Monitoring of Coated and Uncoated Cutting Edge Performance using Infrared Thermography of Chip Temperature

M. S. Alajmi and S. E. Oraby

***Abstract*—**The need is recently justified for new machining inprocess techniques to monitor and/or control machining systems. Recently, cutting temperature assessment using infrared thermography is gaining wide technical acceptance due to the introduction of digital thermal cameras. An infrared thermal camera is mounted on a turning lathe carriage to record the cutting temperatures as cutting speed and feed vary using both coated and uncoated carbide inserts. Also, temperatures gradient, along with SEM micrographs, are analyzed for possible correlation with both regular and irregular cutting edge deformation. While cutting speed proved not to be influential parameter on the depicted temperatures, feed increase tends to lower cutting temperatures. Generally, it is observed that lower heat and temperatures are generated when coated inserts are employed. It is found that cutting temperatures are gradually increased as edge wear and deformation developed.

***Keywords*—**Infrared thermography, cutting temperatures, coated and uncoated carbides, cutting parameters, tool edge wear and deformation.

I. Introduction

CUTTING edge in machining usually deforms in irregular forms [1] with complicated configuration [2] and, this limits the applicability and visibility of most theories and hypothesis offered by the huge available relevant published literature. In recent unmanned machining techniques, such as adaptive control AC system [3], in-process tool performance is monitored and/or controlled according to change in the process variables. Some of the process responses, such as cutting forces [1] and, low-frequency vibration and high-frequency acoustic emission and vibration are also frequently introduced. The selected implemented system should be of design simplicity, sensitivity, and economic visibility. Monitoring cutting temperature in machining using a non-contact infrared thermography [4-7] can produce a promising contribution. it is claimed by Makarow [8] that cutting temperature is the most suitable parameter to correlate the tribological conditions at the tool-work-chip interfaces with tool wear. This indicates the importance to establish a correlation of temperature with parameters of the cutting system that govern the progress of edge wear and deformation.

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The cutting temperature is understood as the mean integral temperature at the tool–chip and tool–workpiece interfaces as measured by a tool-work thermocouple [9]. As indicated by most relevant investigations, temperatures in metal cutting affect both the shear properties of the work material and, cutting edge. Therefore, from one side, they affect the chip-forming process, and on the other hand, they determine the limits of the process and mode of tool wear and deformation. Each of these two topics has been covered by numerous published literatures, for instance [10-13]. According to Astakhov [9], in addition to the inherent contradicted results due to different experimental methodologies and accuracy of calibration, the practical significance and visibility of most the developed numerical and analytical models and their assumptions are still in doubt.

Trent and Wright [12] explained that the cutting forces or power consumptions were not affected by the temperature near the cutting vicinity. Zorev [10] also found that found that the maximum temperature at the end of the chip formation zone was not high enough to cause a considerable reduction in the mechanical properties of plain and alloyed steel. Moreover, Altintas [14] claimed that cutting temperatures could not be considered as a significant factor not only in the cutting mechanics but also in his consideration of dynamic stability and structural errors of the machining system.

According to Shaw [11], the shear plane temperature influences the flow shear stress of the work material and also has a major influence on the temperature of the tool-chip-workpiece interfaces which usually governs the rate of crater and flank wear. Oxley [15] indicated that temperature rise in the deformation zone could possibly affect the mechanical properties of the work material in terms of reduction of the flow shear stress.

Cutting temperatures can be assessed analytically, numerically or, experimentally. Numerical or, analytical methods to assess cutting temperature involve the modeling of heat distribution through tool-chip-workpiece interface regions [16-18] and, numerical FEA and boundary elements [19-20]. Experimental techniques to measure temperatures in metal cutting can be divided into: contact and non-contact methods. Contact temperature measurement involves the use of the well known thermocouples including embedded, running and tool–work. In the embedded method [21], the thermocouple is placed in a small hole made in the cutting tool. In addition to the required wiring and instrumentation, this involves some drawbacks such as the required structural modification of the cutting tool as well as its inability to directly assess temperature values at tool-chip and tool-work interfaces and, therefore, it is difficult to determine the average integral temperature accurately. A wireless monitoring of the temperature using embedded thermocouple is recently proposed [22]. Running thermocouples are used to measure temperatures through the tool-chip deformation zone as insulated constantan tiny wires are embedded in holes of different depths in the layer to be removed by the tool. As this approaches the deformation zone, thermocouples are formed as wires are plastically deformed. Although this method gives an accurate distribution of cutting temperature, its complicated design and experimental manipulation usually limits its practical applications.

In the tool–work thermocouple [15], the average integral temperature at the tool–chip and tool–workpiece interfaces can be obtained as a result of the fact that the tool and work materials are normally different. Inherent problems are the required insulation of the tool and the workpiece from the fixtures and other parts of the machine tool in addition to the proper calibration of the system.

Cutting temperature can be in-process assessed, measured, monitored, and/or controlled by using the emerging promising non-contact infrared thermography techniques [4-7]. Major advantages of such a technique are that it does not interfere with the cutting process and does not affect the design and construction of any of the original system elements.

Infrared cameras are the most suitable for the determination of the temperature distribution in the deformation zone [23].

It is important to mention in the current respect that this approach can only be applied to determine the maximum temperature of surface and chip which does not represent either the cutting heat gradient or the total average cutting temperature. This presents a qualitative strategy to monitor a continuous running of the fixed setting process. Also, among requirements for the accurate implementation of the technique are the available knowledge about surface emissivity (wavelength and bandwidth) [24-25] and, calibration procedures [26].

II. Experimental Setup And Procedures

Several experiments, Table I, are carried out to investigate the effect of process variables (speed, feed and edge deformation), along with type of tool materials, on the cutting temperature and heat generated during three-dimensional rough turning operation at constant depth of cut of 1.5 mm. SPUN 12 03 12 Sandvick coated and uncoated carbide inserts are employed to cut AISI 4140 alloy steel bars of about 100 mm diameter and length 410 mm length, Fig. 1.

Inorder to obtain a fixed spatial resolution during temperature measurements, an infrared thermal FLIR camera with IMMATION software and control system is mounted on the machine carriage to follow the longitudinal feed motion of the cutting tool, Fig. 1. Using a special designed structural support, the location of the camera is adjusted to measure temperatures around the zone of tool tip in both the axial (underside chip surface) and the circumferential rotational (chip topside), Fig. 1.b. The operating parameters and setting of the camera are set and controlled by the control unit. Temperatures are continuously measured and are simultaneously recorded in mpg video format for further analysis using a DVD player, Fig. 1.a.

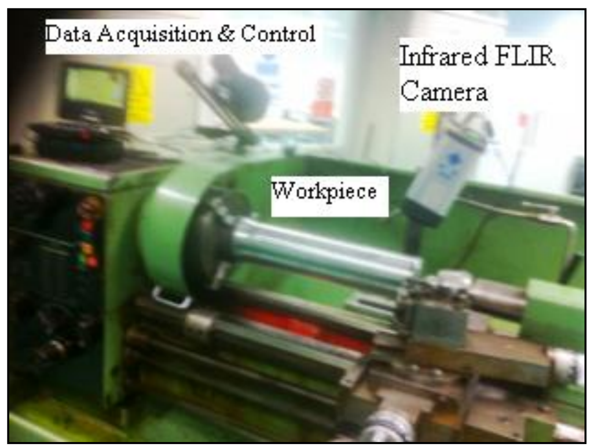
Cutting continues until the edge is failed catastrophically (thermal softening or plastic deformation) or by breakage. Deformed inserts are examined using JOEL JSM 5700 CarryScope scanning electron microscope SEM equipped with SmileShot TM software and control. Micrographs are obtained for edge topography at flank, nose, side flank, and crater regions.

TABLE I
EXPERIMENTS AND PARAMETERS OF COATED AND UNCOATED INSERTS

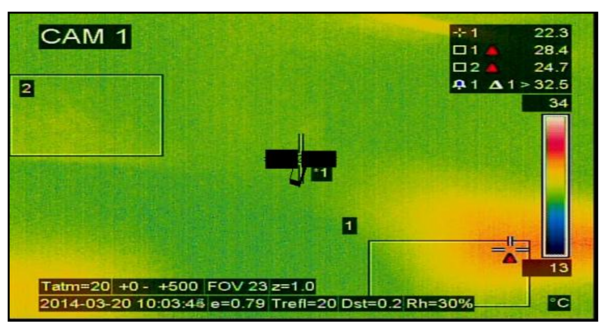
Test#	Cutting Parameters Speed (V) m/min	Feed (f) mm/rev	DOC (d) mm	Diam. (mm)	N (rpm)
T1	115	0.32	1.5	100	360
T2	115	0.18	1.5	100	360
T3	75	0.32	1.5	100	250
T4	75	0.18	1.5	100	250

III. Results, Analysis And Evaluation

For each experiment, the recorded video is analyzed offline and the values of cutting temperature C^o are extracted at regular intervals of five seconds. Figure 2 shows the levels of cutting temperature for experiments listed in Table I.



a) Entire setup

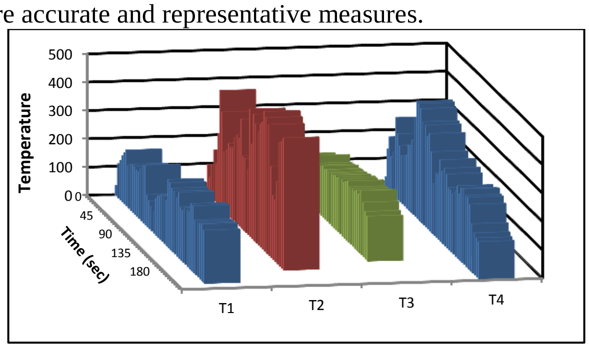


b) Cutting zone location
Fig.1 Experimental setup and Procedures

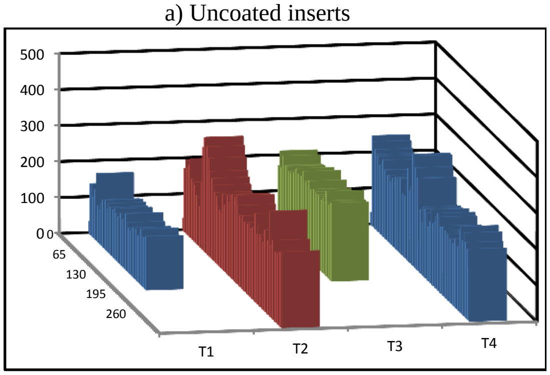
A. Effect of Cutting Parameters on Cutting Temperature

Data recorded for the entire experiments are explained in Fig. 2.a, for uncoated inserts, and in Fig. 2.b for coated ones. Plots explain many aspects regarding the tool material-temperature-cutting parameters interrelationship. Generally, in majority of experiments, it is observed that values of temperature when coated inserts are employed, Fig. 2.b, are lower than those for the uncoated inserts, Fig. 2.a. This is due to the reduced friction on the tool-workpiece interfaces as a result of the existence of the low of friction coefficient TiN outer coating layer.

It is noticed, Fig. 2, that the cutting speed has an insignificant influence on the resulting cutting temperature. However, higher temperature values are recorded as larger feeds are used. Such an unexpected attitude may be explained in the light of the effect of produced chip on temperature distribution hence, the recorded values, Fig. 3. As explained by Fig. 1.b, the system is adjusted so as the camera is exactly directed into the insert cutting face so as to accurately depict the heat within the cutting vicinity. In many cases, low feed at a given rotational speed tend to produced curly unbroken chips, Fig. 3.b rather than a straight long type, Fig. 3.a. While the latter reveal a distinctive definite record, the former seems to represent the ambient environment rather than the cutting zone. The existence of wide fluctuations of temperature values, as cutting continues for T2 and T4, Fig. 2, may support such an observation that higher temperature is detected as chip is stack and crammed around the cutting vicinity while it is reduced as such a intensive jam is resolved. Besides, it is expected that low feed to produce more heat for a single workpiece rotation due to the longer contact pass than that if a higher feed is employed (friction and heat rate). The use of chip breaker may enhance such a technical problem leading to more accurate and representative measures.

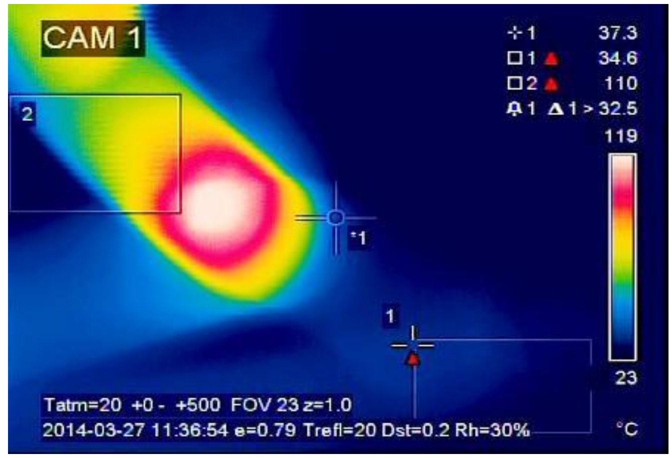


a) Uncoated inserts

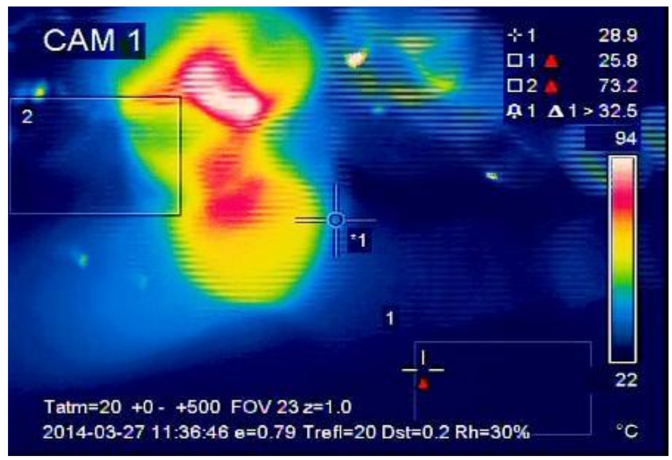


b) Coated inserts

Fig. 2 Levels of cutting temperature at different speeds and feeds



a) Long straight chips

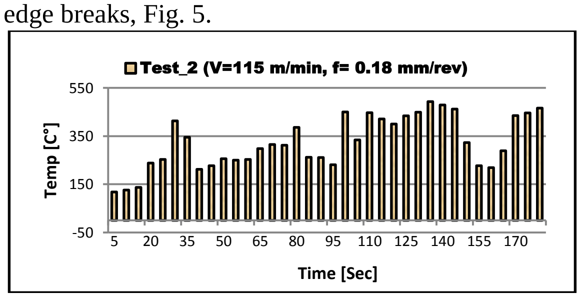


b) Curly unbroken chips

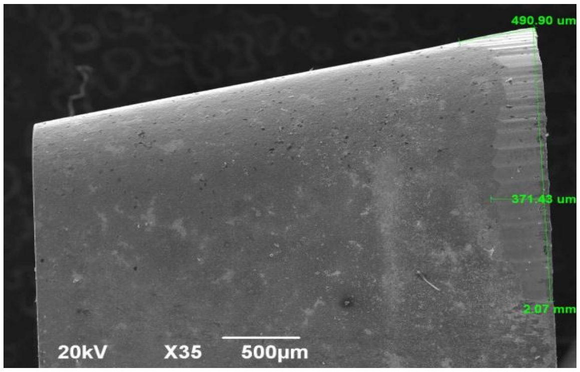
Fig. 3 Effect of produced chip type on temperaturedistribution

B. Effect of Cutting Edge Deformation on Cutting Temperature

Cutting edge may be deformed either in regular progressive pattern, Fig. 4, or in random or catastrophic breakage, Fig. 5. As explained by Figs. 4 & 5, although fluctuations encountered in the recorded cutting temperature, an increasing trend may be observed as flank wear width spreads out. Wider wear flank land leads to more friction on tool-workpiece and tool-chip interfaces producing more cutting heat and temperature. As friction and forces increase, cutting edge is thermally deformed leading to an edge sudden breakage, Fig. 5. Higher cutting temperature values are resulted as edge enters the failure interval reaching its maximum level when tool edge breaks, Fig. 5.

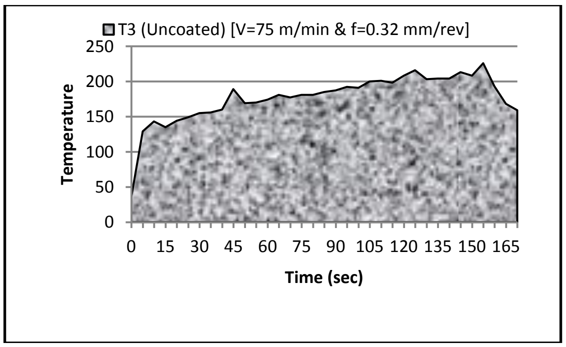


a) Time-Temperatures

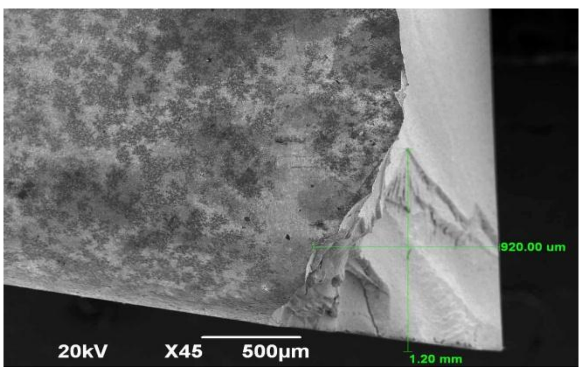


(b) SEM micrograph of T2

Fig. 4 Edge Wear-Temperatures for T2



a) Time-Temperature



b) SEM micrograph of T3

Fig. 5 Edge deformation-temperatures for T3

IV. Conclusions

An infrared Camera is used to monitor the effect of cutting speed and feed; along with edge deformation and the tool surface condition, on the produced heat around the cutting vicinity. Cutting speed is found to have no significant effect while the cutting feed increases heat as it decreases. As tool edge deforms progressively or randomly, a corresponding temperature rise is observed. Heat produced is observed to be less when coated tools are used.

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