THEORETICAL STUDY OF TEMPERATURE DISTRIBUTION AND HEAT FLUX VARIATION IN TURNING PROCESS

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ABSTRACT

The heat generation during metal cutting processes affects materials properties and the tool wear. Knowledge of the ways in which the cutting conditions effect the temperature distribution is essential for the study of thermal effects on tool life. Analyses of three-dimensional transient temperature distributions in a metal cutting process using a finite element code the Deform 3-D was presented in this paper. The effects of the rake angle, cutting speed, feed rate, tool and workpiece materials on the temperature and heat flux are studied. The results show that increase in cutting speed and feed rate increases the cutting temperature while increasing rake angle reduces the cutting temperature. Results indicated that, as cutting speed increased from 103.2 to 250 m/min an increased in temperature equal to 21.9% occurred. With a reduction in rake angle from 5° to -5°, temperature increased by 12.3%. As the feed rate increases from 0.16 mm/rev to 0.25mm/rev, the temperature increases in a 13.82%.

KEYWORDS: Finite Element Simulation; Cutting Temperature Distribution, Metal Cutting Process. Chip-Tool Interface Temperature. Tool Geometries

دراسة نظرية لتوزيع درجات الحرارة و اختلاف الفيض الحراري في عملية الخراطة

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الموجز

ان الحرارة المتولدة خلال عملية قطع المعدن تؤثر على كلاً من خواص المعدن وعلى عمر اداة القطـع. ومعرفة الكيفية التي بها ظروف القطع تؤثر على توزيع درجة الحرارة ضرورياً لدراسة التأثير الحراري على عمر الاداة. تم في هذه الدراسة تحليل توزيع درجة الحرارة الثلاثي الابعاد باستخدام نموذج عناصر محددة Deform 3D يستخدم للتنبؤ بدرجة الحرارة الانتقالية والفيض الحراري في عملية القطـع. دُرس تأثير كل من سرعة القطع، معدل التغذية، زاوية الجرف ومعدن الاداة على درجة الحرارة والفيض الحراري. بينت النتائج ان زيادة كل من سرعة القطع ومعدل التغذية تزيد من درجة حرارةالقطـع بينما زيادة زاوية الجرف تقلل منها. درجة الحرارة تزداد بمعدل 21.9% عندما تزداد سرعة القطـع من 103.2 الـى 250 م/دقيقـة، وعندما يزداد معدل التغذيـة مـن 0.16 الى 0.25 مم/دورة تزداد درجة الحرارة بمعدل 13.82% و عندما تقل زاوية الجرف من 5+ الى 5− تصل الزيادة في درجة الحرارة الى 12.3%.

NOMENCLATURE

Cp	heat capacity (W/m K)		Greek symbol
h	heat transfer coefficient(W/m^2K)	α	thermal diffusivity (m^2/s)
k_T	thermal conductivity of metal (W/m K)	ρ	metal density (kg/m^3)
$q^=$	heat flux (W/m^2)	τ	frictional stress
T	temperature (K)	μ	coefficient of friction
t	time (s)		subscript
σ	stress (Pa)	∞	medium
		n	normal

INTRODUCTION

During a cutting process, the mechanical energy resulting from the plastic deformation developed at the primary shear plane and at the chip–tool interface is converted into heat **(Lazard, 2005)**. Studies have shown that the chip and the environment dissipate a great deal of this heat while the reminiscent is conducted both into the workpiece and into the cutting tool. However, this small quantity of heat conducted into the tool (8–10% of the total heat rate) is enough to create high temperatures near the cutting edges, which in some cases can reach the level of 1100 °C **(Carvalhho et al, 2005)**.

It is clear that the determination of the exact temperature rise in the tool–chip interface has been recognized as an important factor in achieving the best cutting performance. That is the reason why several researchers have become interested in determining the temperature histories on the rake face of cutting tools. Many of temperature measurement techniques have been developed over the years, to determine the temperature distribution of the tool chip interface, rake face, cutting tool, workpiece, chip surface, etc.(**Grzesik, 2006)**. The methods commonly adopted by the researchers are the metallographic method, i.e., micro hardness and microstructure analysis, embedded and tool chip thermocouples, thermal radiation, thermo sensitive paints, powders of constant melting point **(Chung, 2007)**, thermocouple techniques. Thermocouple-insert techniques**, (Herchang et al, 1998)**, hybrid technique and heat source methods. etc. **(Shijun et al, 2008)**.

However, direct measurements of temperatures at the tool–chip–workpiece interfaces are very difficult due to the cutting movement and the small contact areas involved **(Carvalhho et al, 2005)**. Due to these experimental difficulties many analytical and numerical methods solution have been employed to predict machining temperature the moving heat source method, the image sources method, the finite difference method, the semi-analytical methods and the finite element method.

A review of the most common experimental techniques for temperature measurement in metal cutting processes reveals that these techniques can be classified as: direct conduction, indirect radiation, and metallographic. **(Haci et al, 2005)** measured the cutting forces and averaged tool tip temperature in turning AISI 1040 steel hardened at HRc 40. The effects of feed rates and cutting tool geometry, approaching angles and rake angles on cutting forces were evaluated. During the tests, the depth of cut and cutting speed were kept constant and each test was conducted with a sharp uncoated tool insert. The cutting force components and temperature variations on tool face (in secondary shear zone) were determined. In this way, the essential information about the validity of selected values was obtained. It was found that the average deviation between calculated and the measured temperature was 42% for the same experiments. **(Abhang et al, 2010)** studied average chip-tool interface temperatures experimentally using the tool work thermocouple technique. Based on the parametric study, a first-order and second -order empirical models of the chip-tool interface temperatures has been developed for turning of EN-31 steel alloy with tungsten carbide tools. The results are analyzed statistically and graphically. The metal cutting parameters considered are cutting speed, feed rate, depth of cut and tool nose radius. The results show that when cutting speed increases from 39m/min to 189m/min the increase in temperature in cutting zone of 174%. As the feed rate increases from 0.06mm/rev to 0.15mm/rev, the temperature increases in 38.57%. **(Abukhshim et al, 2005 A)** have also studied the heat partition using an uncoated cemented carbide-

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cutting tool in high speed turning of AISI/SAE-4140 alloy steel. Experimental results are presented of temperature measurements on the tool rake face during orthogonal cutting at cutting speeds ranging between 200 and 1200 m/min. These measured temperatures are compared with temperature fields in the cutting tool obtained from a finite element transient thermal analysis. It is shown that the tool–chip contact area, and hence the proportion of the secondary heat source conducting into the tool, changes significantly with cutting speed; it decreases with the cutting speed in the conventional and the transition regions but increases in the HSM region approaching 65% at 1200 m/min.

(**Rech et al, 2005**) analyzed the effective heat flux transmitted into the tool during the machining operation on 27MnCr5 steel of the workpiece. The temperature is measured by the thermocouple fixed to the insert holder. The inverse heat conduction problem is solved so as to estimate the heat flux transmitted into the tool for the various tested coatings

However, direct measurements of temperatures at the tool–chip–workpiece interfaces are very difficult due to the cutting movement and the small contact areas involved and may not give any accurate estimate of the temperatures (**Abukhshim et al, 2005 B**). Due to these experimental difficulties, metal cutting researchers have developed many modeling techniques including analytical techniques slip line solutions, empirical approaches, the boundary-element method of heat conduction and finite element techniques (**Marcio et al, 1997**).

(**Pradip et al, 2005**) carried out a parametric study to investigate the effect of operating conditions on the thermal characteristics of the tool, chip and the workpiece. The heat conduction model would be used to predict the temperature distribution in the tool, chip and workpiece. The workpiece material that was considered free machining steel and the cutting tool-tip material was tungsten carbide. Additionally, the model takes into account the geometry of the work-piece/chip/tool, convective losses, and the temperature dependent thermo-physical properties of the materials. The major operating parameters that have significant effect on the heat generation and distribution temperatures are, cutting speed, feed rate and depth of cut. It can be noticed that the maximum temperature in the tool increased from 709.36 K to 1320 K as cutting speed is increased from 29.6 m/min to 155.4 m/min. A series of numerical simulations had been done by (**Hong et al, 2005**), to investigate the effect of machining parameters (cutting speed, depth of cut and tool-tip radius) on the finish hard turning of AISI H13 steel using finite element model. The results obtained from this research indicated that the maximum workpiece temperature increases from around 646 to 922.78°C, the maximum tool temperature increases from 147.6°C to 406.78°C when the cutting speed increases from 150 to 750 m/min. The maximum workpiece temperature increases from around 804.9 to 934.58°C, the maximum tool temperature increases from 352.2 to 385.28°C. When the depth of cut increased from 5 to 20 µm, the maximum workpiece temperature increased from 876.9 to 1081.98°C.

(**Jaharah et al, 2009**) have predicted 3D Finite element modeling using DEFORM software on the finish hard turning of AISI 1045 steel. The effect of cutting tool geometries on the effective stress and temperature were studied. The tool geometries studied were various rake angle (α) and clearance angle (β) in the range of -5° to 5°, and 5° to 9° for α and β respectively. The effect of various machining parameters of cutting speed (100m/min to 300m/min) and feed rate (0.15mm/rev to 0.35mm/rev) were also investigated. Nose radius (Rn) and depth of cut were kept constant at 0.4mm and 0.18mm respectively. Simulation results for negative rake angle shows minimum temperature of 605°C was obtained using rake angle of -5° and clearance angle of 5° with cutting speed of 100m/min and feed rate of 0.15mm/rev. The results show that the effective cutting temperature on the cutting edge were between 605°C and 2080°C.

Finite element analyses were performed by (**Bareggi et al, 2007**) using software DEFORM 3D. An AISI 1020 steel workpiece (1.5mm of length) was modeled and tungsten carbide (WC) using as a work-piece. In order to get the correct value of steady state temperature in the insert, a lower heat capacity value has been used. The cutting conditions using are cutting speed: 270m/min, feed: 0.06mm/rev and depth of cut: 0.5mm. And the insert configuration: rake angle = 0°, nose radius =

0.2mm, investigations indicate that there is a reduction in temperature when the high velocity air jet is applied during metal cutting.

Under severe conditions, the temperatures at tool–chip interface and around the cutting edge can be critically high, resulting in an excessive tool wear or even a premature tool failure. Therefore, it is necessary to develop an accurate cutting process simulation to identify optimum cutting conditions in terms of tool material and tool geometry in order to improve cutting process. The tool–workpiece interface region can be shown in **Fig. (1)** (**Bonnet et al, 2008**).

In the present study temperature distribution and heat flux variation in turning process studied by varying the cutting speed, feed rate, tool geometries of the rake angle and tool materials.

THEORETICAL FUNDAMENTALS

In this section, the heat conduction model is be used to predict the temperature and heat flux distribution in the tool and work piece interface (See **Fig. (2)**). The unsteady state three-dimensional heat-conduction equation, can be written as (**Molinari et al, 2005**):

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q(x,y,z,t)}{k_T} = \frac{1}{\alpha_T}\frac{\partial T}{\partial t} \tag{1a}$$

Where K_T is the thermal conductivity, T the temperature, $\partial T/\partial\eta$ the derivative of temperature, α_T the thermal diffusivity coefficient, ρ the density, C_p the heat capacity, t the time and T_∞ the medium temperature.

This equation is subjected to the following boundary conditions (**Raja, 2008**):

in the regions exposed to the environment:

$$-k_i \frac{\partial T}{\partial n} = h(T - T_\infty) \tag{1b}$$

ANALYTICAL MODEL

For the heat transfer calculations, the following assumptions are made :

i) The contact between the tool and the chip is thermally perfect. Hence a very large value of the interface heat transfer coefficient (h is used and it is fixed to 1000 kW/m^2

ii) The boundaries that are sufficiently away from the cutting zone remain at the room temperature (T_∞=20 ℃)

iii) The chip and the tool loss heat due to heat convection on the free surfaces on the work piece

iv) Heat losses due to radiation is very small and it is neglected.

At the tool–work piece interfaces:

$$-k\frac{\partial T}{\partial n} = q''(T) \tag{1c}$$

Initial condition:

$$T(x,y,z,o) = T_\infty \tag{1d}$$

Where heat flux could be calculated from (**Syed et al, 2009**).

$$q''(t) = h(T - T_\infty) \tag{2}$$

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where h is the heat transfer coefficient in W/m²/K.

CUTTING TOOLS, WORKPIECE, AND CUTTING PARAMETERS

A Lagrangian finite element code was applied to construct a thermo mechanical finite element model of the plane-strain orthogonal metal cutting with a continuous chip formation produced by plane-faced uncoated carbide tools. The work piece is modeled as thermo-elasto–plastic with material of choice AISI 1045, 1030, 1025 & 316h. The work piece is fixed in all directions, and the tool is considered to be rigid and moving towards the work piece at the cutting speed (v_c). For this model the tool materials are 15%Co, coating TiC and WC. According to the FEM model, the cutting parameters used are the feed rate (f) which is assigned to four different levels varying from 0.16 to 0.25 mm/rev. The rake angle (γ) is changed to 5,0 and -5. The cutting speed (v_c) changes from 100 m/min to 250 m/min and depth of cut (d) was kept constant at 2 mm. The shapes of tool used in this work are arranged in **Table 1**, while the temperature dependent thermo-physical properties (modulus of elasticity, thermal conductivity, and heat capacity) of the tool and work piece are given in **Tables 2** & **3** respectively (**User's manual, 2007**).

FINITE ELEMENT MODELING

In the present work, a 3D analytical simulation was performed for modeling the cutting process using Deform-3D Finite Element code. The automatic generation of the elements was not adopted since this would cause a uniform meshing and the result will not be that accurate, so the very fine mesh density is defined at the tip of the tool and at the cutting zone to obtain fine process output distributions. The work piece has a size of 4.5×2.5×0.8mm, which was initially meshed by means of 1401 iso-parametric quadrilateral elements while the tool, modeled as rigid, was meshed into 11025 elements. The deformation of the material was described by using a reliable model proposed by Oxley law. The friction modeling plays a significant role on the results such as cutting forces; temperature and tool wear in the metal cutting simulation. In the early metal cutting simulation, the simple Coulomb friction model was used to the whole contact zone with a constant friction, coefficient model (**Cenk, 2009**).

$$\tau = \mu\sigma_n \tag{3}$$

Where, τ is the frictional stress, σ_n the normal stress and μ the coefficient of friction with value of 0.5. The initial geometry and mesh are presented in **Fig. 3 (a)**, the heat transfer is allowed on the tool-work piece contact area.

RESULTS AND DISCUSSION

In this section, the heat conduction model will be used to predict the temperature and heat flux distribution in the tool and work piece interface region.

Verification Of The Constructed Model

To validate the predicted results obtained from the present constructed finite element model, the simulation results were validated by comparing them to the appropriate results provided in **Ref. (Grzesik et al, 2005)** cutting parameters in this reference are: cutting speed v_c =103.2 m/min, feed rate f =0.16 mm/rev, the work material is AISI 1045steel and depth of cut =2mm. **Figure 4** shows the comparison between the present work and previous works. **Figure 4 (b)** represent the work piece while **Figure 4 (c)** represent the tool. The percent of error in temperature measurement is about 0.88% in the work piece side and 0.63% in the tool side.

Temperature Distribution Through The Work piece And Tool Face
(a) Temperature Distribution Through The Work piece

It should be noticed, as in **Figure 5** that the maximum temperature value through the work piece progresses with the tool movement. This figure is drawn for the contact region at different times, when the tool progress on the work piece the contact region has a maximum temperature.

(b) Temperature Distribution Through The Tool Face

The temperature distribution in different nodes on the tool was shown in **Figure 6.** The maximum node temperature is obtained exactly in the middle contact between the work piece and tool. The highest temperature of the tool surface, about 470^oC, was located at a distance nearby the tool tip, this was due to high heat generation in the contact region between tool and work piece. As the node is far of the cutting edge, it has temperature lower than the nearest node.

Effect Of Cutting Conditions On Tool-Work piece Interface Temperature

The temperature in the interface would be affected by the cutting speed, the feed rate and the tool geometry. It was also depended on the physical properties of the work piece and tool materials.

(a) Effect Of Cutting Speed On Temperature Distribution

Figure 7 (a) was performed at different cutting speeds and at f=0.16mm/rev, γ =-5°, and at the same distance from the cutting edge (x=1.8643mm). It indicated from that figure at the speed of 103.2 m/min, the maximum temperature is 548^oC, while at the speed of 250 m/min maximum temperature is 720^oC. In the cutting process when high cutting speed was used maximum stresses are obtained, and these stresses are more concentrated in the tool tip which may cause plastic deformation of tool edge. High temperatures are generated in the contact area because of plastic deformation of work piece material and friction along the tool/chip interface; this induces an increase in temperature in the cutting zone. When the cutting speed increases from 103.2 m/min to 250m/min, the increase in temperature was equal to 21.9%, which indicated that the tool-work piece interface temperature is closely connected to the cutting speed.

On the other side, **Figure 7 (b)** is drawn for temperature versus time at three values of the cutting speed, it is indicated from that figure the maximum temperature is about (976^oC at interval of time=0.001093 ms) for v=200m/min, (T_{max}=759.2 ^oC at t=0.001447 ms) for v=150 m/min and (T_{max}=659 ^oC at t=0.00212 ms) for v=103.2 m/min, with increasing in the cutting speed, maximum temperature increased and the time in which high temperature occurred reduced. When high value of cutting speed used in the cutting process, this means increase the power to remove more material in a shorter time. Power consumed in metal cutting was largely converted into heat, which leads to increase the heat generation near the cutting edge of the tool, so high value of temperature obtained.

(b) Effect Of Feed Rate On Temperature Distribution And Heat Flux

The distribution of temperature and heat flux along the interface predicted for different feed rate is shown in **Figure 8**. As the feed rate increases, the section of chip increases and consequently friction increases, this lead to increase cutting forces, especially in thrust direction. It is observed that the region of high stresses in the thrust direction turns inward as the feed increases, which may result in the increase in temperatures generated, so the temperature at interface increases. As the feed rate increases from 0.16 mm/rev to 0.25mm/rev, the temperature increases in a 13.82%. The effect of feed rate on the heat flux can be shown in **Figure 8 (b),** it was clear from that figure when the feed rate increased high temperature generated due to cutting large pieces from the metal in one revolution, which transmitted as a heat flux between tool and work piece.

(c) Effect Of Tool Material On Temperature Distribution And Heat Flux

Figure 9 presented the values of temperature **Figure 9 (a)** and heat flux **Figure 9 (b)** for different tool materials. From these two figures, it is easy to understand that the TiC coating induces the lowest temperature rise and heat flux due to the fact that coating tool leading to decrease of the tool–work piece contact area, decrease of the thickness of the secondary shear zone and of the

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temperature at this interface, which lead to a decrease of the heat flux transmitted to the cutting tool, since the flux transmitted depends on the contact area and the heat created at this interface (heat flux density). The uncoated tool induces the highest heat flux in the tool (after 0.002 ms of cutting time: heat flux = 900 W), while the TiC coated tool induces the lowest heat fluxes (600W). The WC has an intermediate behavior (700 W). These results clearly show that the use of TiC-coated tools generally reduces the heat partition into the cutting tool. Lowest temperature distribution can be observed with coated TiC tool, and higher temperature distribution with 15% Co due to the lower effective thermal conductivity for TiC and highest thermal conductivity for 15% Co.

(d) Effect Of Work piece Material On Temperature Distribution And Heat Flux

Four curves have been plotted for different materials (these materials were selected because of their suitability and widely used in the model by previous researcher) as shown in **Figure 10 (a) and (b).** The temperature dependent properties should be considered when calculating the cutting temperature, so the thermal properties of the work piece such as the thermal conductivity and specific heat as functions of (T) are shown in **Table 3 (User's manual, 2007)**. From that table it was clear that the heat capacity for the four materials equal, so they behavior depending on thermal conductivity. For the same range of temperature AISI1025 and AISI1030 have the same behavior of thermal conductivity, while AISI1045 has a larger value at a lower temperature, AISI 316h has a lower thermal conductivity than other materials. Thermal conductivity of these four materials was depending on temperature and effect on the temperature distribution in the contact region, so the curves oscillated and overlap with each other depending on variation of their thermal properties.

(e) Effect Of Rake Angle On Temperature Distribution And Heat Flux

In this part of the study, effect of rake angle on the distribution of temperature in both work piece and tool was analyzed. The rake angle is one of the most important parameters, which determine the tool and work piece contact area. There is generally an optimum value for the rake angle, increasing of the rake angle over its optimum value has a negative effect on the tool performance and accelerates the tool wear. In this analysis, three different rake angles (-5º,0º, 5º) are used . The effect of different rake angles on temperature distribution was shown in **Figure 12.** Maximum temperature is reaches to 656 ^{o}C, 605 ^{o}C and 593 ^{o}C when rake angle is equal to -5º, 0º and 5º respectively. It can be noticed with a reduction in the rake angle, promotes a longer contact length and hence a larger contact area with more heat conducting into the tool, therefore high heat will be generated, so the temperature increases when the negative rake angle is used. On the other side by increasing the positive rake angle (higher shear angle produces), the cutting forces were decreased; the reason is that the tool can plunge into the work piece easily. In this study for the same time of simulation (t=0.0015 ms), the temperature increase by 12.3% when rake angle reduce from +5° to -5°.

(f) Effect Of Tool Shape On Temperature Distribution And Heat Flux

Geometry is found to affect local steady-state temperatures in the cutting tool. The tool geometry is designed to cut various work piece metals by forming chips in a smooth way, while also providing a strong cutting edge. Many index able inserts have combinations of chip breaking functions to cope with light cuts at the corner and larger depths of cut along the cutting edge. At one end, insert geometry for finishing will have an area comprising smaller feeds and depths while at the other end, a rough-turning geometry will have a large feed and depth values. The finishing insert uses the geometry at the corner of the insert while the roughing one uses a relatively long part of the main cutting edge. The tool shape details are arranged in **Table 2 (User's manual, 2007),** these tools have the same noise radius and height, the different between these tools is the shape. The effect of the shape of tool on temperature and heat flux behavior drawn in **Figure 13,** at the beginning of cutting process TNMA has the largest value of temperature than the other shapes, when cutting process progress VNMA has the large value of temperature and TNMA has the lowest value. At the ending of cutting TNMA has the large value of maximum temperature than the other shapes of tool,

It was clear that these curves are overlap with one another in such a way that depending on the contact area in the time of cutting, and on the approaching angle forming between tool and work piece.

CONCLUSIONS

This paper presents approaches for modeling the prediction of the temperature distribution and heat flux at the interface with the commercial package DEFORM 3D. A parametric study was carried out to predict quantitatively the temperature level and heat flux at the interface with cutting speed, feed rate, rake angle, tool geometry, tool material and work piece materials. The main conclusions, deduced from the present work, can be summarized as follows:

1. The maximum temperature value through the work piece progresses with the tool movement, maximum value of temperature obtained at the contact region between the tool and work piece during the cutting process.

2. Interface temperature is closely connected to cutting speed. With increase of cutting speed, an increase occurs in the interface temperature. When the cutting speed increases from 103.2 m/min to 250m/min, the increase in temperature was equal to 21.9%

3. Interface temperature also increased with the feed rate, as the feed rate increased from 0.16 mm/rev to 0.25mm/rev, the temperature increased in a 13.82%.

However, the cutting speed appeared to have more pronounced effect on the cutting temperatures than the feed rate.

4. Rake angle have a considerable effect on cutting temperature on the interface. The temperature increased by 12.3% when rake angle reduce from $+5^o$ to -5°.

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User's manual of DEFORM-3D version 6.1. 2007. 18th Oct.

Table 1 Tool different shape using (**User's manual, 2007**).

Name	shape	properties
CNMA 432		IC = 1/2, T = 3/16, R = 1/32 B = 0.1216, H = 0.203
TNMA 332		IC = 1/2, T = 3/16, R = 1/32 B = 0.7188, H = 0.203
VNMA 332		IC = 1/2, T = 3/16, R = 1/32 B = 0.5087, H = 0.203
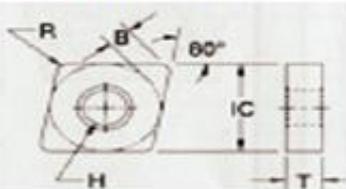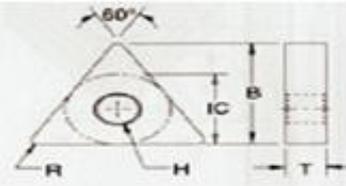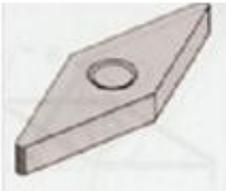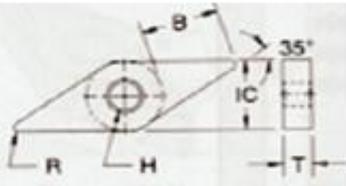
Table 2 Mechanical and thermal properties of the tool (**User's manual, 2007**).

Material	15% Co	TiC	WC
Thermal expansion	6.3×10^{-6}	7.7×10^{-6}	5×10^{-6}
Young's Modulus GPa	524.2	650.3	496
Thermal conductivity W/mK	82.24	38	59.98
Heat capacity	5.7945	16	15.0018

Table 3 Thermal properties of work piece materials (**User's manual, 2007**).

Material	Young's Modulus GPa	Thermal conductivity W/mK	Heat capacity J/kgK
AISI 1045	$Y=-0.02\times T^2-65.3\times T+2122646$	$K=7\times10^{-6}\times T^2-0.0184\times T+44.57$	$Cp=75.62\times T^2-332.27\times T+238$
AISI 1030	Same as AISI 1045	$K=8\times10^{-6}\times T^2-0.0369\times T+53.7$	$Cp=15.2\times T^2-101\times T+477.25$
AISI 1025	Same as AISI 1045	$K=8\times10^{-6}\times T^2-0.036\times T+53.7$	Same as AISI 1030
AISI 316h	$Y=-0.037\times T^2-79\times T+212334$	$K=-3\times10^{-5}\times T^2+0.029\times T+14.36$	Same as AISI 1030
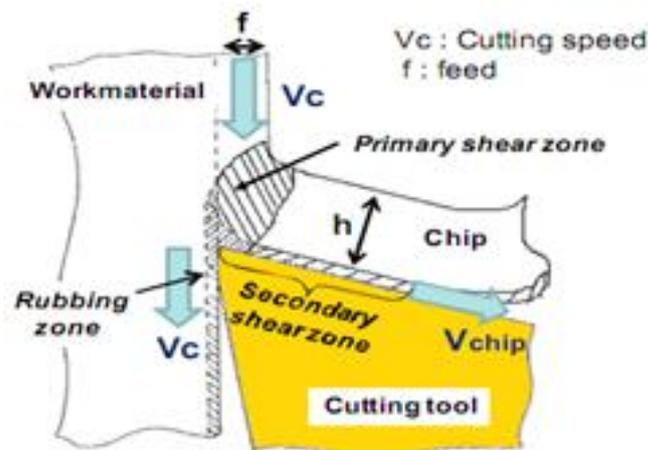
Figure 1 Heat sources during cutting (**Bonnet et al, 2008**)
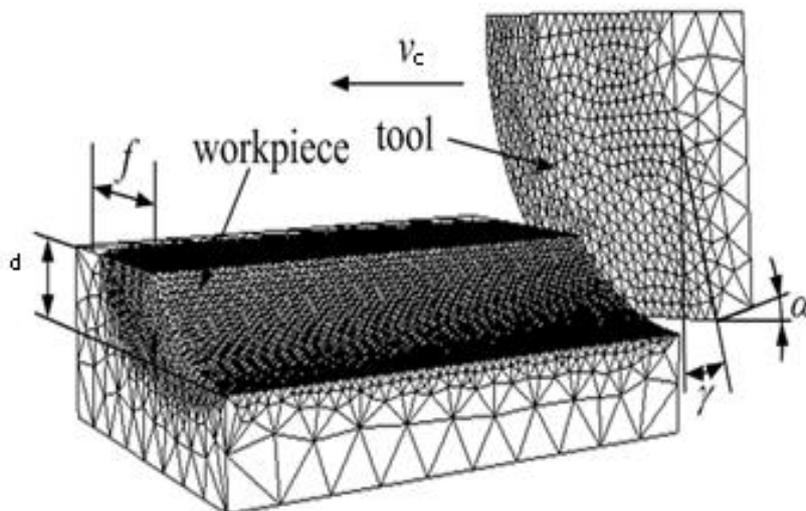
Figure 2 Simulation model of the turning process used
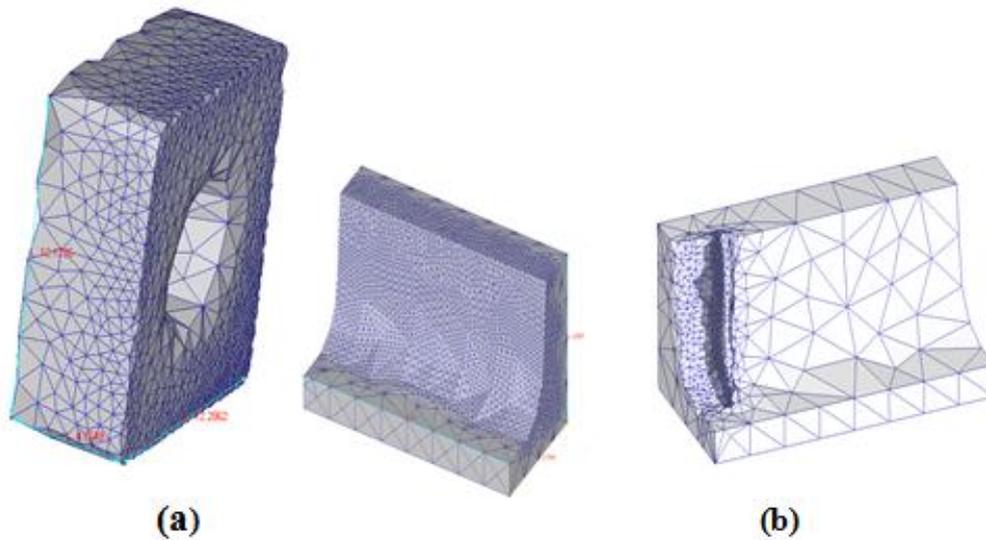
Figure 3 The unreformed mesh of both the tool and the work piece.
a) before the simulation. b) after deformation.
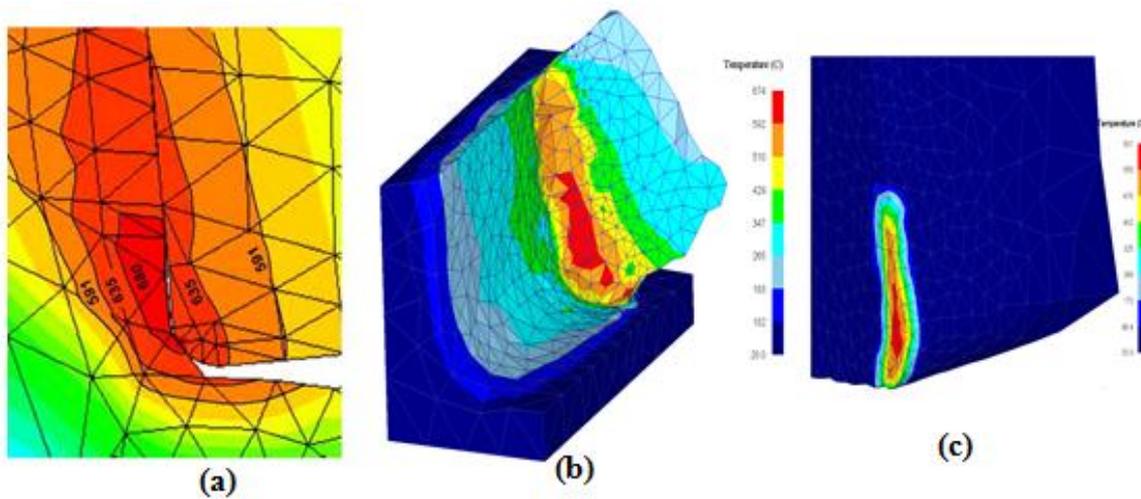
Figure 4 Comparison between computed values of the interface temperature
and (**Grzesik et al, 2005**) (b) Work piece (c) the tool.

t =0.0011ms   t =0.00165ms   t=0.0022ms
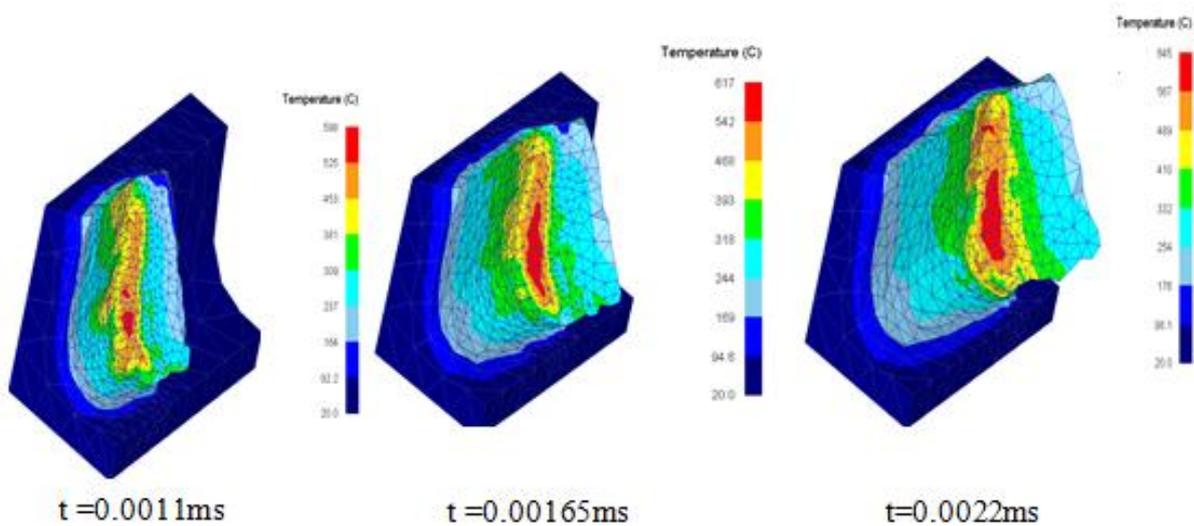
Figure 5 Maximum temperature with the tool progress.

(a)   (b)
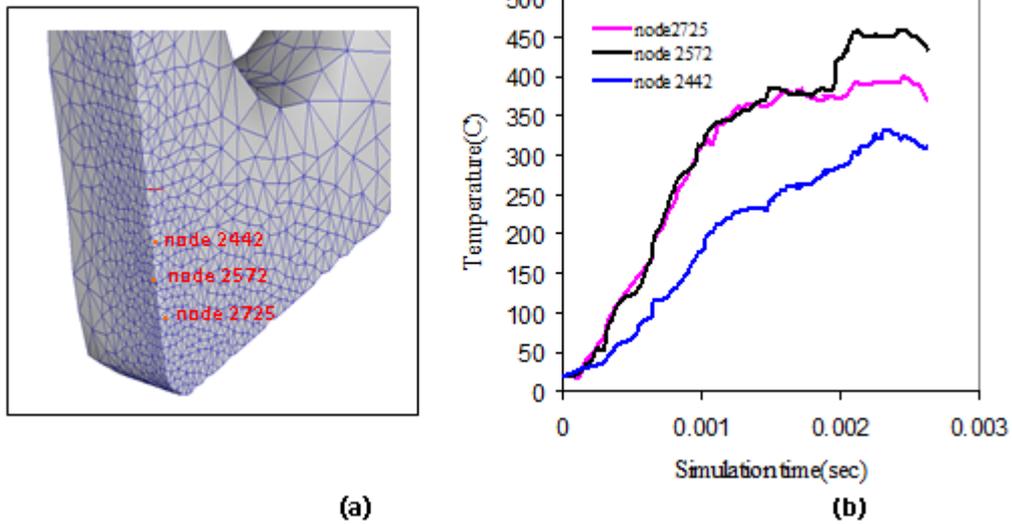
Figure 6 Temperature history of tool nodes.(a) Position of nodes on tool face.
(b) Temperature history of tool face nodes.
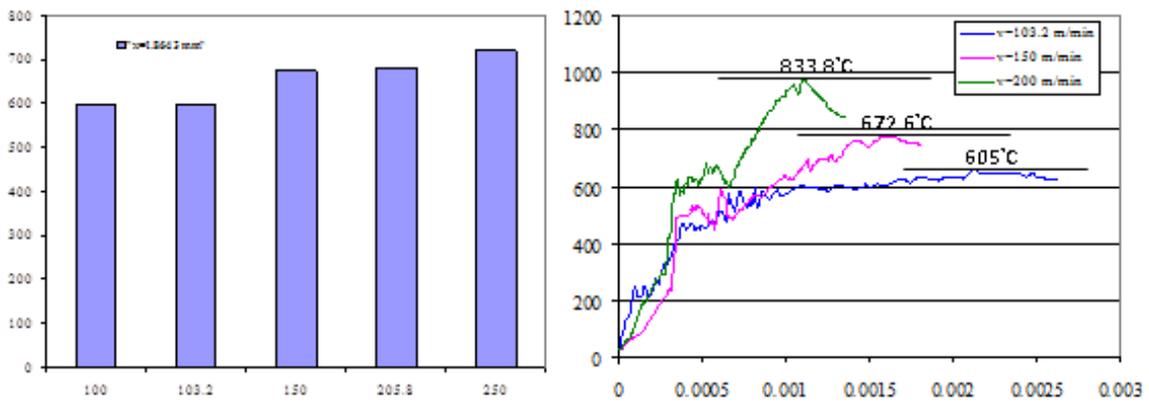
Figure 7 (a) Temperature vs. cutting speed at same distance from the cutting edge at f=0.16mm/rev, γ =-5°.

Figure 7 (b) Temperature vs. time at different cutting speed

(a)   (b)
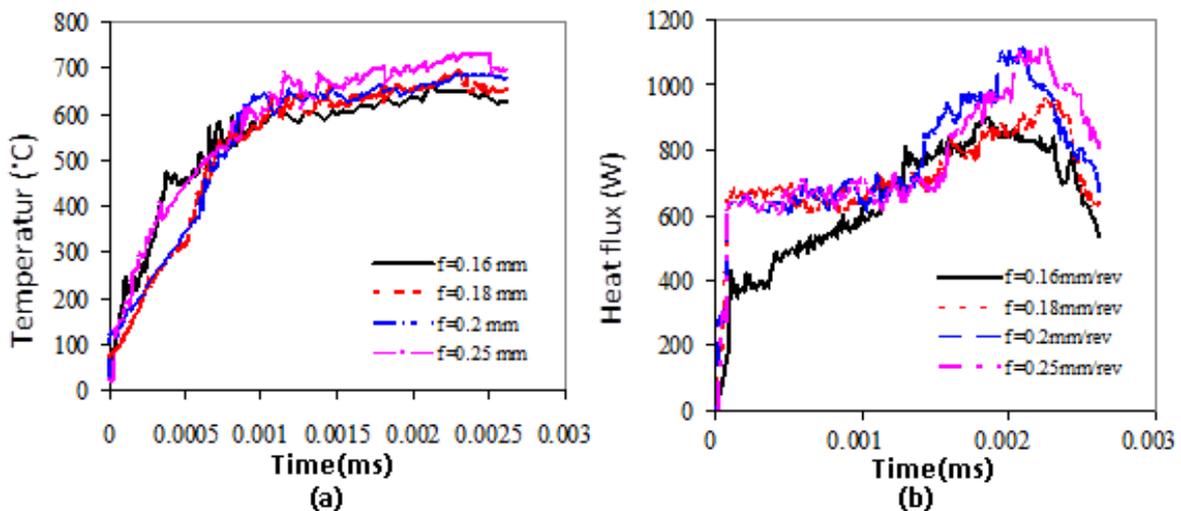
Figure 8 Effect of feed rate on (a) temperature distribution, (b) heat flux
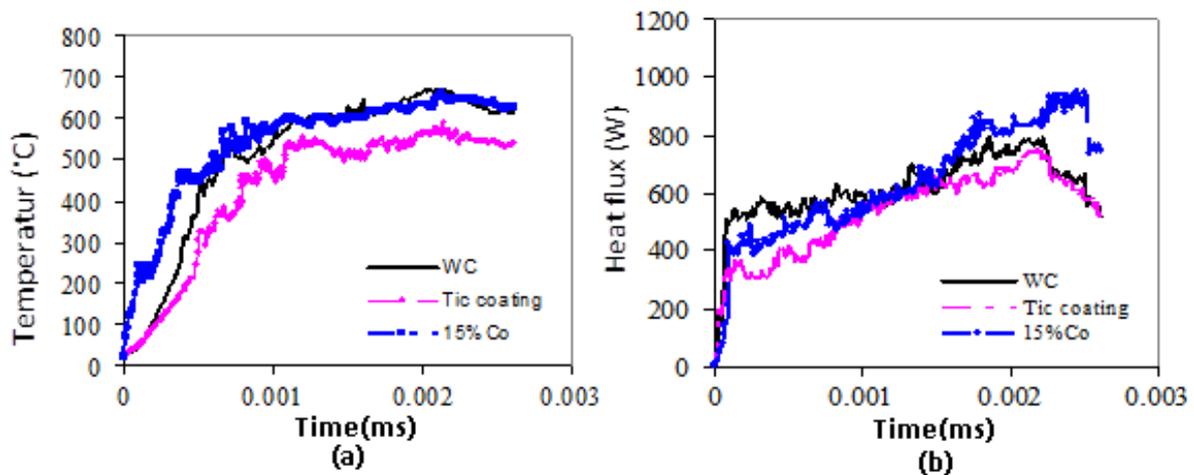
Figure 9 Effect of tool material on (a) temperature, (b) heat flux
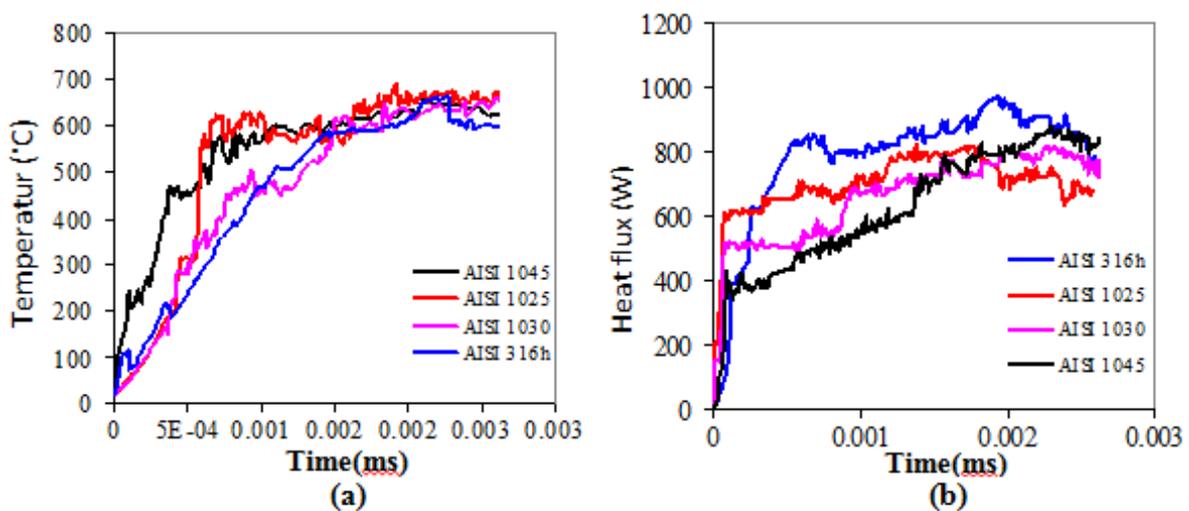
Figure 10 Effect of work piece material on (a) temperature, (b) heat flux
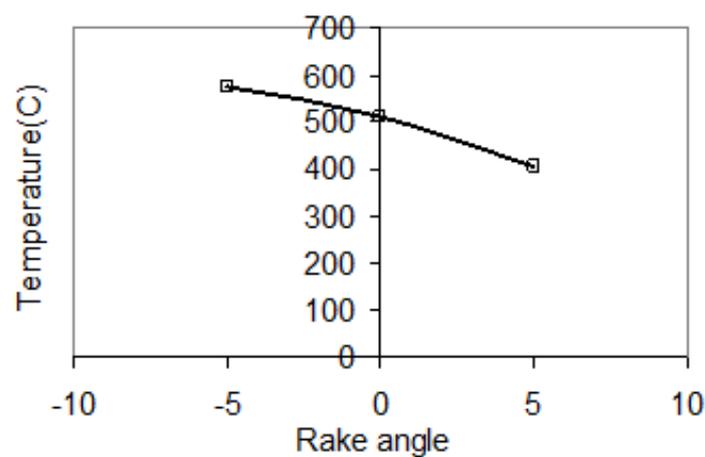
Figure 11 Effect of rake angle on temperature.
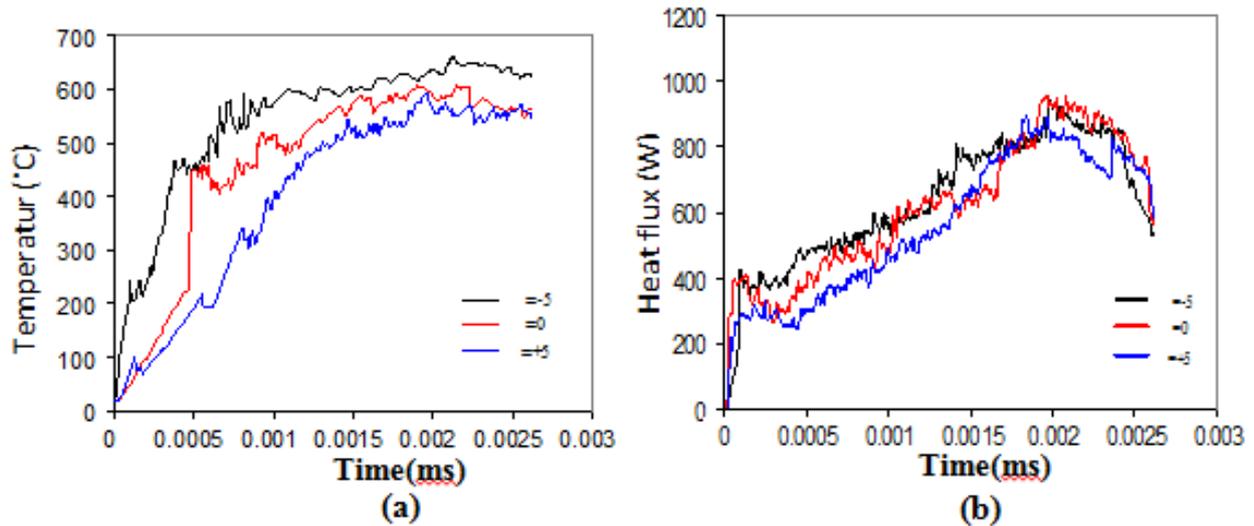
Figure 12 Effect of rake angle on (a) temperature, (b) heat flux.
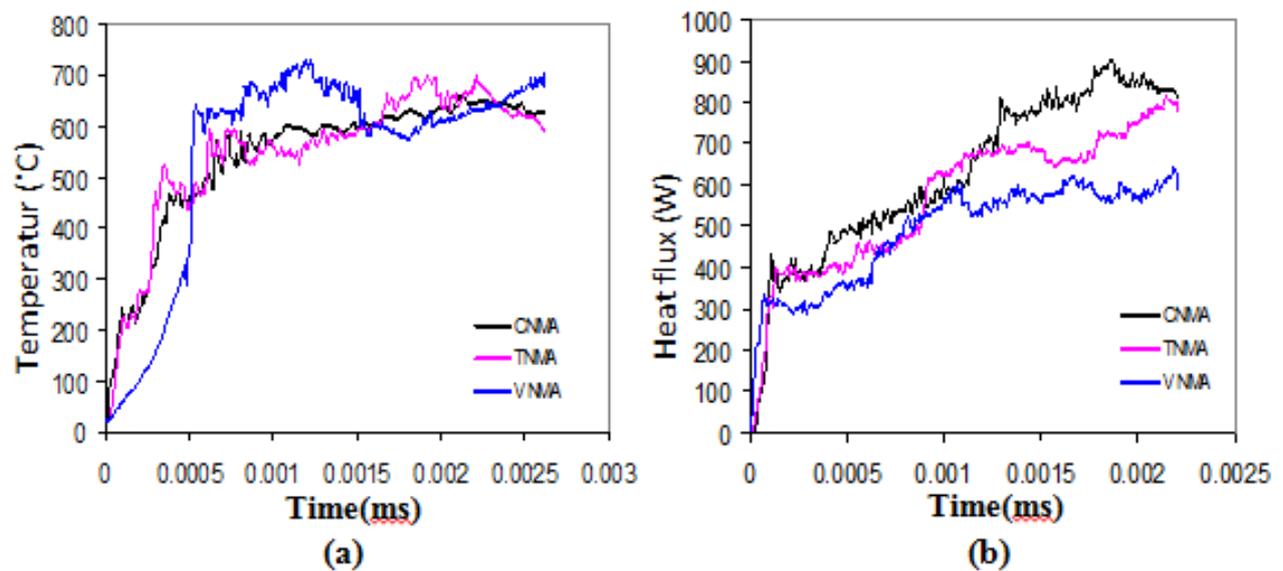
Figure 13 Effect of tool shape on (a) temperature, (b) heat flux.