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Micro-milling of a sprue structure in tungsten carbide-based metal matrix composite

E. Uhlmann[1, 2], J. Polte[1], M. Polte[2], C. Hein[1], T. Hocke[2], C. Jahnke[1]

[1]Fraunhofer Institute for Production Systems and Design Technology IPK, Germany
[2]*Institute for Machine Tools and Factory Management IWF, Technische Universität Berlin, Germany*

christian.jahnke@ipk.fraunhofer.com

Abstract

Many industries rely on plastic components manufactured by micro-injection moulding. There is a high potential to further increase the cost-effectiveness by machining the moulds needed for this process from non-ferrous metals and reinforcing the parts of the mould, which experience high loads during the micro-injection moulding. Inserting tungsten carbide particles locally into the surface of these non-ferrous metals is one possibility of reinforcement. The resulting metal-matrix-composites (MMC) exhibit the needed wear resistance, while the ground material can be machined very effectively through micro-milling. In contrast, the Micro-milling of these MMC-materials is challenging and so far not state of the art. Thus, this investigation is concerned with the development and qualification of micro-milling parameters for tungsten carbide-based MMC-materials. Binderless polycrystalline diamond as innovative cutting material was applied for this purpose. The goal of the milling parameter development was to optimize the surface roughness and the form accuracy for machining an aluminium bronze workpiece reinforced with tungsten carbide particles through laser injection. Based on an analysis of a wide range of process parameters, an optimised milling strategy was applied to machine a sprue structure from the described MMC-material. Different parameter sets are evaluated by analysing the form accuracy and measuring the surface roughness of machined structures. A surface roughness of Ra = 80 nm and form accuracy of a = 3 µm could be achieved with optimized micro-milling parameters and qualified the developed parameters for industrial applications.

Micro-milling, metal matrix composite

1. Introduction

The production of plastic parts by injection moulding is widespread due to its high cost-effectiveness [1]. The injection moulding tools, also called moulds, need to meet high requirements regarding surface roughness and form accuracy a [2]. The moulds are usually machined from hardened steel, because of local high loads during the injection moulding process. Since micro-milling with coated cemented carbide tools is the preferred machining process for manufacturing moulds, the high hardness H of this material limits the productivity [3]. The occurring wear of the milling tools is severe, reduces their life time t_L significantly and affects the quality of the machined moulds negatively. A solution for this challenge is the use of a non-ferrous metal as a base material with improved machinability and a localized reinforcement in regions of high loads. Sufficient reinforcement can be achieved by inserting tungsten carbide (WC) particles into the surface of the base material [4]. This leads to the formation of a WC-based metal-matrix composite (MMC). Further research about milling these MMC-Materials needs to be conducted in order to qualify this new solution for industrial applications. Recent studies suggest, that binderless polycrystalline diamond (PCD) is a promising new cutting material for WC-based MMCs [5, 6]. The possibility to machine these materials through micro-milling and the potential for further improvement by optimization of the milling parameters was shown. Thus, the subject of this investigation is to show the feasibility of machining WC-based MMC-materials through micro-milling with binderless PCD as cutting material.

2. Experimental setup and methodology

Optimized milling parameters have been applied to machine sprue structures from the described MMC-material as a test geometry to show the potential for industrial application. Details about the sprue structure can be taken from figure 1. The same geometry was milled from the moulding steel 1.2344 for reference. Two parameter sets for machining the sprue structure from the MMC-material are presented here, which will be referred to as sprue 1 and sprue 2. In case of sprue 1, the depth of cut a_p = 10 µm, the stepover a_e = 20 µm, the spindle speed n = 39,000 1/min and the feed per tooth f_z = 2 µm were chosen. For sprue 2, the feed per tooth was reduced to f_z = 0.8 µm. Comparable finishing parameters have been selected for the steel 1.2344 sample. The used MMC-material comprises spherical WC-particles, which have been inserted into the surface of a CuAl10Ni5 base material by laser melt injection. MMC-workpieces have been prepared at the Bremen Institute for Applied Beam Technology BIAS, Bremen, Germany. Binderless PCD ball-nose milling tool, with a diameter D = 1 mm and a number of teeth z = 1, was applied for machining the MMC-material. It was provided by SUMITOMO GMBH, Willich, Germany. The machining was conducted using the 5-axis high precision milling centre HSC MP7/5 from EXERON GMBH, Oberndorf, Germany. The surface roughness Ra of the milled structures was measured on the sprue ground with the surface measurement device Hommel-Etamic nanoscan 855 from JENOPTIK AG, Jena, Germany. A cut-off wavelength λ_C = 0.25 mm and an evaluation length l_n = 1.25 mm were applied for this purpose. The 3D measurement system InifiniteFocus from Alicona Imaging GmbH, Graz, Austria, served to create a 3D-image of the machined sprue structures and to analyse the form accuracy a from that.

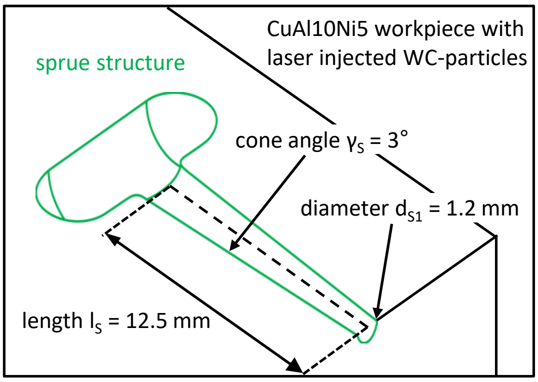

Figure 1. Schematic depiction of the main geometrical features of the milled sprue structure

3. Experimental results

The evaluation for different sprue structures is depicted in figure 2 and figure 3. The two sprue structures that have been machined from the MMC-material are compared to a reference sample machined from steel 1.2344. According to the state of the art, the feed per tooth f_z was considered as a critical parameter [5, 6]. It can be seen, that the reduction of the feed per tooth from f_z = 2 µm to f_z = 0.8 µm has a significant effect on the measured process results. Figure 2 shows the surface roughness Ra. The value for the steel sample is Ra = 40 nm. The described reduction of the feed per tooth f_z decreases the surface roughness from Ra = 170 nm in case of the sprue 1 to Ra = 80 nm for sprue 2.

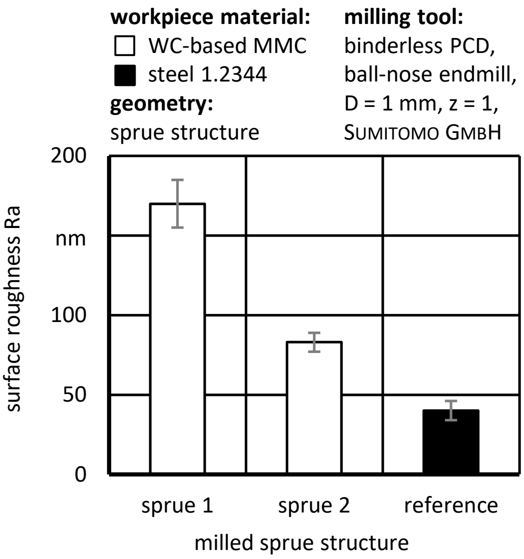

Figure 2. Surface roughness Ra for milled sprue structures machined from WC-based MMC-material and steel 1.2344

A comparison of the accomplished form accuracies a, measured from 3D-image of each sprue structure, can be taken from figure 3. The reference sample made from steel 1.2344 reaches a form accuracy of a = 4 µm. The same value can be achieved for the WC-based MMC by applying the parameters from sprue 1. A reduced feed per tooth f_z again has a positive effect on the form accuracy a, if the result for sprue 2 is considered. In this case a value for the form accuracy a = 3 µm was achieved.

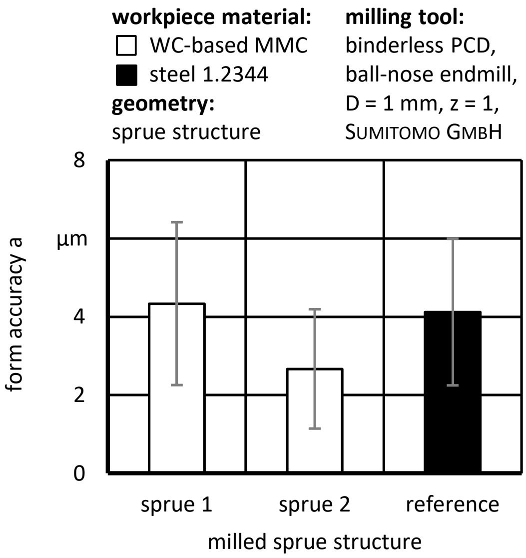

Figure 3. Form accuracy a for milled sprue structures machined from WC-based MMC-material and steel 1.2344

4. Summary

This investigation shows, that the micro-milling of WC-based MMC-materials can lead to high quality process results. A surface roughness Ra = 80 nm and a form accuracy a = 3 µm could be achieved in milling the sprue structure from figure 1. The experimental results suggest that a further improvement is possible through continued parameter optimization, especially in case of the surface roughness Ra. These findings demonstrate the potential of innovative MMC-materials for industrial applications and for enhancing the wear resistance of injection moulds in particular. Further research is needed to confirm these observations for more complex geometries and to take machining efficiency into account.

Acknowledgement

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