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Tool wear and surface roughness in micro-milling of aluminium and high-alloyed aluminium materials using cutting tools made of binderless carbide

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Abstract

Micro-milling can be applied for manufacturing in a wide range of materials and complex geometries. This process is especially important for the aerospace industry. High-alloyed aluminium is a common material for aerospace applications with complex micro- and macro-geometry due to its high wear resistance. The costs-effectiveness of producing these parts can be increased by using tools with improved wear behaviour and higher life times. However, wear-resistant tools are often associated with higher tool costs, which reduces the cost-effectivness of the whole production. An innovative solution is offered by the use of a cutting tool made of binderless tungsten carbide.

The micro-milling of conventional and high-alloy aluminium with a new cutting material based on a binderless tungsten carbide is analysed in this investigation. The absence of a binding phase leads to an increased hardness and improves the wear behaviour of these tools. Therefore, tools with a tool diameter of D = 10 mm were manufactured and there machinability was successfully proven. The feasibility of these innovative tools is demonstrated in a series of experiments. The experimental investigations were carried out on the five-axis high precision machine tool PFM 4024-5D PRIMACON GMBH, Peißenberg, Germany, with a workpiece made of TiAl 48-2-2. A surface roughness of Ra = 0.202 µm was detected after a path length due to primary motion lc = 70 m without any noticeable wear marks on the cutting tool. These results show the economic potential for milling tools based on binderless carbide for achieving high precision surfaces while reaching high lifetimes.

Binderless carbide, milling, toolwear, surface roughnes

1. Introduction

Manufacturing through cutting processes is the subject of extensive research in recent years. The high number of tool and mould manufacturers on the market leads to a extensive competition in this sector and thus to a high demand of technological advances, in order to be economically successful. The tool costs K_P in correlation with the tool life t_s and obtaining the needed quality of the machined components are increasingly important. The choice of the right cutting material is a key factor in this consideration. The cutting material most commonly used in industrial cutting processes are various kinds of cemented carbides. They are mainly used in tool and mould making, precision engineering and for medical applications [1, 2]. Cemented carbides are made of tungsten carbide particles (WC-particles), combined with a cobalt (Co) binder material. The toughness and plasticity of the cemented carbide strongly depends on the content of binder material. However, the Co binding phase exhibits a cubic face-centred (cfc) lattice from a temperature $\vartheta > 420$ C (under cutting conditions), which favours the influence of abrasive wear. The resetting of the binding phase increases the surface roughness of the cutting tool and the preceding tungsten carbide particles reduce the surface quality of the machined surface. If a tungsten carbide particle is almost completely exposed, it breaks out and leads to a defect of the cutting edge. In addition, the price for cobalt has increased by over 200 % in recent years, due to the growing demand for products like high-performance accumulators and batteries. As the electromobility sector will continue to grow in line with current trends, further price increases are to be expected. This has a direct impact on the price of cemented carbides with cobalt as the binding phase [3, 4].

The cutting material binderless tungsten carbide (binHM) offers a possible alternative for cutting processes. Due to its high hardness H > 2700 HV, binHM promises increased path length due to primary motion l_c through reduced tool wear as well as reduced machining times t_B through a possible increase in cutting speed. At the same time, this innovative cutting material is independent of the growing price for Co as binding material. The presented study is concerned with evaluating the feasibility of binHM for industrial applications by conducting milling experiemtents with this cutting material on aluminium-alloy workpieces.

2. Experimental methodology

In order to generate an basic state of knowledge, it is necessary to manufacture tools from binderless WC and to carry out an initial milling experiments with them. For this purpose, tools illustrated in Fig. 1 with a tool diameter of D = 10 mm were manufactured. The tools were examined using a scanning probe microscope JCM-5000 Jeol, Akishima, Japan and their suitability was analysed. After a positive assessment, the tools were subjected to a wear and precision investigation. Before starting the relevant investigations, an initial determination of the application parameters was carried out. For this purpose, the process parameters of the tools were defined by means of slot milling. The machining forces F as well as the resulting surface roughness and edge sharpness r were considered.

Figure 1. Prototypical milling tools made of binHM

Subsequently, the performance of the binHM tools under the conditions of the predetermined process parameters were investigated in face milling experiments. These experiments comprise a maximum tool paths with a path length due to primary motion of $l_c = 70$ m. The achieved surface quality was determined after path lengths due to primary motion of $l_c = 15$ m, $l_c = 30$ m, $l_c = 45$ m and $l_c = 70$ m.

3. Experimental procedure

The experiments were carried out on the five-axis high precision machine tool PFM 4024-5D, PRIMACON GMBH, Peißenberg, Germany. For the evaluation of the surface roughness Ra and Rz, the opto-mechanical measuring system Nanoscan 855 from HOMMEL-ETAMIC, Ratingen, Germany was applied. In addition, the 3-component dynamometer type Z21317AT from Kistler Instrumente AG, Winterthur, Switzerland was used to measure process forces F.

The initial series of slot milling experiments includes a variation of the process parameters feed per tooth f_z, depth of cut a_p and spindle speed n. The final process parameters for the first series of experiments are a tooth feed of $f_z = 0.1$ µm, a depth of cut $a_e = 0.5$ mm and a width of cut $a_p = 0.5$ mm. With the process parameters mentioned and a width of cut $a_p = D$, surface roughness values in the range of Ra ≈ 0.297 µm and Rz ≈ 1.162 µm could be achieved. The occurring feed forces F_f were within a reasonable range of $F_f = 10$ N.

3.1. Surface roughness

Based on the preliminary tests to determine the process parameters, the surface roughness was measured during the face milling experiments with two comparable Tools. Surface roughness in the range of 0.202 µm ≤ Ra ≤ 0.335 µm were achieved using up milling and down milling. As can be seen in Fig. 2, only very slight variations of the surface roughness Ra for increasing path lengths due to primary motion up to lc = 70 m are recognisable. The differences between tool 1 and tool 2 are due to the problems that still exist in the tool manufacturing process. The results of the surface roughness Rz measurements are within a range of 0.886 µm ≤ Ra ≤ 1.384 µm. The influence of the cutting length due to primary motion lc on the surface finish Rz corresponds to the surface roughness Ra curves illustrated in Fig. 2.

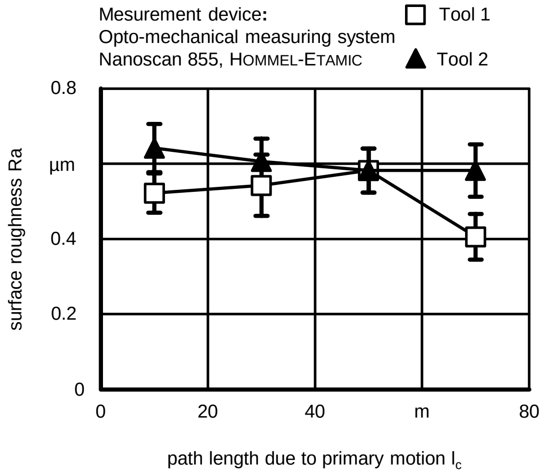

Figure 2. Representation of the surface quality Ra in relation to the path length due to primary motion l_c

3.2. Toolwear and geometric accurancy

During the face milling experiements, an initial analysis of the wear behaviour of the tools was carried out. From the results of the surface roughness Ra and Rz and the SEM images of the tools before and after the milling process shown in Fig. 3, a positive result can be observed. The depicted cutting tool does not show any signs of wear after a path length due to primary motion $l_c = 70$ m. Just the defects resulting from the manufacturing process are visible.

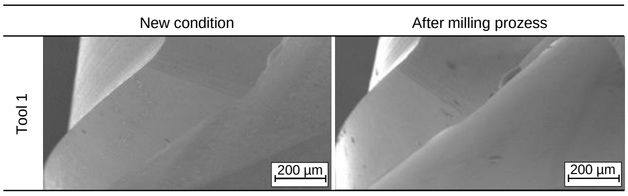

Figure 3. Representation of toolwear before and after milling of a path length due to primary motion $l_c = 70$ m

4. Conclusion

The first experiments on the application of milling tools made of binderless tungsten carbide demonstrated the major potential of the new cutting material. The milling tools used with a tool diameter of D = 10 mm were convincing under the given conditions due to the promising surface roughness. The observed wear behaviour clearly showed the potential of the cutting material. No chemically induced instabilities could be detected, and the significantly higher hardness H resulted in no chipping due to the milling process. In future development steps, the manufacturing strategy will be revised and suitable process parameters will be analysed in detail.

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