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## COBEM-2017- 2151 VORTEX TUBE AIR COOLING IN THE TURNING

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**Abstract.** *The vortex tube is a fully mechanical device capable of producing two streams of air in opposite directions, with different temperatures, hot air and cold air, based exclusively on its geometry, with only one air inlet. In this work the objective is to apply the cold air generated by the vortex tube in the cooling of the turning process, specifically, turning of SAE 1045 steel and cast iron FC250 with tungsten carbide insert, compared to the process dry and flood by means of temperature measurements using an infrared thermal camera. The results showed that the application of the vortex tube air cooling reduces by approximately 12% the temperature in the rake face cutting tool compared to the SAE 1045 steel dry turning. For cast iron FC250 the use of the cold air with the vortex tube the machining temperature in the tool reduces approximately 15% when compared to dry condition.*

**Keywords:** *Vortex Tube, Turning, SAE 1045 steel, Cast Iron FC250, Temperature.*

### 1. INTRODUCTION

The machining process is the fundamental step for manufacturing workpieces, in the industry the machining processes are very used. Among the manufacturing processes the most used is the process of machining with removal of material, to provide quality and precision in low cost (Trent, 1984).

In the process of machining with material removal is commonly used a cooling system which has cutting fluid. Researches indicate that the use of cutting fluid in machining is being reduced (Diniz *et al.*, 2013). Exposure of cutting fluid to the operator increases your chances of getting skin cancer by 50 % (Miranda, 2003).

In the process of machining the cutting fluid has as one of the main objectives, the cooling of the cutting tool. The vortex tube is shown as an alternative to application of cutting fluid in the machining.

Vortex tube is a mechanical device operating as a heating and cooling machine without any moving parts, by separating a compressed gas stream into a low total temperature region and a high one (Gutak, 2015). A vortex tube separates a compressed inlet air stream into a hot air stream and a cold air stream ranging from - 50 °C to 255 °C (Hilsch, 1947). The vortex tube makes use of only compressed air, which is the cause of the cooling. Figure 1 illustrates the device and your components.

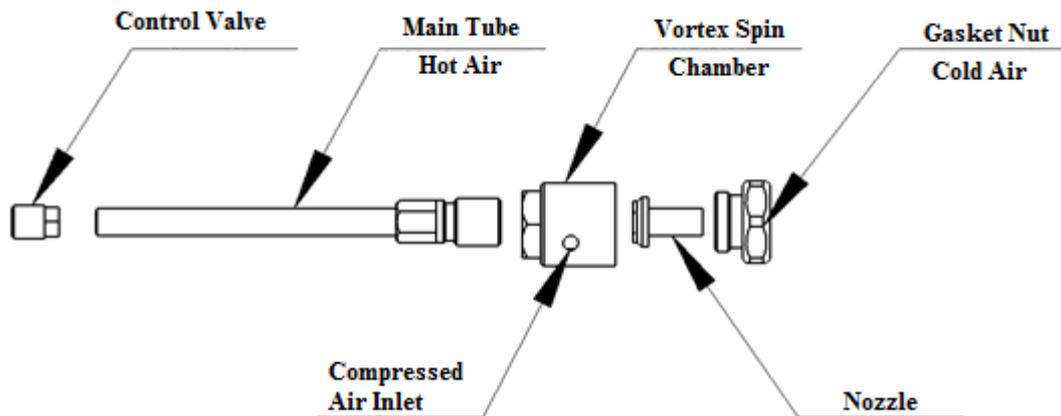


Figure 1. Vortex tube and your components

The ratio between the length of the hot air tube and the internal diameter of the hot air tube should be a minimum of 10 for the cooling effect to be exerted on the cold air outlet (Martynovskuu and Alekseev, 1957). The vortex tube used in this work has dimensions of 215 mm in length of the hot air tube and internal diameter of the 10 mm hot air tube, thus having a ratio of 21.5 taking into account the relation of previous works (Saidi and Valipour, 2003).

This work aims to analyze the efficiency of the vortex tube in the external cylindrical turning process. For this same process will be analyzed the working temperatures of the cutting tool for different cooling conditions, using the vortex tube, flood and dry.

## 2. EXPERIMENTAL PROCEDURE

The following materials and methodology will be presented for this work.

### 2.1. Materials

In this work the following materials were used:

- Thermographic camera - Fluke Ti90;
- Compressor Schulz 175 lbf/pol<sup>2</sup>;
- High-speed steel cutting tool Bedame N151 2-300;
- Classe Class K hard metal inserts;
- Sint Vegetable-based synthetic soluble cutting fluid ME-3 - Quimatic/Tapmatic;
- Pneumatic polyurethane hose 10 mm diameter;
- SAE 1045 Steel with a diameter of 50.8 mm and 200 mm in length;
- Conventional Lathe model Mascot MS-205 - Nardini;
- Vortex tube developed by Senai - Ítalo Bologna from Goiânia-GO.

### 2.2. Methodology

External cylindrical turning of SAE 1045 steel was conducted on an engine lathe Nardini® with different cooling settings and cutting conditions.

The objective of this study was to study the temperature of the cutting tool during machining comparing three refrigeration conditions: application of cutting fluid in abundance (jet), dry (without refrigeration) and cold air with the use of the Vortex tube.

#### 2.2.1. Vortex Tube Temperature Assays

The instrumentation used to verify the functioning of the vortex tube was performed by means of a thermographic camera, whose purpose was to measure the tube inlet and outlet temperatures. The main objective of the thermographic camera is to display an image of the thermal radiation emitted by a body. The images captured by the camera were

processed using the SmartView software, whose objective was to find the temperature gradient, through a line, which captures the region to be measured, inserted in the file.

The principle of operation of the camera is to capture the thermal radiation emitted by the object that is in the area marked by the camera lenses, these convert to energy that is concentrated by thousands of infrared sensors in an electronic signal. The signal is processed in order to display a thermal image or video on the camera display (Flir, 2016).

### 2.2.2. Temperature measurement in external cylindrical turning of SAE 1045 steel

The workpieces were turned from 50 mm of the outer diameter down to 49 mm, in three consecutive passes of 20 mm of cutting length for each cutting condition. In the workpieces tests, between each pass of 20 mm cutting length was machined a groove of 3,0 mm width, so that the same initial temperature conditions remain, the grooves will pause the feed until the initial temperature reestablishes.

Two cutting speeds were used in the tests, 46 and 75 m/min, feed (f) and the depth of cut were kept constant at 0,65 mm/rev and 1,0 mm in all tests, respectively. Three different cooling settings were tested, i.e., dry (no cooling), vortex tube air cooling and flood cooling, each test was duplicated changing the cutting speed.

Cutting temperatures were monitored during machining using an infrared thermal camera, Fluke® Ti90. The infrared thermal camera was attached to top rake face cutting tool. The temperature measurement location is specified as in Figure 2.

Tungsten carbide inserts, Sandvik DNMG 15 06 08-PM 4325, were used in the machining experiment. The tool holder and the cutting insert form a 0° rake angle and 11° relief angle. Only one cutting tool was used for all the tests.

The images obtained by the infrared thermal camera during the tests were analyzed using the software *SmartView*®. Figure 3 shows the analysis of the images obtained by the infrared thermal camera.



Figure 2. Experimental setup using infrared thermal camera



Figure 3. Temperature gradient at cutting tool tip

The same cutting condition was used for the three cooling conditions. Table 1 shows the cutting conditions of the tests, it is observed that only the cutting speed and the machining diameter are changed in order to change the cutting speed.

Table 1. Cutting conditions used in the tests using SAE 1045 steel

External cylindrical turning of SAE 1045 steel		
Rotation - n (rpm)	500	315
Cutting feed - f (mm/rot)	0,65	0,65
Machining diameter - D (mm)	48	49
Cutting speed - $V_c$ (m/min)	75,4	46,5
Tool start temperature - $T_i$ (°C)	32	32

For the application of the jet cutting fluid, the injection nozzle already installed in the lathe was used with ME-3 - Quimatic/Tapmatic synthetic soluble cut fluid, the flow rate at which the fluid was applied was 0.35 l/min. The percentage of fluid used was 5.2% on the Brix scale. The vortex tube developed by the Senai-Italo Bolonga in Goiânia was used for the application of the cold air, the inlet pressure of the compressed air injected into the chamber of the device was 8 bar, which pressure was limited by the available compressor.

### 2.2.3. Measurement of temperature in the external cylindrical turning of Cast Iron FC250

The shear rate used in the previous experiment was not yet sufficient to obtain a considerable variation in tool temperature in the machining. With the increase of the rotation of the machine and with the same machining parameters of the previous experiment, the formation of the chip would affect the integrity of the thermographic camera. For this it was necessary to exchange material, with FC250 Cast Iron, the formation of the chip does not affect the integrity of the thermographic camera, thus being able to work at higher speeds compared to the previous experiment.

The experimental procedures were the same as those used in the previous experiment, changing only the cutting conditions described in Table 2.

Table 2. Cutting conditions used for Cast Iron FC250

<b>FC250 Cast Iron External Cylindrical Turning</b>			
Rotation - n (rpm)	2500	1250	630
Cutting feed - f (mm/rot)	0,2	0,2	0,2
Machining diameter - D (mm)	38	37	36
Cutting speed - $V_c$ (m/min)	298	145	71
Tool start temperature - $T_i$ (°C)	32	32	32

### 3. RESULT AND DISCUSSION

#### 3.1. Vortex Tube Temperature Measurement

In the initial analyzes, the pressure was varied three times (4, 6 and 8 bar) and the control valve was modified in two open and closed configurations. In Table 3, the best values obtained through the SmartView software were indicated, where TQ and TF mean hot and cold temperature, respectively.

Table 3. Relation between temperatures, pressure and valve opening.

Pressure	Air Outlet	Valve open	Valve closed
4 bar	Hot	34,2°C	42,8°C
	Cold	4,2°C	5,5°C
6 bar	Hot	36,5°C	44,2°C
	Cold	0,2°C	2,5°C
8 bar	Hot	38,8°C	44,7°C
	Cold	-7,8°C	2,3°C

It can be seen from Table 3 that when the control valve is opened, lower temperatures are obtained at the cold end. The temperatures in the cold air outlet and the hot air outlet vary according to the inlet pressure of the vortex tube, as well as the variation of the opening of the hot air outlet valve.

In the graph of Figure 4 it is possible to observe the relation of temperatures with the pressure injected. The best values obtained were related to the pressure of 8 bar, as can be observed in the figure below, where TQA, TFA, TQF and TFF indicate the temperature at the exit of hot air with the valve open, temperature at the exit of cold air with the open valve, temperature in the hot air outlet with the valve closed and temperature in the outlet of cold air with the valve closed, respectively.

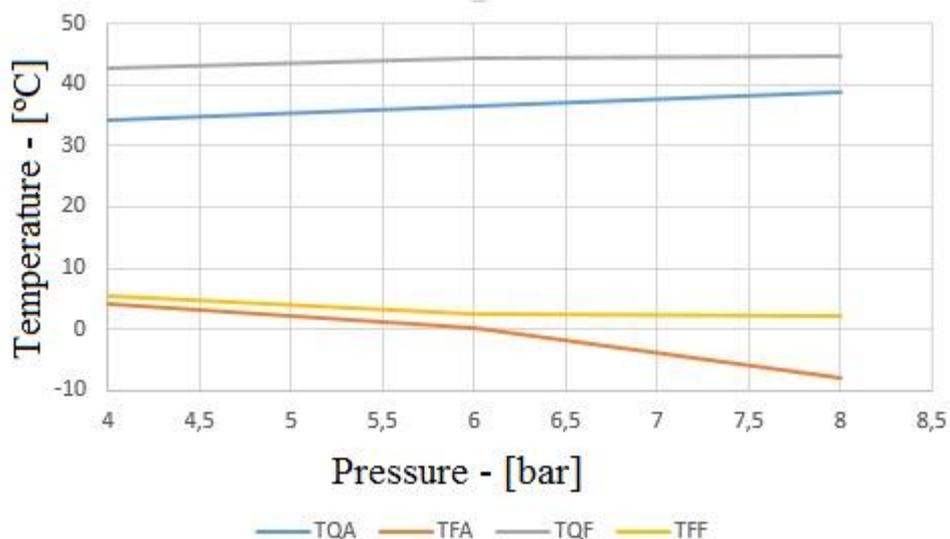


Figure 4. Relation between temperature and pressure

Figure 5-a indicates the highest temperature value obtained in the experiments. With the aid of the software a line was inserted in the image in order to obtain the temperature gradient. In Figure 5-b the temperature variation plot was obtained.

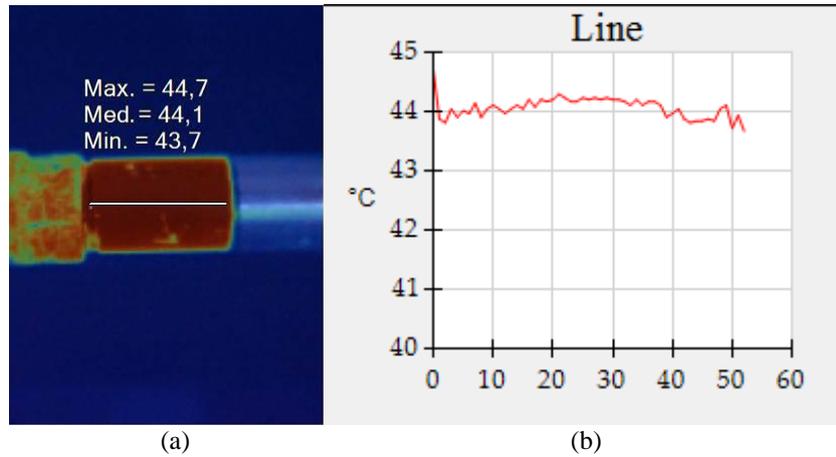


Figure 5. Temperature gradient in hot air outlet

The fluid that has been inserted into the turning process is related to the temperature at the cold outlet of the device. Figure 6-a shows the best temperature values in the cold duct, and Figure 6-b shows the temperature variation in the duct.

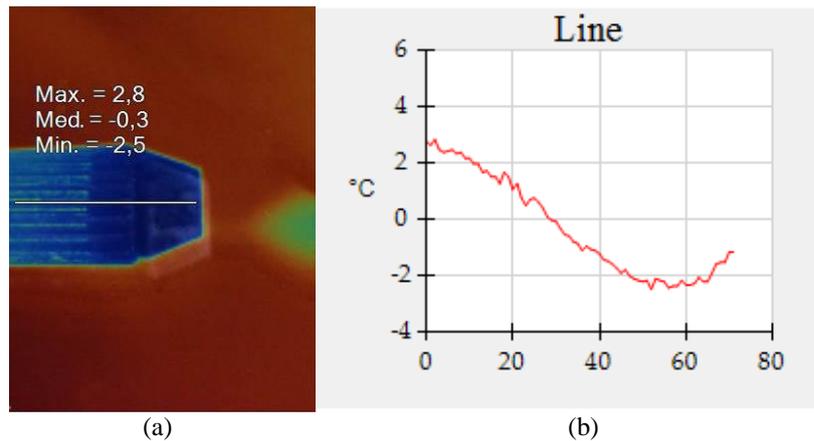


Figure 6. Temperature gradient in the cold air outlet

With the lowest temperature in the duct, a frontal photo was taken from the cold exit nozzle for a better analysis, a temperature drop was observed, as can be seen in Figure 7-a, temperature variation in Figure 7-b.

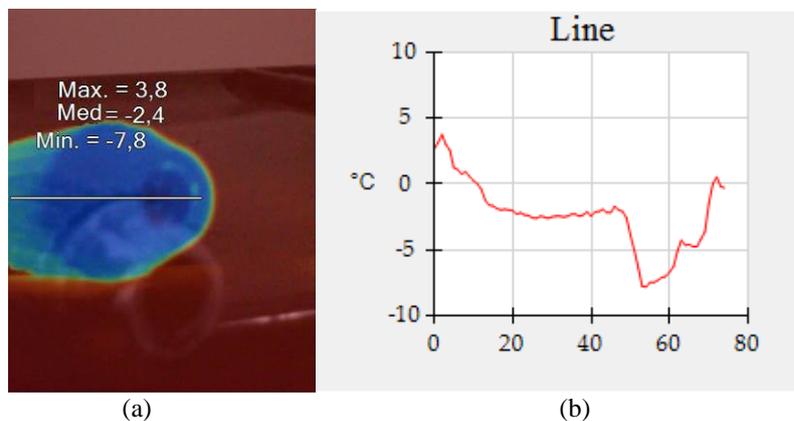


Figure 7. Frontal temperature gradient of the cold air outlet

### 3.1.2. Temperature measurement in external cylindrical turning of SAE 1045 steel

Table 4 shows the results obtained in the temperature measurement test on the external cylindrical turning of SAE 1045 steel, changing the type of cutting tool cooling and the cutting speed.

Table 4. Temperature of the cutting tool under diferente cooling conditions.

Cutting Speed (m/min)	Temperature °C		
	Dry	Flood	Vortex Tube
75,4	297,8 +/- 1,1	267,2 +/- 4,8	268,6 +/- 3,6
46,5	304,3 +/- 7,1	269,7 +/- 7,3	267,4 +/- 7,5

It is found that at close cutting speeds, the temperature variation in the rake face cutting tool is irrelevant. When comparing the process to dry and flood/vortex tube, the temperature reduces by approximately 12% with the use of cutting fluid and air cooling.

The application of cold air in the rake face cutting tool is shown to reduce the temperature, however with less efficiency than the application of the flood cutting fluid. Figure 8 shows in graph form the temperature results of the cutting tool in the external cylindrical turning process, using dry turning, flood cutting fluid and vortex tube air cooling.

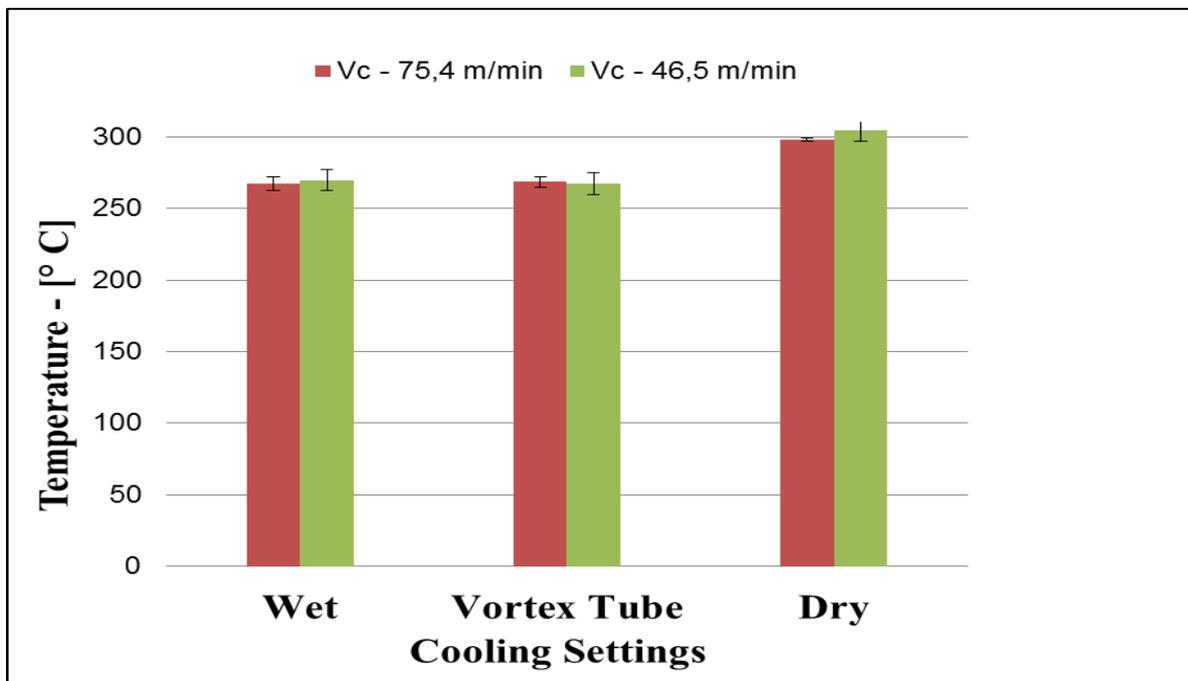


Figure 8. Results of external cylindrical turning of SAE 1045 steel under different cooling conditions

### 3.1.3. Measurement of temperature in the external cylindrical turning of Cast Iron FC250

Cast Iron FC250 when machined forms chip discontinuous in chips which tends to cause a dispersion of temperature at the tool outlet, thus being a lower temperature when compared to other materials. Figure 9 illustrates chip formation during machining as well as tool outlet temperatures for each tool lubrication-cooling condition: Cutting Fluid Jet, Vortex Tube, and Dry. From Figure 9 it is possible to observe the formation of the chip in chips, thus preserving the integrity of the thermographic camera. In the machining of the SAE 1045 steel the chip formation was continuous which was detrimental to the integrity of the thermographic camera.

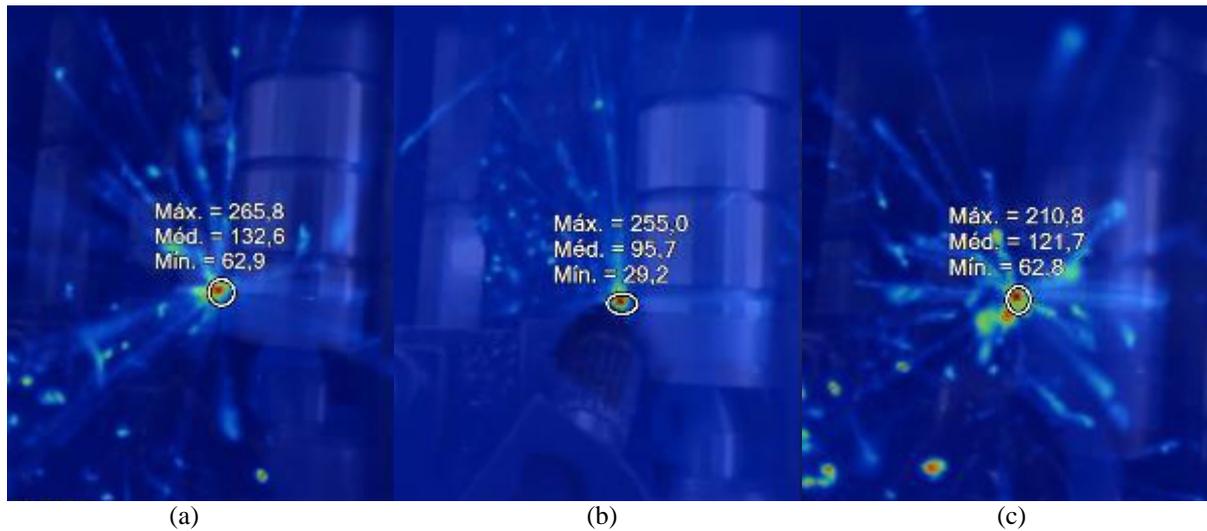


Figure 9. Measurements of temperatures in the cutting tool with different lubrication-cooling conditions

From the data collected by the thermographic camera it was possible to plot the graph of Figure 10 which illustrates the machining temperature of the cutting tool during machining using three different cutting speeds as well as for the three lubrication-cooling conditions: Fluid flow cutting, using the vortex tube and drying.

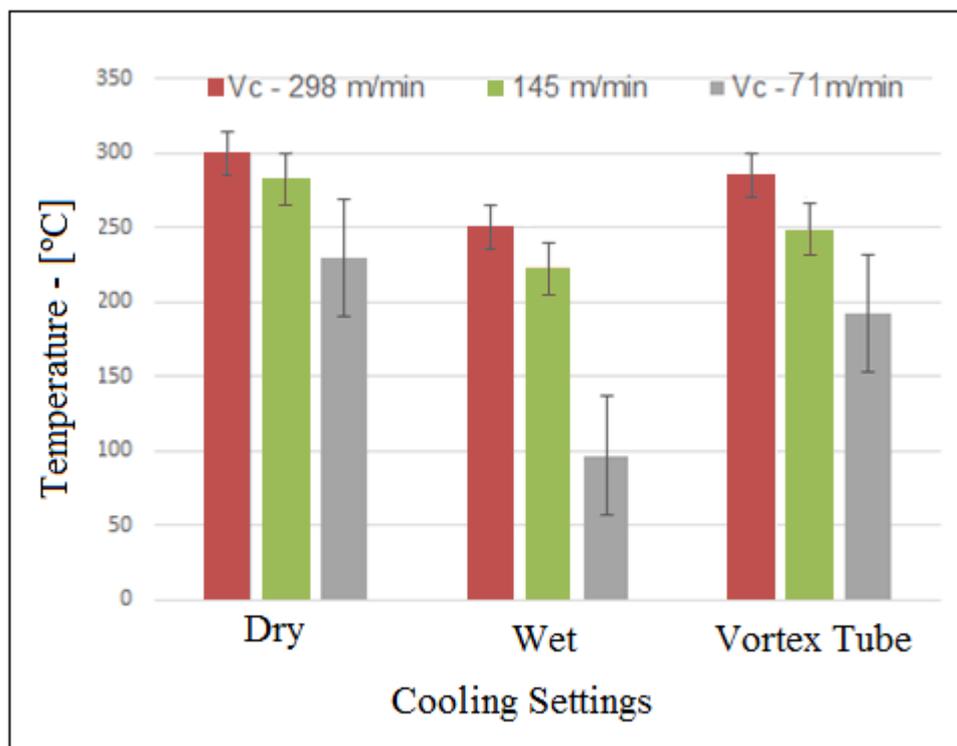


Figure 10. Cutting temperatures for different lubri-cooling conditions and varied cutting speeds

By increasing the cutting speed it is possible, as expected, that the machining temperature of the tool also increases. The use of the spurt of cutting fluid tends to decrease the temperature of the tool in the machining. The vortex tube in turn showed better results than the dry condition, but did not exceed the gushing condition.

#### **4. CONCLUSIONS**

The temperature variation in the rake face cutting tool was small for the two selected cutting speeds;

The results obtained showed that the vortex tube air cooling is effective in reducing the temperature in the rake face cutting tool;

The application of flood cutting fluid is more efficient in decreasing the temperature than the use of the vortex tube.

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