Micromilling of Titanium and Titanium Alloys

J. Ettelt, D. Biermann

Department of Machining Technology, Technische Universität Dortmund, Germany

ettelt@isf.de

Abstract

This paper deals with the investigation of micromilling of titanium grade 1 and TiAl6V4 with cutter diameters of one millimetre and less. The evaluation of an economic and effective production of microstructured components made of titanium and titanium alloys is the aim of the presented studies.

1 Introduction

Titanium and titanium alloys offer a high application potential in many fields since they show favourable physical and mechanical properties, such as low density and high corrosion resistance [1]. The application areas of these materials cover medical and measurement engineering, machine and system engineering, aerospace engineering as well as the automotive industry. However, titanium and titanium alloys belong to the group of materials that are hard to machine because of low thermal conductivity, low elastic modulus and high yield strength, which causes a high thermal and mechanical load of the cutting tool. There are already many publications dealing with the machining of these materials in macroscale [2], and there is an increasing tendency to apply microcomponents and implants made of high strength materials such as titanium and titanium alloys. The featured analyses are based on a previous study by Hoffmeister and Hlavac, which compared the milling of TiAl6V4, Inconel 718, and cold worked steel 90MnCrV8 [3].

2 Experiment

Titanium grade 1 with a hardness of 159 HV 0.02 and TiAl6V4 with 382 HV 0.02, the most common titanium alloy, were compared in order to show the differences between these materials. To identify the main influencing factors and technological correlations, micromilling analyses were implemented with cutter diameters of

1 mm, 0.5 mm, and 0.2 mm. The process parameters (feed, cutting speed, depth and width of cut) were varied and the number of experiments were reduced by applying design of experiments. These parameters were studied in up milling as well as in down milling to analyze milling forces, surface roughness, chip form, and tool.

3 Results and discussion

3.1 Material

The most significant difference between the two materials is their ductility. Pure titanium is very ductile and therefore, like in macroscale, an increased burr formation and comparatively worse surface quality is likely to develop. In addition, the tool breaks more often when downscaling the tool diameter. This is caused by the more complicated removal of chips through the axial slots when machining with smaller cutter diameters. When the material removal rate increases above a critical value, the material "smears" in the flutes, which can be seen in figure 1. In this case, cutting is not possible and leads to an early tool breakage.

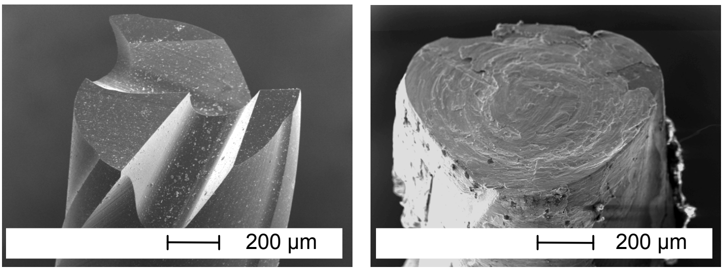

Figure 1: New 1 mm cutter and with clogged flutes after machining titanium grade 1

This conclusion is supported by an increased measured load in z-direction, which can be explained by the chip accumulation in the axial slots. For a better stability, a tool with an increased chisel edge compared to the cutter diameter has to be used. However, this reduces the size of the axial slot, which aggravates the chip removal problem. The use of minimum quantity lubrication with a high flow rate can improve the chip removal in this context. There are generally two options to solve this problem: an adaptation of the tool geometry, for example by enhanced axial slots, or the systematic use of lubrication. Both approaches will be examined more closely in further investigations.

3.2 Parameter

It was discovered that, when cutting with diameter d = 1 mm, the cutting speed in the investigated range has neither an influence on the surface quality nor on the mechanical load of the cutter. This effect is caused by a low thermal load while micromachining. In the macroscale an increased formation of built-up edges caused by an increased heat input at higher cutting speeds is noticed. In microscale, a built-up edge can be recognised which is independent of the cutting speed. Based on these results, the cutting speed for further experiments was kept constant at $v_c = 50$ m / min.

The main influencing factor on the surface quality and mechanical stress is the depth of cut a_p. With increasing depth of cut, the surface quality gets worse and the mechanical stress increases. The latter can also be observed in macroscale and is caused by the larger chip volume. An influence of feed or width of cut on the generated surface quality cannot be noticed. The depth of cut correlates with the assured removal of the chips. When the chip removal is decelerated, it influences the effective range of the cutting edge. If the Chip adheres to the cutting edge, a decreased surface quality is generated, which demonstrates a correlation between the size of the axial slots, chip formation, and surface quality. As figure 2 shows, up milling leads to an increased tendency to burr formation. When burr has no influence on the application, up milling is to be preferred, since a better surface quality can be produced during a lower load on the tool. For the same conditions, Rz = 0.132 µm and Rz = 0.536 µm were achieved for up milling and down milling, respectively. The higher surface quality when up milling is caused by the reduction of the built-up edge.

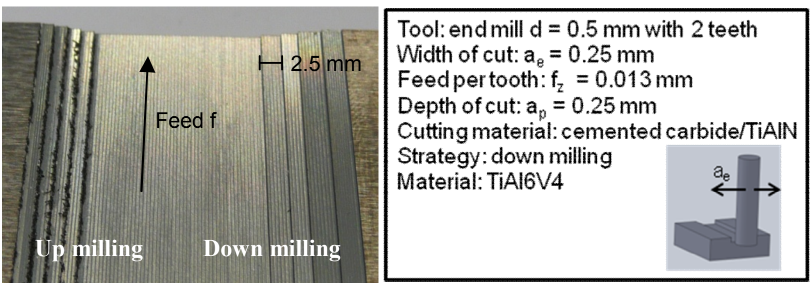

Figure 2: Burr formation when milling TiAl6V4 with 0.5 mm diameter end mill

The material is pushed onto the cutting edge as a result of the increasing undeformed chip thickness, which reduces the welding on of chips.

However, this effect decreases due to the comparatively low heat input when downscaling the tool diameter so that, at a cutter diameter of d = 0.2 mm, the surface quality and mechanical stress are almost the same in both milling direction (up and down milling).

4 Conclusion

For the machining of titanium grade 1 and Ti6Al4V, using cemented carbide end mills of diameter 1 mm, 0.5 mm, and 0.2 mm, up milling is recommended. However, the possibility of burr formation cannot be eliminated.

Using the same process conditions, TiAl6V4, compared to titanium grade 1, resulted in a better surface quality at lower mechanical stress of the tool.

When milling pure titanium, special attention has to be paid to the chip removal through the axial slots in order to prevent premature tool failure.

To get the best possible surface quality, low depths of cut (above the minimum undeformed chip thickness) of about a_p = 15 µm are recommended independently of the cutter diameter. As a recommendation for milling titanium and titanium alloys, the following values can be used: v_c = 50 m/min and $f_z = 0.016 \cdot d$, bearing in mind that the process should always be adapted to specific requirements, such as the requested material removal rate or the hardness of the material.

References:

[1] Lütjering, G.; Williams, J.C.: Titanium, Engineering Materials and Processes, Springer-Verlag Berlin Heidelberg, 2007

[2] Ezugwu, E.O.; Wang, Z.M.: Titanium alloys and their machinability – a review, Journal of Materials Processing Technology 68, 262-274, 1995

[3] Hoffmeister, H.-W.; Hlavac, M.: Micro-Milling of Titanium- and Nickel-Based Alloys, Proceedings of the 6th euspen International Conference, Baden bei Wien, 124-127, 2006