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The effect of tool coating and cutting conditions on tool Temperature

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Abstract: A good prediction of the temperature in the cutting tool for machining facilitate the optimization of cutting condition to achieve long tool life and low production cost. This paper presents a comprehension between a numerical models Finite element method, software (DEFORM 2D) and experimental work carried out using infrared imager camera model (FLUK Ti:32) had been used in orthogonal cutting processes performed by means of uncoated and coated carbide tools. The thermal experiments are conducted with low carbon steel (AISI 1010), using different cutting tools, cutting speeds and feed rates. The results show that the tool temperature distribution rises with increasing of cutting speeds and feed rates. In particular, it was observed that by the proper selection of the thermal properties of the coating and the workpiece materials, which result in a substantial increase in the interface temperature, the effect of a thermal barrier in the top layer of the coating can occur.

Keywords: Turning process, Temperature measurement, Infrared, FEM (Deform-2D).

I. Introduction

Machining is widely used to produce metal parts and components in industry. To be able to produce at lowest cost the metal cutting tools needs to be run at their optimal performance. The cutting data used for the tools therefore needs to be adjusted for high production rate and long tool life. Since tool wear is greatly affected by the temperature at the interface between insert cutting edge and the chips being cut from the work piece see Figure 1, it is important to be able to predict insert edge temperature. With good prediction of the temperature, cutting data may be optimized prior to the machining assuring high productivity from the beginning in machining new part and components [1]. During a metal cutting operation, high temperatures are generated because of plastic deformation of workpiece material and friction along the tool/chip interface. Determination of the temperature effect in tool, chip and workpiece is important for process efficiency because the temperatures have a great influence on the rate of tool wear, tool life strength of the workpiece material, mechanics of chip formation and cutting forces. There are two important areas where heat is generated in the contact zone. These zones are the primary and secondary deformation zones. The primary deformation zone generates heat from plastic deformation and softening of the tool material which is caused by high temperatures. This is the zone created by chip formation. The secondary zone generates heat due to frictional sliding and the amount of work done to produce chip deformation [2]. The heat distribution in both zones is due to the depth of cut, feed rates, and cutting speed which is the motion setting on the lathe that determines the rotational speed of the workpiece [3]. One of the most extensively used experimental techniques to measure the temperature in machining is the use of thermocouples. In addition to thermocouples, the infrared (IR) radiation techniques are probably the second most used method for the temperature measurement in machining. In the last two decades, FEM has been most frequently used in metal cutting analysis. Dewes [4] used Agema Thermovision 900 for temperature measurement in high-speed machining of hardened die steel (SAE H13). M'Saoubi and handrasekaran [5] used an infrared charge coupled device (IR-CCD) camera to determine the temperature distribution at the cutting edge of the tool. The camera had 510 x 492 pixel array. AFNOR 32CDV12 steel was machined with a cermet tool for cutting speeds ranging from 100 m/min to 400 m/min and for feeds ranging from 0.15 mm/rev to 0.3 mm/rev. The results show that the maximum temperature point is located on the rake face [4].

II. Cutting conditions

Different cutting conditions were used in the cutting tests. Five different cutting speeds (70, 114 and 188 m/min.), five different feed rates (0.03, 0.1 and 0.2 mm/rev.) and three different cutting tools were tested including: uncoated, (TiN coated), (TiN/Al₂O₃/TiCN) coated (TiCN in the inside layer, Al₂O₃ in the middle layer and TiN on the outside layer). All the inserts had rake angle of (5°) and clearance angle of (5°) and are

suitable for machining different kinds of steels at high speeds and high feed rates. All the inserts had identical geometry designated by International Organization for Standardization (ISO) as SNMM 120412,[5].

III. Experimental Setup and Measurements

In order to validate the tool temperature prediction model in the orthogonal machining process, the temperatures measurement were made with an infrared thermal imaging camera. The specific temperatures measurement device used was IR camera [Models: Fluke Ti32] Fig (1)



Fig (1) : thermal imagers (Fluke Ti32)

The IR camera is focused on this region; starting from the tool tip. The workpiece was carefully integrated into the tool holder on the spindle. Workpiece is rotated and fed into the stationary tool attached to the dynamometer. The thin tube workpiece, the dynamometer, and the cutting insert are placed in order to perform orthogonal cutting tests. The IR camera is focused on this region; starting from the tool tip. The area that is focused in the thermal experiments can be seen in Fig. 2.

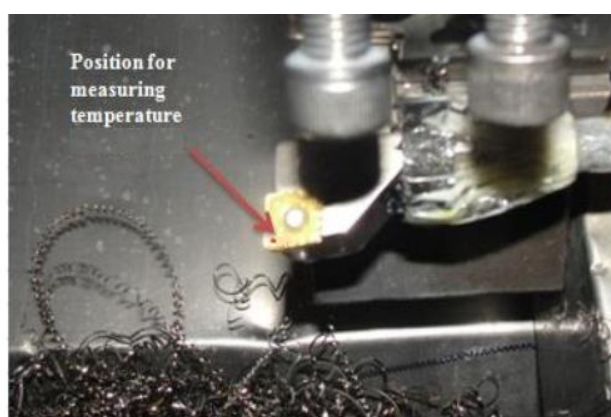


Fig (2) position of measuring temperature

The tool measured temperature distribution with infrared camera and the contour plot that obtained by transferring the thermal image from FLIR Quick Report to special software program (SmartView 3.1) as shown in figure 3.

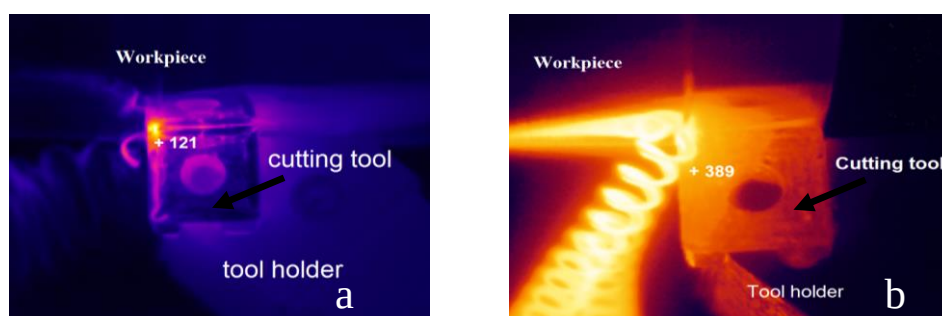


Fig. (3): The IR image obtained in orthogonal cutting (a) (TiC/ Al₂O₃/TiN) carbide insert (b) Uncoated inserts

IV. Finite element Simulations Experiments

In this study, the Finite Element Method software DEFORM-2D, which is based on Lagrangian formulation that employs implicit integration method designed for large deformation simulations with adaptive remeshing, is used to simulate the metal cutting process. The Finite Element model is composed of a deformable workpiece and a rigid tool which discretized by bilinear four-node quadratic. The tool penetrates through the workpiece at a constant depth of cut and variable cutting speeds and feed rates, and the finite element mesh is linked to the workpiece and follows its deformation. The chip is formed by continuous layer meshing the workpiece. The initial arrangement of both the workpiece and the tool in the simulation model is shown in Fig. 4[6]. The upper part of mesh, which constitutes of the removed workpiece material, is finer, to enable the stress, strain, strain rate and temperature in the chip and the tool tip regime to be accurately predicted [5].

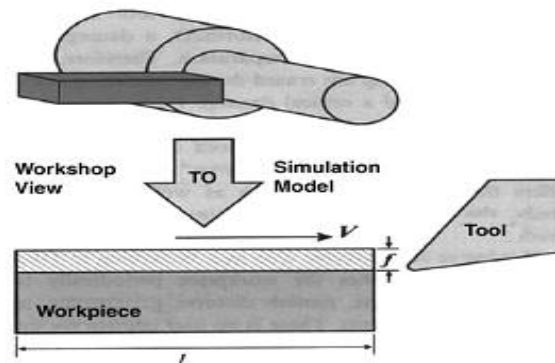


Fig. (4). Simulation model of the turning process

The temperature distribution in the workpiece, tool and chip is shown in Fig.5. In order to compare the differences in the isotherm images for uncoated and coated tools this figure illustrates the magnified temperature distribution in the vicinity of the cutting edge[7].

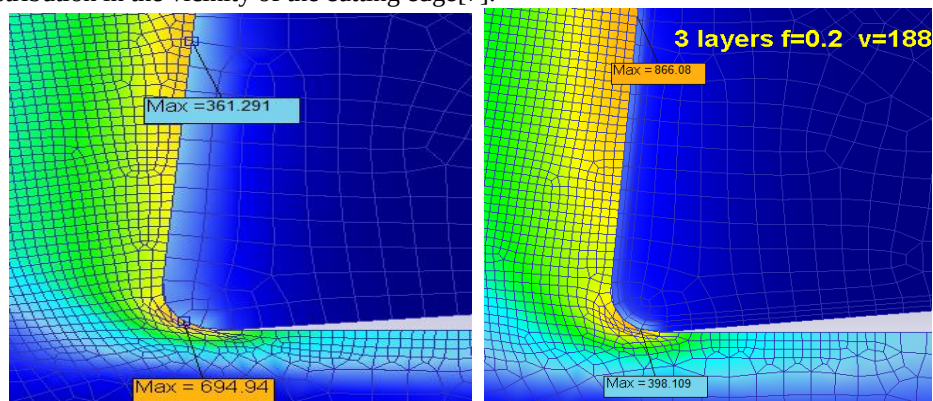


Fig. (5) Contour plots of the temperature rise in the vicinity edge

V. Results and discussion

For the criterion of the maximum tool rake face temperature, the results of every experiment are analyzed separately as shown in Fig 4, and the results are given in Fig.6. Considering the test conditions for the orthogonal cutting of AISI 1010, it is found that for all tested cutting conditions, the predicted cutting temperature shows a similar trend as the measured temperature when it is analyzed. Also it is found that the predicted and measured maximum tool rake face temperatures are located near to the tool tip but not on the tool tip.

It can be observed that as the feed rate increases, cutting temperature rises. The tool temperature will increase due to the increasing in cutting forces where the amount of heat generated during turning increases directly with the cutting forces according to André Stefenon and Harinath Gowd. The cutting forces increase as feed rate increase due to increasing in the shear plane area as Awadhesh Pal said. In addition, an increase in the area of contact between tool and chip yield from increasing feed rate and depth of cut that lead to a higher frictional energy.

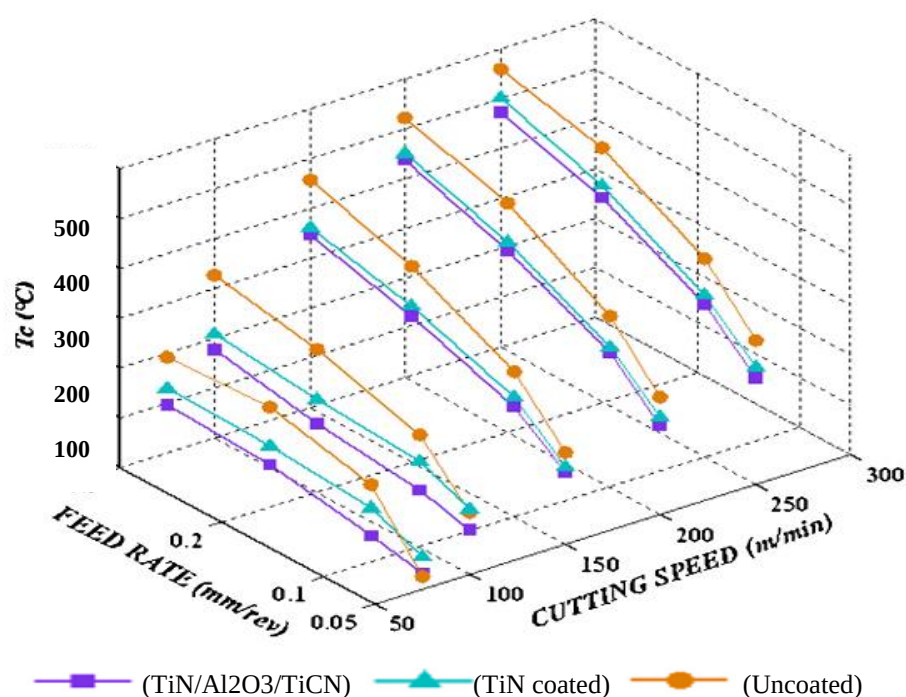


Fig. (6) increasing of tool temperature with increasing of cutting speeds and feed rates.

The same with increasing the cutting speed, the strain rate increases, an increase in the strain rate results in a higher temperature. Increasing in spindle speed causes increasing in tool temperature and this can be explained as following, the total energy in cutting process can be partitioned into shear energy, friction energy, kinetic energy and surface energy. Both the kinetic energy and surface energy represent a small amount and they are usually neglected except kinetic energy that is take into consideration. The friction energy represent the energy dissipated in sliding the chips on the tool face and as a result, heat will generates due to friction action, this energy is sensitive to the velocity of chips as it flows over the tool. So when spindle speed increases, the cutting speed increases which cause increasing in the shear and chip velocities so the shear and friction energies that will be dissipated in the form of heat will increase and as sequences the tool temperature will increase.

As seen in previous figure ,cutting temperature obtained for the coated cutting tools is higher compared to uncoated tools. all coatings applied caused that the fraction of heat which flows into the tool decreases. On the other hand, it can be observed that more heat is transferred to the chip and workpiece. This effect is especially visible for the three layers (TiN/Al2O3/TiCN) coating, Also the substrate of cutting tool is cooler in comparison to uncoated tools and other tools coated with (TiN) coating .This effect can be explained in terms of differences in the thermal properties of the coating components. The thermal conductivity of (Al2O3) layer in the (TiN/Al2O3/TiCN) coating decreases distinctly and it is apparent that at higher contact temperatures , the carbide substrate is partly thermally insulated by the coating because of the thermal conductivity of coatings especially(Al2O3) layer ,which results in an increase in heat flow to the chip and workpiece due to its thermal conductivity properties. As a result, heat flow into the substrate is more difficult than other types of tools. The minimum temperature developed in the cutting tool during machining was found to be (121.5 °C) for the three layers (TiN/Al2O3/TiCN) insert.

For cutting Tools(TiN) show quite tool temperature close to each other through all cutting condition and that behavior can be explained by the main property of (TiN) coatings which play an important role of hardness and wear resistance of cutting tools and less effect of heat resistance . Also can be noticed from previous figures a low decrease in tool temperature through smaller cutting speed and feed rate rather than larger values in all types of cutting tools ,that can be explained by the small sensitivity of the tools to the small amounts of cutting speeds and feed rates .

From previous figure it is observed that cutting speed has a superior effect on the temperature , that with an increase in the cutting speed a higher amount of heat is absorbed by the chip and lesser amount is transferred to the tool and the work piece.

VI. Comparison between Experimental and Numerical Results:

The comparison between measured and predicted values of the tools temperature, Maximum discrepancies can be observed for both (TiN) and (TiN/ Al2O3/ TiCN) coated tools and they are equal to (13 and 11%) ,respectively and for uncoated tools it was less than (5%) as shown in fig 7.

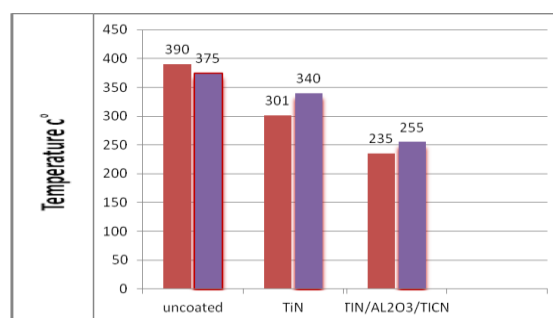


Figure (7) Comparison between measured and computed values of the average interface temperature.

VII. Conclusions

The following specific conclusions can be drawn from the experimental and numerical experiments conducted:

- 1- An increase in cutting speed and feed rate resulted in increasing cutting temperature and tool temperature.
- 2- It is observed that cutting temperature obtained for the coated cutting tools is higher compared to uncoated tools especially visible for the three layers (TiC/Al₂O₃/TiN) coating and the substrate is cooler in comparison to uncoated tools and other tools coated with (TiC and TiC/TiN) layers. This is because of the thermal conductivity of coatings especially (Al₂O₃) layer, which results in an increase in heat flow to the chip and workpiece due to its thermal conductivity properties. Therefore, it can be said that the lower thermal conductivity results in decrease tool-chip contact length.
- 3- The selection of a workpiece material with low thermal conductivity and low heat capacity and a coating material of tool with low thermal conductivity leads to a reduction in the contact length, resulting in the effect of a thermal barrier. As a consequence, heat is concentrated within the thin top layer of the coating to protect the tool against diffusion.
- 4- the finite element model gives reasonable results with experimental results, so the finite element model and material model can be used to predict tool temperature in coating inserts. The maximum relative difference between simulated and measured values is less than (11%)
- 5- Modeling and numerical simulation can provide a fast, economical and very effective to reproduce the cutting phenomena and estimate the quantities characterizing the thermomechanical processing of materials (temperature, efforts, stress, strain, etc.).
- 6- The Infrared imaging is found convenient when determining temperature in the cutting zone due to its fast response and its ability to have no effects on temperature during the cutting process. This so because there is no physical contact.

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