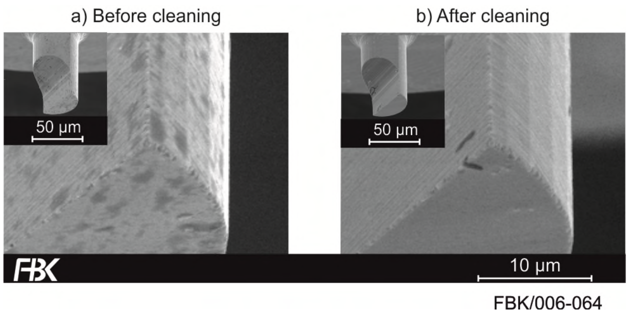

Figure 1. Cleaning of a micro end mill before coating

To study the influence of different coating techniques on the USM mills, a cathodic arc deposition (Arc) and a high ionization plasma-assisted coating (HiPac) were applied.

Fig 2 shows the result of the Arc coating and the extreme high number of macro-particles inherent to this coating technique.

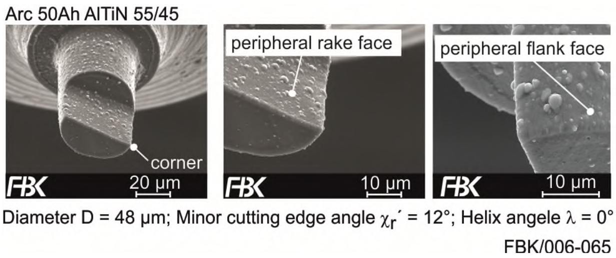

Figure 2. Arc coating of a 48 µm diameter micro end mill

These droplet-like defects were randomly distributed, affecting the kinematic roughness and being detrimental to the milling process of ductile materials.

Fig. 3 compares the USM mills before and after the HiPac coating. With HiPac coating the droplet formation was minimized. SEM imaging shows a coating layer thickness of about 900 nm and an increase of the cutting edge radius from approx. r_β = 0.1 µm to approx. r_β = 1.3 µm.

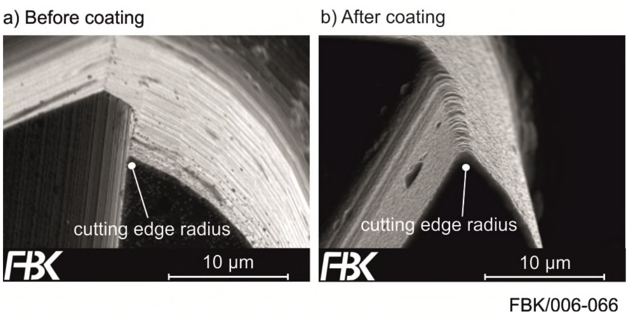

Figure 3. HiPac coating of a 48 µm diameter micro end mill

3. Machining Results and discussion

To compare the cutting ability of the uncoated and coated USM mill, machining tests on a precision three axes micro milling machine were conducted. The geometric changes of the tool due to the coating lead to an increase of the required minimal chip thickness (h_{min}). When the undeformed chip thickness (h) is less than r_β, a negative rake angle is formed. This angle leads to ploughing effects, poor surface quality, burr formation, and higher tool wear. At smaller h the uncoated USM mills produce a significantly better surface quality and smaller burrs compared to the coated ones. To reduce this effect, a feed per tooth of f_z = 4 µm was chosen in slot milling to minimize the influence of the cutting edge radius. The comparison of the milling results of uncoated and coated USM mills is presented in Fig.4.

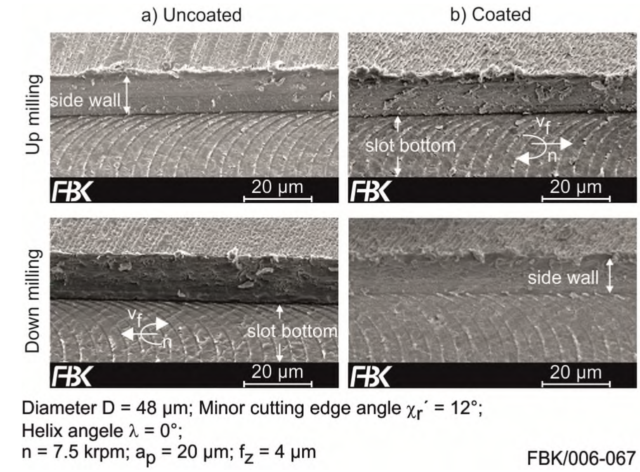

Figure 4. Machining results of coated and uncoated USM mills

The machining test shows similar sidewall quality when cutting with coated and uncoated USM mills. Also the burr formation is similar. Since the applied minor cutting edge angle and feed per tooth are relatively high, typical kinematic roughness on the slot bottom is visible in all cases.

4. Conclusion and Outlook

Coating can be performed on ultra-small micro end mill with diameters smaller than 50 µm. Coating techniques and parameters must be varied in order to avoid droplet formation and rounding of the cutting edges. In this study the HiPac coated tools satisfy the requirements for micro milling. The coating's negative influence on the cutting edge radii can be compensated by the application of a proper feed per tooth avoiding ploughing effects. The initial results show a high kinematic roughness resulting from the feed per tooth. This behavior combined with the high process speed indicates the ability of the coated USM mill for rough milling applications.

Further research will be performed to study the wear behavior of the coated USM mills.

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