Journal of Materials Processing Technology 226 (2015) 60–68

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Analysis of the grain shape influence on the chip formation in grinding

Matthias Rasim*, Patrick Mattfeld, Fritz Klocke

Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Steinbachstraße 19, 52074 Aachen, Germany

ARTICLE INFO

Article history:
Received 20 April 2015
Received in revised form 26 June 2015
Accepted 29 June 2015
Available online 17 July 2015

Keywords:
Grinding
Chip formation
Grain shape
Chip formation phases
CBN

ABSTRACT

In grinding many qualitative models for chip formation have been developed so far, which divide different phases of chip formation. A newly developed experimental single grain scratching method is presented, which enables to observe the chip formation in situ by means of a high speed video camera. Hence, it was possible to detect the transition of the chip formation phases for the first time and to determine specific grain engagement depths at the transition points. Based on experimental investigations using CBN grains and workpieces made of hardened steel 100Cr6 (AISI 52100) the influence of the 3D grain shape on the chip formation was analysed on the basis of characteristic values. Finally, a quantitative chip formation model was derived, which takes account of the 3D grain shape as well as the cutting speed and the status of lubrication. Although the influencing quantity of the different grain shape characteristic differs, it has to be stated that the grain shape in direction of motion as well as in transversal direction has significant influence on the chip formation in grinding.

1. Introduction

The material removal in grinding processes is characterized by a multitude of irregularly shaped, randomly arranged abrasive grains which are located on the circumference of a grinding wheel, and interacting with the workpiece material. Due to this complex engagement conditions the chip formation in grinding cannot be directly represented by the geometric–kinematic engagement conditions. Model assumptions were developed that are able to map the chip formation process in grinding (Brinksmeier et al., 2006). These models consider the path by which the abrasive grain penetrates the workpiece.

Hahn (1966) divided the material deformation during the engagement of an abrasive grain in a workpiece in the three phases rubbing, ploughing and cutting. During rubbing the material is mainly deformed elastically and only slightly plastically. When the grain penetrates deeper into the workpiece, ploughing takes place and clearly visible grooves with lateral bulging are formed. Like rubbing the material removal is negligible. Only by further increasing the penetration depth, the material removal is enhanced due to increased forces and a chip is formed.

Analogous to the description of Hahn, Klocke (2009) presented a model of chip formation in three phases. The first two phases were divided by the type of material deformation, see Fig. 1. In the first phase with the first contact between grain and material friction caused elastic material deformation takes place. Upon initiation of additional plastic deformation as a result of an increasing penetration depth of the grain, the second phase begins. When reaching a specific grain cutting depth T_{μ} the chip removal begins in the third phase. Elastic–plastic deformation and chip removal occur superimposed.

The penetration depth when plastic deformation begins as well as the grain cutting depth depend on the material to be cut, the grinding parameters used, the friction conditions between abrasive grain and workpiece and the shape of the grains (Tönshoff et al., 1992). These models of the chip formation have in common that they reduce the spatial process of chip formation during penetration of an abrasive grain into the workpiece to a plane problem and thus neglect the influence of the grain shape transverse to the feed direction.

However, Martin (1992) treated the interaction of abrasive grain and workpiece as a spatial case. In his model he considered as relevant factors the grain shape, orientation and -depth of engagement as well as the cutting speed. He differentiated the chip formation mechanisms micro cutting peeling machining, micro cutting flow machining, micro ploughing and micro-grooving. The transition between the mechanisms is fluent.

* Corresponding author.
E-mail addresses: m.rasim@wzl.rwth-aachen.de (M. Rasim), p.mattfeld@wzl.rwth-aachen.de (P. Mattfeld), f.klocke@wzl.rwth-aachen.de (F. Klocke).

http://dx.doi.org/10.1016/j.jmatprotec.2015.06.041
0924-0136/

In order to describe the chip formation not only qualitatively but quantitatively numerical models have been developed. Lortz (1979) presented a plane chip formation model based on the theory of slip-line fields, which considered the kinematic condition and the grain shape as a radius. This approach was further developed by Childs (1988) to wedge shaped grains. Furthermore, several mostly 2D Finite Element modelling approaches exist also using idealized grain shapes (Doman et al., 2009). Nevertheless, calculation time (Öpöz, 2012) and getting suitable material models (Denkena et al., 2006) are still common problems.

However, every numerical model needs experimental data for validation. Denkena et al. (2012) presented a new method to experimentally obtain and analyse chip roots during up-grinding. By using a quick-stop device they interrupted the chip formation process and proved that chip formation primarily occurs in the area of large grain engagement.

An often used method for investigation of the chip formation during single grain engagement is the analogy process of single grain scratching. In this process a single abrasive grain is fixed on a rotating carrier wheel and is engaged with the workpiece. Afterwards the process result can be analysed.

Anderson et al. (2011), Brinksmeier and Giwerzew (2003) as well as Barge et al. (2008) observed a decreasing amount of plastic deformation for increasing cutting speeds. Otherwise, due to the high temperatures the shear stress of the material is reduced, which facilitates the formation of chips (Zhao et al., 2013). Cai et al. (2002) stated, that at higher cutting speeds less friction between grain and workpiece is present. With a reduced friction due to lubrication an increasing amount of plastic deformation along the scratch path was proven (Vits, 1985).

Looking at the grain shape an increasing negative rake angle leads to higher plastic material deformation (Xie and Williams, 1993). In addition, the orientation of the abrasive grain respectively the grain shape orthogonal to the feed direction has an influence on chip formation. This has been demonstrated by several authors in relation to the position of the cutting edge (Deng et al., 2014) and the edge angle (Aurich and Steffes, 2011) without deriving a general statement.

Nguyen and Butler (2005) determined depending on the rake angle which grains cause elastic or plastic material deformation or chips when engaging. They also considered the grain engagement in terms of mechanisms during the entire engagement. An analysis of the areas where only elastic deformation, only elastic and plastic deformation or finally the actual chip removal occurs, i.e. the individual phases of chip formation, did not occur. Several analytical

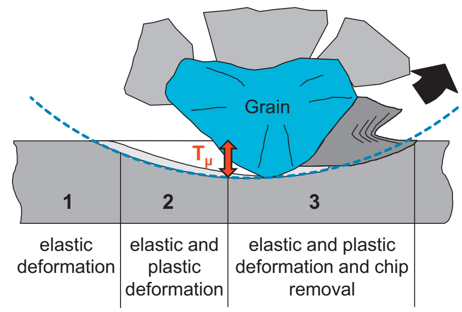

Fig. 1. Phases of chip formation in grinding according to (Klocke, 2009).

force models were presented lately, which considered the different mechanisms during chip formation according to Hahn without being able to quantify them (García et al., 2014; Tang et al., 2009; Yao et al., 2014).

In this publication a newly developed experimental single grain scratching method is presented, which enables to observe the chip formation process visually. Hence, it was possible to detect the transition of the chip formation phases for the first time. Based on experimental investigations the influence of the 3D grain shape on the chip formation is discussed and a quantitative chip formation model is derived.

2. Experimental procedure

In order to be able to evaluate the chip formation and identify the different phases of chip formation, however, it is necessary to observe the chip formation process in situ visually. Due to the geometric and kinematic boundaries of the grinding process, leading to contact times in the microsecond range, with existing single scratching processes using currently existing high-speed camera systems a visualization of the grain and thus the chip formation at the cutting edge is not possible. Due to the large ratio of contact length to grain size, either the image area is chosen large enough to cover the entire contact length or the image resolution can be set high enough to capture the individual scratch grain and thus the contact point between grain and workpiece. Both at the same time are not possible because of the limited number of image points of the camera picture. The high rotational speed of the grain prevents tracking of the camera.

Therefore, it was necessary to modify the experimental setup of the single grain scratching, see Fig. 2. In contrast to the "con-

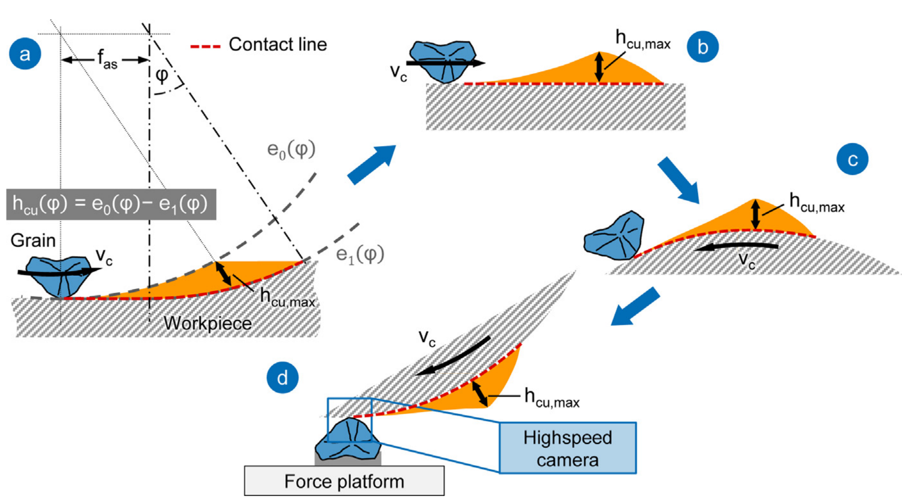

Fig. 2. Experimental methodology for the visual detection of chip formation in single grain engagement.