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Drilling of Inconel 718 with geometry-modified twist drills

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Abstract

The drilling process of Inconel 718, a nickel-based superalloy, is very challenging due to the material properties, the operating conditions and the high quality requirements. Carbides within the material matrix cause an excessive amount of abrasive tool wear. Moreover, a large amount of the heat caused by the machining process, especially in drilling, has to be dissipated by the tool and the coolant, due to the low thermal conductivity of Inconel 718. This high thermal load also restricts the cutting speed. The combination of all attributes limits productivity and economic efficiency when drilling Inconel 718 with cemented carbide twist drills.

This paper presents a method to adapt twist drills considering the mentioned demands by using geometry-modified tools. The aim is to increase the resistance against abrasive wear and to reduce the thermal loads; so that, tool life and bore quality can be improved. The analysis of the new tool geometry was realized by advanced Computational-Fluid-Dynamics (CFD) simulations. The simulations provide detailed information about the coolant flow and consequently the improved cooling of tool regions which are, on the suggested geometry, exposed to very high thermal loads. Experiments showed that the tool life can be increased by up to 50% in contradiction to a standard twist drill. The improvement on the bore quality was shown by determining the roundness deviation and the average surface roughness. In addition, micro hardness tests and metallurgy preparations were conducted to investigate the surface integrity of the bore surface layer. Although the presented geometry only represents a prototype status, the results are impressive. The tool life and the bore quality have been improved, and the simulations showed clearly that there is a significantly better coolant flow, when using the new geometry.

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1. Introduction

The machining of difficult-to-cut materials such as the superalloy Inconel 718 is very challenging because of the characteristics of the workpiece material and the high quality demands for the process results. Especially when drilling with cemented carbide drills productivity and tool life are very limited. Within this paper a method to modify twist drills with respect to a new flank face geometry is presented. Here the flank wear is controlled and limited to a defined maximum. Additionally, with the modified geometry, the critical areas of the tool are provided with a larger amount of coolant without increasing the total volume of coolant needed [1, 2, 3, 4].

Inconel 718 was developed for applications in aerospace turbines; and later, it has been used in a wide range of applications due to its outstanding material properties. Examples beside the aerospace and gas turbine industry are automotive applications, and the medical and chemical industries. The mechanical properties such as creep-, tensile-, fatigue- and rupture-strength remain on a high level for temperatures up to 700 °C [1]. During machining, different material characteristics of Inconel 718 lead to very high thermo-mechanical tool loads and a high wear rate, e.g. work hardening and the high-

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temperature strength. Additionally, a large amount of heat has to be dissipated by the tool and the coolant because of the low thermal conductivity of the workpiece material. Abrasive and adhesive mechanisms dominate the wear as a result of the high amount of carbides within the metal matrix and the adhesive tendency of the large portion of nickel in the alloy [3, 4, 5, 6]. Especially when drilling Inconel 718 high tool loads lead to low productivity and limited tool life. Due to the high temperatures in the cutting zone, the cutting speed has to be limited up to v_c = 50 m/min. Typically used feed rates are around f = 0.10 mm/rev [2, 7]. In order to reduce the thermal load and support the chip evacuation an internal cooling with high pressure is commonly applied. The use of MQL or no coolant leads to a large amount of subsurface damage and very short tool life [7, 8].

When drilling with twist drills, internal cooling channels are used to supply sufficient cutting fluid to the cutting zone. The exits of these channels are located on the flank face which leads to an indirect cooling of the cutting zone. To enhance the cooling effect and to reduce the thermal load different design elements can be used. By changing the geometry, the diameter and the location of the cooling channels a higher coolant flow rate and convection can be achieved. Furthermore, the form of the flutes, the end and length of the cooling channels and even the form of the tool chuck influence the efficiency of the cooling [9, 10, 11]. A major drawback when supplying the coolant via the flank face of a tool is the poor cooling effect. Because of the small gap between tool and workpiece the velocity of the coolant has to be twice as large as the maximum cutting speed to fill this gap properly. *Obikawa* and *Yamaguchi* proved this fact by a CFD-simulation of a turning process [12]. The method presented here shows a way to improve the wear resistance of cemented carbide drills and to improve the efficiency of the supplied coolant fluid. This is achieved by a new flank face geometry. The influence on the tool wear, the bore roundness deviation and average surface roughness and the surface integrity will be presented, as well. Additionally a CFD-simulation was used to analyze the influence on the coolant flow in detail.

2. Experimental procedure

2.1. Workpiece material

The workpiece, a round plate consisting of Inconel 718, had a diameter of d = 200 mm and a thickness of t = 34 mm. The fully annealed material fulfils the standards of the aerospace industry with respect to the metallurgic composition, heat treatment and mechanical properties. Some selected properties are listed in Table 1.

Table 1. Selected properties of the workpiece material Inconel 718

Property	Value
Ultimate tensile strength at room temperature	$R_{m,RT}$ > 1400 N/mm²
Ultimate tensile strength at T = 649 °C	$R_{m,649°C}$ > 1100 N/mm²
Elongation	a = 17…23 %
Hardness	H > 450 HV30
Thermal conductivity	λ = 11.1 W/(m · K)
Thermal expansion	α = 12.6 · 10^{-6} K^{-1}

2.2. Twist drill design

The improvement of cemented carbide twist drills by a modification of the flank face was tested on drills with a diameter of d = 6.8 mm for a maximum drilling depth of l = 34 mm (l/D = 5) provided by Guehring KG, Albstadt, Germany. Macro- and micro-geometry of the tools comply with a standard tool designed for the machining of difficult-to-cut materials. The used cemented carbide had an amount of 5 % Cobalt and an average grain size of d_m = 0.5 µm. For an elimination of potential influencing factors, no coating has been applied. Furthermore the flutes were ground to achieve a median surface roughness below Rz = 0.5 µm. The low surface roughness has been chosen to improve the chip evacuation and to reduce the risk of chip jamming and a resulting tool failure.

The modified flank faces are inspired by a similar modification on cutting inserts for turning and milling. The utilization of a flank face backspace in a defined distance to the cutting edge this modification limits the maximum width of flank face wear. Due to this, process forces and the impact on the subsurface integrity can be hold on a constant level and tool life can be extended. Improvements in tool life range between 40 % and 250 % depending on the process and the workpiece material [13, 14, 15, 16].

To adapt such a flank face geometry for a twist drill, several specific features when drilling have to be considered. Due to the changing cutting speed and the varying geometry the mechanical load differ along the cutting edge [17, 18]. Especially when drilling Inconel 718 the process forces are very high. Previous experiments showed feed forces up to 2500 N when a worn tool was used. Furthermore the tool wear in drilling differs in many ways from that in turning or in milling processes [6, 7, 19, 20, 21]. The resulting flank face modification based on all the above mentioned factors is shown in Fig. 1.

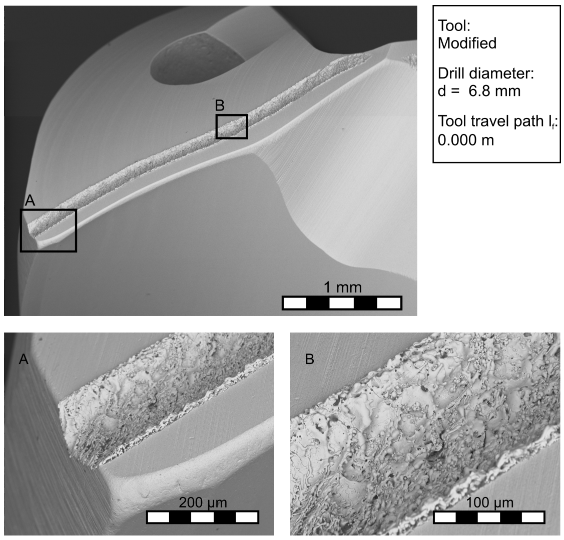

Fig. 1. Twist drill with modified flank face

As can be seen within the overview picture (Fig 1. upper