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Numerical Determination of Process Values Influencing the Surface Integrity in Grinding

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Abstract

Internal traverse grinding with electroplated cBN wheels using high-speed process conditions combines high material removal rates and a high surface quality of the workpiece in one single grinding stroke. In order to capture the macroscopic and mesoscopic thermo-mechanical loads onto the workpiece during internal traverse grinding, numerical simulations are conducted at the two scales. This results in a hybrid approach coupling two finite element models with a geometric kinematic simulation. The article focuses on the influence of multiple grain engagements onto a surface layer region using a two-dimensional chip formation simulation.

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Keywords: Grinding, Finite Element Method, Multi-scale modelling, Geometric modelling

1. Introduction

High-speed internal traverse grinding (ITG) with electroplated cBN grinding wheels meets the industrial requirements of high material removal rates and high form quality in the hard machining of bores. In contrast to the plunge grinding process, the ITG grinding wheel possesses a small width of only a few millimetres and is divided in two functional zones using the peel variant. Most of the material removal takes place in the conical roughing zone, whereas the final surface formation is generated in the cylindrical finishing zone. In order to achieve high surface qualities, the single-layer cBN wheel can be touch-dressed by truing tools resulting in a smoothing of the workpiece topography during the process [1]. According to the process conditions, the thermo-mechanical loads during ITG are concentrated on a small contact area which may have a negative effect on the surface integrity of the finished workpiece [1]. In contrast to other machining processes, the material removal during grinding is constituted by multiple subsequent grit engagements. Hence, the surface integrity of the resulting surface is not only dependent on the last grain in contact, but on the entire engagement history of the material region under consideration. In the regime of process simulations, the modified initial conditions for a single grain simulation should be taken into account, if one aims at the prediction of surface integrity quantities.

Nomenclature

v_s	Grinding wheel velocity, circumferential
v_w	Workpiece velocity, circumferential
v_{fa}	Axial feed velocity
h_{cu}	(Single grain) undeformed chip thickness
$h_{\max}$	Maximum height after cut
$h_{\min}$	Minimum height before cut
t	Time step
ϱ	Workpiece material mass density
θ, θ_0	Temperature, reference temperature
$c(\theta)$	Temperature dependent heat capacity
Δz_{ps}	Plane strain thickness of the meso-scale FE model

In the present work, a numerical study is performed to estimate the influence of multiple grain engagements onto the surface layer and the chip formation. A hybrid modelling approach is used, combining a two-dimensional finite element (FE) model on a meso-scale and a geometric-kinematic simulation, cf. [2]. The FE model determines the local loads to be applied onto the workpiece as a function of the undeformed single grain chip thickness h_{cu}, the grain rake angle γ and the grinding wheel velocity v_s. In order to estimate the chronological sequence of h_{cu} for a defined section of the workpiece, the geometric-kinematic simulation is used.

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Table 1. Geometric-kinematic simulation parameters

Description	Parameter/Type	Value	Unit
Workpiece material	AISI 52100	60-64	HRC
Grinding wheel	Electroplated cBN	B181	
Roughing zone angle	χ	7.5	°
Width of roughing zone	w_{rz}	4	mm
Width of finishing zone	w_{fz}	4	mm
Total touch-dressing removal	$a_{\mathrm{ed,td}}$	16	μm
Workpiece velocity	v_w	2	m/s
Grinding wheel velocity	v_s	120	m/s
Axial feed	a_f	0.75	mm
Total radial stock removal	$a_{\mathrm{e,tot}}$	0.15	mm
Lateral dexel grid resolution	Δ_{res}	6.25	μm

2. Geometric-kinematic simulation

The global material removal in grinding processes results from numerous single grain engagements. In order to estimate the meso-scale parameters during grinding, e.g. h_{cu}, geometric-kinematic simulations can be used, considering the topography of the grinding wheel [3,4]. The workpiece and the tool in this type of simulation can be built up by different modelling techniques, such as dexel and wire- or point-based methods or constructive solid geometry (CSG), cf. [5].

In the present ITG simulation approach, the grinding wheel and the grits, respectively, are represented by CSG elements, cf. [6]. According to the ideal growth of cBN, [7], the grains are defined as an intersection of a cube, an octahedron and a tetrahedron. By manipulating the size of these three primitives, different grain shapes can be generated. The protrusion heights of the grains and the grit size are represented in the simulation by distributions based on microscopy measurements, cf. [8]. Prior to the simulation procedure, the workpiece dexels are generated with the initial diameter of the workpiece and the grinding grains are located relative to the macro-scale geometry of the grinding wheel and in conformity with the corresponding distributions, see Fig. 1.

To represent the touch-dressing within the simulation, the grains are intersected with an ideal cylinder according to the touch-dressing diameter resulting in a flattening of the grains in the finishing zone. In every simulation step, the workpiece and the tool model are moved corresponding to the process kinematics of ITG. When a CSG-grain comes in contact with the workpiece dexels, the numerical material removal is computed by an intersection between both elements resulting in the reduction of the length of the dexel. The simulation parameters used in the present study are depicted in Table 1.

In order to determine h_{cu} in a defined section of the workpiece as input values for the FE chip formation model, the chronological sequence of this value has to be estimated for a representative dexel over the entire process. In geometric-kinematic simulations, h_{cu} can be estimated by the difference between the maximal dexel height before the cut and the minimum dexel height after the cut [9], cf. Fig. 1b. When a grain penetrates the workpiece, this calculation is performed by dividing the contact area of the grain and the dexel grid in cutting slices according to the y-coordinate in the dexel grid (Fig. 1c). By using such a procedure, the local h_{cu} can be calculated for every grain engagement, which is shown for an example grain in Fig. 2. Furthermore, the current stage of the workpiece topography and the grain cutting path can be affected by the h_{cu} progress over the grain engagement at the representative dexel (Fig. 2a and b). For further considerations, the average h_{cu} is estimated per grain engagement.

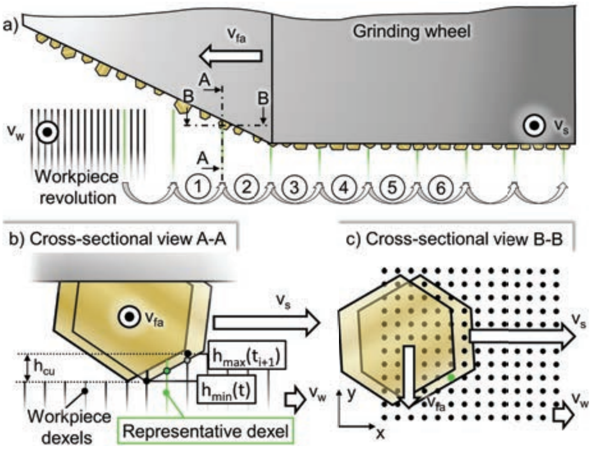

Fig. 1. Structure and procedure for geometric-kinematic modelling of ITG: a) Cross-sectional view of the modelled grinding wheel and the CSG-grains: The workpiece dexel grid (black lines) and the representative dexel (green line) move with an axial feed per workpiece revolution a_f in axial direction and rotate with the workpiece circumferential velocity v_w. b) Cross-sectional view A-A: Estimation of h_{cu}. c) Cross-sectonial view B-B: Dexel grid definition according to the direction.

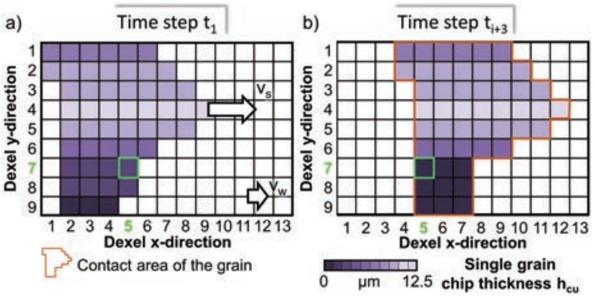

Fig. 2. Locally calculated h_{cu} within the contact area between grain and dexel grid at two different time steps t_1 (a) and t_{i+3} (b). The green area denotes the representative dexel. Note the difference of the contact area shape between subfigures a) and b) due to the changing engagement conditions.

In Fig. 3, the chronological sequence of h_{cu} for the representative dexel pointed out in Fig. 2 is depicted. The material removal at this certain position is plotted against workpiece revolutions (as in Fig. 1a), showing h_{cu} of the currently engaging grain, which is represented by its unique colour. The major material removal takes place within the second revolution of the workpiece, which is due to the high material removal rate in the roughing zone of the tool. In the roughing zone region at workpiece revolution 2, it can be observed that the same grain cuts the exact same workpiece region twice, see Fig. 3, dark blue and dark green bars. As can be seen, the h_{cu} decreases with increasing workpiece revolutions, which means that the position of the representative dexel comes in contact with the grains of the finishing zone, cf. Fig. 1. With respect to the position of the representative dexel, the entire material removal takes place conducting 13 grain engagements in total. The h_{cu} sequence of grain engagements computed with respect to this representative