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EXPERIMENTAL INVESTIGATION ON THE EFFECT OF CUTTING PARAMETERS ON CUTTING TEMPERATURE DURING TURNING OF X200Cr12 WITH COATED AND UNCOATED INSERTS

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Abstract: One of the most important phenomena associated with machining operations is the cutting temperature because it affects the life of the cutting tool. Cutting parameters and insert material are the important conditions that affect temperature in turning. In this study, tests were carried out on X 200 Cr 12 steel during turning process. In ordre to measure the cutting temperature of the tool, the thermocouple method was used. The results illustrate that cutting temperature increases with depth of cut, feed rate, and the rotational speed. Due to the high conductivity of the insert coating, the tool cutting temperature reaches much higher levels than in the case of uncoated inserts. The conductivity of the insert affects the cutting temperature. The most influential parameters on the cutting temperature are feed rate and depth of cut.

Key words: Cutting temperature, turning, thermocouple, X200Cr12, hard machining

1. INTRODUCTION

Hard turning is relativ new process that uses high-performance cutting tools and specific cutting geometries. This process was designed to replace very expensive processes, such as abrasion, and for better environmental protection without the need for lubrication. The cost and the operating range of a tool-material couple to be machined make the exploitation of the tools very difficult. The part most influenced by machining is the cutting insert. Cutting insert is interchangeable cutting tips that can be rotated or flipped without changing the tool's overall geometry because they are detachable. It is a shaped component of a hard metal compound that was created through die casting and sintering of a tungsten carbide powder and other binder metals mixture. In addition, the microstructure of the material can affect the final part and the wear of these inserts, [1].

In particular, the use of cutting fluids is an important parameter since it makes it possible to limit the rise in temperature in the cutting zones, however, with a view to protecting the environment and the health of the operators, the current trend is to limit, and even eliminate, the use of lubricants.

In the case of machining hard metallic materials, the use of cutting fluids is very harmful because the geometry of the tool is modified by the deposit of a material on the cutting face, [2]. Temperature is one of the most important phenomena associated with metalworking because it can reduce the life of cutting tools. Cutting conditions, tool material and workpiece material are factors that profoundly affect the evolution of the cutting temperature, [3].

The increase in cutting temperature during machining leads to some problems: tool wear which reduces tool life and thermal damage causes insert fractures [1, 2].

Several scientific researches, on the cutting temperature during machining, have been carried out in order to determine the cutting parameters that minimize the cutting temperature.

Rosseto et al., [4], measured the cutting temperature using a thermosensitive varnish. The varnish is deposited on the tool and changes color at a well-defined temperature value. The border between two colors presents the isotherm.

Casto [5] used a method inspired by that put in place by Rosseto et al., [4]. It consists of introducing a powder, whose melting point is known, between two parts of a wafer.

In the Trigger et al [6] study dynamic thermocouples were used to determine the cutting temperature during machining operations. The thermocouples are linked to the tool and the workpiece. At the interface between tool and workpiece, a junction has been formed. It plays the role of a thermocouple. Matsumoto, [7] used thermocouples to study the evolution of temperature as a function of cutting conditions and material hardness. Using a thermocouple implanted at a depth of 0.025mm, it has been shown that with increasing cutting energy, hard steel causes more heat to spread through the workpiece than soft steel.

Bouzid [8] optimized the thermal contact between the thermocouple and the walls of the holes by using a silver glue which ensures good fixation of the thermocouples and good thermal conductivity. The disadvantage of this technique is that the response time of these thermocouples only allows the analysis of stationary regimes.
Lazard [9], uses two thermocouples which are inserted at two different places in a wafer. To reproduce the experimental conditions, a noise is added to the evolution of the temperature. The evolution of the temperature at the tip of the tool is estimated by an inverse model.
Riza et al., [10] used an infrared camera to estimate the cutting temperature for a milling operation of AISI H 13 steel. They concluded that cutting temperature and cutting forces are complementary.
Ghafarizadeh et al., [11] used a type K thermocouple integrated in the tool during the machining operations of a CFRP part. The thermocouples are placed at a distance of 0.2 mm from the cutting area. They noticed that the cutting temperature increases linearly with the cutting speed.
Infrared thermography has been used in the work of Saez-de-Buruaga et al., [12] to estimate tool cutting temperature and thermal fields. In their study, the cutting temperature was measured on the side faces of the tool.
Jinfu Zhaoa et al., [13] used a two-color infrared thermometer to measure the cutting temperature while machining Inconel 718 with a ceramic tool. In this work, the authors tried to eliminate the emissivity effect in order to improve the authenticity of the measured cutting temperature.
The most widely used method for measuring the cutting temperature in research work is the thermocouple method, [14-17]. This method consists in placing the thermocouples in contact with the cutting insert as close as possible to the point of contact tool/part.
Tamilarasan et al., [18] used RSM for modeling and analysis of cutting temperature using speed, feed, depth of cut as parameters for Al alloy.
Tamilarasan & Marimuthu [19] proposed an approach to RSM methodology coupled with gray relational analysis to obtain suitable cutting parameters for machining tool steel using TiN + TiAlN coated WC inserts. During machining, the reaction of the cutting temperature has been measured and optimized in order to improve the machined surfaces.
Kumar et al., [20] used genetic algorithm to find the best combination of cutting parameters providing lower temperature rise during machining of Al 6061 T6.
The advantage of thermocouples is the simplicity of use for simple acquisition and this at a lower cost, but this type of method does not effectively give precise temperature values, it depends mainly on the position of implantation of the thermocouples.
In this work, a study of the evolution of the cutting temperature during the turning of X200Cr12 steels according to the cutting conditions (spindle rotation speed, depth of cut and feed rate) was proposed. The effect of the coating on the variation in cutting temperature was also studied through an experimental approach which relied on a comparison between machining with a coated and uncoated cutting insert. The objective is to select the optimum cutting parameters leading to minimizing the cutting temperature during machining. Selecting the optimal cutting parameters increases the life of the cutting tool used for machining X200 Cr 12 steels in the first place and eliminates the use of cutting fluids in the second place.

2. EXPERIMENTAL METHOD

2.1. Materials and equipment

All temperature tests were carried out on cylindrical parts with a diameter D=40mm and a length L=600mm.

Fig.1. Shape of the part used in the tests

The material of the pieces used in the tests is X200Cr12, a tool steel with high chromium content, this type of steel presents the minimum risk of deformation during heat treatments, [Φ21]. It has excellent wear resistance (high wear resistance), [21].
The chemical composition of the material used is described in Table 1.

Table1. Chemical composition of X200Cr12

Chemical elements	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)
X 200Cr12	2	0.29	0.31	0.011	0.009	12	0.259

The insert holder assembly used in tests is presented in figure 2.

Fig. 2. Cutting tool (tool body)

In this study, two 80° rhombic inserts manufactured by Sandvik Coromant France are used: the first uncoated (CNMG120404-SF) and the second coated (CNMG120404-M34)

- Insert 1: CNMG120404-SF

The geometric parameters of this insert are shown in figure 3.

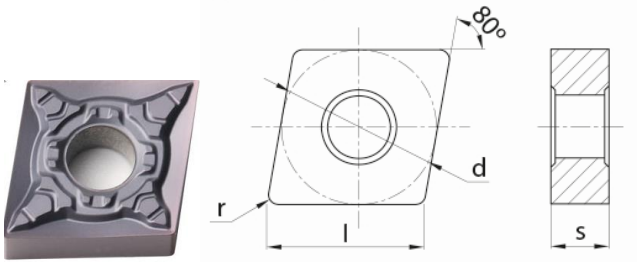


Fig.3.Insert CNMG120404-SF

Table 2 gathers the Manufacturer's specifications of the cutting insert.

Table 2. Manufacturer's specifications

I	0.488"
d	0.5"
r	0.16"
s	0.187"
Material	Carbide
Insert type	Negative
Hardness	1850 HV

Figure 4 represents the microscopic visualization of the CNMG120404-SF insert. SEM images were taken by Phenom Prox X (Phenom-World, Netherlands).

Fig.4. Microscopic visualization of the insert CNMG120404-SF (Scale bar: 10µm)

– Insert 2: CNMG120404-M34

The geometric parameters of this insert are shown in figure 3.

Table 3 gathers the Manufacturer's specifications of the cutting insert.

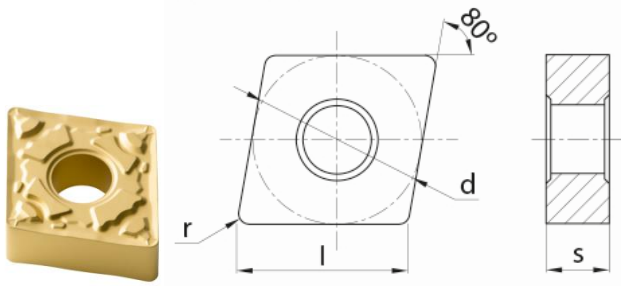


Fig.5. Insert CNMG120404-M34

Table 3. Manufacturer's specifications

I	0.488"
d	0.5"
r	0.16"
s	0.187"
Material	Carbide
Insert type	Negative
Hardness	1850 HV
Coating specifications	PVD TiN + $(Ti.Al)N$ + TiN : 4µm

Figure 6 represents the microscopic visualization of the CNMG120404-M34 insert. SEM images were taken by Phenom Prox X (Phenom-World, Netherlands)

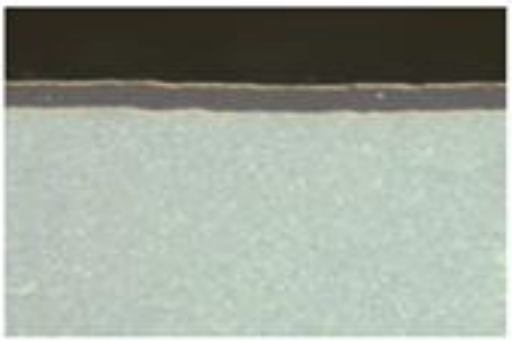


Fig.6. Microscopic visualization of the insert CNMG120404-M34 (Scale bar: 10µm)

The machine used in our work is a parallel lathe (Figure 7).

Fig.7. The machine used (Manufactured by Emco)

The range of rotation speeds available on the machine varied from 30 to 2500 rpm, while the range of feeds available on the machine varied from 0.045 to 0.787 mm/rev.

2.2. Temperature measuring

For the measurement of the cutting temperature a measurement interface is used: Cobra3 CHEM-UNIT (figure 8). This interface is operated with a computer.
This equipment isn't only for temperature measurement. It offers the wide range of measurements for pressure, force, voltage, current, etc.
For temperature measurement an input for a temperature probe (Pt1000) and three inputs for thermocouples (type K) are available.

Fig. 8. The Cobra3 CHEM-UNIT

Fig. 9. Thermocouple type K

The tool-workpiece thermocouple enables the in-process measurement of a thermoelectric voltage and current during machining generated by the Seebeck effect at the interface between two electrically conductive materials. For this study, the cutting temperature in the tool is measured using NiCr-Ni type K thermocouples manufactured by PHYWE (Figure 9) with the following dimensional parameters: Cable length: Cable: 2m, Sensor length: 100mm, Sensor end diameter: 0.5mm. The temperature measurement range for these thermocouples is 50°C to 1100°C.
For data acquisition we used a P4 GHz PC, 2 GB of RAM equipped with "MEASURE" software developed by PHYWE. (Figure10).

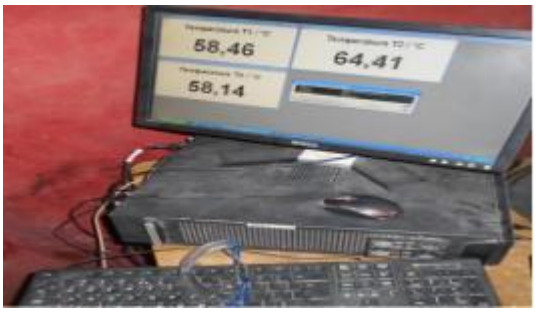


Fig.10.The PC used

For the placement of the thermocouples on the cutting tool, two holes with a diameter of 2 mm are made on the insert holder to facilitate the use and assembly of the thermocouples.

Fig.11.Drilling of the insert holder for making two holes

For the temperature measurement three thermocouples are used, whose positions on the tool are defined by figure 12.

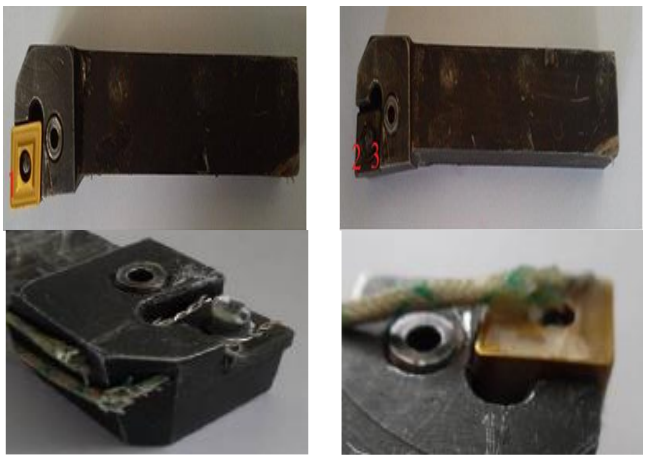


Fig.12. Locations of thermocouples

– Position 1: to measure the temperature T1;
– Position 2: to measure the temperature T2;
– Position 3: to measure the temperature T3.

The cutting temperature acquisition system includes all the elements shown in Figure 13.

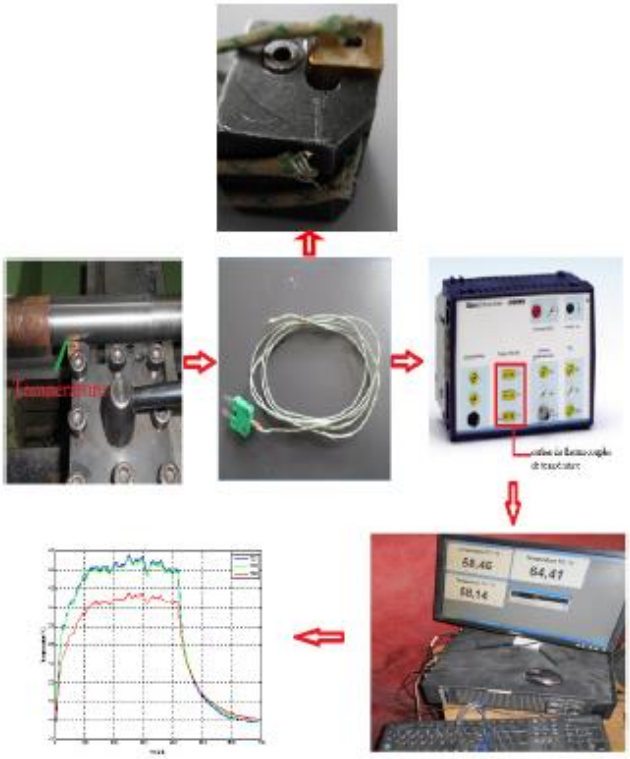


Fig.13. Measuring principle

3. RESULTS AND DISCUSSIONS

3.1. Fidelity study of the measurement system

The calibration of the thermocouples was carried out by a comparison technique according to ASTME 220 (1986) with respect to a reference or an external standard.

On the software, the calibration is carried out as follows: Calibrate the temperature sensors; select calibrate, adjust T1, T2 and T3 to reference temperature; click calibrate and ok.

In order to study the fidelity of the measurement system, temperature measurement tests were carried out, with identical cutting conditions. $a = 0.1mm$, $f = 0.045mm/rev$, $n = 440rpm$ Figure 14 illustrates the curves of cutting temperature for four tests carried out on steel X200Cr12.

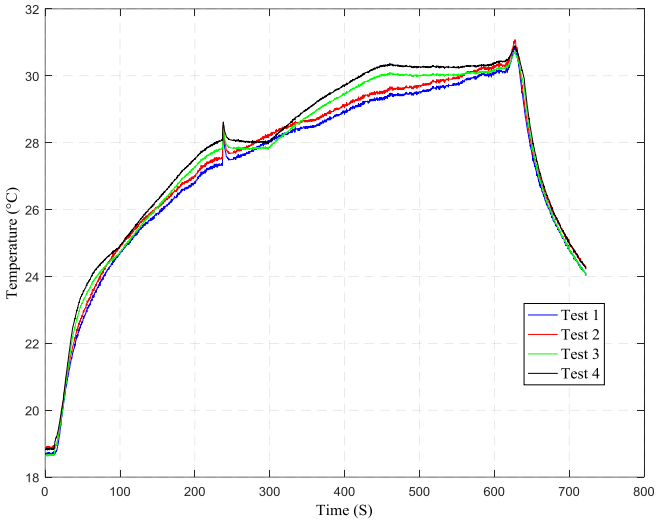


Fig.14. Fidelity of the measurement system

Table 4. Result of system reproducibility tests

Test	Temperature (°C)
Test 1	30.19
Test 2	30.38
Test 3	30.27
Test 4	30.45
Average	30.3225
standard deviation σ	0.1

Table 4 presents the results of the system reproducibility tests.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{4}\left(T_i - \overline{T}\right)^2} \quad (1)$$

The standard deviation is 0.1 so the temperature values are grouped around the average, so it can be said that the temperature measurement is homogeneous for the four tests.

Two types of insert (coated and uncoated) were subjected to temperature measurement tests. In the following, we present the temperature results on each grade, highlighting the influence of time and temperature. Coating, rotational speed, feed per revolution and depth of cut.

3.2. Influence of time and coating inserts

During the experimental work it noted that the cutting temperature increases with cutting time, then it decreases when the machining operation is finished (no contact between the tool and the part). This variation takes the same shape for all the tests and whatever the cutting conditions used. The stability of the measured cutting temperature is obtained by using small values for the tool feed.

In some tests we did not reach the temperature stability threshold, especially for large feed (reaching this threshold requires a large length of the part, which is not possible in the machine used).

The analysis of the curves of the variation of the temperature allowed us to classify the curve obtained in four classes.

Class 1: In this type of curve, the temperature stability threshold is reached (figure 15) so the maximum cutting temperature is reached. This type of curve is obtained for low values of feed rate, depth of cut and rotational speed.

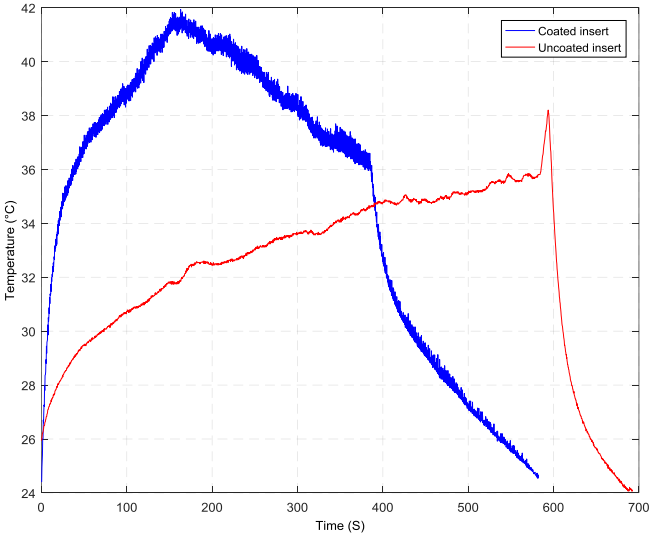


Fig.15. Curve of temperature / time (curve class 1) for: $f = 0.045\ mm/rev$, $a = 0.1\ mm$ et $n = 440\ rpm$

Class 2: In this type of curve, the temperature stability threshold is almost reached (figure 16). In this type it can be said that the maximum cutting temperature is the same as obtained on the curve with a small difference. This type of curve is obtained for average values of feed rate, small depth of cut and high rotational speed.

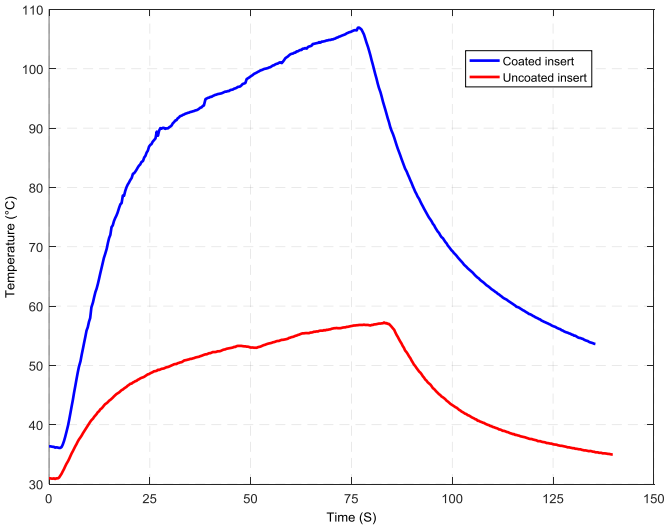


Fig. 16. Curve of temperature / time (curve class 2) for:
$f = 0.157\ mm/rev$,
$a = 0.1\ mm$ et $n = 1500\ rpm$

Class 3: In this type of curve the temperature stability threshold is not reached (figure 17), but the high cutting temperature is comparable to the maximum cutting temperature on the curve. This type of curve is obtained with average values of feed rate, depth of cut and rotational speed.

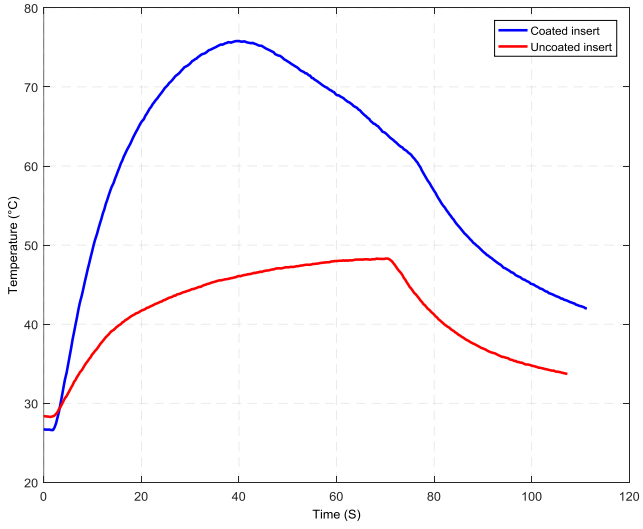


Fig. 17. Curve of temperature / time (curve class 3) for:
$f = 0.157\ mm/rev$,
$a = 0.15\ mm$ et $n = 900\ rpm$

Class 4: In this type of curve, the temperature stability threshold is not reached (figure 18) and the high cutting temperature is not comparable with the maximum cutting temperature on the curve. This type of curve is obtained with high values of the feed rate, of the depth of cut, but with medium rotational speed.
In the figures (15 to 18), it is clear that the influence of caoting insert on the cutting temperature during machining of X200Cr12 steel. The coating insert lead to an increase in cutting temperature. This remark is due to the difference in the thermal conductivity of the coating and the substrate.

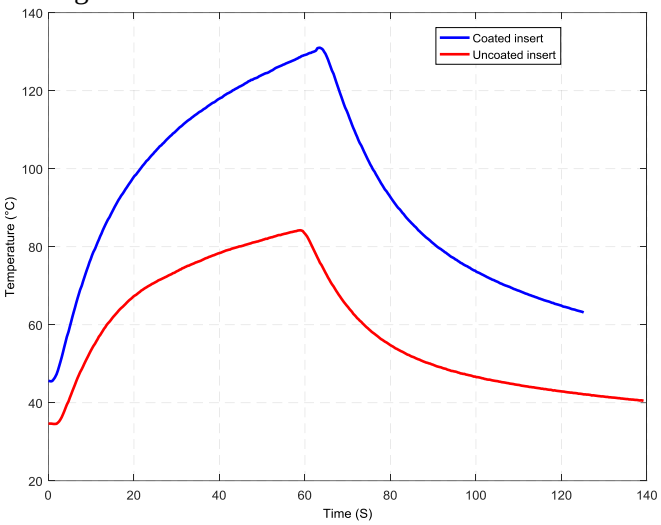


Fig. 18. Curve of temperature / time (curve class 4) For :
$f = 0.225\ mm/rev$, $a = 0.25\ mm$ et $n = 900\ rpm$

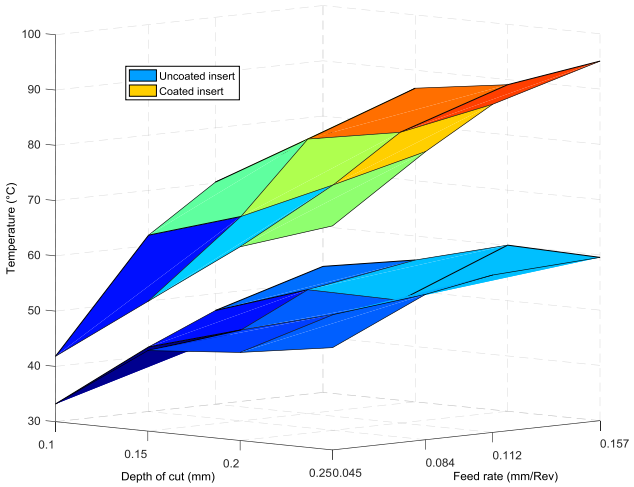


Fig. 19. 3D representation of cutting temperaturefor n= 440 *rpm*

The shape of the temperature curves for coated and uncoated wafers remains the same as shown in Figure 19.

3.3. Influence of the feed and speed of rotation

The results obtained during the temperature measurement tests are shown in the figures below. The influence of feed per revolution and depth of cut when machining steel X200Cr12is shown in the figures below.
The influence of feed rate on the cutting temperature during turning of X200Cr12 is observed. As is clear from the figures, an increase in feed per revolution causes an increase in cutting temperature. This is because an increase in feed per revolution causes friction between the chip and the cutting tool, which will also cause an increase in energy in the system, which increasing cutting temperature. This behavior is constant when machining X200Cr12 steel for the different rotational speeds.

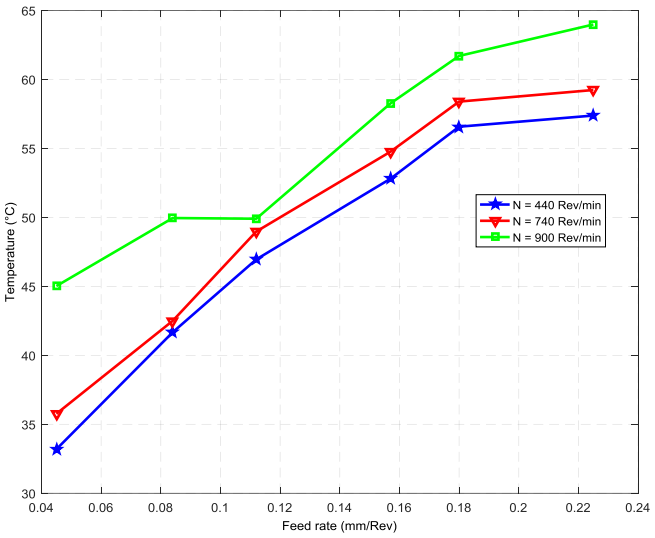


Fig. 20. "Cutting temperature / Feed rate" curves for a = 0.1 mm

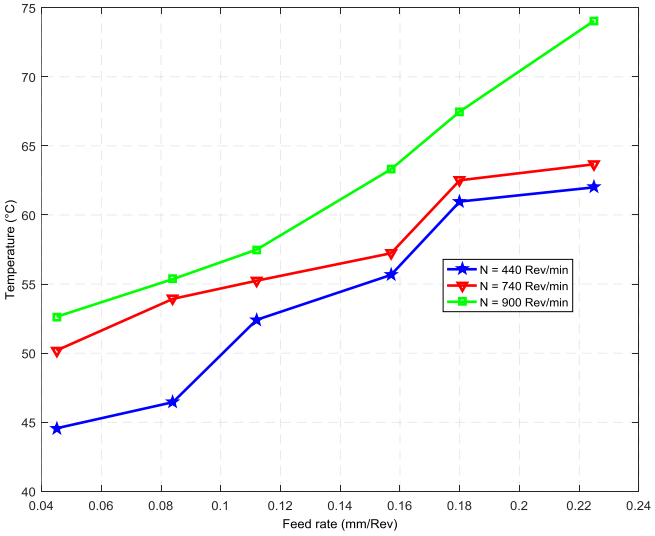


Fig. 21. "Cutting temperature / Feed rate" curves for a = 0.15 mm

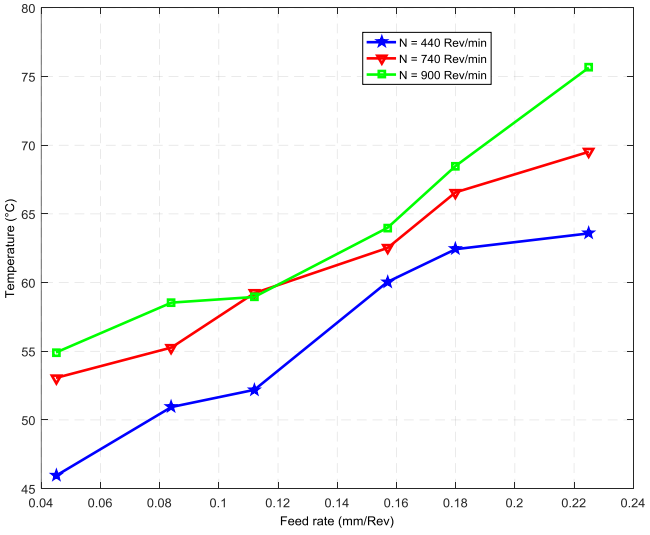


Fig. 22. "Cutting temperature / Feed rate" curves for a = 0.2mm

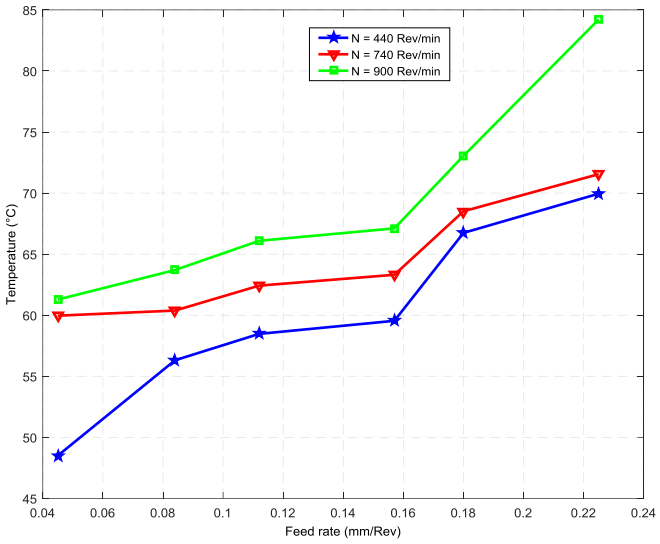


Fig. 23. "Cutting temperature / Feed rate" curves for a = 0.25 mm

The influence of the rotational speed on the cutting temperature during the machining of steel X200Cr12 is observed in the figures (21 to 23), it can be observed that an increase in the rotational speed produces an increase in cutting temperature. This result is due to the fact that an increase in rotational speed produces an increase in cutting forces. More energy is required to remove material further and further away from the cutting temperature. This behavior remains constant during the machining of steel X200Cr12for the different values of the depth of cut.

3.4. Influence feed rate and depth of cut

The influence of depth of cut on cutting temperature during turning of steel X200Cr12 is illustrated in the figures (24 to 26).

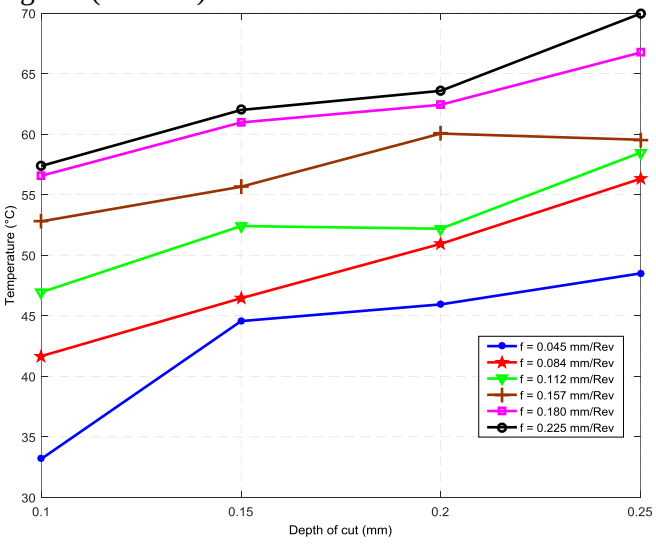


Fig. 24. "Cutting temperature / depth of cut" curves for n = 440 rpm

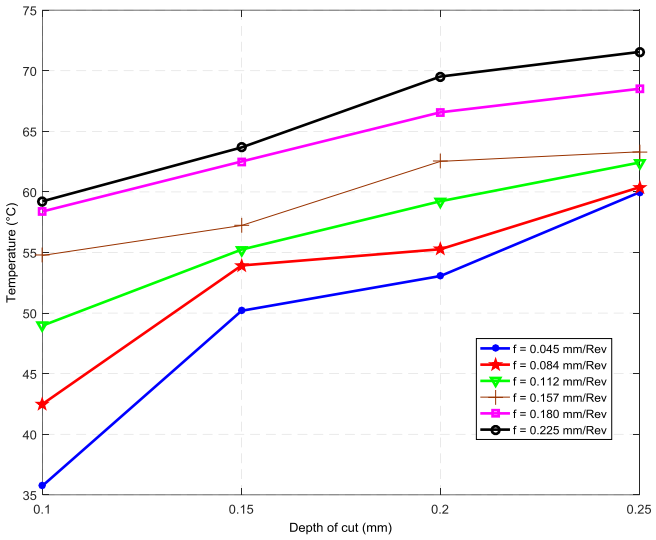


Fig.25. "Cutting temperature / depth of cut" for n= 740 rpm

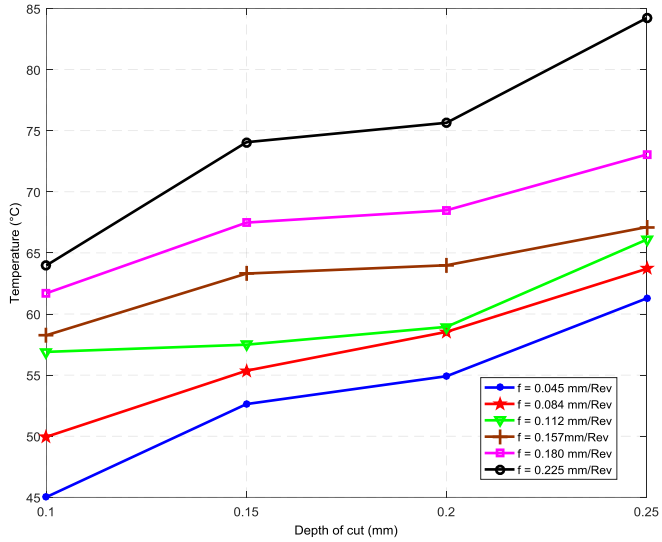


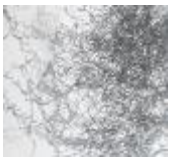
Fig.26. "Cutting temperature / depth of cut" for n = 900 rpm

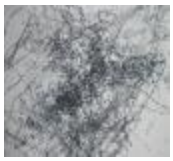
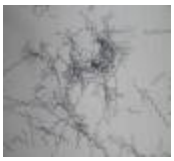
Figures (24 to 26) illustrate the influence of the depth of cut on the cutting temperature of X200Cr12 steel.
As observed the cutting temperature increases as the depth of cut is increased.
If the material of the machined part is plastically deformed, most of the energy is transformed into heat, because the part has undergone large deformations, while the elastic deformation represents only a small part of the total deformation. Therefore, increasing depth of cut represents the greatest compression in the tool-work interface which increases the energy delivered to the system when cutting material. This behavior remains constant when machining steel for the different feed per revolution values.

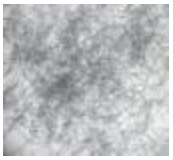
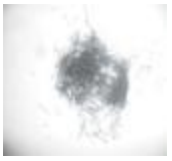
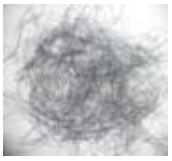
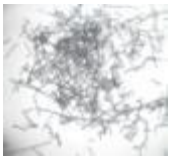
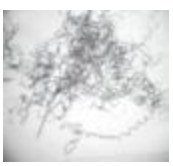
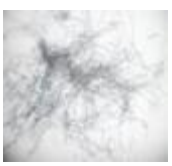
3.5. Chip morphology

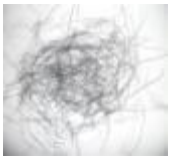
The different morphologies of the chips obtained during turning operations with the coated insert are presented below (Table 5).
The photos are taken by a Samsung M11 digital camera at real scale.

Table 5. Chips obtained with the coated insert

a (mm)	f (mm/Rev)	n= 440 (rpm)	n= 740 (rpm)	n= 900 (rpm)	n= 1230 (rpm)	n= 1500 (rpm)
0.1	0.045					
	0.084					
	0.112					

	0.157					
	0.18					
	0.225					
0.15	0.045					
	0.084					
a (mm)	f (mm/Rev)	n= 440 (rpm)	n= 740 (rpm)	n= 900 (rpm)	n= 1230 (rpm)	n= 1500 (rpm)
0.15	0.112					
	0.157					
	0.18					
	0.225					
0.2	0.045					

	0.084					
	0.112					
	0.157					
	0.18					
	0.225					
a (mm)	f (mm/Rev)	n= 440 (rpm)	n= 740 (rpm)	n= 900 (rpm)	n= 1230 (rpm)	n= 1500 (rpm)
0.25	0.045					
	0.084					
	0.112					
	0.157					
	0.18					

	0.225					

The analysis of the figures above allowed us to classify the morphologies of the chips into three classes:

–First Class: Most chips are grain type. This type is obtained in the case of the use of a large depth of cut, a large feed and a low rotational speed.

–In the second class: most chips are fragmented continuous chips. This type of chips is obtained in the case of choosing a maximum depth of cut, a maximum feed and an average or maximum rotation speed.

– In the third class: most chips are continuous chips. This type of chips is generally obtained for small values of cutting conditions.

4. CONCLUSIONS

Through this work, a strategy to determine the influence of the cutting parameters on the cutting temperature in turning of a hard material has been proven. The aim is to obtain, when machining X200Cr12 steel, low values of the cutting temperature, which will contribute to increasing the life of the cutting tool.

The main contribution of this work lies in the proposal of a wide range of values of cutting conditions for the case of turning of X200Cr12 steel with coated and uncoated inserts. An experimental procedure was presented with the various tests carried out to establish the effect of cutting conditions on the evolution of temperature in cutting insert.

The results found show that the cutting temperature in the tool increases with the increase of the cutting parameters.

The results found show that the cutting temperature varied with the conductivity of the insert material.

The results found are consistent with research carried out with other researchers.

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