Characterisation of Burr Formation in Grinding and Prospects for Modelling

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Abstract
Increasing industrial requirements on the precision of edge geometry lead to the investigation of burr formation, particularly in finishing operations such as grinding. The objective of the presented research is to understand the mechanisms of burr formation in grinding. Following a description of previous research and existing approaches to understand burr formation in grinding, experimental investigations in flat surface grinding of tempered steel are described. Based on the previous studies and the experimental results, a descriptive model of burr formation in grinding is proposed.

Keywords:
Grinding; Burr Formation; Descriptive Model

1 INTRODUCTION

A main objective of industrial production is reliable and cost-efficient manufacturing of workpieces with defined geometrical and technological properties. Due to the material deformation during the process, cutting operations always lead to the creation of micro- or macroscopic burrs. If the size and shape of burrs does not affect the functionality of the workpiece no further production step is required, otherwise a subsequent deburring process is necessary. Being a no value adding process, deburring is an undesirable additional production step extending the process chain and increasing manufacturing time and cost. Furthermore, even slight workpiece damage by subsequent deburring processes can not be tolerated if the related machining process is a precision finishing operation, such as many abrasive machining processes.

Since burr generation in cutting cannot be avoided completely, the main objective of the research is to control the burr generation in order to create burrs of a tolerable size and shape, which

- are acceptable with regard to the workpiece functionality or
- ensure a safe subsequent deburring process by an appropriate separation behaviour.

For both approaches a basic understanding and therefore a comprehensive investigation of the influence-cause-relations of the burr formation mechanism is essential.

2 BURR FORMATION IN GRINDING

Under common operating conditions grinding burrs are comparatively small and can often be found only at the microscopic level. Depending on the field of application even these microscopic burrs can affect the functionality of a workpiece. Furthermore, the increased application of high performance grinding processes, which cause an increase in burr size with a resulting effect on the functionality of the workpiece, lead to the investigation of burr formation mechanisms in grinding. Resulting burrs are located at the edges of the workpiece and can be classified as entrance burr, side burr and exit burr (Figure 1a). These burrs vary in size and shape and are created through different formation mechanisms.

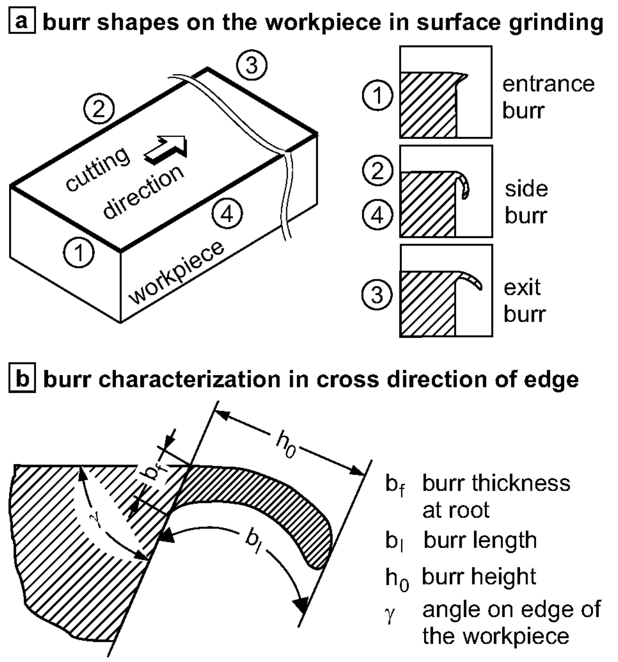


Figure 1: Burrs at workpiece edges [1].

Various variables affect the grinding process itself and therefore the burr formation (Figure 2).

influences on burr formation in grinding			
workpiece	cutting tool	kinematics	machine tool
• geometry • physical properties • ...	• grinding wheel topography • physical properties • ...	• machining operation • cutting parameters • ...	• mounting • static and dynamic stiffness • ...

Figure 2: Influences on burr formation in grinding [2].

3 PREVIOUS WORK

The main focus of research on burr formation in metal cutting has been on processes with defined tool geometry such as turning, milling or drilling. Several models have been developed to explain the burr formation there. Pekelharing [3, 4] investigated burr formation mechanisms in interrupted cutting with defined cutting edges such as milling. He detected a negative shear zone as the cause of the burr formation at the exit edge of the workpiece. Depending on the exit edge geometry the macrogeometric chip is bent along the shear zone or separated. Ko and Dornfeld [5] developed a model for orthogonal cutting to explain the burr formation in ductile materials. They subdivided the finish of the cutting process into the steps initiation of burr formation, development of burr formation and final burr formation. Finite Element Simulations of the burr formation in orthogonal and oblique cutting were developed for example by Hashimura et al. [6]. It can be concluded that the deformation of chip and edge as well as the breakout at the end of the cutting process shape the exit burr in machining processes with defined tool geometry. Various variables, such as cutting parameters, exit edge angle of the workpiece, geometry of the cutting tool, material properties of the cutting tool and especially of the workpiece, affect the cutting process and therefore the burr formation.

In cutting processes with defined cutting edges, the macroscopic chip formation and the burr formation at the exit edge are directly coupled. This is not the case for burr formation in grinding. The material removal along the contact length between grinding wheel and workpiece is caused by single microscopic grits and leads to a microscopic chip formation, whereas the burr formation at the workpiece entrance and exit edges takes place along the complete contact width of the grinding wheel.

Only a few studies, namely by Kawamura and Yamakawa [7], Yamakawa et al. [8], Hofman and Kvasnicka [9], Barth et al. [2] and Aurich et al. [10] concentrated on burr formation in grinding. Kawamura and Yamakawa [7] carried out experiments without coolant by using a reciprocating table type surface grinder. Therefore, the grinding conditions are characterized by a high forward velocity and a low depth of cut. Results of these experiments are:

- Among the analyzed entrance, side and exit burrs, the exit burr is by far the largest in size. Therefore, all following investigations concentrate on the formation mechanism of the exit burr.
- A zone of plastic deformation at the exit edge could be detected. The expansion of this plastic zone can be prevented by an increase of the exit edge angle which leads to a reduced burr size. The shape and size of the burr can be considered to be closely related to the plastic flow at the end of the workpiece.
- A section at the end of the exit edge, which is theoretically removed by the wheel depth of cut, remains at the edge. The burr is developed mainly by this uncut section.

Parallel to the experimental investigations, Yamakawa et al. [8] investigated the burr formation in grinding by Finite Element Modelling without considering material removal or producing burrs in the simulations. However, they detected a plastic flow area, created during the grinding process and extended in the vicinity of the workpiece end, and proposed that this behaviour was the reason for burr formation. Further on, a tendency for heat concentration at the workpiece end could be observed as the exit edge angle becomes more acute. As a consequence of this, a decreasing exit edge angle leads to a more pronounced deformation of the workpiece end due to decreased rigidity. Hofman and Kvasnicka [9] investigated burr formation in grinding using cutting conditions similar to Kawamura and Yamakawa [7]. Among others they obtained the following results:

- The material in the burr next to the burr root area was significantly elongated in the feed direction and compressed in the in-feed direction in surface and subsurface layers.
- The microhardness in the burr root area was higher than the microhardness of the basic material.
- The plastic flow zone begins to extend at a specific angle. The burr thickness at the root is equivalent to the depth of the plastic zone when it reaches the edge.

Barth et al. [2] investigated the differences in burr formation in conventional grinding and grinding with superabrasives in flat surface up cut grinding using coolant oil. Significant differences in burr formation with different angles on the workpiece edges, grinding wheels and cutting parameters were detected. They explained the generation of burrs due to the effect, that the edge of workpiece does not offer sufficient resistance against plastic deformation due to acting forces. As a result, the remaining material on the workpiece edge is deformed and bent over the edge.

4 EXPERIMENTAL INVESTIGATIONS AND RESULTS

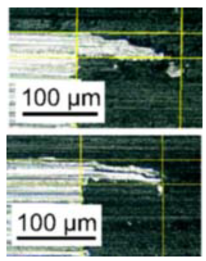
As a first step to investigate burr formation in grinding, experimental investigations with varying cutting conditions were made to analyze burr formation. Flat surface up cut grinding experiments of tool steel 90 MnCrV8 (AISI 02) were conducted on a high performance grinding machine with coolant oil. Using conventional and superabrasive grinding wheels with different grain sizes and materials, two different experimental setups were carried out under variation of the cutting parameters, such as depth of cut, cutting speed, feed rate, workpiece geometry and hardness. During the grinding process, the forces and temperatures were measured. Correlations between process forces and temperatures during grinding and characteristic burr parameters (Figure 1b), evaluated after the grinding process, had been detected [10].

The size and shape of the burrs vary widely. In addition to small burrs, generated under conventional cutting conditions (Figure 3a), big spiral burrs were generated under high performance cutting conditions (Figure 3b).

a **Conventional grinding wheel type**

Cutting conditions:

Grit size	60mesh = approx. 251 µm
Abrasive	Aluminum oxide
Cutting speed	35 m/s
Feed rate	0.6 m/min
Hardness	50 HRC
Exit edge angle	90°
Depth of cut	0.2 mm



b **Superabrasive grinding wheel type**

Grit size	126 µm
Abrasive	CBN
Cutting speed	100 m/s
Feed rate	1.2 m/min
Hardness	60 HRC
Exit edge angle	60°

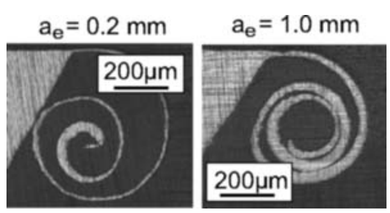


Figure 3: Metallographic sections of grinding burrs.