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The impact of cooling methods on the maximum temperature of the processed object during side milling

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Abstract. This article presents the changes in temperature distribution concerning the processed object during side milling. The analysis included the influence of selected cooling methods (cold air from vortex tube, cooling with compressed air, and without cooling) on the maximum temperature of the processed object during the process of milling. Measurement of the maximum temperature was conducted with the use of thermocouples and a thermal camera.

1 Introduction

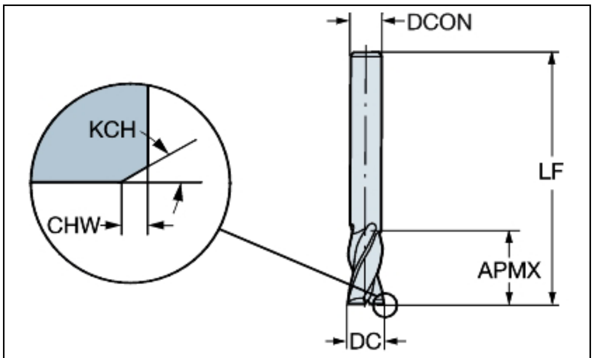
During the process of machining, heat is generated as a result of elastic and plastic deformation of the material and of friction occurring between the contact surface and the processed material[1-8]. An additional source of providing heat to the area of machining it the work of friction of chips against the surface of the tool. The temperature present within the area of machining influences the shape and size accuracy of created objects [9-14]. It has a significant meaning during performance of precision parts of machines with high reliability[15-23], as well as prototypes [24] i.e. contactless face seals [4-8] of gyroscopes etc. [24-26]. It may, additionally, cause deformation of the processed object and the tools [27-35]. Excessive amount of heat delivered to the tool results in a loss of cutting properties of the tools and, consequently, in damaging the tool, which has a significant impact on production costs and efficiency of performed processing. Monitoring of temperature is very important due to the need for selection of proper conditions to perform the process of machining. Heat is dissipated from the machining area through the tool, processed object, created chips, as well as other sources, e.g. by lifting or usage of liquids: cooling liquids and cooling and lubricating liquids. The largest amount of heat is dissipated from the machining area through chips. That is why its shape, cross-section, and method of tearing off is one of the essential factors that influence distribution of temperatures within the area of machining. Conducting the process of machining with the use of cutting fluid cools the tool and the processed object. Additionally, it decreases friction that occurs within the area of machining, which leads to a lower amount of released heat and lower demand for power required to conduct processing [36-38].

The measurement of average temperatures within the machining area has been mainly based on contact methods by using thermocouples, as well as contactless methods that are based on the phenomenon of heat radiation [39].

2 Methods

Tests were performed on a vertical machining center AVIA VMC 800. The tool used for the experiment was a tow-edge solid end mill produced by Sandvik Coromant - R216.32-12025-AK38A H10F with diameter of 12 mm. Table no. 1 presents the basic geometrical dimensions of the tool used for processing.

Table 1. Geometrical dimensions of the tool.



DC = 12 mm	DOC = 12 mm
LF = 100 mm	KCH = 45º
APMX = 38 mm	CHW = 0.1 mm

The process of side milling was performed at depth of a_p = 30 mm, side feed a_e = 0.5 mm and feed rate of f = 300 mm/min. Turning speed of the spindle was 10,000 rpm. The tested material was a 30x40x10 mm rectangular sample made of copper. Figure no. 1 presents geometrical dimensions of the sample along with the arrangement of thermocouples. K-type thermocouples of

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1 mm in diameter were used to measure the temperature. They were placed 10 mm inside the processed object.

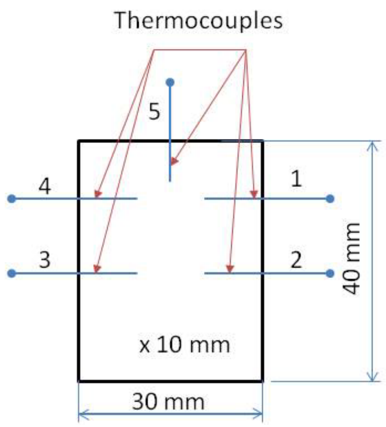

Fig. 1. Geometrical dimensions of the sample.

Apart from contact measurement conducted with the use of thermocouples, the experiment station also included a thermal camera Flir i7. Specification of that camera has been presented in table no. 2.

Table 2. Specification Flir i7 camera

Resolution	140x140 pixels
Thermal Sensitivity	0.1 ºC
Temperature Range	- 20 ÷ 250ºC
Accuracy	± 2ºC
Spectrum	7.5 ÷13 µm
Frame Rate	9 kHz
Emissivity	0.1 ÷ 1.0

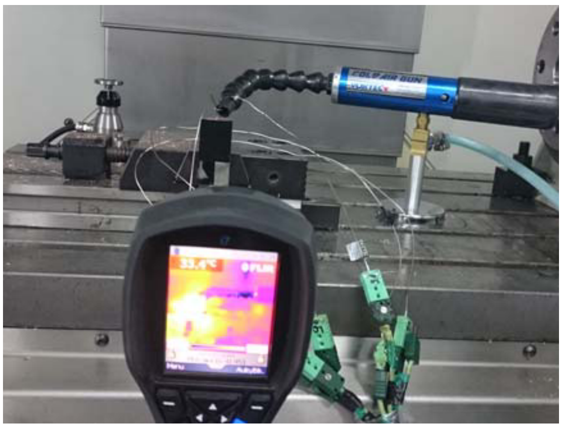

Fig. 2. Experiment station used for measurement.

The experiment was to conduct machining attempts and measure the average and maximum temperatures inside the processed object and on its front wall. The machining processed was conducted several times on one sample in order to determine the distribution of temperatures together with changes in the distance of the measurement point from the source of heat. Additionally, it was decided to conduct an experiment without the use of cooling, with the use of cooling for the machining area by using compressed air, and by using a vortex tube. That device allows division of the stream of compressed air into a stream of hot and cold air that is directed at the machining area. Figure no. 2 presents the experiment station used for measurements.

3 Results

Table no. 3 presents the average and maximum temperature values obtained during processing without cooling. It was observed that the highest values of average temperatures were noted at the distance of 2mm of thermocouples from the machining area. The farther the source of heat from thermocouples, the lower the temperature. The analogous dependency has been noted for measurement made by the thermal camera.

Table 3. Temperature values obtained Turing process without cooling.

Temp, ºC	Distance of thermocouples from the machining area, mm					
	4.5	4	3.5	3	2.5	2
Thermo. 1	101	108	108	128	134	140
Thermo. 2	90	98	108	114	119	123
Thermo. 3	75	80	88	93	95	98
Therm. 4	82	87	96	103	105	110
Thermo. 5	90	97	108	115	119	124
Camera	97	104	115	124	131	142

Figure 3 presents charts that describe the change in temperatures during the processing without cooling at the distance of thermocouple distribution of 2.5 mm from the source of heat in form of the operating tool. It was noticed that the maximum temperature of 134ºC was obtained for thermocouple no. 1 that was the farthest from the source of heat. Accumulation within that area is caused by the fast and constant flow of heat from the beginning of the processing. Average results of temperature measurement for thermocouples 1 and 2 differ from one another although they have been placed on the same wall. It is caused by the distance of thermocouples from the upper and lower edge where some part of the heating energy directed to thermocouple no. 2 is obtained by the grip, as well as the lower unprocessed part of the sample. Analogous situations occur in the case of other measurements.

Table no. 4 contains results of measurement of the average and maximum temperatures for processing with the same technological parameters. Additionally in that case, cooling of the machining area with a vortex tube was applied. During measurement, the noted temperature of air at the outlet from the tube was about – 29 ºC. After analyzing the results, it was noticed that cooling of the machining area with cold air does not significantly affect the results of the average temperatures noted by the vortex tube and the maximum temperature recorded with the thermal camera.

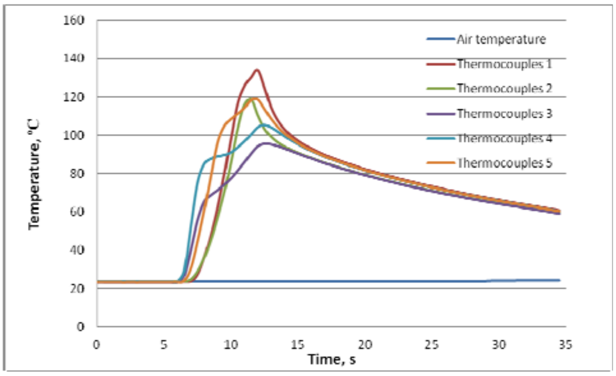

Fig. 3. Change the temperatures during the processing without cooling at the distance of thermocouple distribution of 2.5 mm.

Table 4. Temperature values obtained Turing process with cooling by Vortex tube.

Temp, °C	**Distance of thermocouples from the machining area, mm**					
	4.5	**4**	**3.5**	**3**	**2.5**	**2**
Thermo. 1	109	117	126	128	147	154
Thermo. 2	100	104	112	114	120	126
Thermo. 3	83	84	90	91	95	98
Thermo. 4	89	93	99	100	105	110
Thermo. 5	98	105	110	112	118	124
Camera	99	115	120	120	126	142

The maximum average temperature for processing with cooling is by 14 ºC higher than in the case of processing without cooling. It may be caused by lack of dissipation of heat from machining area through the tool that heated to a high temperature due to conducting the previous processing.

Table 5. Temperature values obtained Turing process with cooling by compressed air.

Temp, °C	**Distance of thermocouples from the machining area, mm**					
	4.5	**4**	**3.5**	**3**	**2.5**	**2**
Thermo. 1	108	113	125	131	137	146
Thermo. 2	96	99	109	114	119	126
Thermo. 3	81	84	89	86	97	101
Thermo. 4	88	91	100	104	108	113
Thermo. 5	97	100	110	115	120	127
Camera	97	101	118	120	125	138

In the case of processing with cooling in the form of compressed air, values of temperatures were recorded in table no. 5. The recorded air temperature at the nozzle outlet was 24ºC. The average and maximum recorded temperatures in that case of processing do not significantly deviate from the values recorded for previous processing attempts with cooling by the use of compressed air from a vortex tube or without cooling.

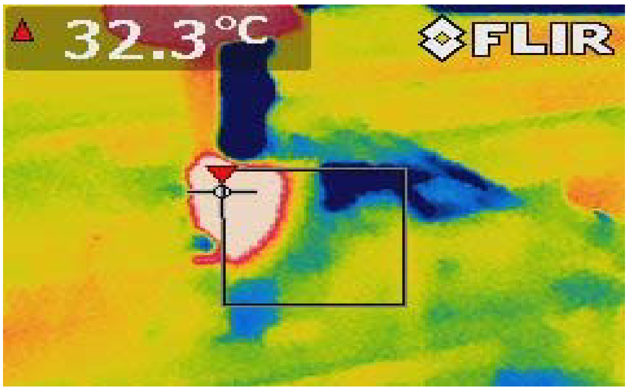

Fig. 4. Example image obtained with the thermal camera during measurement.

Figure no. 4 presents the example image obtained with the thermal camera during measurement. The noted temperature in that case was 32.3 ºC and was observed during the start of machining. In the picture, one may clearly notice the direction of release of heat to the remaining part of the sample, while the temporary maximum temperature was in places where the material was divided.

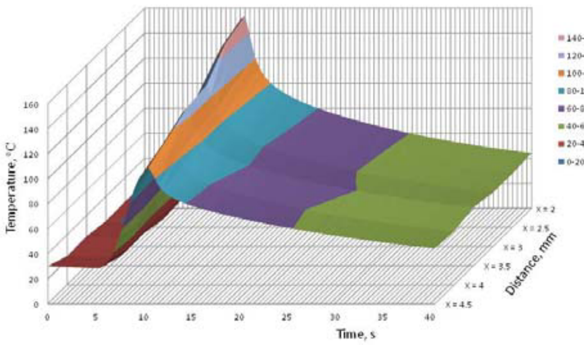

Fig. 5. Changes of the temperature during the processing with cooling by the use of a vortex tube.

Figure 5 presents the chart describing changes of temperature during the processing with cooling by the use of a vortex tube. The highest temperature was noted for that type of machining and amounted 154 ºC, while the cooling process of the processed object was the fastest and amounted 51 seconds to reach temperature of the processed object below 30 ºC. Application of cooling in the form of compressed air required 77 seconds after finishing the process to decrease temperature of the processed object below 30 ºC, while in the case of processing without cooling - 104 seconds.

4 Conclusions

The analysis of the experiment allowed formulation of the following conclusions:

1. Processing by using the cooling method with compressed air or cold air from a vortex tube does not

decrease the maximum average value of temperatures of the processed object.
2. The highest temperature was noted for thermocouple no. 1, which results from accumulation of heat and no dissipation of it from the area by contact with the machining grip.
3. Analysis of temperatures inside the sample performed with thermocouples is similar to values of temperatures recorded by the thermal camera.
4. The cooling method of the machining process significantly affects dissipation of heat from the processed object after the machining process is finished.
5. Maximum temperatures recorded during processing with cold compressed air result from limited heat capacity of the tool arising from accumulation of heat stored from the previous processing.

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