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Wear behaviour of HIPIMS coated micro-milling tools with cutting edge preparation for machining steel moulds

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Abstract

Micro-milling is an appropriate process for the industrial production of precision parts in the mould and die industry. Decisive for a long tool life is the wear resistance, which can be improved by cutting edge preparation technologies and tool coatings. Especially the improvement of the coating technology with the high power impulse magnetron sputtering (HIPIMS) provides improved tool wear behaviour and longer path length l_c. Further studies compare two different HIPIMS-coatings of micro-milling tools for machining the mould steel X13NiMnCuAl4-2-1-1. Furthermore, the tool wear could be reduced due to cutting edge preparation using immersed tumbling process. In consequence of the increased cutting edge radii r_β the measured active forces F_a increased slightly. Best results were achieved for micro-milling tools with cutting edge preparation and AlTiN coating.

Keywords: Immersed tumbling, coating, micro-milling tools

1. Introduction

Wear behaviour of conventional milling tools and inserts can be improved due to cutting edge preparation and coating of the tools. Both technologies influence the micro-geometry of the tools in terms of the cutting edge radii r_β and the chipping of the cutting edge R_s [1, 2]. With decreasing tool diameter D and reduced undeformed chip thickness h the influence increase [3, 4]. For an improved tool wear as well as proper cutting conditions of micro-milling tools it is essential to get a better knowledge about the targeted cutting edge preparation for the manufacturing of small homogeneous cutting edge radii r_β, their transferability after the coating process and effects to the cutting process.

In this contribution defined cutting edge geometries using the immersed tumbling process are manufactured and two different HIPIMS-coatings made of AlTiN and TiAlSiN are selected. Thereby, tungsten carbide tools with diameter D = 1 mm are used. In milling experiments the wear behaviour of the tools is analysed and evaluated. Further, the cutting forces F_c are measured and the active forces F_a with increased tool wear are examined.

2. Cutting tools

Within the experiments cemented carbide micro-milling tools with tool diameter D = 1 mm were used. The tools were divided into six tool groups and three groups were prepared using the immersed tumbling process. Subsequently, two prepared and two unprepared tool groups were coated. Between every process scanning electron microscope (SEM) images of the cutting tools were taken and the cutting edge micro-geometry was analysed with an optical measurement device InfiniteFocus from the company Alicona Imaging GmbH, Grambach, Austria.

With the immersed tumbling process small cutting edge radii r_β and decreased chipping of the cutting edges R_s can be achieved even for micro-milling tools with complex cutting edge geometries [5, 6]. Within the process the tools were clamped into tool holders and dragged through a container filled with the lapping medium. Two independent drives move the tools over a planetary gear system through the container. For the investigations a machine tool DF-3 Tools from the company Otec Präzisionsfinish GmbH, Straubenhardt, Germany, was used. In the experiments the lapping media H 4/400 consisting of walnut shell granulate with grain diameter of $0.4\ mm \leq d_G \leq 0.8\ mm$ and a polishing paste with diamond particles was selected. As process parameters a depth of immersion $T_E = 100\ mm$, a processing time $t_B = 180\ s$, a rotational speed of the rotor $n_R = -80\ 1/min$ and a rotational speed of the holders $n_H = -40\ 1/min$ were chosen.

The tools were coated with HIPIMS-coatings from the company CemeCon AG, Würselen, Germany, using a machine tool CC800® HIPIMS. The first coating with the name FerroCon is made of AlTiN with a measured hardness of H = 2,041 HV10. The second one with the name InoCon made of AlTiSiN has a hardness H = 3,387 HV10. Both are eligible for the machining of steel and steel alloys up to H = 70 HRC. The layer thickness of all coatings was $s_D = 3\ \mu m$.

The measurement results of the cutting edge micro-geometry concerning the minor cutting edge S' are presented in figure 1. Prepared cutting edges showed an increased cutting edge radius $r_\beta = 4.7\ \mu m$ and decreased maximum chipping of the cutting edge $R_{s,max} = 0.40\ \mu m$. After the coating process the cutting edge radii r_β are slightly increased by nearly constant maximum chipping of the cutting edges $R_{s,max}$. For unprepared cutting tools the maximum chipping of the cutting edge $R_{s,max}$ was reduced by 35 % on average.

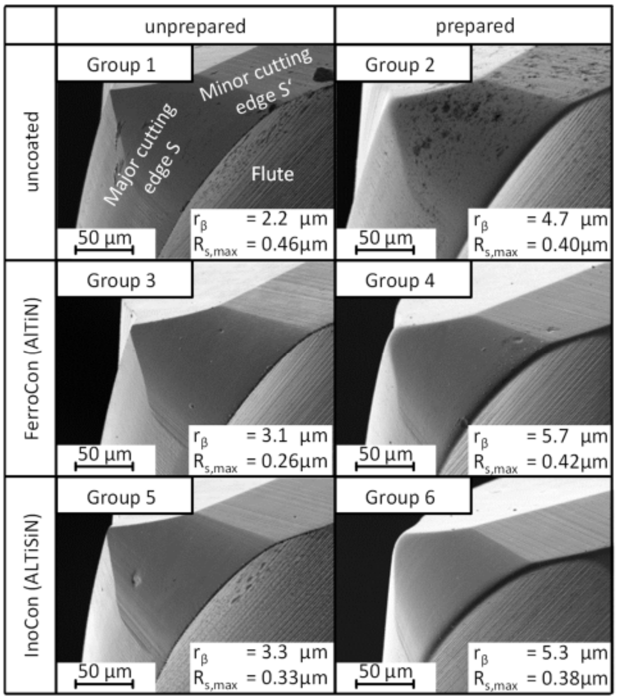

Figure 1. SEM images of the micro-milling tools

3. Milling experiments and results

The experiments were carried out on a five-axes high precision machine tool PFM 4024-5D from the company PRIMACON GMBH, Peissenberg, Germany. After different path length l_c SEM images of the tools were taken and the tool wear was analysed. Further, the forces were measured with a piezoelectric dynamometer MiniDyn 9256C2 from the company KISTLER INSTRUMENTE GMBH, Ostfildern, Germany. The measurement results of the maximum flank wear land VB_{max} as well as the active forces F_a are presented in figure 2.

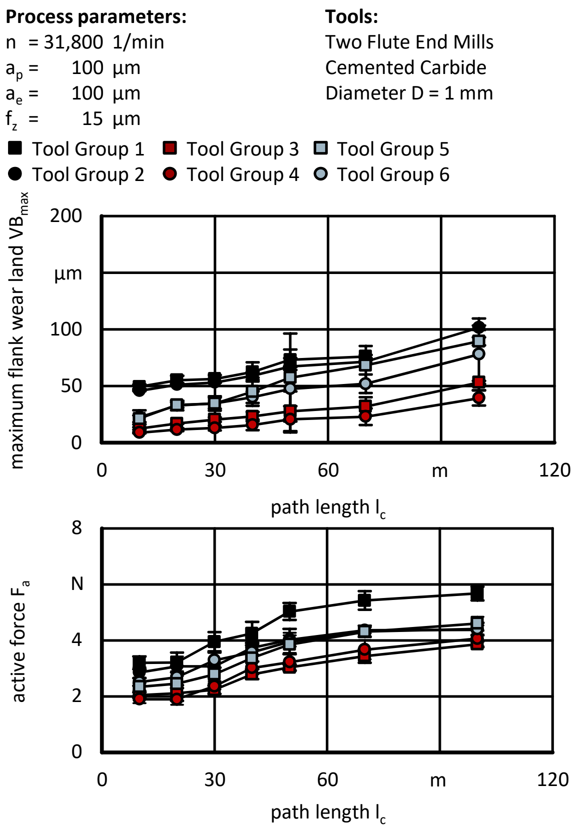

Figure 2. Maximum flank wear land VB_{max} and active forces F_a while micro-milling X13NiMnCuAl4-2-1-1

The results show a decreased tool wear for cutting tools with prepared cutting edges and improved micro-geometries. Especially for coated tools the coating adhesion was improved and less coating failure was determined. Further, the correlation between the increasing active forces F_a with increasing tool wear as well as with the coating failure could be shown. After a path length l_c = 100 m the maximum flank wear land VB_{max} of the AlTiSiN was more impaired than the slightly softer coating made of AlTiN. Best results were achieved with the prepared and AlTiN coated micro-milling tools of group 4. The tools showed a decreased maximum flank wear land VB_{max} by 73 % after a path length l_c = 70 m in comparison with unprepared and uncoated micro-milling tools.

4. Conclusion

The tool wear of micro-milling tools can be improved by cutting edge preparation as well as the tool coating after the grinding process. Both technologies influence the cutting edge micro-geometry. In this contribution defined cutting edge micro-geometries using the immersed tumbling process as well as the HIPIMS technology were manufactured. Thereby small cutting edge radii r_β = 4.7 µm were machined by the preparation technology and a further increasing of the cutting edge radii r_β after the coating process can be determined. In milling experiments the tool wear and the active forces F_a were examined and the correlations between increasing tool wear and active forces F_a could be shown. In general, cutting tools with prepared cutting edges showed less tool wear.

In further investigations the influence of the changed cutting edge micro-geometry by cutting edge preparation and coating process on the surface quality and burr formation will be evaluated. Furthermore, the influence of the process parameters concerning improvement of tool wear will be analysed using prepared and coated micro-milling tools.

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