CIRP Annals - Manufacturing Technology 63 (2014) 631–653

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Cutting edge geometries

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ARTICLE INFO

Keywords:
Machining
Cutting edge
Tool geometry

ABSTRACT

Tool life and performance are decisively determined by cutting edge geometry. An appropriate shape of the cutting edge improves wear resistance, tool life and process reliability. This paper reviews major developments in cutting edge preparation technologies and methods of cutting edge characterization. Moreover, the influences of cutting edge geometry on chip formation, material flow, as well as mechanical and thermal loads on the tool are discussed. The essential modeling and simulation approaches are presented. Effects on surface integrity are described. Finally, an overview of important perceptions for prospective research and development in this field is provided.

1. Introduction

1.1. Motivation

The cutting edge shape and the cutting edge condition are of crucial importance for machining operations. During the cutting process the impact of high thermal and mechanical loads on the cutting edge result in wear. Moreover, the quality of the machined surface is affected by the cutting edge shape. The demands of modern production are high productivity and high process reliability. One place these demands can be met is in cutting edge preparation [134].

In Fig. 1 the main effects of a cutting edge preparation are summarized. In addition to the reduction of the chipping after grinding and burrs after sintering the preparation can be used as a post-coating treatment. Before the coating process, cutting edge preparation influences the surface topography and the residual stresses in the substrate. Regardless of the cutting procedure, the advantages of cutting edge preparation are scientifically proven by many investigations [18,41,134]. This research shows that the cutting edge preparation leads to an improved cutting performance due to an enhanced cutting edge stability. In general, pre-treatment causes a better wear resistance of the tool by reducing chipping and initial crack formation along the edge as well as increasing its mechanical strength. Furthermore, adhesion strength is influenced by cutting edge preparation, thus the application of the coating can be facilitated by a smoothed surface of the cutting edge. The optimal cutting edge form regarding the machining process is related to the machining conditions and the specifications of tool and workpiece material [8,22,47,49,157].

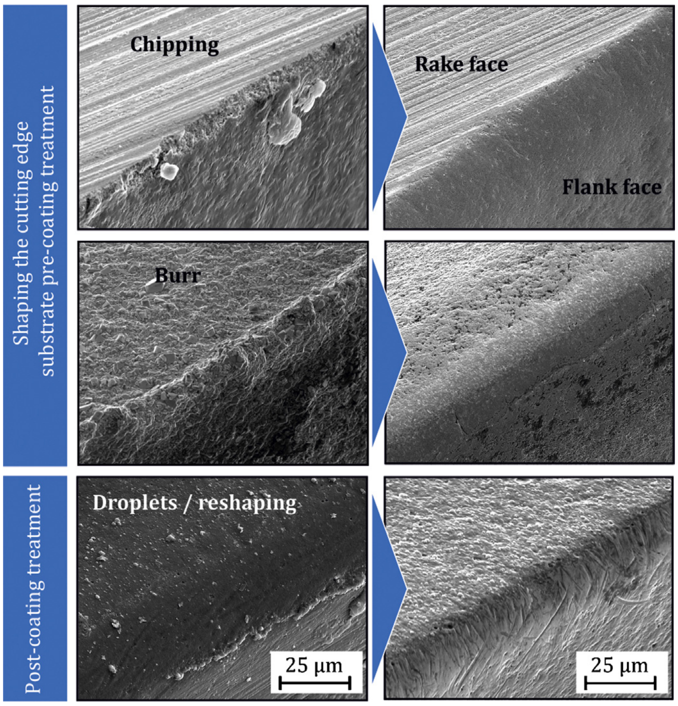

Fig. 1. Main effects of the cutting edge preparation [8].

1.2. Historical developments

The first mention of rounded cutting edges can be found in [60]. Fischer mentioned in 1897 that cutting edges are not to be regarded as entirely sharp. The first international mention of rounded cutting edges can be found in Chien [34], Albrecht [1] and Masuko [95]. The authors described independently the influence of rounded cutting edges on process forces.

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http://dx.doi.org/10.1016/j.cirp.2014.05.009
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In orthogonal turning operations, Chien investigated the influence of the tool tip on process forces, material deformation and finished surface. Chien determined that the magnitude and direction of the force depend on the tool tip, on the workpiece material and tool tip size. Chien also introduced an extra force component due to the cutting edge rounding. Albrecht studied the influence of rounded cutting edges and introduced the mechanism of ploughing into the metal cutting theory, whereas Masuoko described the effect on process forces as indentation force. Major early results on the influence of round cutting edges in machining are documented [10,84,132]. In 1966 Nakayama et al. [99], traced the increasing specific energy for chip formation while reducing the chip thickness back to the cutting edge rounding. The evolution of publications on this topics over time shows rapidly increasing interest in this research topic.

As displayed in Fig. 2, the trend of a defined rounded cutting edge geometry is reasonably new compared to the history of cutting tools in general. A major reason seems to be the early lack of accurate and reproducible production processes. The preparation of cutting edge radii was mainly done by manual processes at that time. The development of new more accurate measurement has led to an increase in the application of prepared cutting edges. Current developments strive to a specific design of the cutting edges for different machining operations. From a current perspective of tool performance, the future cutting edge geometries may be adjusted to the cutting and workpiece material, machining process, and even on machining conditions [8,155]. An important current question is the commercial feasibility of such application tailored cutting edges for tool producers.

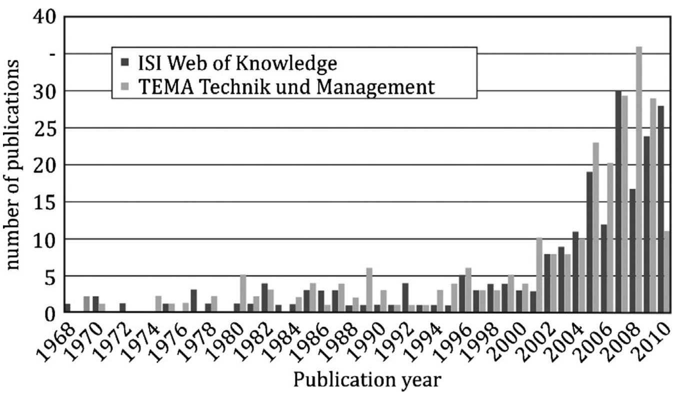

Fig. 2. Publications related to rounded cutting edge geometries.

1.3. Cutting edge definitions

The cutting tool geometry and parameters describing the macroscopic and microscopic tool shape are depicted in Fig. 3. The spatial dimension of a cutting tool is termed as its macrogeometry. In contrast, the microgeometry describes geometrical details of the active part of the cutting tool underneath the macrogeometric defining quantities. Accordingly, microgeometry defines the shape of the cutting edge, which is the transition between the rake face and the flank face of a cutting wedge. The characterization of the cutting edge shape (microgeometry) is feasible by means of profile sections of the wedge. Hence, an appropriate differentiation between microgeometry and macrogeometry is required. This is demonstrated in Fig. 3 with regard to contact conditions in the chip formation zone. The rake angle is predetermined by the macroscopic tool form. It can either be related to the superordinate form of the wedge or to the orientation of a chamfer. The latter is the case if the chamfer is more strongly describing the machining situation in comparison to the superordinate form of the wedge. The effective rake angle is specified by the actual existing rake angle of the cutting tool at a certain contact point of workpiece and cutting tool during cutting process. The section of the cutting tool where the effective rake angle begins to differ from the (nominal) rake angle defines the transition between tool macro- and microgeometry.

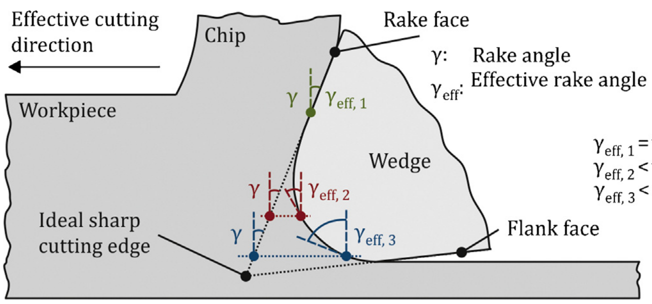

Fig. 3. Transition from macroscopic to microscopic tool shape with regard to cutting conditions.

For the intersection of rake and flank face, three fundamental cutting edge shapes are currently defined. These shapes are sharp, rounded and chamfered. A combination of different chamfered and rounded shapes is also possible [37,65,146,161]. A sharp cutting edge implies that the transition between the rake and the flank face is neither rounded nor chamfered. In practice, it is not possible to produce an ideal sharp cutting edge shape [8,115].

Due to the fact that "sharp" cutting edges are not indefinitely sharp and rather have an irregular and chipped profile, there is no specific parameter for their description [40,115]. Furthermore, sharp cutting edge shapes, that means cutting edges without a measureable size of cutting edge rounding and/or chamfer, are not suitable for many machining tasks because of their lower stability against mechanical loads in comparison to a rounded or chamfered shape [21,37,62,116]. As already stated, cutting edge preparation is used with sharp tools to create a more appropriate cutting edge shape. Particularly, cutting edge designs that are tailored to specific machining tasks show a high potential to improve tool performance. To generate these specific designs accurately, a detailed characterization of the shape of transition between rake and flank face is essential [8,129,155]. For this purpose, different characterization and measurement methods are available.

2. Characterization and measurement

Once cutting edge geometry is defined, its influence on the cutting process can be determined. For rounded cutting edges the radius is still a frequently used parameter for characterizing the cutting edge microgeometry. Generally, this shape is not circular and so this is an oversimplification. As a consequence, different methods for characterization have been investigated. Tactile or optical measurement devices have been investigated with variable numerical results [8,131,155]. A standardized procedure, however, does not exist yet. In the following, different methods of cutting edge characterization and measurement are introduced with their specific advantages and disadvantages. This section is based on the work of CIRPs Collaborative Working Group "Cutting Edge Geometry" installed between 2005 and 2008.

2.1. Methods for characterization

Cutting edge geometry is characterized by microgeometry and edge topography. The edge topography describes the surface structure of the cutting edge. It is highly impacted by microscopic damage like burrs or chipping [37,89,153]. Measurements of surface roughness are commonly used to describe the chipping along the cutting edge. The measurement is carried out parallel to the cutting edge [62,63,89,129]. A schematic illustration of a chipped cutting edge topography after a grinding process is depicted in Fig. 4. In the following, methods for characterization of chamfered and rounded cutting edge shapes are introduced: a cutting edge chamfer is a straight intersection of rake and flank face with sharp transitions but this transition is not infinitely sharp. Chamfered cutting tools exist with different chamfer