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Substitution of coolant by using a closed internally cooled milling tool

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Abstract

The saving of raw materials plays a major role in industry and is becoming increasingly important. In the field of cutting technology, the aim is to maximise practices such as the substitution of coolant and the steady increase of tool life in order to make an effective contribution towards environmental protection. Concerning the saving of coolant and to enhance the performance in dry machining a milling tool with a closed internally cooled system was developed. Heatpipes are applied which ensure improved heat dissipation from the cutting edge because of their excellent thermal conductivity. The dissipated heat is subsequently delivered to the surroundings via a heat sink. This contribution describes how the performance of a standard tool can be enhanced by the integration of a closed internally cooled system. Simulations of the heat distribution in the tool have been conducted to design and optimise the prototype. Hence, milling tests on duplex steel and temperature measurements in the cutting process have been carried out to verify and further optimise these simulation results.

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Keywords: Milling; internal cooled; heatpipe; dry machining; duplex steel; sustainable manufacturing

1. Introduction

The process of dry machining is becoming increasingly important due to rising requirements regarding the economic, technological as well as environmental aspects of Life Cycle Engineering. The presented tool system makes an important contribution to this. Consequently, by using the closed internally cooled milling tool productivity can be increased, cost and waste can be reduced.

A specific case of application is the production of functional surfaces, where dried coolant residues have to be removed for further manufacturing steps. An additional energy- and resource-intensive cleaning process is unavoidable. Another reason to avoid the use of cooling lubricants is the occurrence of thermal shocks. When processing difficult to machine materials the cold coolant leads, in combination with the high cutting temperatures, to high thermal loads on the tool. Especially in milling, due to the continuous entry and exit of the tool, recurring heating and cooling phases occur. This thermal shock is additionally reinforced by the use of cooling lubricants and can cause cracking and premature failure of the tool [1].

Compared to conventional wet processing the average cutting temperatures are higher in dry machining at the same process parameters. This increase in temperature leads to a greater thermal stress of the cutting material and the wear protection layer. If the same process parameters of wet processing are transferred to dry processing, above all the thermally induced tool wear rises [2]. This includes especially the tribochemical wear, which can be subdivided into diffusion and oxidation wear. High process temperatures also favor the abrasive wear. This wear mechanism is intensified by the softening of the cutting material at high temperatures [3].

An alternative to wet processing and dry machining is the use of a closed internal cooling system. Until now, turning tools with a closed internal cooling system have mainly been developed and scientifically studied. One approach is the dissipation of the heat through a fluid. Therefore, the tool has cooling channels and the fluid transports the heat from the cutting zone. Various scientists have already investigated this

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cooling strategy. In all studies, a reduction of the cutting temperatures and increasing of tool life could be detected [4-9]. A further possibility for the heat dissipation from the working zone is the use of heatpipes. The decisive advantage of heatpipes is the low thermal resistance in a small space. This principle of heat conduction has been investigated in turning and drilling tools [10-12]. In drilling of cast iron the tool life, compared to dry processing, could be increased by 125 %.

The aim of the presented work was to develop a more economical way to substitute coolant instead of using conventional dry cutting processes. Therefore, a milling tool using heatpipes for heat dissipation was realised. Simulative analyses of the heat distribution, milling tests to verify the tool performance and temperature measurements were carried out.

Nomenclature

a_e	Radial depth of cut
a_p	Axial depth of cut
f	Feed
f_z	Feed per tooth
l_c	Cutting length
PVD	Physical vapour deposition
Q	Heat generation rate
$Q_{transient}$	Heat generation rate for transient simulation
Q_w	Material removal rate
t_c	Cutting time
$t_{cooling}$	Cooling time
$t_{cutting\text{-}edge}$	Cutting time per edge
t_{diff}	Temperature difference in transient simulation
t_{global}	Global tool temperature
t_{local}	Local Heatpipe temperature
t_{max}	Maximum temperature in transient simulation
$t_{max(1)}$	Maximum temperature of standard tool
$t_{max(2)}$	Maximum temperature of cooled tool
$t_{max(cooled)}$	Maximum temperature of cooled tool measured with thermography camera
$t_{max(pyro)}$	Maximum temperature measured with pyrometer
$t_{max(standard)}$	Maximum temperature of standard tool measured with thermography camera
$t_{max(thermal)}$	Maximum temperature measured with thermography camera
$t_{VB0.3}$	Tool lifetime at VB = 0.3 mm
VB	Width of flank wear land
v_c	Cutting speed
z	Number of cutting edges

2. Experimental setup

2.1. Development of a closed internally cooled milling tool

The aim of the presented work was to develop a closed internally cooled milling tool that enables an extension of the tool life on the one hand, and increases of the process parameters at similar tool wear on the other hand. Moreover, the total cost of application of the closed internally cooled tool compared to wet processing should be kept low, regarding this as an important economic criterion. To achieve this, heatpipes were used to allow the generated heat to dissipate. This also offers the advantage of no additional peripheral equipment for cooling as well as no need for reconstruction of the machine spindle. Heatpipes are a closed two-phase system, which are filled with a working fluid and characterized through a high thermal conductivity. Depending on the application and the temperature range, an appropriate medium has to be selected [13]. For evaluation and comparison of the tool wear, the standard cutting head CoroMill® 390 of Sandvik Coromant with a diameter of 40 mm was used for integrated the internal cooling.

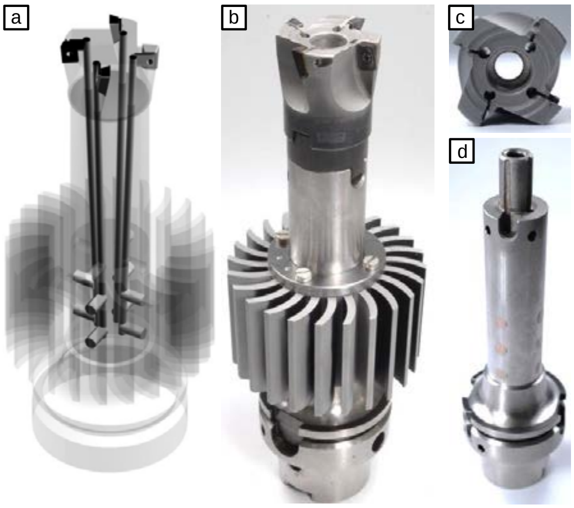

Fig. 1. Closed internally cooled milling tool (a) Model; (b) Tool; (c) Cutting head; (d) Cutter arbor with heat coupling elements

The heatpipes were integrated into a defined angle in the milling cutter. Thus, the impact on the tool stability and the centrifugal force, which affects the functionality of the heatpipes, were reduced. The backflow of the medium is also facilitated. For an even better heat dissipation, a heat sink was used. The fins are oriented in the direction of rotation, so that a maximum amount of air passes the heat sink. The heat transfer from the indexable inserts to the heatpipes and the transfer from the heatpipes to the heat sink is realized by heat coupling elements made of tungsten copper (Fig. 1; a, b, c, d).

2.2. Milling tests

The milling tests were performed on a 5-axis milling machine from MAP Werkzeugmaschinen GmbH, type LPZ 900. To compare the reference tool and the closed internally cooled milling tool in dry cutting, machining tests in face milling, with a down milling feed direction, were carried out.

For the investigations, austenitic-ferritic duplex stainless steel X2CrNiMoN22-5-3 was used. This steel is mainly used because of its outstanding properties with regard to corrosion resistance and ductility in combination with tensile and yield strength.

Cutting inserts R390-11 T3 08M-MM 1040 from Sandvik Coromant were used for milling. This PVD-coated cemented carbide is particularly suitable for austenitic and duplex steel. For analysis of tool wear, the flank wear VB was measured until reaching the defined tool life criterion VB_{max} = 0.3 mm.