Influence of Kinematics on the Surface Integrity in Orthogonal Turn-Milling of Aluminium Matrix Composites

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Abstract

This paper deals with the investigation of orthogonal turn-milling of aluminium matrix composites using CVD (chemical vapour deposition) diamond tipped end mills. The influence of eccentricity, tool position and milling strategy on the surface integrity is described. The results show that the lowest roughness values can be achieved by positioning the tool *below the work piece axis*, using an *eccentricity* e = 2.5 mm and choosing *up milling*.

1 Introduction

The significance of saving resources during manufacturing as well as usage of products will strongly increase in the next years. A possibility to meet this challenge is the application of lightweight design, for example by using innovative materials like aluminium matrix composites (AMCs). AMCs consist of a ductile aluminium matrix alloy with embedded hard ceramic particles for reinforcement. The properties of the material can be varied in a wide range by changing the type and proportion of the components. Higher strength, Young’s modulus and abrasive wear resistance compared to unreinforced alloys make AMCs an attractive choice for the manufacturing of light, highly loaded components. However, the excellent properties lead to a poor machinability of these materials. The high hardness of the ceramic particles causes abrasive tool wear and leads to a drastic reduction of the tool life. The ductile aluminium phase tends to form built-up edges, which can cause surface defects. Furthermore, particles can be ripped out of the matrix. This results in flaws like voids or scaling on the component surface [1], which decrease durability under dynamic load. The characteristics of these defects mainly depend on the size of the ceramic particles. In order to minimise these effects, material with a small grain size of the particles has to be used.

Because a high-quality surface is an essential requirement in many applications, it is necessary to find adequate machining processes. Orthogonal turn-milling constitutes a promising process for the finish machining of rotationally symmetric work pieces. As a combination of turning and milling, this process offers the opportunity to use the advantages of the two single processes. The relatively simple kinematics of turning is combined with the interrupted cut of the milling process, which results in short chips and lower thermal stress of the cutting edge.

2 Experimental

The material used in the machining tests consists of a matrix similar in composition to AA2017 and 15 % volume proportion of Al_2O_3 particles with a grain size in the range of 200 nm to 2 µm. The material was heat treated to condition T4. The specimens have a length of 15 mm and a diameter of 12 mm. CVD diamond tipped end mills (∅ = 6 mm) are used to resist the high abrasive impact of the ceramic particles. The tools have a special design. The front cutting edges run horizontally (Fig. 1). For the machining tests minimal quantity lubrication (polyolester oil, 27 ml/h) is used. The following machining parameters are kept constant during the tests:

Table 1: Constant machining parameters

Parameter	Value
axial feed f_{ax}	0.15 mm
depth of cut a_p	0.50 mm
speed ratio λ	200
cutting speed v_c	377 m/min

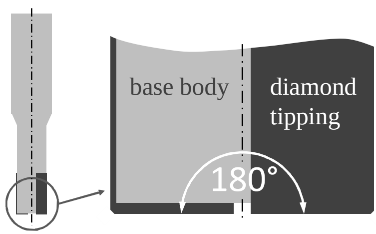

Figure 1: Geometry of the end mill

Because of a typically used clockwise rotation of the tool, the direction of rotation of the work piece determines the milling strategy (*up or down milling*). Together with changing the tool position (*above* or *below* the axis of the work piece) there are in principle four possible variants of orthogonal turn-milling (Fig. 2).

Furthermore, the *eccentricity e* is varied between 0.5 mm and 2.5 mm (-0.5 mm and -2.5 mm) in the machining tests. The investigations are supposed to point out the influence of these parameters on the surface integrity.

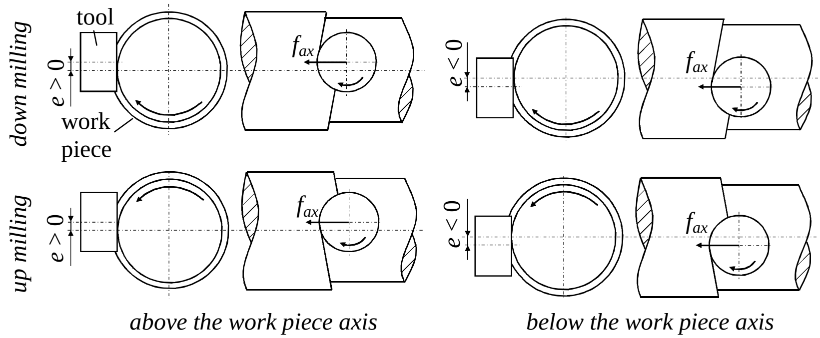

Figure 2: Tool position and milling strategy in orthogonal turn-milling [2]

3 Results and Discussion

The surface integrity of the machined surfaces is evaluated by tactile roughness measurement (longitudinal) and SEM micrographs. The results of the roughness measurements are shown in Fig. 3. It can be seen that the lowest roughness with a mean value of Ra = 0.16 µm is achieved by applying *up milling*, tool position *below work piece axis* and an *eccentricity e* = 2.5 mm.

A higher eccentricity leads to lower roughness values for a tool positioned *below the work piece axis*. In this case roughness values determined in *up milling* are slightly lower than in *down milling*. If the tool is positioned *above the work piece axis* there is no significant influence of the eccentricity on the roughness during *down milling*. When using *up milling* a significant lower roughness at an *eccentricity e* = 0.5 mm can be seen.

In general, *up millling* produces a lower or equal roughness values in comparison to *down milling*. Also using a lower eccentricity leads to a reduced scattering of the roughness measurements.

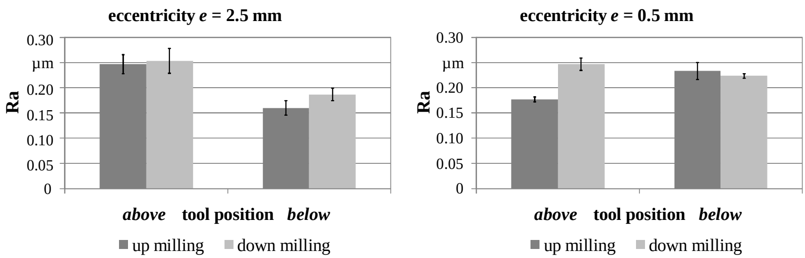

Figure 3: Influence of the determined parameters on surface roughness Ra

The SEM micrographs in Fig. 4 show the influence of the eccentricity on the surface structure. Eccentricity affects the direction of the cutting edge relative to the work piece in the area of chip formation. The surface structure shows that with a lower eccentricity the tool marks run almost perpendicular to the work piece axis. With an increasing eccentricity the direction of the tool marks approaches an orientation parallel to the work piece axis. The roughness values show that tool marks occurring at low eccentricities and hence running crosswise to the measuring direction necessarily lead to higher roughness values. In fact the completely different engagement conditions seem to have a much higher influence on the formation of the surface structure and should be investigated more closely.

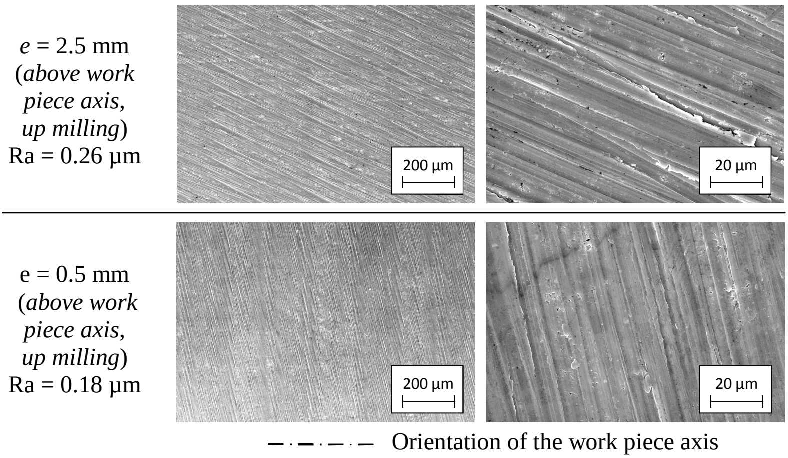

Figure 4: Influence of the eccentricity on the surface structure

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