Modelling, Simulations and experimental Verification of Size Effects in Burr Formation

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1 Abstract

The modern manufacturing has high demands on the cutting process. Today, the precision of the workpiece and the by-products of the machining process are some of the main parts of research. Burrs are some of the by-products. They result from the deformation of the workpiece material near the workpiece edge, caused by the forces of the cutting process. The removal of this by-product requires a big partial amount of the manufacture costs. Especially in the micro machining burrs are difficult to remove. This work deals with the size effect in the burr formation in the drilling process.

2 Introduction

In the metal-cutting manufacturing the nuisance adhering residual material is called burr [1]. Most of the theoretical investigation is based on the two-dimensional orthogonal cut. In this model the cutting process is reduced to a two-dimensional plane process without any chip forming in the depth. Such experiments have a low reference to often used practical cutting processes, but they are useful for basic investigation on elementary cutting processes. A. Stoll [2] uses orthogonal cutting to demonstrate size effects during the burr formation. She shows that there is a non-linear gradient of the burr geometry and of the ratio of the cutting force to the passive force during the burr formation. Built upon this investigation, the experiments are transferred into the three-dimensional cutting process. For this, the often practical used drill process has been selected for the present investigations.

3 Burr formation in drilling operations

3.1 Basics of the drilling process

The investigations in this work are focused on the deformations during the exit of the tool in the cutting process. Drilling of through holes can be split into three time parts.

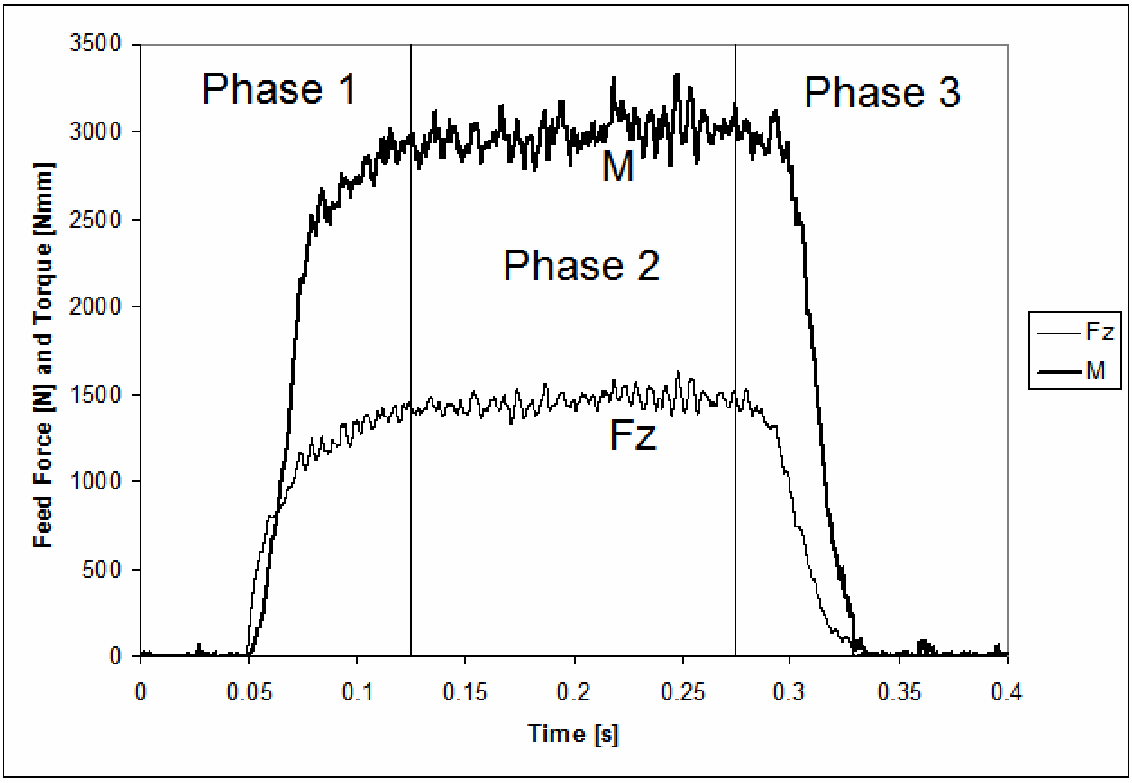

Figure 1: Phases of a drilling operation (5 mm drill diameter)

In the beginning the top of the drill has only contact with the workpiece. In this phase 1 the drilling operation is more a forming process than a cutting process, as only the chisel edge has workpiece contact. It deforms the workpiece material in front of the drill top and centers the drill. This period is characterized by a rising of the cutting forces and the torque. When the main cutting edges of the drill get in complete contact the real cutting process and phase 2 begin. During this phase 2 the cutting forces and the torque is approximately constant. When the tool comes close to the workpiece edge, phase 3 with the burr formation starts. Here, the cutting force and the torque fall. The burr formation process ends with the ending of the drill process.

3.2 Burr formation

Influences on the burr formation processes are very miscellaneous, like in the normal cutting process. In the following figure 2 the main influences are shown, but between the influences there are many interactions, which are hard to define.

Tool wear, no ideal workpiece material and much more influence are hard to reproduce and not constant. Therefore it is impossible to reproduce a burr to one hundred per cent. For burr formation only tendencies can be predicted.

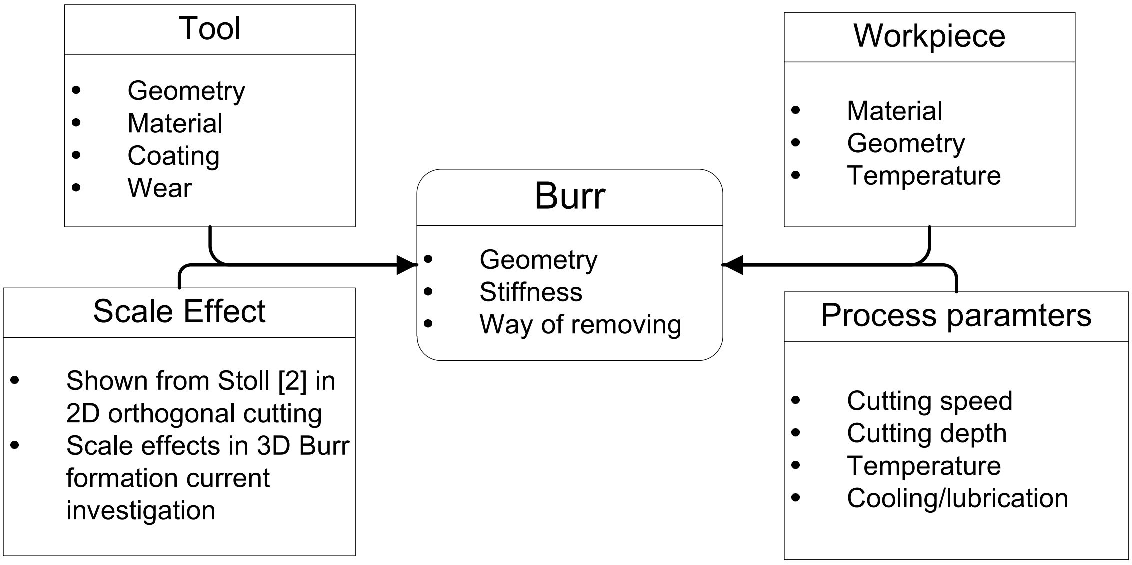

Figure 2: Influences on the burr formation

There exist different kinds of burrs for drilling. Min, Kim and Dornfeld [3], as well as Ko and Lee [4], defined different types of burrs, which are shown in figure 3.

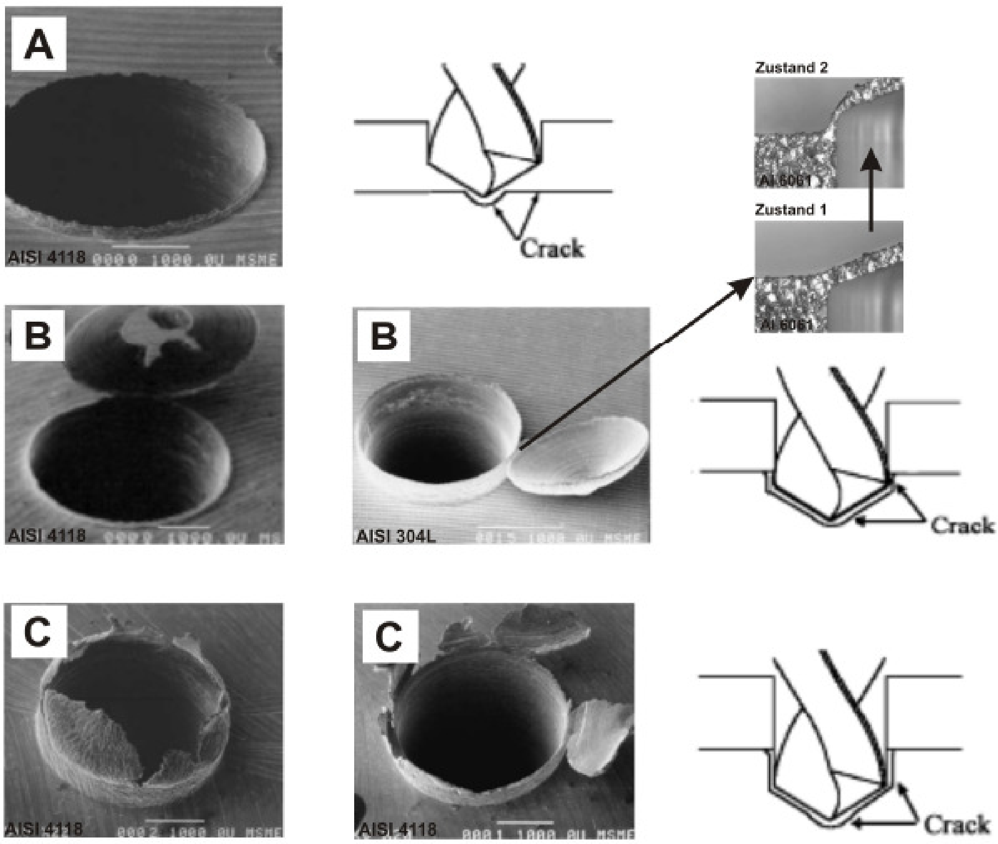

Figure 3: Drilling burr types [3], [4]

Type A is the so called ring burr. It has a low burr height and is very continuous in thickness and height.

Type B is the interstage between type A and C. This burr has areas with vertices and areas with a continuous ring burr. This kind of burr often has a drill cap.

Type C is the so called crown burr. The crown burr is significantly higher than the ring burr; the height is non-uniform.

4 Scale effects in macroscopic drill operations

4.1 Setup of the macroscopic drill operations

For the drilling experiments in the macroscopic level drill diameters from 2mm up to 14mm in 1mm steps were tested. Uncoated HSCO standard drills were used. The cutting angle (38°), the clearance angle (5°) and the nose angle (118°) are the same for all drills. The workpiece material was Ck45. The drill exit surface of the workpiece was grinded. The cutting speed for all sizes of drills was 25m/min, which was provided by the drill tool company. The depth of the cut depends on the drill diameter. So the ratio between diameter and depth of the cut was constant 60. As a result of the scaled revolution speed and the scaled depth of cut, the feed of the drill in axial direction was for all drill sizes 265mm/min.

The experimental setup was made up of a regular machining centre with a horizontal spindle, a Kistler™ force measurement system and a thermographic camera (ImageR 3100) from Infratec. The thermographic camera was used for videotaping the drill exit surface during the burr formation process. The goal of this was to define the temperature distribution of this area during the burr formation. For this the camera takes pictures in a frequency of 10Hz. With the help of these pictures the temperature distribution over the drill radius could be calculated. In the following figure 4 the experimental setup is shown.

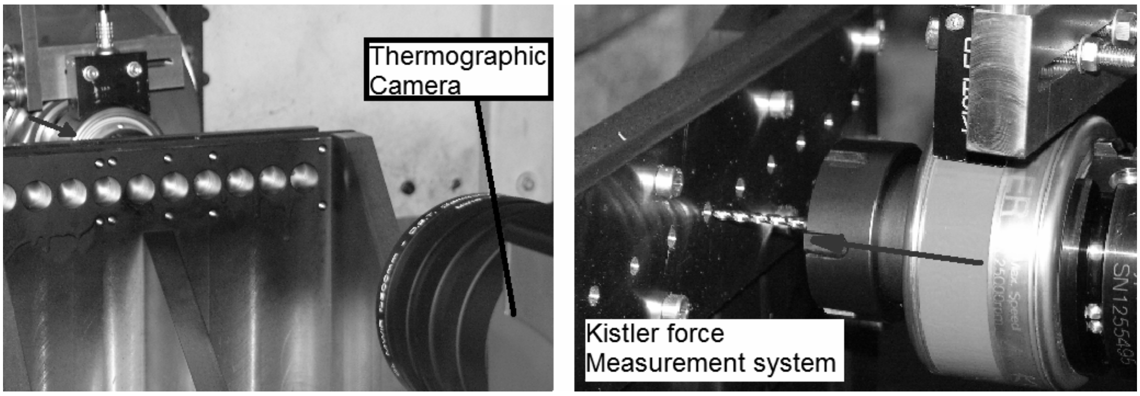

Figure 4: Experimental setup

With this setup it was possible to measure the forces and the temperature during the burr formation. But the most important result of the burr formation process is the geometry of the produced burr.

The geometries of the burr are in the micro size and the stiffness is undefined and very low. So a mechanical scanning is not possible. First tests with a confocal microscope showed that the rough craggy surface of the burr makes a measure system, which is based on reflection, impossible to use. Tests with a normal light optical microscope showed that it is possible to take microscope pictures from the burr with a high resolution. For this the burrs were photographed with a light optical microscope with a digital camera in approximately 90° to the exit surface. Afterwards, the geometries were measured in the digital picture.

4.2 Axial force and torque path during burr formation

For the measurement of the cutting forces during the burr formation a rotating dynamometer of Kistler™ was used. With this the torque and the axial force of the drill can be measured. The path for both over the time was saved in a frequency of 10,000Hz. The axial force Fz for the drilling holes bigger than 11mm diameter was too high for the measurement system. So only the torque is portrayed here. In the following figure 5 the torque path during the burr formation of the drills with different diameters are showed.

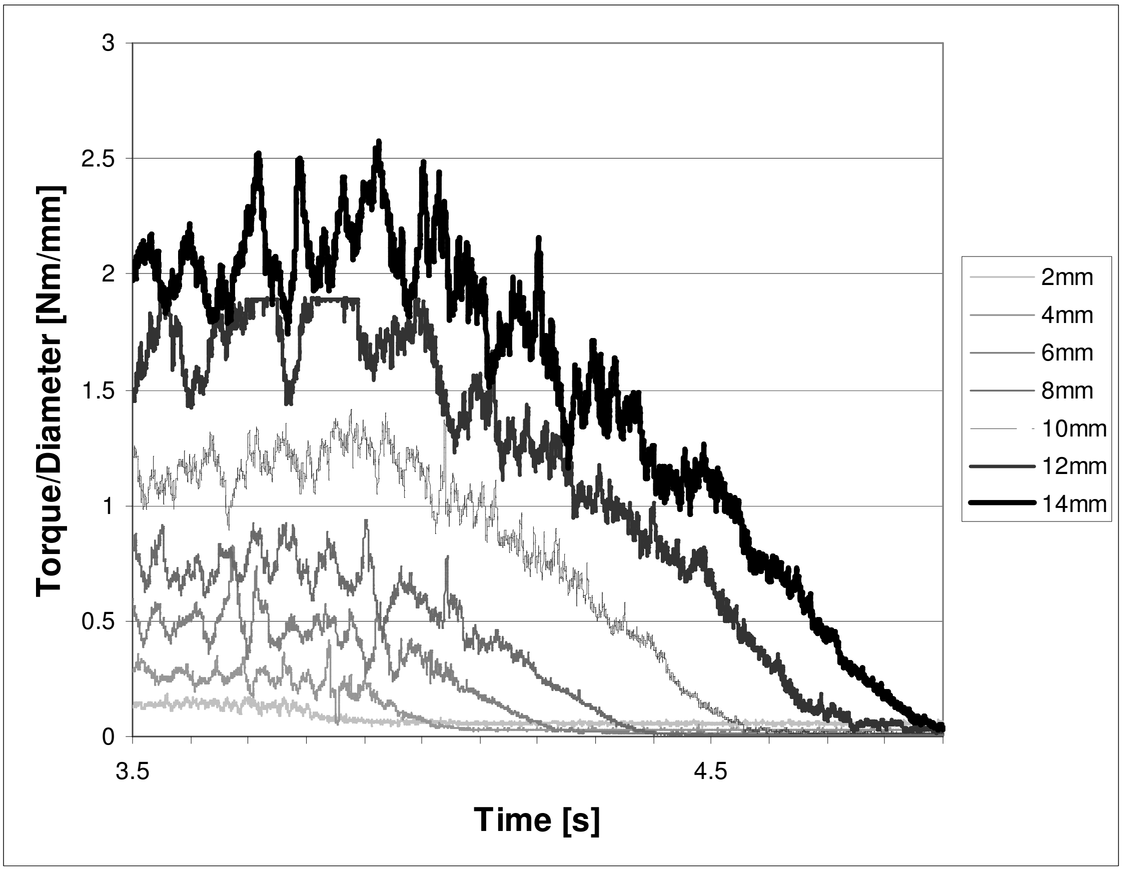

Figure 5: Torque during the burr formation

The paths show that there are no big differences between the paths of torque for the different diameters. With the size of the process the maximum torque values rise up, based on the quadratic rising chip volume. The frequencies and the amplitudes of the graph rise up according to the drill diameters. This is based on the falling ratio speed and the increasing of the radius of the cutting force initiation point.

4.3 Geometries of the drilling burrs

The most important property of the burr is its geometry. In chapter 3.2 the different types of burr are listed. These types are qualitative properties, but for an effective comparison quantitative values are important. One of the most important quantitative properties is the burr height. This is the right-angled distance between workpiece exit surface and the top of the burr. In the case of burr type C the highest value was used. For all diameters (2-14mm) five holes were drilled and for all the burr height was measured. The average values for each diameter were determined and mapped in the following figure.

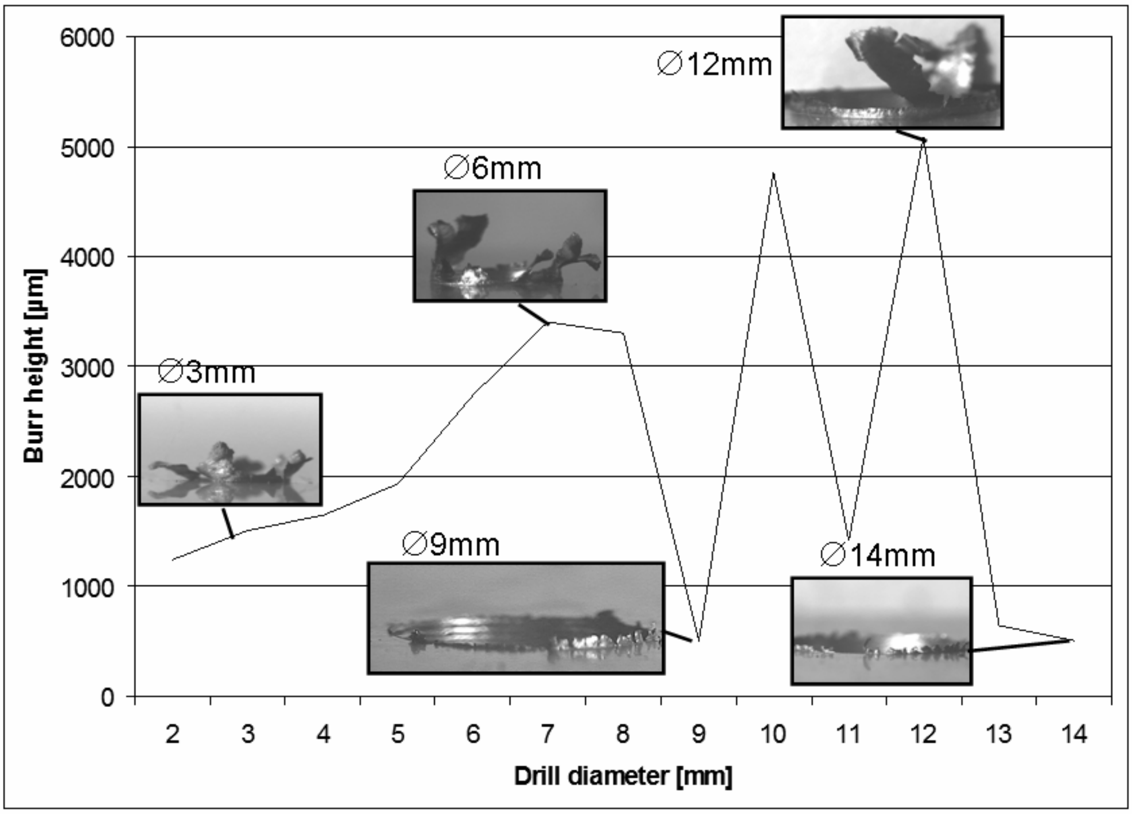

Figure 6: Comparison of the average burr heights for selected drill diameters

The figure shows that the path of the burr height in the range between 2mm drill diameter up to 6mm is almost increasing arithmetically. The burr type is type C, a non-uniform crown burr. In the range between 7mm drill diameter up to 12mm the burr types often alternate between type C, B and A. Height and types changed not only between the diameter, they also changed in one and the same diameter. The conclusion of this is that the burr formation process in the range between 7mm drill diameter up to 12mm is unstable. The higher drill diameters, 13 and 14mm, have a ring burr, which, in comparison to the lower drill diameters with crown burr, is proportionally low. The reason for this effect could base on size effects.

4.4 Temperature distribution of the exit surface during burr formation

For machining of metals the temperature is very important. The temperature has influences on the tool properties, the workpiece properties and the interactions between them. In short, the temperature characterizes the cutting process. Burr formation is a part of the cutting process. For the burr formation the temperature of the workpiece material in the burr formation zone has a high influence on the arising burr. Generally for metals, the ductility rises up with the workpiece temperature and the flow stress falls. The consequence for the burr formation is an increase of the burr formation and the burr geometries increase with the rising workpiece material ductility [1,5].

For measuring the surface temperature a thermographic camera was used. In the following figure the temperature distribution over the radius is shown. The minimum of the y-axis with 160°C is based on the available measurement ranges of the thermographic camera. Because of the maximum temperature values around 430°C the measurement range from 160°C up to 500°C must used.

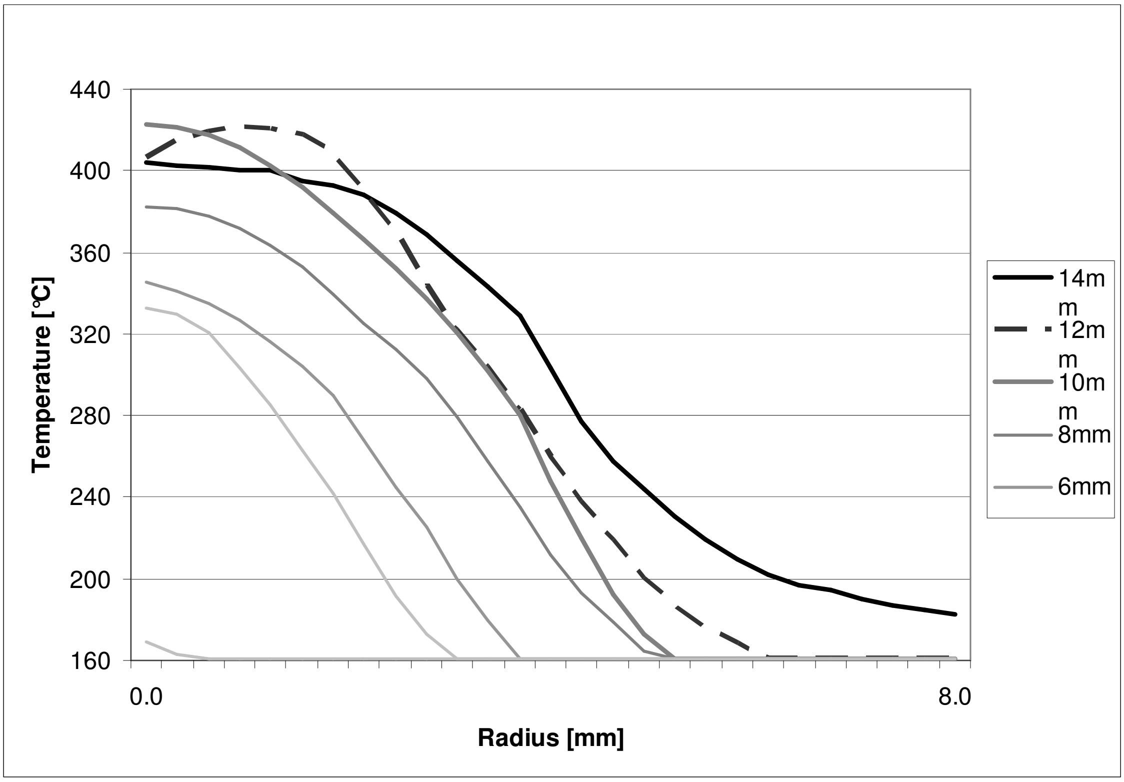

Figure 7: Temperature path over the radius before drill exit

The represented temperature paths show the distribution at that point in time before the drill breaks through the workpiece surface. At this point in time the temperature of the workpiece material has the highest value and it is possible to compare the different drill diameters. The diagram shows that the levels of the path for the diameter 1-6mm rise up. The temperature level of 7mm is much higher. For all diameters higher than 6mm no significant trend is identifiable. The maximum temperature value for all drill diameters bigger than 6mm is around 400±50°C. The heat radius rises up with the diameter. Only 7mm and 8mm drill diameters are an exception.

Measuring of higher temperatures and their distribution often has a high measuring error. A big part of this mistake is due to the reason that the metal surface is not a perfect “black emitter” on which the calculation of the heat and radiation is based. So it makes sense to simplify the measuring results. For this only the maximum value for every distribution is shown in the following diagram in figure 8.

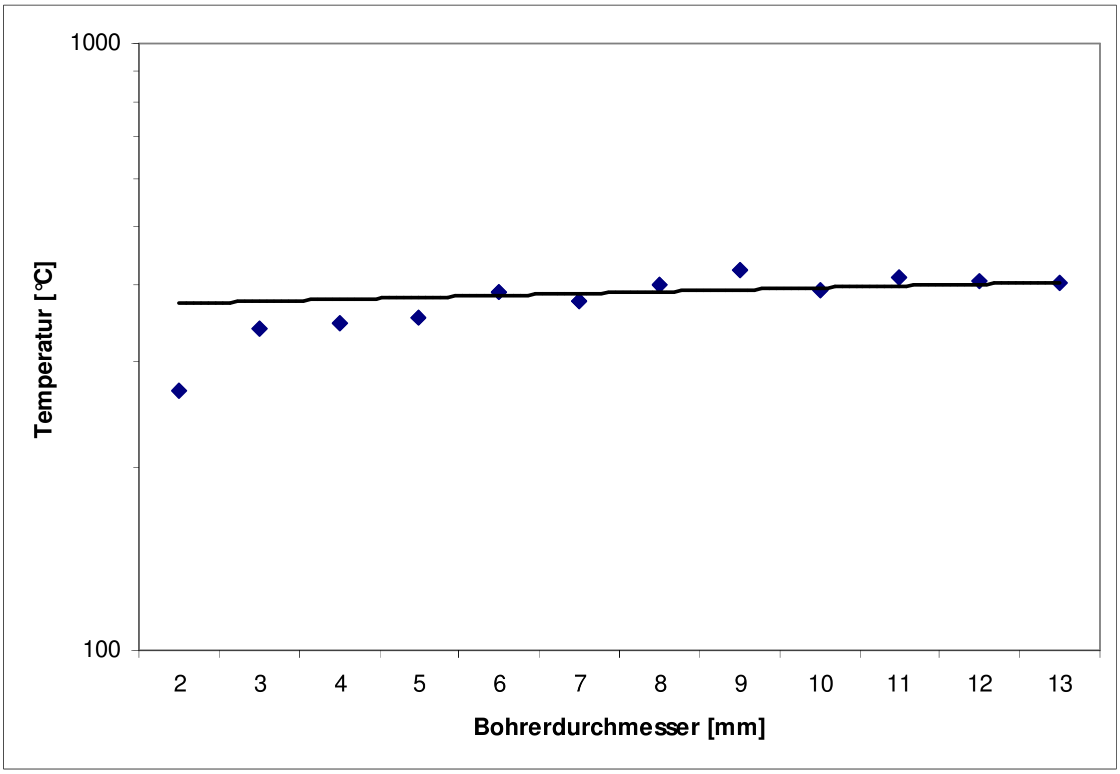

Figure 8: Maximum temperature values

The path of the maximum temperature value for drill diameters bigger than 7mm is logarithmic. For diameters smaller than 7mm the slope changes. Concluding from this, the temperature distribution has a size effect which is around 7mm drill diameter.

5 Conclusion for the macroscopic drill operations

The measurement of the torque shows that the torque rises up with the drill diameter. This is based on the quadratic rising of the cutting volume. The path of the torque shows no significant variation over the drill diameters. Concluding, there were no considerable scale effects of the torque during the burr formation detected.

Analyses of the arising burr geometries show that the size of the drilling process has an influence on the burr type and the burr height. When drill diameters are 6mm or bigger, the burr type changes from type C to type A. This change has a slow transition in the drill diameter range between 7 to 12mm. In this range both burr types exist and also the burr height varies. For the drill diameters 13 and 14mm only ring burrs with a relative low burr height exist. This effect is a size effect in burr formation during drilling operations. The thermo measurement during the burr formation shows some scale effects, too. The path of the temperature over the radius before the breakthrough of the drill through the surface shows high varieties in the distribution. The path for the drills smaller than 6mm has approximately the same temperature path, but on different temperature levels. For the higher drill diameters the path of the temperature over the radius has significant differences in path and level. This effect is visualized in the path of the maximum value over the drill diameter, as well. For drill diameters below 7mm the slope of the path changes, and for drill diameters bigger than 7mm a logarithmic slope was measured.

Concluding of the temperature distribution and the burr geometries, scale effects around 6mm and 7mm drill diameter were measured. The cutting depth for 6mm was 0.1mm and for 7mm drill diameter it was 0.116mm. The cutting speed was for all drill diameters the same (v_c=25m/min). The cutting edge radius and the roughness of the tool faces will be measured in the next investigation.

6 Preview

6.1 Scale effects in microscopic Drill operations

After the investigations in the macroscopic level the drilling experiments should be enlarged in the microscopic level. Drill experiments in the range of 1mm drill diameter down to 0.05mm are planned. The goal of these experiments is to get information about the burr formation in the microscopic level and the effect when the feed per ratio of the drill passes the size of the grain. In comparison to the macroscopic researches the cutting forces and the temperature distribution during the burr formation will be measured.

6.2 Scaled surface finish

The macroscopic experiments in this work have shown scale effects for the temperature during the burr formation and in the arising burr geometries and types. In the experiments the diameter was scaled and with them the ratio speed ($v_c \rightarrow$constant) and the feed per ratio (f/d=60). The tool geometries like cutting angle, drill angle and clearance angle were constant. The cutting edge radius and the surface roughness of the tool were approximately constant, as well. But these properties of the tool must be scaled, too, in order to get information about a real scaled cutting process. In the next step of the macroscopic drill experiments the cutting radius and the surface roughness of the cutting surfaces will be scaled. In the moment, the preparations of the tools are running.

7 Acknowledgement

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