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Influence of different asymmetrical cutting edge microgeometries on surface integrity

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Abstract

The importance of cutting edge microgeometries in machining operations has been proven time after time again. Not only with regard to wear, but also as an important factor influencing the resulting surface integrity. In this paper the influence of asymmetric cutting edge microgeometries and different process parameters on the resulting accumulated plastic strain, plastic strain rates and surface layer microstructure of AISI 4140 in cutting experiments and FE-simulations is investigated. To characterize the cutting edge microgeometries a recently published method considering the process parameters such as cutting angles is used.

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1. Introduction

Machining processes utilizing geometrically defined cutting edges, such as turning or milling, induce profound changes in the surface layers of the workpiece. These changes can be beneficial e.g. for wear resistance and product lifetime. One affected surface layer characteristic is residual stress distribution, which is deepened and driven to higher compressive stresses by utilizing larger tool radii or relative roundness. Another is microstructural manipulation such as grain refinement of the surface layer, which follows a similar trend. Surface layer hardness can also be influenced by varying process parameters of cutting operations [1-4].

In this context, simulations and experiments utilizing the steel AISI 4140 have already been conducted. The resulting nanocrystalline surface layer thickness was analyzed contingent on the process parameters concurrent with the microgeometry of the cutting edge [5]. Asymmetrical cutting edge microgeometries, however, did not facture into this analysis to date. Therefore it is currently not fully understood how asymmetric cutting edge microgeometries influence the formation of nanocrystalline surface layers, and which geometrical or process related parameters are best suited to quantify this influence.

This work focuses on the microstructural changes in the surface layer. Orthogonal cutting experiments on a broaching machine and 2D simulations with asymmetrical cutting edge microgeometries are conducted to analyze the influence of said microgeometries. The cutting edges are characterized by a method introduced in [6].

2. Cutting edges

2.1. Influence of cutting edge geometries on surface integrity

It is well known, that the surface integrity after machining is influenced by the macroscopic- and microscopic cutting edge geometry, which changes important factors like temperature distribution or material flow during machining [7]. Chamfer angles and radii for instance were analyzed in hard turning regarding tool performance and resulting surface roughness concluding, intelligent tool preparation can raise tool life and lower surface roughness [8]. Further works include but are not limited to the influence of tool preparation on residual stresses in bearing steels [9], and the resulting microstructural changes in AISI 4140 [5]. Recently Denkena and Biermann summarized preparation techniques and known resulting influences of cutting edge geometries on various objectives, concluding that effects of cutting edge preparation on surface

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integrity are not yet fully understood [10]. Advancements in FE-Simulations and modelling of materials have led to the possibility to predict a number of surface characteristics after machining with good accuracy, most noteworthy for this work the surface layer grain refinement for machining of AISI 4140 [11].

2.2. Cutting edge characterization

Regarding the cutting edge characterization Denkena and Biermann [10] conclude, that the most feasible approach to date still is the form-factor method as shown in Fig. 1.

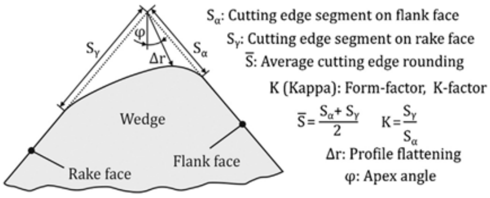

Fig. 1. Characterization of cutting edges by form-factor method [12]

Complementary to this method are process related parameters as shown in Fig. 2. The shown parameters for the process related cutting edge characterization so far were determined by experiments or simulations only and mostly used for tool life analyses. The next addition to process related cutting edge characterization was made in 2015 by Rehe [6]. By conducting milling experiments and analyzing the chip formation Rehe determined all of the parameters shown in Fig. 2 based on the cutting angles for AISI 4140 QT. The local cutting angles at the positions of h_{min} (ploughing zone height) and h_{tr} (transition zone height) where identified as $-32\pm4°$ and $-61\pm2°$ respectively. By identifying the said local cutting angles it is possible to characterize a cutting edge regarding to h_{min} and h_{tr} without conducting experiments. His following analysis was again tool life motivated and focused on the contact lengths and resulting types and speeds of wear for different micro-geometries. Even though Bassett [4] demonstrated a similar approach in 2012 through the dependence of h_{min} on L_α, experiments were still required to identify h_{min}.

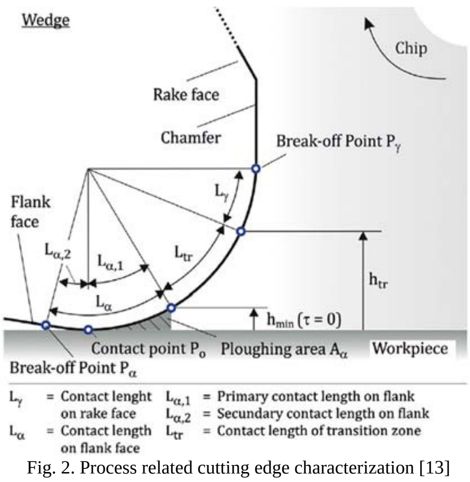

Fig. 2. Process related cutting edge characterization [13]

3. Experiments

Experiments were carried out on a Karl Klink vertical broaching machine. The setup featured a static tool, while the clamped workpiece moves downward with the set cutting speed v_c. The dimensions of the workpieces were *80x4x20 mm*, with the cutting depth being applied to the height of *20 mm*. A Walter Tools cutting edge type WKM P8TN 6028833 with a cutting wedge angle of *90°* was utilized. The uncoated cutting edge was prepared by brushing with a SiC-filament-brush with a grain size of 180, and on a drag finishing machine DF4815 of the company OTEC GmbH. The cutting tool microgeometry was determined by a confocal light microscope of the NanoFocus AG and subsequently characterized rake angle dependent utilizing the mentioned geometric dependencies demonstrated in [6]. Process parameters of the orthogonal cutting experiments which were conducted with AISI 4140 QT as well as the cutting edge parameters are listed in Table 1. The chosen parameters ensure the full immersion of the microgeometry into the material. The cutting angles in combination with the cutting edge geometry allow for a wide scatter of most, but not all process related cutting edge parameters shown in Fig. 2, barring chamfers. The workpieces' microstructure was optically quantitatively analyzed using a Focused Ion Beam (FIB) system.

Table 1. Parameters of orthogonal cutting experiments with AISI 4140 QT.

Experiment/ workpiece	Cutting speed v_c [m/min]	Cutting depth h [µm]	Rake angle γ [°]	S_γ [µm]	S_α [µm]	K [-]
1	75	54	-3	54	173	0.3
2	75	54	-15	54	173	0.3

4. FE-simulations

The FE-simulations were conducted with ABAQUS/ Standard utilizing the same basic model as in [11] with a constant friction coefficient obtained from [14]. The measured cutting edge microgeometries were fitted elliptically for S_γ and S_α in order to generate their simulated counterparts. In addition to simulations following the experimental setup, 11 cutting edges with a wedge angle of *90°* characterized geometrically as per Fig. 1 and Fig. 2 with a range of geometries and process parameters as shown in Table 2 were used. Grain refinement was modelled strain and strain rate dependent with a Zener-Hollomon approach as described in [11], starting with a homogenous grain size of *10 µm*.

Table 2. Simulated cutting edges and cutting parameters

Series		Cutting speed v_c [m/min]	Cutting depth h [µm]	Rake angle γ [°]	S_γ [µm]	S_α [µm]	K [-]
1	from	75	30	-7	8,5	8,5	0.2
	to				150	150	5.0
2	from	100	50	-7	30	30	0.5
	to		100		60	60	2.0
3	from	150	50	-7	30	30	0.5
	to		100		60	60	2.0
4	from	75	54	-15	54	173	0.3
	to			-3			