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Increasing Energy Efficiency in Turning of Aerospace Materials with High-Pressure Coolant Supply

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Abstract

In the field of machining difficult-to-cut materials like titanium or nickel-based alloys, the application of high-pressure coolant supply may result in a significant increase in productivity and process stability. Due to enhanced cooling and lubrication of the cutting zone and thus reduced thermal tool load, tool wear can be decreased which allows higher applicable cutting speeds. Furthermore, the process stability can be increased as a result of effective chip breaking and chip evacuation. Since energy efficiency is very crucial, pressure and flow rate have to be adjusted carefully and in accordance with the cutting parameters to guarantee best results with less energy. For this purpose, experimental investigations were carried out with variation of the coolant flow rate for a given coolant pressure in order to find the minimum required value for a certain machining task with the overall aim to prevent waste of the media used. To maximise the positive effect of high-pressure coolant supply strategy on productivity and process stability, specially designed coolant jet guidance geometry on the rake face was also investigated and compared to conventional tools in turning aerospace materials TiAl6V4 and Inconel 718.

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Keywords: High-Pressure Coolant Supply, Turning, Aerospace Materials, Waterjet Assisted Machining

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1. Introduction

Titanium and nickel-based alloys or stainless steels, that are widely spread in aerospace applications belong to the group of difficult-to-cut materials [1,2]. The machining of these high-temperature alloys is characterised by low

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productivity and low process stability due to their physical properties. Major problems during machining are low applicable cutting speeds, long machining times and thus high manufacturing costs as well as the formation of ribbon and snarled chips, especially in continuous cutting processes like drilling or turning.

2. State of the Art

In conventional machining processes, the area of chip formation is most commonly flooded with coolant. In this way, the coolant does not penetrate into the cutting zone and secondary shear zones, which are the most thermally stressed areas of the cutting tool. Instead, the coolant uncontrollably flows around the cutting zone and preliminarily impinges on the chip's top side. By using the rake face sided high-pressure coolant supply, a focussed and targeted coolant jet is directed into the wedge between chip bottom side and tool rake face [3]. A liquid wedge is formed which effectively cools and lubricates the cutting zone. As a result, the tool wear is reduced which is an optimum prerequisite to increase the cutting speed. Sharman has shown that the conventional flood cooling is effective to extend tool life when easy-to-cut materials are machined at low cutting speed. In machining difficult-to-cut materials with increased cutting speed, higher cutting temperatures are generated [4]. Some researchers report that the high temperatures at the cutting zone cause the coolant to vaporise and to generate a vapour barrier, which may prevent an effective cooling of the tool in the region of the cutting edge [5]. By using high-pressure coolant supply, the vapour barrier may be displaced, enabling the coolant to get closer to the cutting edge, thus leading to enhanced cooling of the tool [5,6]. Furthermore, the mechanical jet force acting on the chip's underside acts as a liquid chip former reducing the upward bending radius of the chip. As a result, the tool-chip contact zone is reduced by up to 50% in comparison to the conventional flood cooling [3,7,9]. The chip bending can be influenced by the hydraulic jet force which mainly depends on the coolant supply pressure and flow rate [3,10,11]. However, it has to be taken into consideration that the tool-chip contact length decreases significantly with increased coolant pressure. If the tool-chip contact area is reduced too much, the generated temperature and mechanical load will act on a small area close to the cutting edge and lead to an increased specific tool load that may result in cutting edge break-outs [7,8]. Kaminski et al. have shown, that it is possible to achieve a 40% reduction in tool temperature by the use of HP-coolant supply compared to conventional flood cooling [5]. The shorter contact length and reduced friction in this area also resulted in a larger shear plane angle and reduced chip compression, proving that chip formation is significantly influenced by the high-pressure coolant supply [16]. Moreover, Palanisamy et al. detected that the application of coolant below a pressure of 90 bar in turning titanium alloys results in increased frequency of chip serration, shear-band thickness and average chip thickness compared to a pressure of 6 bar [12]. The mentioned effects generally allow an automated manufacturing process of difficult-to-cut materials and an increase in productivity compared to the state of the art. Requirements for this technology are a sealed machine interior with an extraction system for aerosol mist as well as a high-pressure pump with a filter system. Appropriate high-pressure tool holders with integrated nozzles for directed and focused coolant supply are available on the market. Besides the positive effects of the high-pressure coolant supply and studies performed in the past, its acting principles and scientific explanations are not yet completely analysed and require further research [13,14]. The understanding of the fundamental mechanisms is necessary for improving the energy efficient use of this coolant supply strategy and its optimal adjustments against the background of profitability [13,15]. The aim has to be, to achieve maximum productivity and process reliability gains with minimum pressure and flow rate (= low pump power required) and, above all, with the appropriate ratio of pressure and flow rate that is carefully coordinated with the cutting parameters and the tool design. One possibility to increase the productivity is the effective supply of the coolant to the cutting edge through specially designed tools. Even chip breaking geometries can adversely affect the coolant delivery. Very often, the coolant jet primarily hits the chip breaking geometry and hence is deflected. In practice, this phenomenon is often not recognised and the pressure of the coolant supply is further increased which results in higher energy consumption of the high-pressure pump. For an unhindered coolant supply and an energy efficient use of the high-pressure technology, specially designed tools are necessary.

3. Experimental Setup and Procedure

In this study, the effect of coolant parameters (flow rate and pressure) and tools with specially designed jet guidance geometry were investigated in longitudinal external turning on a CNC-lathe type Monforts RNC 400plus with high-