Lifetime of HiPiMS TiAL-coated and pico-second Laser structured cemented carbide turning tools

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Abstract
The cutting tool is a key element in the material removal process. Cemented carbide tools are well established as they exist in a large variety of substrate compositions and offer the possibility to deposit a wide range of coating. Surface properties of the cutting edge determine the tool lifetime and coatings can add a significant increase. High Power Impulse Magnetron Sputtering (HiPiMS is a new coating technology able to deposit hard and dense layers. Pico-second LASER machining allows micro-structuration of difficult to machine material like cemented carbides without thermal impact. The combination of HiPiMS coating and ps –Laser micro-structuring was applied to the cutting edge of standard cemented carbide turning tools. For different combinations of HiPiMS –coated, ps-LASER structured tools, lifetimes in standard steel turning operation have been studied using and compared to lifetimes of standard coated and uncoated tools. A significant increase of tool lifetime having HiPiMS & ps-Laser structured tools and using minimum liquid lubrication compared to commercial, standard coated tools could be observed.

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1. Introduction

Continuously increasing demands of the manufacturing industry concerning cutting performance, or to decrease costs as well as to reduce environmental impact requires the development of cutting tools with increased lifetime and performance as well as to optimize processes strategies and parameters. Today coated cemented carbide tools are the most frequently used cutting tools and continuous improvement of substrate composition as well as of coating material and coating deposition technologies significantly increase their wear resistance and lifetime. Precise manufacturing of the shaped tool without damaging the base material nor the (cutting edge) surface is another challenge necessary to apply such coatings.

The HiPiMS deposition technique is an innovative development of the physical vapour deposition process (PVD). Very short pulses of less than 200 μs having high power densities of up to several kW/cm^2 of the target are generated. These high energetic pulses lead to a high electron density in the target area which creates a high ionization degree of the sputtered target material (up to 90%). These ions can be accelerated by a negative bias voltage to the substrate. The increased kinetic energy of the ions results in higher densities and increased mechanical properties of the coatings. Benefits like higher wear resistance and higher coating adhesion compared to DCMS coatings had been reported in hard turning of steel [1].

The hard base material requires advanced machining technologies to obtain desired complex and very precise shapes of the cutting tools. Grinding or electro-discharge machining (EDM) are normally used, but both can create a heat affect zone and thus weakening the surface area. It was shown [2] that short pulse Laser machining is able to remove the EDM- created HAZ-zone without generation of microcracks. This method also allows to micro structures / textures on the surface easily. Such micro-structures are supposed to be able to improve friction behaviour as well as improve lubrication at the cutting edge.

Cutting liquids serve to take away process heat, e.g. cool down tool and workpiece, help to remove chips and reduce friction. It was shown [3] that minimum quantity lubrication (MQL) can significant reduce tool temperature as well as reduce friction, both resulting in reduced tool wear.

In the present study we compared the tool lifetime using standard coated and non-coated commercial tools as well as tools having different combinations of HiPiMS and Laser textured ones in turning of standard steel. The turning experiments have been based on ISO-standard procedures (ISO 3685) using MQL and dry lubrication. An experimental plan was used to determine the influence of the different factors (coating, structuring, MQL).

2. Experimental setup

2.1. Material used

Typical sintered carbide used for standard cutting tools has a grain size of about 1 μm and composition about 10 % cobalt binder and 90 – x% tungsten carbide, where x represents a few 1 % of other carbide or other components (for ex. Cr to improve corrosion resistance). To develop the technology parameters for Laser machining we used the EMT210 grade from the Swiss manufacturer Extramet (https://www.extramet.ch/) . This grade has an average grain size of 0.8 um, 10 % cobalt and 89.0 % WC, 1 % are other carbides. For the final experiment turning lifetime tests commercial inserts of simple shape, e.g without any chip cutter and similar composition (according manufacturer) had been chosen: Sandvik TCMW 11 02 04 H10 . Some of these inserts had been textured by Laser and / or coated with HiPiMS. From the same manufacture the identical insert but with a CVD Ti(C,N)+Al_2O_3+TiN coating e.g. TCMW 11 03 04 3215 was selected for comparative testing e.g. HiPiMS – commercial coating.

2.2. LASER Machining

Several recent studies showed that texturing of cutting edges can improve tool/ machining performance or increase tool lifetime [4], [5] Thus the combination of HiPiMS coatings on Laser structured tools seems to very promising. A homemade system based on commercially available laser, Ekspla Atlantic series, using λ = 532 nm, 10 ps-long pulses at repetition rates of 100 kHz combined with a galvoscanner intelliScan 14 (ScanLab) was used. The set-up is described in detail in (ISEM). In this previous study the author showed that using this LASER steel material could be removed by cold ablation, e.g. without creating heat affected zones at the machine surface, e.g. without micro-cracks as material is not melted but directly evaporated which is different from standard thermal based lasers (using nano-second pulses). Although WC carbide has very specific material properties, in particular the melting / fusion temperature of WC grains, metallurgical analyses of the Laser machined surface did not show any difference in composition than raw material, also no micro cracks had been observed.

Based on the promising results of [4] lines perpendicular to the cutting edge had laser machined. The chosen line distance (hatch) was 120 μm, each line having a depth of a about 10 microns and a width between 80 et 90 (μm), see figure 1.

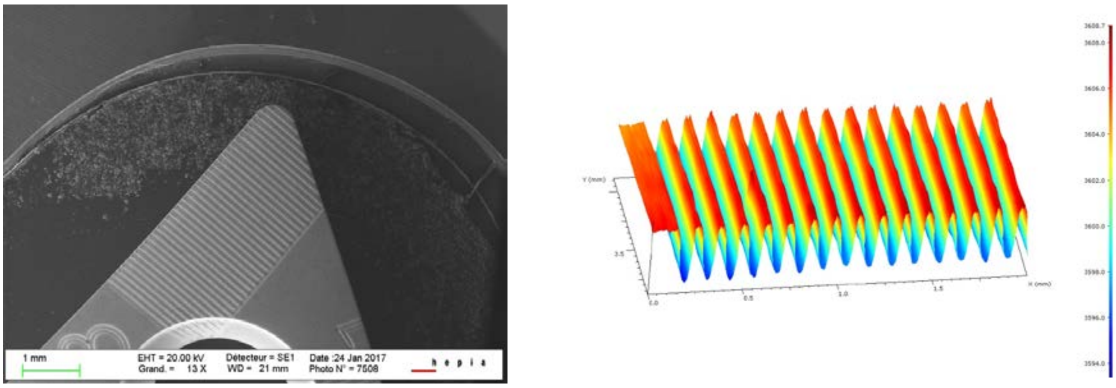

Fig. 1: left Laser structure cutting edge, right cutting edge mesure with perthometer

2.3. HiPIMS

The coatings deposition on cutting tools is mainly realized to add a new feature and improve the properties of the base material like corrosion resistance, hardness or tribological behavior. The main difference between classical sputtering PVD technology (magnetron sputtering) and HiPiMS deposition is the use of very short but intense voltage pulses to the cathode and thus increasing the plasma density. Typical sputtering power is about several W/cm^2 while HiPiMS allows some kW/cm^2. In our study we used a HiPiMS power supply from Hüttinger Electronic, model TruPlasma HighPulse 4008. It allows to generate voltage pulses of up to 2000 V with a peak current of 4000 A.. The substrate holder was also connected to a DC power supply (model TruPlasma Bias 3018 (Highpulse). As target we used a 6 mm thick TiAl (50:50) 50x14 cm size plate.

Before coating deposition, the substrates were degreased and ultrasonically cleaned in acetone and ethanol solutions and dried by filtrated air. The substrates were mounted on a rotating carrousel to obtain a homogenous deposition. The substrates were cleaned by ion bombardment using Ar, followed by the deposition of a TiAl layer and TiAlN top layer. During coating deposition, Ar gas (99.999%) was introduced into the chamber with N_2 gas (99.999%) injected near the substrate holder to maintain a constant pressure of 7.0×10^{-3} mbar. Deposition was performed in dynamic mode, with 2 rotations/mn. During the HiPIMS process, a voltage of -800 V was applied on cathodes with a frequency of 500 Hz and a pulse time of 80 µs. TiAlN coating thickness was about 2 µm. The bias voltage and N_2 flowrate had been optimized to achieve a maximum hardness of up to 3000 HV with excellent adhesion to the WC-Co substrates. An optimum Bias (-75V) was applied during TiAlN deposition and a TiAlN stoichiometry close to 50:50 was confirmed by EDS analysis (N:(Ti+Al) ≅ 50:50). Potentio-dynamic corrosion tests also confirmed a significant increase of corrosion resistance on coated carbon steel, e.g. corrosion rate for TiAlN on carbon steel substrates was only about 9.2 µm/year (compared to 106 µm/year for non-coated carbon steel, also the corrosion current density was only 0.8 µA/cm^2 (respective 9.0 for non-coated carbon steel). This showed a considerable increase in the density of TiAlN coatings.

2.4. Cutting experiments

For the turning experiments we used a Harisson, model ALPHA 330 ″s″, with a maximum power of max. 7,5 (kW). spindle speed of 3500 (tr/min). The machine was equipped with a homemade lubrication system based on pressured air. Metall-O-Fluid 38 from Oelheld GmbH, Germany, was used as lubrication liquid for the tests performed with MQL.As cutting material round bars with diameter 80 mm of turning steel EN 10277-3/10278 were selected.

Cutting tests had been done following a design of experiments to determine the influence of the different elements (e.g. coating, Laser texturing and MQL) and to reduce the number of necessary test. A 3 factors (Laser structuration, depot HiPiMS and MQL) with 2 levels (yes/no) DOE was chosen to limit number of test to 8. Machining parameters are: cutting speed Vc = 200 m/min, feed f= 0.2 mm/tr, depth a_p =1 mm. The experiments had been interrupted (at least) about every 5 minutes to measure the wear of the cutting edge according ISA 3685-(1993) standard using an optical microscope equipped with a camera. Additional tests had been performed to validate found results and compared with commercial tools.

3. Results and Discussion

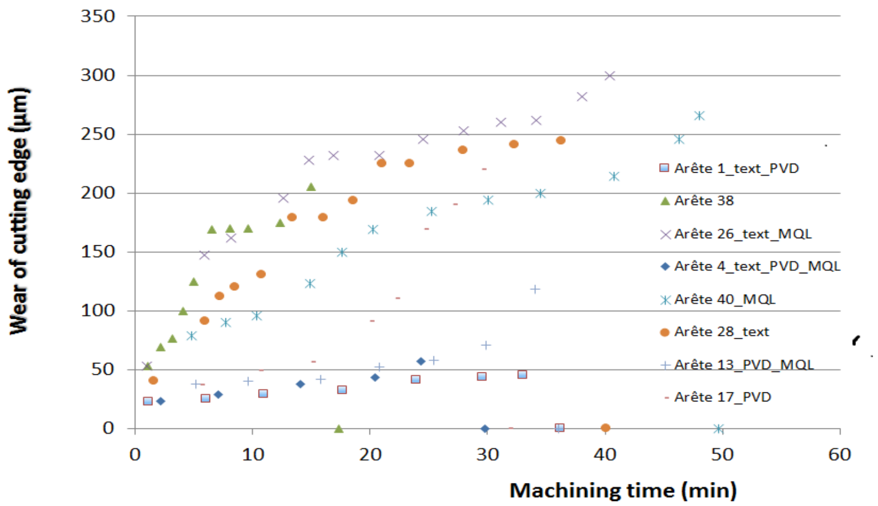

Fig. 2 Tool lifetime for different samples

Fig. 2 shows the increase of the measured tool wear (in um) with ongoing machining time for all 8 machining tests. Entries with showing “zero” tool wear after more than 10 minutes of machining indicate nonlinear tool failure like edge brake. The theoretical behaviour shows a linear increase of the wear with machining time after a short “running in” period with high wear, followed by a fast increase at the end of life, which is defined at a wear of 300 µm. Coated tools clearly show very low wear and best results are obtained by the combined HiPiMS coated, Laser structure tool using MQL. This test combination was repeated and compared with a similar commercial coated tool (Sandwick TCMW 110304 3215), see fig.3. Comparing wear after 25 min of machining the Pareto impact of the 3 factors and their combination could be determined giving highest impact (25) for HiPiMS coating, followed by the combination of Laser texture combined with MQL (12), only MQL has an impact of 9. Laser texturing (6) and the combination of HiPiMS and Laser (4) has lower impact.

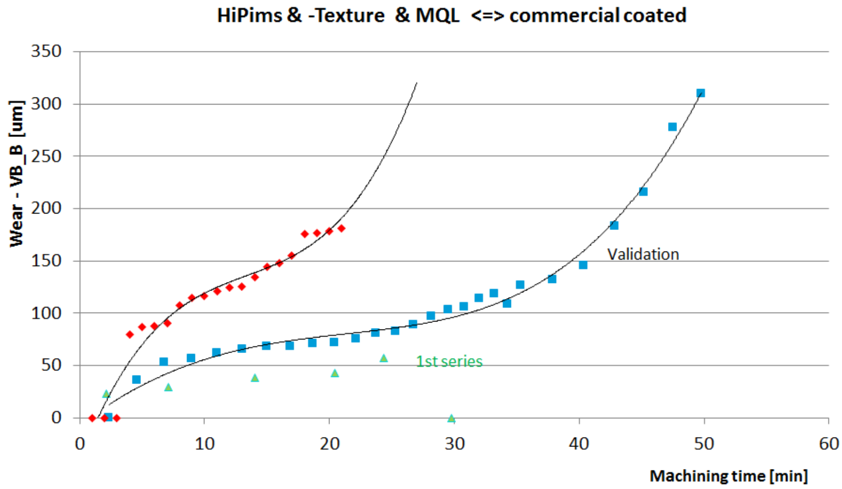

Fig. 3 Validation test and comparison with commercial coated tool.

4. Conclusions

The study clearly showed a significant increase of tool lifetime of HiPiMS TiAlN coated tools having microstructures machine by picosecond Laser by at least 3 times compared to commercial coated tools. The main impact is coming from the HiPiMS TiAlN coating, but no optimisation concerning the texture geometry neither its orientation relative to the cutting edge was performed. As tribological behaviour depends on surface to depths ratio, orientation and covered surface area of the texture, as well on the kind of lubricant, only futures studies can clarify this potential.

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