Cutting edge preparation to enhance the performance of single lip deep hole drills

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Abstract

An improvement in the efficiency of the cutting process requires high tool performance. For the tool performance the microscopic cutting edge shape is very important. By preparing the cutting edge the tool performance can be improved due to the reduction of the cutting edge chipping and the creation of a defined stable edge rounding. In this study, the influence of a cutting edge preparation on the deep hole drilling process is investigated. The aim is to increase the feed rate by a specific cutting edge design.

1. Introduction

Single lip deep hole drilling is commonly used in several industrial applications to manufacture bore holes with diameters in the range of \(d = 0.5 \ldots 40\) mm with a high length-to-diameter-ratio \((l/d\text{-ratio})\) up to \(l/d = 200\). In addition to the high \(l/d\text{-ratio},\) a major advantage of the single lip deep hole drilling is the ability to generate high bore hole qualities. The main characteristics are minor deviations in diameter and straightness, high shape accuracy and high surface quality of the bore hole [1]. Thus, bore holes can be manufactured very efficiently without subsequent processes for increasing quality, such as reaming or honing. A disadvantage of single lip deep hole drilling is the high mechanical tool load during the cutting process that limits the feed rates in particular for smaller diameters. This adversely affects the efficiency of the process [2, 3].

To improve the efficiency of the cutting process, the microscopic shape of the cutting edge is particularly important. This can be adapted to the cutting process by a cutting edge preparation to enhance the tool performance [4]. In this research the influence of cutting edge preparation using an abrasive water jet blasting process is analyzed for single lip deep hole drilling. For this purpose, mechanical load, tool wear, bore hole quality and chip forms are ascertained for different cutting edge designs. The aim of the study is to investigate the influence of cutting edge preparation on the cutting process so as to generate a specific cutting edge design for an improved feed rate.

2. Cutting edge preparation

Cutting edge preparation aims to an improvement of tool performance through an increase in edge stability. This is achieved by reducing of cutting edge chipping and generating a defined rounding of the cutting edge [4]. The cutting edge chipping \(R_s\) is a parameter representing the roughness along the cutting edge and a major factor with respect to microscopic quality [5]. The cutting edge shape is specified by the average cutting edge rounding slateral that is used to quantify the material removal at the flank and rake face compared to an ideal sharp cutting edge [4]. To improve tool performance the cutting edge rounding has to be adapted to the specific machining task. An increase in the cutting edge rounding leads to negative effective rake angles at low feed rates and an enhancement of ploughing in the cutting process. Ploughing means that most workpiece material which is directly in front of the cutting edge...
Drills, which have been measured by a fringe projection microscope, are compared. In addition to a ground and unprepared cutting edge design (A), slightly (B) and moderately (C) and heavily (D) rounded cutting edges were produced in this abrasive water jet blasting process. The different values for the average cutting edge rounding slateral were generated only by varying the jet feed speed. In this way, the material removal at the flank and rake face of a single tool is symmetrical and the inner and outer cutting edges are rounded equally. A slower jet feed speed produces a higher impact time of the abrasive jet on the blasted area. This leads to an enhanced material abrasion of the cutting edge so that a higher rounding is accomplished.

The cutting edge preparation has a significant influence on the cutting edge chipping Rs of the different tools (Fig. 1). The ground single lip deep hole drill (A) has the highest value. Due to the preparation, the cutting edge chipping decreases considerably, even though the prepared tools show similar values for Rs. Therefore, the impact time of the abrasive jet blast has only a small influence on Rs. Thus, a distinct smoothing is already achieved with a short impact time of the abrasive medium.

3. Influence of the cutting edge design on the cutting process

The single lip deep hole drills with the four different cutting edge designs (A – D) are applied using two different values of the feed rate f. In addition to a conventional feed rate of f = 0.03 mm/rev, a greatly increased feed rate of f = 0.05 mm/rev is chosen for machining of 42CrMo4+QT (AISI 4137) with a low sulfur content. Deep hole drilling oil is used as cooling lubricant. The cutting speed of vc = 60 m/min is kept constant throughout the experiments.
3.1. Influence of the cutting edge design on the tool wear

In Figure 2 the influence of the cutting edge design on the tool wear is shown for the feed rates applied. The quantitative comparison of the tool wear is given by the width of flank wear land VB. This was measured along the drilling length at the flank faces of the tools. The related values are averaged over fixed reference points along the inner and outer cutting edge. Furthermore, scanning electron microscopic (SEM) pictures of the outer cutting edge and corner area expresses the tool wear qualitatively.

For the conventional feed rate of \( f = 0.03 \text{ mm/rev} \) the tools with different microscopic shapes have a similar wear over the drilling length produced. The comparison of the SEM pictures shows slight and uniform flank wear forms along the cutting edge. After a drilling length of \( L_f = 15,000 \text{ mm} \) the slightly and moderately rounded tools B and C have the lowest values for VB. At this conventional feed rate and due to the low tool wear, clear advantages in tool life from cutting edge preparation can be expected only for a greater drilling length.

The enhancement of the feed rate to \( f = 0.05 \text{ mm/rev} \) leads to an increased tool wear, particularly for the corner area. Therefore the advantages of the cutting edge preparation are obvious. The general increase in width of flank wear land along the drilling length is particularly depending on the heavy corner wear of the outer cutting edge. Due to the high wear progression and the explicit corner wear, the ground tool A was not applied anymore after a drilling length of \( L_f = 10,500 \text{ mm} \). All prepared single lip deep hole drills have considerably less wear over the same drilling length. The greater stability of the cutting edge leads to an increased tool life for the enhanced feed rate, in comparison to the ground tool. The best tool performance is given by single lip deep hole drill C with the moderate rounding. The flank wear along the cutting edge is slight and uniform. Only in the corner area can major material removal be observed. Due to this, the width of flank wear land over the whole drilling length is only insignificantly greater than for the conventional feed rate.
3.2. Influence of the cutting edge design on the mechanical tool load

The comparison of the mechanical tool load for the different cutting edge designs and feed rates is presented in Figure 3 with respect to the feed force $F_f$. The values along the drilling length are illustrated.

The uniform increase in the feed forces along the drilling length, for all tools investigated, when applying conventional feed rate of $f = 0.03$ mm/rev, is due to the uniform wear. Ground tool A generates the lowest feed forces. Due to the cutting edge rounding, all prepared tools show higher feed forces. This shows the greater pressure on the chip formation zone, when using prepared tools [13]. The amount of ploughing is increased for increased cutting edge rounding. This leads to greater workpiece deflection in front of the cutting edge and result in a higher mechanical tool load. The high values for the feed force generated by the heavily rounded tool D are noticeable. It can be assumed that the value for the ratio of the size of cutting edge rounding to the undeformed chip thickness has become unfavorable. Despite the considerable mechanical load the tool wear of single lip deep hole drill D is only marginally higher in comparison to the ground tool A. Consequently, the greater edge stability of prepared tools is shown.

The feed rate increase to $f = 0.05$ mm/rev leads to a significant enhancement of feed forces for all tools studied due to the higher undeformed chip thickness. Just as when applying the feed rate of $f = 0.05$ mm/rev, the prepared tools produce a higher feed force than the ground tool in the initial phase of the drilling length.
Due to the high wear, the mechanical load at the ground cutting edge A increases sharply already after a short drilling length. At the end of the drilling length its feed force value is clearly superior to the prepared tools. The increase in mechanical load is less and more uniform for tools B, C and D. The mechanical load on the heavily rounded tool D is similar to slightly and moderately rounded tools B and C for the feed of \( f = 0.05 \text{ mm/rev} \). This is caused by the higher feed rate which results in a smaller and more favorable ratio of the size of the cutting edge rounding to the undeformed chip thickness.

### 3.3. Influence of the cutting edge design on bore hole quality

The bore hole quality was measured with respect to the surface roughness, the bore diameter, the roundness and the straightness accuracy. The influence of the cutting edge design and feed rate on the mean surface roughness \( R_z \) is shown in Figure 4. Furthermore, Figure 4 shows pictures of the chips generated.

The lowest values for the mean roughness depth \( R_z \) and hence the best surface qualities are produced when ground tool A is used at both feed rates. Due to the cutting edge preparation, the average values and the spreads of values rise marginally. The greatest mean roughness depth \( R_z \) was measured for the moderate rounding of tool C. Thus, it is probable that the greater deflections of workpiece material caused by the cutting edge rounding have a disadvantageous influence on the surface quality. The variation of feed rates leads to a small increase in roughness for all the tools as well. On the one hand this is conditioned geometrically; on the other hand the greater tool wear adversely affects the surface.

Long chip forms are produced when the conventional feed of \( f = 0.03 \text{ mm/rev} \) is applied. These chip forms are unfavorable for removal out of the bore hole. When the feed rate is increased, a clear improvement in chip breakage can be seen. Therefore, the chip forms are considerably shorter. The microscopic shape of the cutting edge has no significant influence on the chip forms.

In Figure 5 the values for the bore diameter and the roundness and straightness deviation are shown with respect to the influence of the cutting edge design and the feed rate. The respective average values and the spreads of values are shown for the entire drilling length.

The feed rate and the cutting edge design have no clear influence on the average values for the bore diameter, even though an influence on the spreads of values is noticeable. With the feed rate of \( f = 0.03 \text{ mm/rev} \) the spreads of values are reduced, particularly for the greater roundings of tools C and D, compared to the ground cutting edge design A. At the higher feed rate all the prepared tools produce clear noticeable smaller spreads of values.

Cutting edge preparation has a positive influence on the roundness deviation \( T_k \) at the feed rate of \( f = 0.03 \text{ mm/rev} \). Consequently, the rounded tools have lower values and smaller spreads of values for \( T_k \) compared to the ground tool. Due to the feed rate increase, there is only a marginal influence on roundness deviation. At this feed rate, all rounded tools have lower average values as well.

The straightness deviation \( \Delta r \) is not clearly affected by cutting edge preparation at the conventional feed rate of \( f = 0.03 \text{ mm/rev} \). Compared to the ground tool, the slightly and the heavily rounded tools produce higher values for \( \Delta r \), while the moderately rounded tool generates lower ones. The spreads of values are greater for all prepared tools. The increase in feed rate to \( f = 0.05 \text{ mm/rev} \) leads to greater straightness deviations for all the tools investigated. There is a marked increase in straightness deviations for ground and slightly rounded cutting edge design. In contrast to this, the greater roundings of tools C and D show a smaller increase for \( \Delta r \) when the feed rate is \( f = 0.05 \text{ mm/rev} \).

In summary, cutting edge preparation has mainly a positive influence on the bore diameter, the roundness deviation and the straightness deviation. The moderate rounding of cutting edge C produces the best results at both feed rates. This means, that compared to a ground cutting edge design, with cutting edge C improved average values or lower spreads are achievable.

### 4. Summary

In this research the influence of cutting edge preparation of single lip deep hole drills was investigated. The aim was to understand its influence on the cutting process and to identify a specific cutting edge design for improving tool performance. The single lip deep hole drills applied were prepared by using an abrasive water jet blasting process. In addition to a ground cutting edge, three different degrees of cutting edge roundings were used in the experiments. The results have shown that a cutting edge preparation leads to an improved tool life caused by increased cutting edge stability. However, the mechanical tool load increases due to the cutting edge rounding. A greater deflection of workpiece material in front of the cutting edge leads to the higher feed forces occurring. The surface roughness is adversely affected due to preparation, though this influence is below one micron with respect to \( R_z \). Further characteristics of bore hole quality, like bore diameter and the roundness and straightness deviation, are influenced positively for the most part.

The use of a moderate and uniform rounding of the cutting edge with \( S_{\text{lateral}} \approx 20 \mu m \) is recommended for the
drilling process studied. With this cutting edge design, an increase in feed rate from \( f = 0.03 \text{ mm/rev} \) to \( f = 0.05 \text{ mm/rev} \) is possible without there being a significant decrease in tool life. This corresponds to a reduction in drilling time of more than 60%. With the exception of surface roughness, bore quality is also favorably affected by this cutting edge design.

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