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Strategies for grinding of chamfers in cutting inserts

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ABSTRACT

In order to increase tool life and improve workpiece quality, cutting processes with geometrically defined cutters demand inserts with a prepared cutting edge. Chamfers are widely used in many processes, since they can provide edge strengthening without damaging the chip flow. In order to achieve a stable and reliable cutting process, uniform chamfer geometry along the insert and high edge quality are necessary. For this, proper grinding strategies for chamfer manufacturing must be taken into account. With the objective of getting knowledge about the chamfer manufacturing process, strategies for grinding of chamfers are investigated in this paper. Chamfers were ground on PCBN, mixed ceramic and cemented carbide cutting inserts with a vitrified bond diamond grinding wheel. A single grain chip thickness model is used to characterize the process and different grinding strategies are analyzed in terms of reduction of chamfer geometry deviation. It was found that high insert rotational speeds increase the edge chipping and that the cutting insert material has a considerable influence on the chamfer geometry deviation.

1. Introduction

Usually sharp edges are not applied in cutting processes, since they lead to low tool life and consequently, to unstable processes. In this way, different kinds of edge micro geometries are prepared by tool manufacturers, like chamfers, roundings, chamfers with roundings and asymmetric roundings [1]. Different micro geometries are needed in accordance to the application of the insert. Chamfers are often manufactured on PCBN and ceramic inserts, while roundings are mainly prepared on PCD and cemented carbide tools [2]. However, Yen et al. [3] affirm that rounded cutting edges are normally used in finishing processes and chamfers in roughing and interrupted cutting. Commercial inserts have chamfer angles in the range of 10°–35° and chamfer widths from 100 μm to 200 μm. Roundings use to be symmetric and range from 30 μm to 125 μm.

In machining of hardened steels, chamfers are commonly applied to optimize the chip formation and increasing the tool life [4]. The edge micro geometry plays an important role in this process since the cut occurs at the tool tip and only small depths of cut and feeds are used [5].

Zhou et al. [6] demonstrated that the use of chamfered PCBN tools causes higher cutting forces in dry hard turning, but lower flank wear than tools with positive or 0° rake angles. Additionally, high temperatures contribute to the plastic softening of the workpiece material [7]. Moreover, during cutting, workpiece material is compressed over the chamfered tool and acts like an edge, increasing the edge strength and reducing tool wear [8].

In hard turning of 42CrMoS4 steel, Kress [9] notes that a minimum chamfer angle of 20° must be applied in order to achieve higher tool lives. Such an angle reinforces the wedge cutting and helps avoiding edge chipping at the beginning of the cutting process. A further increase of the chamfer angle does not benefit the process, since the crater formation is favored and the cutting forces increase [9]. Klocke and Kratz [4] show that in hard turning of AISI 5115 the crater position can be changed by varying the chamfer parameters, which influence the local chip flow speed, local deformation and contact length between rake face and chip.

Therefore, the choice of the chamfer parameters plays an important role in the process design. Furthermore, the preparation process must also be considered. Differences of the target edge geometry to the produced one affect cutting forces [10] and, consequently, tool life as well. As a result, a regular micro geometry of the cutting edge is important to achieve a reliable and reproducible process.

Chamfers are produced by plunge-face grinding. This process offers the proper kinematics and enables the manufacturing of the flank faces and cutting edge in one insert clamping. Another advantage is the high flexibility to improve edge quality, so that changes of grinding parameters do not cause variation in the micro geometry. Cutting insert materials are brittle and their grinding

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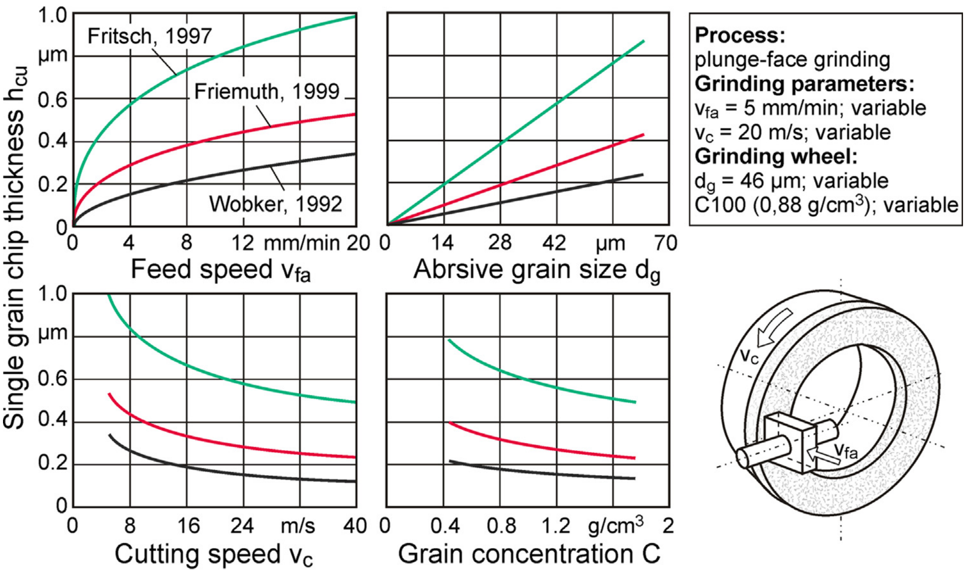

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Fig. 1. Comparison of different single grain chip thickness models [12–14].

is dominated by the formation of micro-cracks and the resultant breaking out of fragments. With the penetration of grains in the material, radial and lateral cracks are formed. Chip removal results from the lateral cracks, while axial cracks lead to a permanent damage of the workpiece peripheral zone [11]. In this context, the single grain chip thickness is an important factor, which describes the contact relations between workpiece and grinding wheel. Thus, it enables the characterization of the influence of different process input parameters on the workpiece quality. Main factors affecting this variable are the feed rate and the cutting speed, the wheel grain size and the grain concentration. Feed rate and cutting speed are related to the kinematics of the process, while wheel grain size and concentration describe the grinding wheel layer.

Despite the importance of the application of insert edge chamfers, no investigation regarding their manufacturing was found. Considering the lack of knowledge about this subject and the need of chamfered edges in determined cutting processes and insert materials in order to increase tool life, strategies concerning the right choice of methods and conditions for producing edge chamfers are investigated in this study. Experiments will be carried out in order to achieve a regular micro geometry in the entire insert and a high edge quality. A single grain chip thickness model is applied to characterize the process. This characteristic value will be correlated with the edge chipping after chamfer grinding.

1.1. Considerations about single grain chip thickness models for plunge-face grinding

Models for the calculation of the average single grain chip thickness in plunge-face grinding of cutting inserts were developed by Wobker [12], Fritsch [13] and Friemuth [14]. In all cases, there is no intention to obtain an absolute and validated value of the chip thickness, but to develop a characteristic value in order to characterize the influence of different input parameters. All authors use the continuity equation and the same hypotheses. Thus, cutting overlap of different abrasive grains, elastic deflections and grain wear are neglected and all abrasive edges have the same geometry. However, Wobker and Friemuth consider the abrasive grains as spheres, while Fritsch as pyramids. Moreover, different approaches are used to calculate the number of active cutting edges. Wobker assumes that the active grains are those with 50% of the grain size out of the bonding, Fritsch uses an inverse linear relationship between the number of active edges and the grain protrusion, Friemuth creates the “alternative grain protrusion”, which describes the difference between average chip thickness and grain protrusion. He considers that the number of active edges varies linearly with this new parameter and the proportionality factor corresponds to the edge density of the grinding wheel.

Despite the observed differences, all models demonstrate the same tendency of variation of the average single grain chip thickness in relation to grinding input parameters (Fig. 1), though the absolute values vary. In all cases, experimental results show that the calculated average single grain chip thickness is a proper characteristic value to be correlated with output variables of the plunge-face grinding process.

Friemuth transferred the obtained model to the grinding of flank faces at insert corners. He notes that the contact length l_k between grinding wheel and insert is not constant (Fig. 2) and accordingly the mechanical load varies during insert rotation.

However, for a complete characterization of the mechanical load during insert rotation, the variation of the rotational speed would have to be taken into account, but it is considered constant in that case.

2. Materials and methods

Experimental tests to investigate the grinding of chamfers are carried out on a five-axes grinding machine Wendt WAC 715 Centro (Fig. 3). This machine allows a maximum rotational speed 1625 min^{-1} and maximum power 3 kW. Two of the axes are linked to the grinding wheel: the *X*-axis is responsible for the axial feed movement and the *W*-axis enables the oscillation of the wheel and a complete utilization of the grinding layer. The remaining three axes move the insert: the *A*-axis determines the grinding direction in relation to the grinding wheel; the *B*-axis allows an inclination of the insert in order to grind chamfers; and the *C*-axis rotates the insert, enabling the grinding of the entire insert (straight flank faces and insert corners). Additionally, the *L*-axis is responsible for the feed movement of the dressing roll.

For the measurement of the grinding forces, two Kistler sensors type 9213 were mounted on the workpiece clamping system of the machine in the normal and tangential directions. The acquisition