# NUMERICAL STUDY OF CUTTING TEMPERATURE DURING DRILLING PROCESS OF THE C45 STEEL

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***Abstract:*** Optimize the process and save time and cost are the main motivations for cutting tools modeling. Thus, the modeling of the drilling is a means for reducing the time and cost of designing new drill geometries.
This work aims to propose thermal models in 2D and 3D in order to estimate the drill cutting temperature with and without metal coating during a drilling operation by using the digital simulation software Comsol Multiphysics.
The results of thermal simulations for both types of drills with and without metal coating obtained underlines the importance of particular coatings TiN in the propagation of heat and the cutting temperature elevation.
***Key words:*** drilling, temperature, simulation, finite element method.

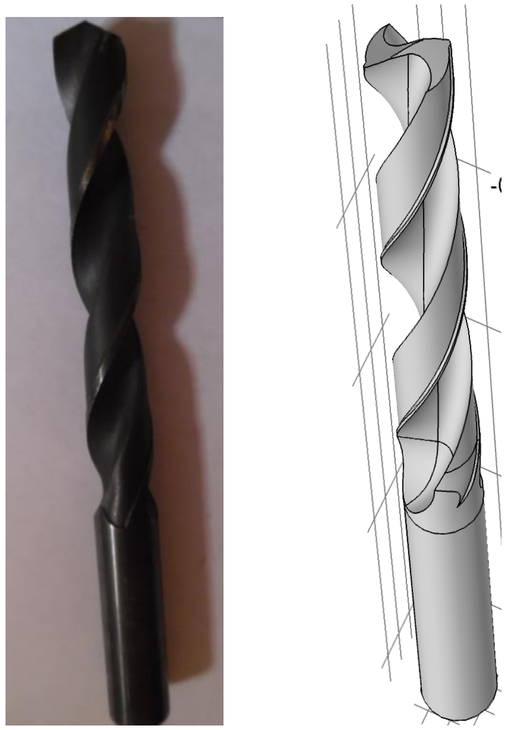
## 1. INTRODUCTION

The drilling is one of the most used in machining operations to assemble manufactured parts, drilling at the cutting tool made by a drill still by far the most used in industry, [8, 9, 15].
However, the machining operations (drilling, milling, trurning) inevitably cause damage such as delamination, thermal and mechanical degradations, [2]. Several researches is conducted on the heat problem in metal cutting, there is hardly a consensus on the basic principles. Accurate and repeatable heat and temperature prediction remains challenging due to the complexity of the contact phenomena in machinig, [1]. During drilling operations, temperature distribution in the workpiece is an important parameter as it adversely affects product quality including residual stress, dimensional error, and the hardness of the machined surface, [8, 10, 11, 13].
The thermo-mechanical effect is very important in the machining. The effect occurred during material removal processes leads to heat generation in the cutting zone, [3]. The thermal cutting phenomena produced by the drilling process are one of the most influential factors on the quality of the holes made, [5].
Many methods and techniques are used for measuring the machining cutting temperature. We find in the literature different types of these methods: numerical, analytical and experimental, [4].
In recent years, with the development of computer and numerical computation technology, finite element method (FEM) is widely used in metal cutting study, which has become the effective method to study cutting mechanism and process parameters optimization, [7, 8, 12].
The numerical model allows determining the evolution of the temperature of piece obtained during drilling [6, 14]. The majority of thermal models were developed based on turning operations. However, the authors of some studies have examined the distribution of cutting temperature in the drill and in the workpiece, [8].
In this study, the thermal phenomena during the drilling process of C45 steel have been studied, by a thermal modeling 2D and 3D in order to estimate the drill cutting temperature with and without metal coating, during a drilling operation. The software used in this study is the Comsol Multiphysics, based on the finite element method.

## 2. THERMAL MODEL OF CUTTING TEMPERATURE

A finite element method is widely used, since it allows treating the problem in 3D case with fewer simplifying assumptions, unlike analytical approaches, [12]. This method is made possible by advancements in computing and computer processing powers and thus it has been used for almost all computer aided design methodologies in recent years, [11].
The 2D and 3D simulation of the thermomechanical phenoma of drilling process used the finite element method is very interesting, because it allows studying the phenomenon of temperature fields in the tool and workpiece. This can help to optimize the geometry of the drill or cutting conditions.

For the majority of drills, the cutting geometry is defined by two surfaces. For a classic drill (drill helical flutes) the point is conical, major edges formed by the intersection of flute surfaces and flank surfaces defined by the conical tip, are rectilinear and the same for the central edge which corresponds to the intersection of the two surfaces flank, figure 1a.
A 3D model developed by the software COMSOL Multiphysics, based on the reals dimensions of a classical drill helical flute, 16 mm in diameter, figure 1b.



a). b).

Fig. 1. a) Helicoidal drill real, b) The 3D model

The 3D simulation of the operation of drilling by the finite element method is very interesting because it possible to obtain an indication of the flow of chips and the morphology of these. It provides access to the fields of stresses and temperatures in the tool and the workpiece, this can help to optimize the geometry of the drill or the cutting conditions.
Two phases of the drilling operation can be simulated:
- The drill penetration phase: in this case, the drilling is simulated from initial contact of the drill with the piece to be drilled, figure 2a;
- The next phase of drilling that is the realization of the hole from a depth h. In this phase, the piece is supposed already pierced with a hole depth h and the drill begins drilled from that depth, figure 2b.
The workpiece is modeled by a 20 mm cube length, thickness 10 mm in 3D using COMSOL Multiphysics software.

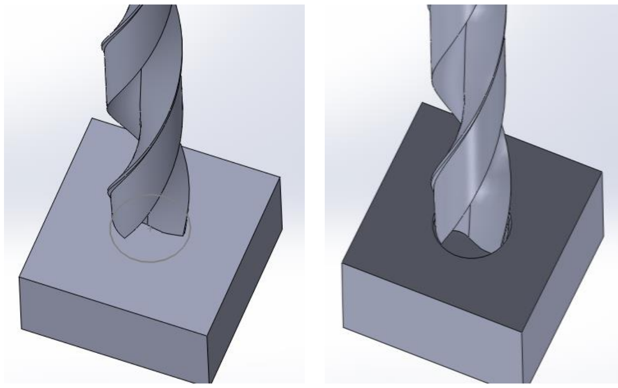


Fig. 2. Representation of the two types of simulations

The development of a direct solution to the problem is realized through a numerical process that integrates COMSOL Multiphysics commercial software. The integrated heat flux within the drilling process varies due to the existence of chips and the variability of torque. The general equation of conduction in a cartesian coordinate system (x, y, z) is established and given as follows:

$$\frac{\partial T}{\partial t} = \alpha \left( \frac{\partial^2 T}{\partial^2 x} + \frac{\partial^2 T}{\partial^2 y} + \frac{\partial^2 T}{\partial^2 z} \right) \quad (1)$$

or $\alpha = \frac{k}{\rho c_p}$ is called the thermal diffusion coefficient.

**2.1 Boundary conditions**

The drilling process influences the generation of heat transfer to the workpiece from three regions of the drill bit, including the chisel edge, cutting lips, and margins, [8].
The contact surface tool / chip is constant. Consequently, the evolution of the wear is not taken into account in the model.
To determine the temperature field in the drilling process, the boundary conditions must be given as follows:
- Heat exchange with environment

$$-k \frac{\partial T}{\partial z} = h\left(T - T_\infty\right) \quad (2)$$

- Heat exchange with the work-piece

$$-k \frac{\partial T}{\partial z} = q_0 \quad (3)$$

- In the others regions of the drill

$$-k \frac{\partial T}{\partial \eta} = h(T - T_\infty) \quad (4)$$

- Initial conditions

$$T\left(x, y, z, t\right) = T_0, \quad \text{at} \quad t = 0 \quad (5)$$

where: T is calculated temperature, h (W/m$^2$.°C) is the heat transfer coefficient by convection, $T\infty$ the environment temperature, $q_0$ (W/m$^2$), the heat flux.
The numerical resolution of differential equations of the physical phenomenon has been realized using the COMSOL Multiphysics software. Also, COMSOL Multiphysics allows adjusting any boundary conditions, as well as modelling the geometry so as to faithfully represent the investigated system, [12].
The solution of thermal phenomena of the cutting tool, taking into account all the boundary conditions, is made stationary and non-stationary regime from the discretization of the integrated heat transfer equation in the computer code COMSOL Multi-physics.
The geometric model of the whole cutting tool is meshed using triangular elements. These elements are complete integration elements and the choice of this type of element is based on the geometric configuration of the entire 3D model and also takes into account the diffusion of heat.

## 2.2. 2D model of the whole-piece tool-chip

The figure below shows the geometry of the whole tool-workpiece-chip in 2D developed by COMSOL Multiphysics.

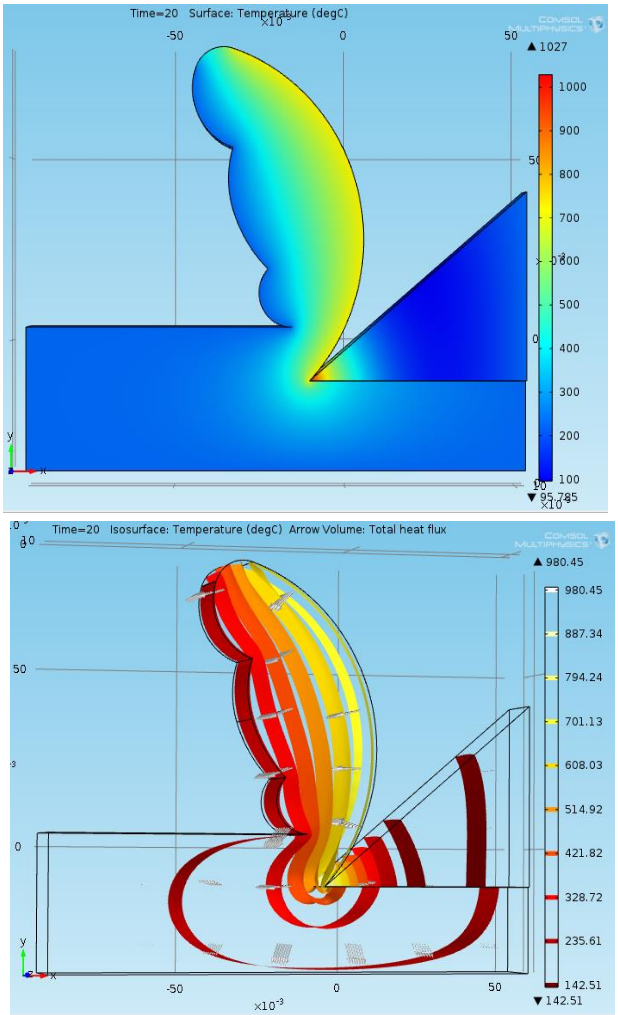



Fig. 3. Thermal and isothermal 2D fields of the whole tool-workpiece-chip

Figure 3 shows the thermal and isothermal distribution in the tool, workpiece and the chip, during drilling operations. In this figure, we see that the maximum working temperature occurs on the secondary shear zone in cutting tool. The transfer of heat in the tool is affected primarily by diffusion.
The distribution of flows is not done in an equivalent manner and depends of course of cutting conditions and thermal properties of materials.
The heat generated is distributed on; the tool, the workpiece and the majority being evacuated through the chip.

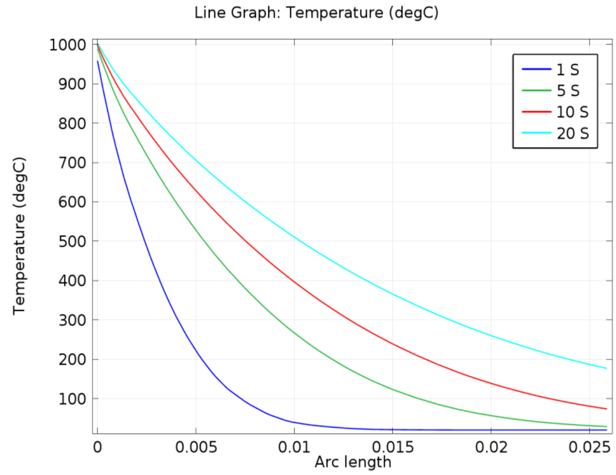



Fig.4. The cutting temperature according of the tool-workpiece contact point

Figure 4 shows the temperature increases near the contact point of the tool, it attained the value up to 1000°C, then we notice a reduction in temperature when in moving away from the contact point for different time t = 1s, 5s, 10s and 20s.

## 2.3. Thermal simulations in 3D drill without metal coating

The purpose of this simulation section is the comparison between both types of drill bits, with and without metal coating.
The temperature distribution of the tool without coating mettalique depending time during the machining with the orthogonal cutting is simulated using the COMSOL commercial software.
The figure 5 shows, drill bit simulations obtained with a high speed-steel drill bit (AISI 4340), we can observe successively: The drill meshing, the thermal distribution in the tool and isothermal Contours.
These positions implantations thermocouples are chosen based on the experimental work for measuring the drill cutting temperature during the drilling operation, for example the of work A. Taskesen and al, [10]. In the method of tool-thermocouple system, a thin wire and thermocouples are epoxied in the clearance face of the drill near the cutting edge through the coolant holes of drill bit, (figure 6), [10].

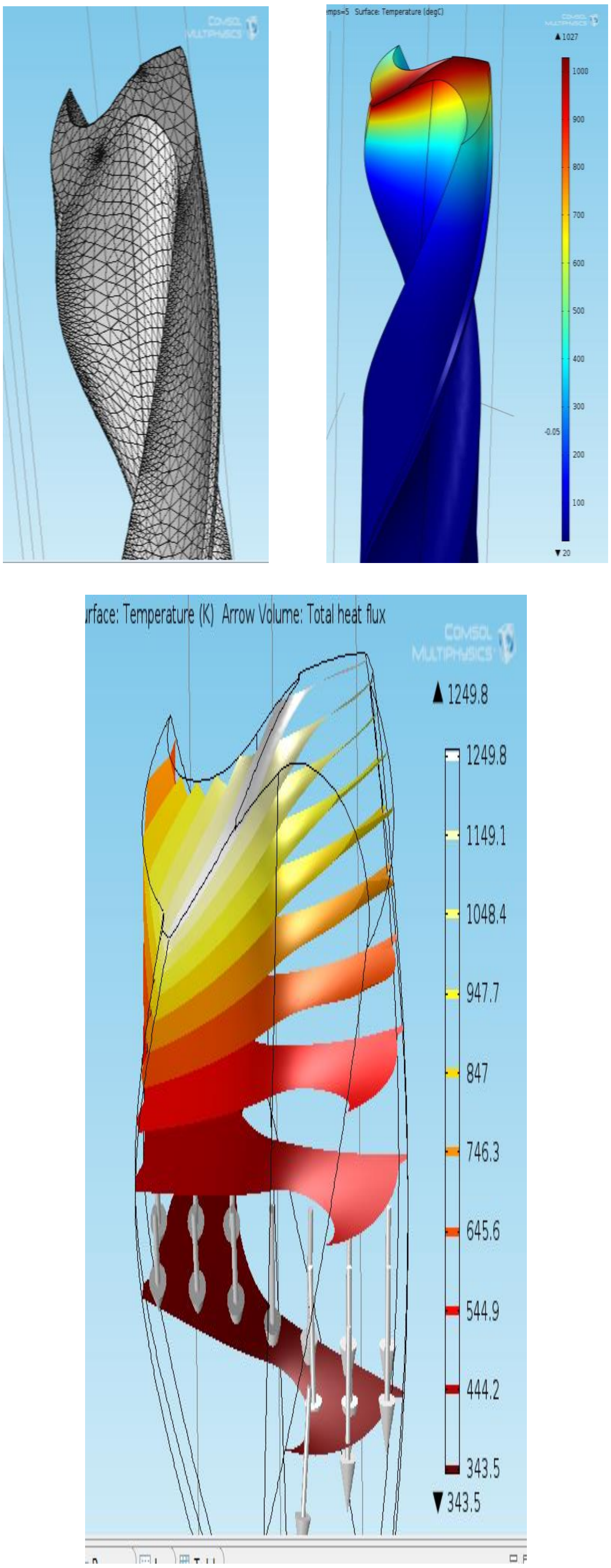



Fig. 5. Mesh and thermal field simulation drill without metal coating

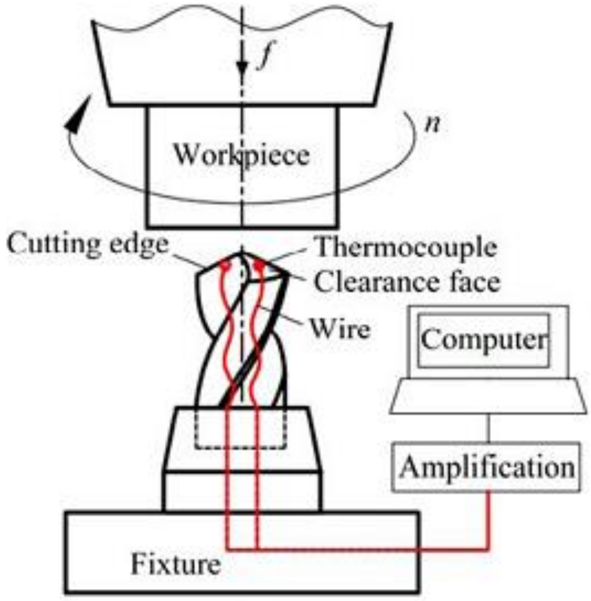



Fig. 6. Temperature measurement methods during drilling process: Thermocouple embedded in tool, [10]

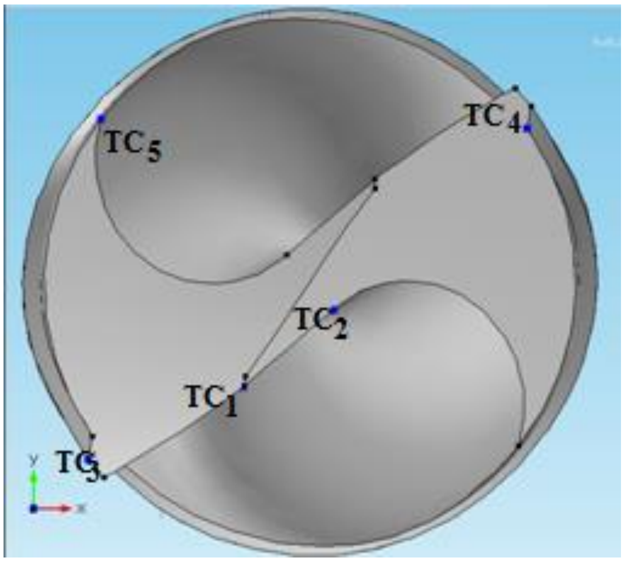



Fig.7. Positions of thermocouples installed in the drill

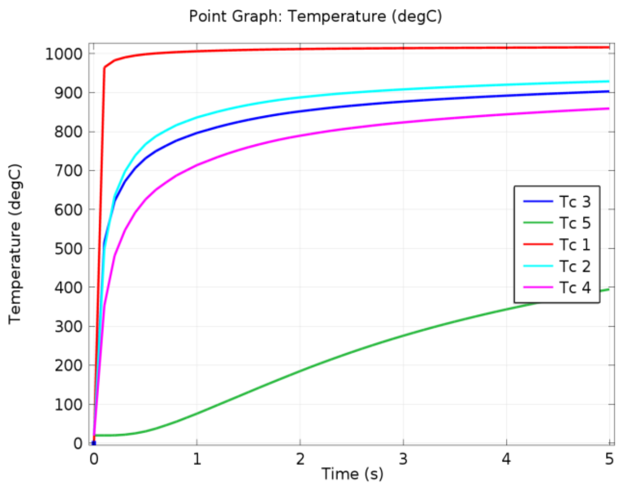



Fig. 8. The temperature evolution as a function of time drill without metal coating

Figure 7 shows the installation of thermocouples in the drill withe and without metal coating to estimate the temperature cutting during the drilling operations. The figure 8 shows the shape of the cutting temperature versus time of the drill without metal coating, for TC1, TC2, TC3, TC4 and TC5.

### 2.4. Thermal simulations in 3D drill with metal coating titanium nitride

The figure 9 shows drill bit simulations obtained with titanium Nitride drill bit (Titanium beta-21S), we can observe successively: the drill meshing, the temperature distribution on the body of the tool and the isothermal contours.

The figure 10 shows the evolution of the cutting temperature versus time of the drill with metal coating, for TC1, TC2, TC3, TC4 and TC5.

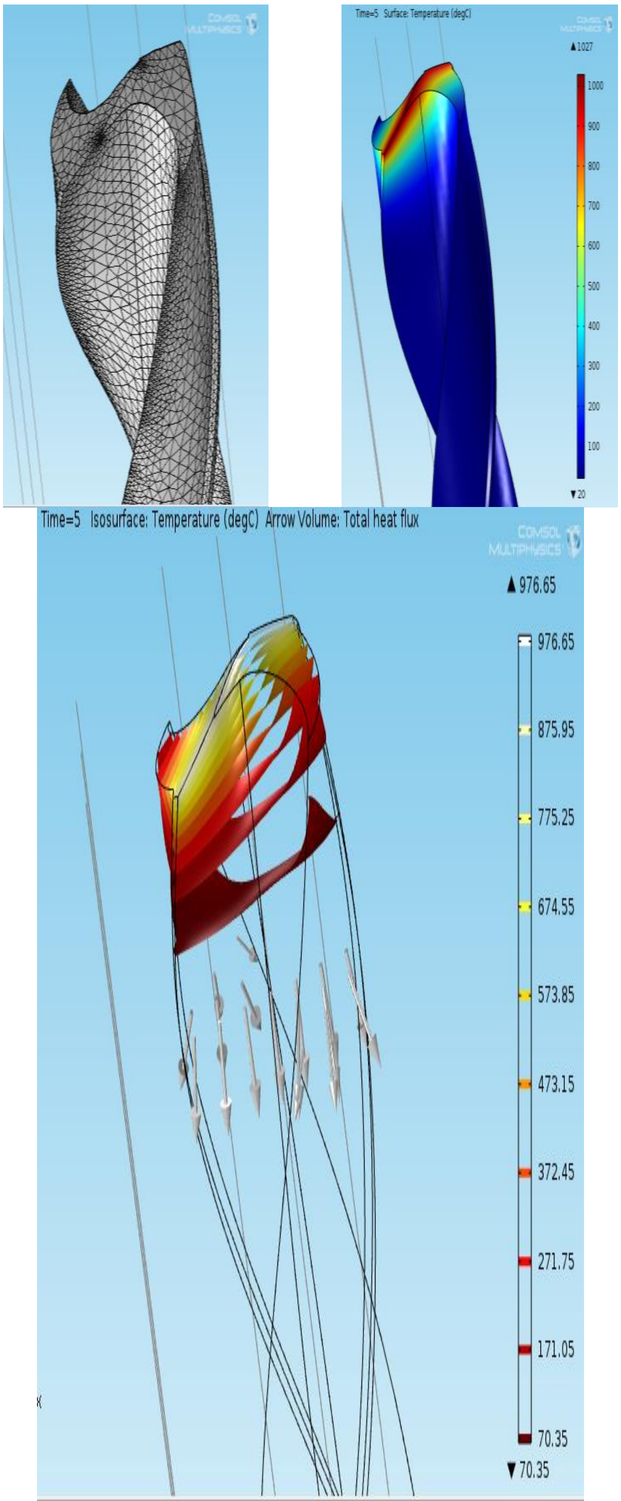



Fig. 9. Mesh and thermal field simulation drill with metal coating Titanium Nitride

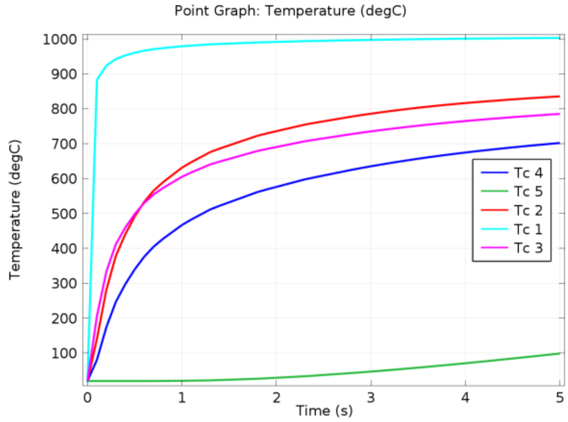



Fig. 10. The temperature evolution as a function of time drill with metal coating Titanium Nitride

## 3. RESULTS AND DISCUSSIONS

Figures 5 and 9 illustrate the evolution of cutting temperature ranges on the drill with and without metal coating.

We clearly observe the isothermal distribution difference and the heat density of two drillers used, the coated drill shows a more heat resistant behavior with less heating compared to uncoated drill.

The figures 8 and 10 show the evolutions of the cutting temperature versus time, obtained by numerical simulation for the two drills with and without coating.

The analysis of these curves allows us to observe that cutting temperature gradually increases with caused by cutting during the descent of the bit into the workpiece, and we note that temperatures are stable when come in a certain stage.

Increasing temperature near the contact point of tool, it attained the value until 1000 °C.

The figures show that the temperature produced with the uncoated drill is more important than that generated with the coated drill.

The significant effect of the metal coating, in particular titanium Nitride (TiN) on cutting tools was the wear and life in general.

## 4. CONCLUSIONS

The aim of this study is to propose a thermal model in 2D and 3D to estimate the cutting temperature during a drilling operation using digital simulation software Comsol Multiphysics, based on the finite element method.

All the thermal simulation results of the drill with and without coating obtained underlines the importance of particular coating titanium Nitride (TiN) in the propagation of heat and temperature rise in the cutting tools, wear and tool life.

Despite advances in information technology, simulation of machining processes in 3D especially if drilling faces many difficulties, because of the complex form of the drills.

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Received: May 20, 2016 / Accepted: December 10, 2016 / Paper available online: December 20, 2016