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Simulation based analysis and optimisation of the cutting edge micro shape for machining of nickel-base alloys

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Abstract

The modification of the cutting edge micro shape by wet abrasive jet machining is utilized to increase the performance of cutting tools by means of productivity and tool life. However, for numerous cutting processes the optimal micro shape of cutting edges is still unknown. In this regard, the paper deals with a method to predict optimized cutting edge micro shapes using FE-Simulation. The method includes the consideration of the local process conditions like radius dependent cutting speeds in drilling processes depicted by the example of drilling a nickel-base alloy. In this paper first simulation analyses are compared to experimental investigations. In addition, predictions of the mechanical loads dependent on the applied cutting edge micro shapes are presented.

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Keywords: Cutting edge; Design optimization; Finite element method (FEM); Modelling; Nickel alloy

1. Motivation

Cutting edge preparation is utilized to increase performance and lifetime of cutting tools. In this regard, the specific micro shape of the cutting edge takes crucial influence on the capability of respective tools. Current investigations reveal that especially the prepared size and transition contour between the rake face and the flank face of the cutting wedge determine the machining process as well as the tool and the workpiece related objectives [1, 2, 3]. In this context and in terms of cutting edge optimization, it is very important to consider the current engagement situation of the tool referred to the machining process. Due to the active cutting part of the cutting edge, the micro shape is described as the zone where the nominal rake angle differs from the effective rake angle [4].

The adjustment of the cutting edge micro shape by different preparation processes is generally based on empirical knowledge or is obtained in iterative investigation steps. Thus, improvements of the cutting tool are carried out by elaborating experimental studies. Due to the elaborate investigation methodology where the number of experiments is often limited and restricted to one workpiece material the ideal cutting edge micro shape commonly remains unknown. Consequently, it is desired to develop a numerically assisted approach for cutting edge optimization with respect to the machining condition including the material and the process parameters like cutting speed and feed.

In Fig. 1 (a) the wear development of a ground and a specifically prepared tool are compared when drilling AISI 4140. The microscopic view of the ground tool depicts breakouts and signs of wear anywhere along the cutting edge. In accordance, the width of flank wear land of the ground tool is clearly visible. The prepared tool reveals no visible breakouts and is subject to only minor signs of wear. The specific preparation of the prepared tool relates to the parameters describing round shaped cutting edges according to Denkena et al. [4, 5]. The basic parameters are the cutting edge segment on the rake face S_γ, the cutting edge segment on the flank face S_α, the profile flattening S_β and the apex angle φ, which are schematically shown in Fig. 1 (b). In consideration of the different wedge angles of the drill bit, the setting of these parameters was optimized through an initially applied FE-simulation approach to improve wear resistance of drilling tools when machining AISI 4140 [6, 7].

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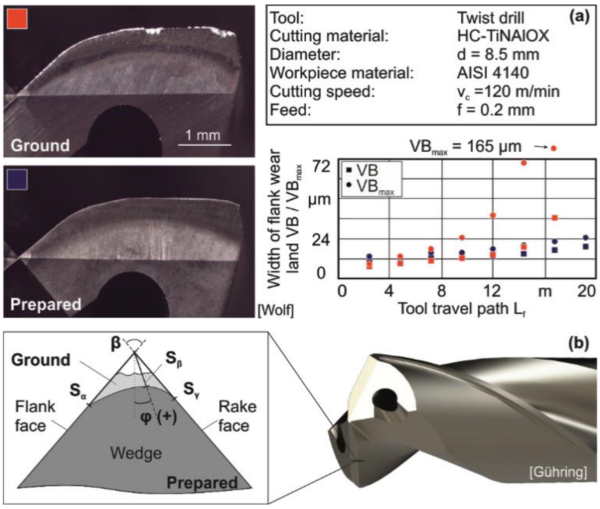

Fig. 1. (a) Wear resistance of one ground and one prepared cutting tool; (b) basic parameters to describe prepared cutting edge micro shapes.

Especially for drilling nickel-base alloys appropriate designs of cutting edge micro shapes are required to improve the tool lifetime [8]. In this regard, the application and the enhancement of the simulation approach to predict optimized cutting edge micro shapes will be introduced in this paper. First simulation results and the validation of the same are presented using the example of machining Inconel 718. In order to validate the simulation results, experimental chip formation investigations with prepared cutting parts are presented. The applied cutting edges are prepared by wet abrasive jet machining.

Nomenclature

α	Clearance angle
β	Wedge angle
γ	Rake angle
γ_{eff}	Effective rake angle
φ	Apex angle
μ	Coulomb friction factor
h	Uncut chip thickness
v_c	Cutting speed
F_c	Cutting Force
F_n	Normal Force
S_α	Cutting edge segment on flank face
S_β	Profile flattening
S_γ	Cutting edge segment on rake face
S	Average cutting edge rounding
R^2_{adj}	Adjusted r-squared

2. Modelling and Simulation

2.1. Simulation approach

The application example of optimizing cutting edges at drilling tools by FEM simulation suggests using a three-dimensional simulation approach to consider the entire engagement situation of the cutting edge. However, 3D-simulations require a high computation performance and long calculation times. Due to the reduced degree of freedom two-dimensional simulations are solved more quickly while the spatial resolution can be increased significantly. Therefore, 2D-simulations are capable to capture the influence of cutting edge micro shapes on the occurring conditions in chip formation processes. In order to use this approach for optimizing drilling tools the drilling process has to be transferred into a two-dimensional process. The procedure is illustrated in Fig. 2.

The drilling process can be subdivided into a set of orthogonal cuts along the cutting edge. These orthogonal cuts can be used for the 2D-simulation under consideration of a plane-strain deformation. Regarding determined process parameters of a certain drilling process, the local process conditions are incorporated in the optimization scheme by the application of an experimental design with a variation of the cutting speed v_c as well as the cutting edge micro shape. Each simulation represents the chip formation on a fixed position along the cutting edge of the drilling tool with a certain micro shape. Due to the radius dependency of the cutting speed and the wedge angle ß both parameters are linked and can be included as one combined parameter in the experimental design. In addition, the rake angle γ is determined by the wedge angle and the clearance angle α. The objective of the simulations is the thermo-mechanical tool load in terms of wear rate as calculated by the wear model of Usui et al. [9]. Consequently, the obtained wear rate is used to setup regression models or DACE-models [10]. These models enable the prediction of the wear rate for any parameter set in the investigated space. Therefore, optimization algorithms can be applied to identify micro shapes that minimize the tool wear for any position on the cutting edge.

The simulations are carried out by using the software DEFORM-2D V11.1 by SFTC. It is widely-used for chip formation simulations due to a good accessibility of simulation parameters and an automatic remeshing routine. The material behaviour is considered as plastic with a Johnson-Cook flow stress model [11] and normalized Cockroft and Latham damage criterion with parameters proposed by Klocke et al. [12]. The cutting wedge is modelled as a non-deformable rigid body with

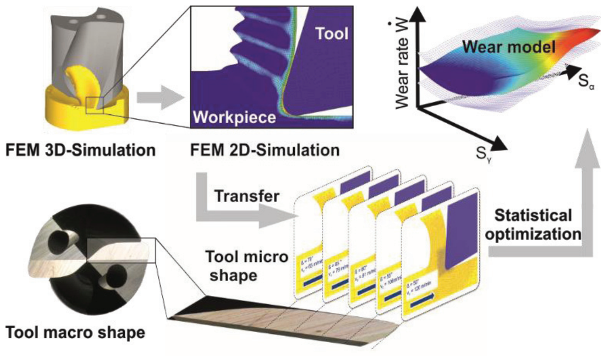

Fig. 2. Simulation approach to identify optimized cutting edge micro shapes.