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Heat Dissipation in Turning Operations by Means of Internal Cooling

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Abstract

Coolants and cooling strategies are just as important for the cutting process as the materials and tools themselves but do not get enough attention. There is an enormous potential for savings such as increase of the productivity and efficiency. The appropriate selection or combination of coolant strategy and coolants has furthermore enormous influence on various parameters of the surface quality and safety at work. Known and examined technologies such as dry machining or minimum quantity cooling lubrication experienced a resurgence in the industry. This paper shows the experimental setup and the test results of an internal cooled tool holder and cutting insert. This includes the temperatures between deactivated and activated internal cooling and the wear of the cutting insert.

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Keywords: closed loop cooling; internal cooling; indirect cooling; turning; cutting edge

1. Introduction

Efficient cooling strategies in the metal cutting industry are an important part of a sustainable and profitable production. With increasing demands on the machining new cooling systems are needed. Through a suitable choice of the cooling system the productivity, efficiency, sustainability but also the workplace-safety can be increased dramatically.

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1.1. Tasks of the cooling lubricant

The literature describes a variety of tasks of the cooling lubricant, such as the requirements for the cooling lubricants according to Elenz [1]:

- absorbtion of the resulting process heat
- cooling of the machine, work-piece, fixture and tool
- favoring the chip break and chip transport
- reduction of the friction
- reduction of the formation of a built-up edge
- corrosion protection for machine and work-piece

Beside that advantages we must not forget that the coolant also have disadvantages. The demand for energy is rising rapidly because of high pressure pumps, the coolant is often harmful to the skin of the employee (possibly carcinogenic) and strong smell, dirt, dripping tools and slippery floors are expected.

Regarding this facts, Klocke and König [2] give other criterias to the lubricant alongside technical performance, economic, environmental, safety and health technic, such as:

- human compatibility
- emulsifiability
- anti-aging
- bacteria resistance
- washability
- recyclability
- compatibility with materials
- smell
- toxicity

The largest financial aspect is the proper disposal of used coolant, which needs to happen environmentally friendly and in accordance with certain standards. For example, in Germany approximately one million tons special waste where produced annually together (with the indirect waste produced as oil binder or oily cleaning cloths) [3]. Beside those costs, human compatibility also leads to expensive safety risks that you have to fight to avoid injuries.

1.2. Types of cooling

In this chapter an overview of cooling options in the metal-cutting production is presented. From the old-fashioned flood cooling to the latest trends, such as cryogenic-cooling, the most important cooling are briefly outlined.

- Flood cooling

The flood cooling is best suited for grinding where large temperatures or even sparks may arise. This is due to the large water content of the coolant, which is present in the used emulsions. It is the most common type of cooling with cooling jets directed at the active zone (figure 1) for cooling, lubricating and removal of chips [4].

The very good heat dissipation is one of the advantages of this type of cooling but the disadvantage mainly belongs to the large cooling demand (that is not required for all processes) that must also be disposed of even later. By spraying the active zone it comes to a contamination of the tool, work piece, machine, chips and the place of work and causes therefore costly cleanings. This type of cooling is unattractive because there are a lot more efficient, greener and more sustainable solutions.

Fig. 1. Flood cooling.

- High pressure coolant

High pressure systems have been developed already during the eighties and nineties. Thanks research, were precisely aligned coolant jets with very high pressures (100 - 1000 bar) were designed as a part of the cutting tool (figure 2, left side), the processing of difficult to machine materials (e.g. titanium) runs smoothly [5].

At this cooling system the coolant is directed under high pressure exactly in the gap between the clamping base and rake face of the cutting tool (figure 2, right side). Thus, an effective cooling, the reduce of the tool wear compared to conventional cooling methods, the cutting speed and therefore the productivity can be increased with a much lower cooling demand in comparison to the flood cooling [6].

Fig. 2. High pressure cooling.

- Minimum quantity cooling lubrication (MQCL)

The MQCL process could be subdivided in minimum quantity lubricant (MQL) and minimum quantity cooling (MQC) [7]. The different is the used medium that is applied with compressed air: at MQL oils and at MQC emulsions are used. The oils (very small amounts of up to 50 ml per hour are needed) at MQL have a very good lubricating effect that reduces the friction between tool and work-piece but also a low cooling capacity that limits the application of minimum quantity lubrication (MQL). If a strong cooling is needed, MQC with emulsions is used. This process has the disadvantage that the water in the emulsion have a low lubricating effect and MQC is therefore only slightly been used in the industry.

In order to compensate the low cooling capacity of the traditional MQL technique, the MQCL technique cools down the compressed air and remove the heat from the cutting zone. So, the MQCL is an alternative to complex supply and disposal of cutting fluids and energy-intensive production facilities associated with high-pressure pumps [8]. Furthermore, the tool life and surface quality could improve effectively compared with the dry cutting [9]. There is always carried out fresh oil which guarantees best surface quality of the work-pieces. For the transport of the lubricant only small amount of energy is applied and the system, processing parts and chips remain virtually oil free. So the chips can be recycled directly and cleaning costs are omitted [10].

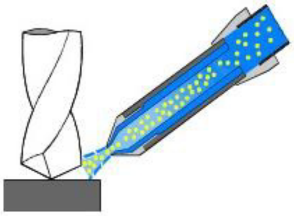

Fig. 3. Minimum quantity cooling lubrication (MQCL).

- Cryogenic cooling

The use of cryogens in machining production was studied already 60 years ago. Not too long ago liquid nitrogen (LN) is used as a cooling medium in turning [11]. With the boom in the aerospace industry and the need for difficult to machine materials (such as titanium, nickel, cast iron and CFRP), cryogenic cooling experienced a resurgence. The two most commonly used cryogens are liquid nitrogen (boiling point -195.82 ° C) or frozen carbon dioxide (sublimation point -78.5 ° C). With cryogenic cooling the tool life could improve by 23% over conventional (flood coolant) machining by cutting hardened steel [12].

Thanks to the nitrogen cooling an increase in cutting speed, higher productivity and longer tool life is possible. The coolant is environmentally friendly without greenhouse effects and toxic properties. There are no exhausting equipments necessary because the nitrogen volatilized completely. The workplace, material, machine, floor and chips remain clean and 100% recyclable [13].

The machining with carbon dioxide is called a pseudocryogenic machining because temperatures of about -78.5 ° C could be achieved. The advantage of CO_2 is, that it is liquid under high pressure (60 bar), easy to handle at room temperature and cheaper to produce than other cryogens.

Fig. 4. Cryogenic cooling.

2. Internal Cooling

All systems above have their own advantages and disadvantages, but one thing they have in common: they all try to cool down the tool from outside and consume a medium (coolant, oil,…). It was therefore researched on a solution for an internal cooling method whose basic concept and results of the cutting tests are presented on the following pages. After extensive research of known internal cooling techniques or concepts, Kromanis [14] concluded that the field is still in conceptual level.

2.1. Experimental setup

The concept of the internal cooling is shown in figure 5. A special cutting insert was fixed on a tool holder which was adapted with holes for in- and outlet. On the inlet side a tube with a throttle (1) and a thermocouple (2) and on the outlet side a tube with a thermocouple (3) and a flowmeter (4) was installed. Furthermore a magnetic thermocouple was mounted on the tool holder (5).

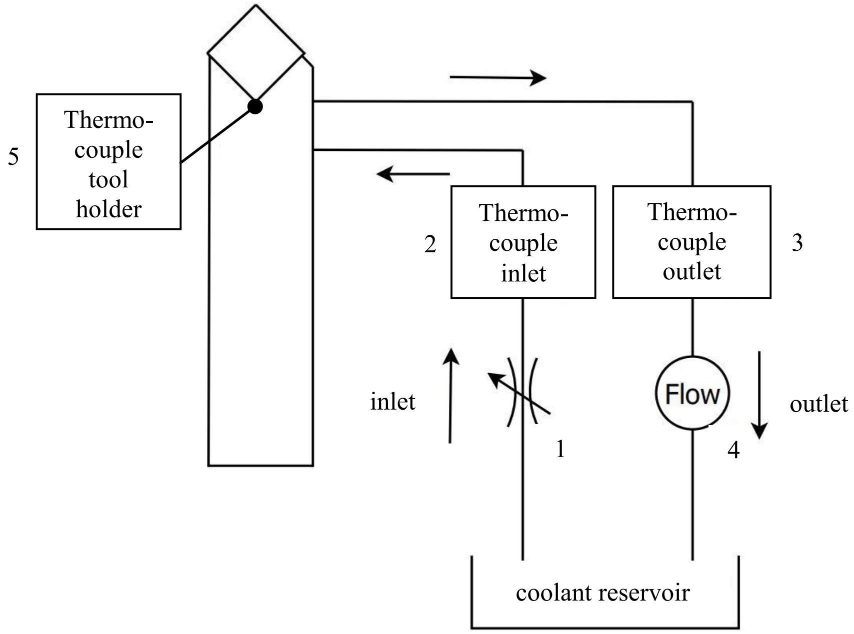

Fig. 5. Experimental setup.

2.2. Cutting test

In the experiments the coolant-temperature of the inlet and the outlet were compared by turning of the material C45E. The work-piece was machined twice with the specified parameters shown in table 1. Two tests were made: The first test was a dry processing and the second test was with internal cooling. Hence, the only difference was the deactivated /activated internal cooling to investigate the effect of this developed cooling method.

Table 1. experimental parameters.

parameters	value	Unit
Material	C45E	
yield strength	490	MPa
tensile strength	700	MPa
Cutting speed	100	m/min
Cutting depth	3	mm
Feed	0,2	mm
processing length	135	mm

3. Experiment Results

3.1. Dry processing (deactivated internal cooling)

The work-piece was machined twice with a new cutting insert and the parameters mentioned above in table 1. As shown in figure 6, there was a rapid and strong heating of the tool holder.

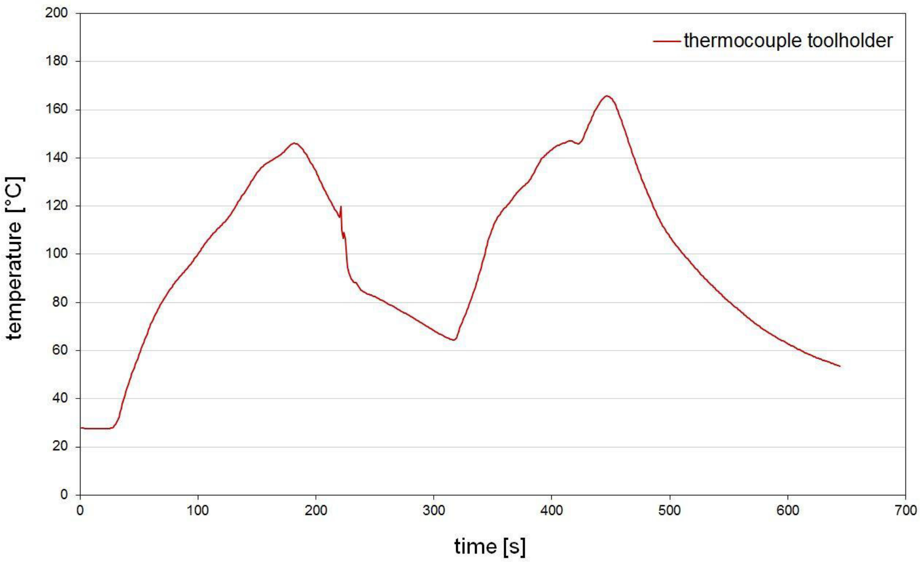

Fig. 6. Measured temperatures with deactivated internal cooling.

At the end of both turning operation the temperature at the main cutting edge was also measured with values between 140 ° C - 160 ° C. In figure 7 the abrasive wear after the process can be seen. The increased thermal load on the cutting insert could be indicated by the blue coloration.

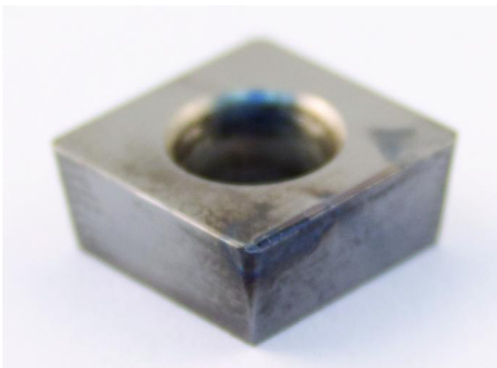

Fig. 7. Wear of the cutting edge with deactivated internal cooling.

3.2. Activated internal cooling

The work-piece was again machined twice with a new cutting insert and the parameters mentioned above in table 1. At this experiment the internal cooling was activated with a flow rate of 1,5 ml/s. With this setting the difference of the inlet- and outlet-temperature was about 15°C (figure 8). Furthermore the influence of the internal cooling could be seen clearly in comparison to the dry machining in figure 6: the temperature of the tool-holder was on a significant lower level so as the temperature at the main cutting edge with values of about 35°C (measured at the end of both turning operations). This lower thermal load could be also indicated by the weaker blue coloration in figure 9. The procedure of the two machining processes with activated internal cooling was a little different: at point 1 in figure 8, the internal cooling was deactivated after processing to investigate the cooling behavior of the tool-holder and the cutting insert without internal cooling. That´s the reason for the longer cool down time after the first machining (CT1, figure 8) compared to the second one (CT2, figure 8) and the gently sloping outlet-temperature. After the cool down of the tool-holder (point 2 in figure 8) the internal cooling was activated again. This can be shown by a step change in the temperature of the in- and outlet. 30 seconds later the second machining was started (point 3, figure 8) and the internal cooling remains active until the temperature of the tool-holder was on the same value as with deactivated internal cooling (point 4, figure 8). The result was a reduced by half cool down time (CT2, figure 8). The initial increase to a much higher temperature at the beginning of the first machining could only be explained by a hot chip that touched the thermocouple of the tool holder.

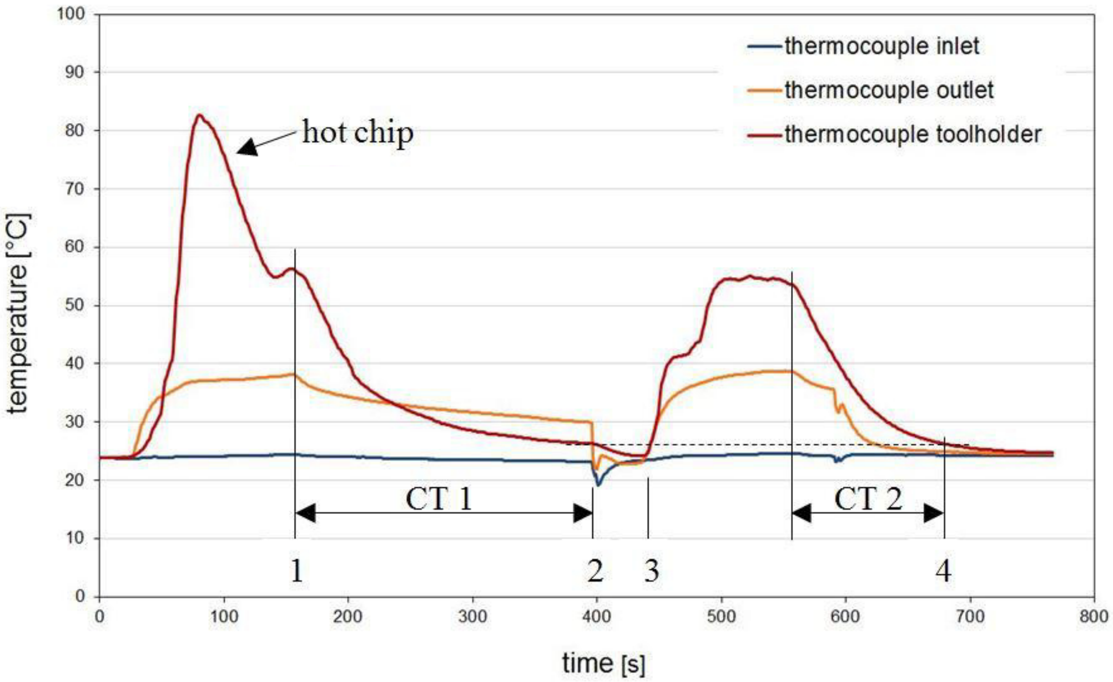

Fig. 8. Measured temperatures with activated internal cooling.

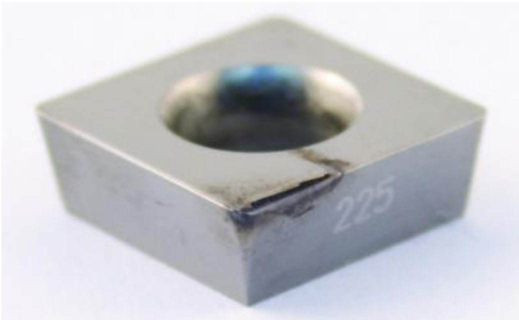

Fig. 9. Wear of the cutting edge with activated internal cooling.

4. Conclusion

Known and examined cooling-technologies try to cool down the tool from outside and consume a medium (coolant, oil,…). This medium must be disposed of even later and by spraying the active zone it comes to a contamination of the tool, work piece, machine, chips and the place of work and causes therefore costly cleanings and disposals. In this paper the experimental setup and the results of an internal cooling system were presented that could solve the problems mentioned above.

The results showed a significant difference at the temperatures and at the tool wear between the two processes. The temperature of the tool holder and the main cutting edge was with activated internal cooling just a third of the dry machining process, which indicates very good heat dissipation.

Those are very positive aspects about the effectiveness of this internal cooling system. Further investigations should perform with other materials and the new method should also be compared with examined cooling technologies.

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