Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 15 (9): 1138-1148, 2015
ISSN 1812-5654

RESEARCH ARTICLE OPEN ACCESS

DOI: 10.3923/jas.2015.1138.1148

Simulation of the Chip Formation and Temperature Distribution by the Fem

[1]M.B. Guemmour, [1]A. Sahli, [2]S. Kebdani and [3]Sara Sahli
[1]Department of Mechanical Engineering, Ibn Khaldoun University of Tiaret, Tiaret, Algeria
[2]University of Science and Technology of Oran (USTO MB), B.P. 1505, El M'naouer, Oran, Algeria
[3]University of Oran, Algeria

ARTICLE INFO
Article History:
Received: June 23, 2015
Accepted: September 18, 2015

Corresponding Author:
M.B. Guemmour
Department of Mechanical Engineering,
Ibn Khaldoun University of Tiaret,
Tiarat, Algeria

ABSTRACT

The distribution of temperature, the deformations and the cutting forces in the cutting zone during chip formation are very important aspects of the process. Therefore, they have great influence in results of machining. Tool wear, the precision of the machining operations and the finishing superface are some of the results that affect the economy of the process. This study has the objective of an evaluation offered potentialities for simulating chip formation using Finite Element Method (FEM). Four models with sufficiently different principles are used to exploring the most recent innovations. In the models, WC tools coated TiN was used to machine AISI 4340 steel. The simulations provide a study and detailed examination of temperature distribution, deformations, cutting forces, flow of material and an enormous amount of information that could be useful for the analysis of new processes and optimization of existing processes. Additionally, they open new horizon in the study of the chip formation. The simulations also demonstrate the complexity of the chip formation process, which creates many difficulties for its analysis using based analytical equations in constants. Some comparisons are established with experimental results found in temperature measurements.

Key words: Cut temperature, deformations, cutting forces, cutting zone

INTRODUCTION

Currently, the increase in industrial production and market competitiveness make companies seek the assimilation of new technologies in the continuous improvement of manufacturing processes. Consequently, the products become every day further refined and qualified and their prices more competitive and affordable to meet the needs and requirements of customers and consumers (Villeta *et al*., 2012; Ducloux, 2014).

According to Trent (1991), the machining operation is the most versatile and most common method of manufacture and recognized as the most popular manufacturing process of the world, transforming into chips somewhere around 10% of all production metals, employing tens of thousands of people throughout the world.

Due to the large amount of materials for tools on the market, you must know the process and understand the wear mechanisms of the tools to make a great choice, aiming economy (Machado and Alisson, 1988). Virtually all mechanical assembly is subjected to some type of machining operation at an early stage, intermediate or final manufacturing, given the fact that it provides a high standard of finish, with flexibility and quality. Parts that are machined products originating from the most diverse manufacturing processes such as casting, forming, welding, etc. (Trent, 1991). Among the machining process, the turning is the simplest and most widely used in the industry as it has high flexibility, compatibility with the environment, low setup time, etc. The turning movement based in part around its own axis, allowing cylindrical parts manufactured by means of a uniform movement of rotation. This requires three relative motions between the workpiece and the tool, namely: Cutting motion, forward motion and depth of movement. The process occurs by withdrawing, in continuous general, the chip of a part or body-of- the test piece. The chip removed by a mono-cutting tool, which should have hardness greater than the hardness of the body of the test piece. An investigation of the cutting temperature is essential to understand the mechanisms of wear of the tool material, thereby improving the process efficiency (Ren *et al*., 2004).

During the cutting operations of metals, the temperature is generated by plastic deformation of the chip in the shear plane and the friction at the interface tool/chip and tool/body-of- the test piece. The distribution of temperature in the cutting zone and especially, heat dissipation depend on machining parameters, tool edge preparation, thermos physical properties of the tool material and body-of-the- test piece such as thermal conductivity, thermal diffusion and heat transfer coefficient. The dissipation of heat occurs through, mainly by the chip, the body of the test piece, the tool and the environment. The temperature generated during machining operation is a crucial factor that determines the wear and tool life, the integrity of the body surface of the test piece, the chip formation mechanism and the thermal deformation of the cutting tool. According to Trent (1991) the cost of machining greatly depends on the material removal rate and can be reduced by increasing the cutting speed and/or advance but there are limits regarding the life of the tool because of the heat generated in cutting edge.

According to Ferraresi (1977), the formation and transmission of heat in the cutting are very complex, because with increasing temperature change the physical and mechanical characteristics of the metalwork. The temperature acting on the cutting edge directly influences the tool wear, limits the application of higher cutting regimes and therefore fixing the maximum conditions of productivity and duration of tools.

According to Ferraresi (1977) in Modern Industry, time is one of the most important factors that influence from the production cost, so there is a great need of decreased production timepiece, particularly reducing time and the number of machining operations without excessive addition to the tool cost. In the cutting process, an optimal temperature would cause the local ductility machining the body of the test piece of the material without causing significant deterioration of the resistance tool (El-Wardany *et al*., 1996). There have been several ways to study the generation and transmission of heat in machining processes and the Finite Element Method (FEM) the latest (Mahnama and Movahhedy, 2012).

The Finite Element Method (FEM) is widely used to get the values of stress, strain, displacement, shear stress, shear rate, plastic deformation (the thickness of the chip is the shear angle), temperature distribution in the cutting zone, etc. The FEM has among its qualities to material savings and time consumption in relation to actual experiments and can estimate the temperature of the cutting tool, chip and test body during the turning process (Hajmohammadi *et al*., 2014).

For the experimental measuring temperature distribution in the region chip formation, there are many techniques, the most common being; calorimetric, thermocouple, thermal coatings and heat radiation. The main objective of this study is to estimate the temperature distribution in the chip formation region using the method of Finite Element Methods (FEM). Will use the software with routine solution ABAQUS/Explicit applying the explicit integration technique in time. This solution is applied to non-linear dynamic problems.

There will also be comparisons of simulated results with the experimental in terms of temperature measured by thermocouples and shear force measured by piezoelectric dynamometer. The comparison between the temperature values used to set the capacity of the simulated model to reproduce reality. The comparison between the force values to establish an order of magnitude between energy estimated by simulation and that spent in real cutting, which is directly proportional to the temperature in the cutting area.

MATERIALS AND METHODS

Many of the economic and machining technical problems are caused directly or indirectly by the action of heat. The heat problem in machining is initially introduced by FW Taylor in 1907 in his article “On the art of cutting metals” in the development of new high-speed steels (Trent, 1991; Longbottom and Lanham, 2006) just for turning operations.

The main sources of heat in the chip formation process are due to the plastic deformation of the chip in the shear region (primary shear zone), chip friction with the release tool surface (secondary shear zone). In addition, the friction of the garment with the incident surface of the tool (or the impact surfaces of the three-dimensional form) as shown in Fig. 1 (Ferraresi, 1977; Rech *et al*., 2005; Grzesik and Nieslony, 2003; O’Sullivan and Cotterell, 2001; Singamneni, 2005).

The temperature in the cutting area depends on the contact between the tool and the chip, the size of the cutting force and the conditions of friction between the tool/workpiece materials. Excessive heat causes a high temperature in the tool side, which softens and accelerates wear of the tool and his break (Saglam *et al*., 2007).

Ay and Yang (1998), Borelli *et al*. (2001), Saglam *et al*. (2006) and Dhar *et al*. (2006), reported that with the increase of the cutting speed used in the operation of the modern machining, the thermal aspects of heat becomes very important. Not only does it directly influences the rate of wear of the tool but also affects the accuracy (recognition with thermal expansion) of the machining and the roughness of the surface finish. However, it is necessary to calculate precisely the rate of heat generation in cutting and the temperature distribution on the workpiece surface. This prediction of the

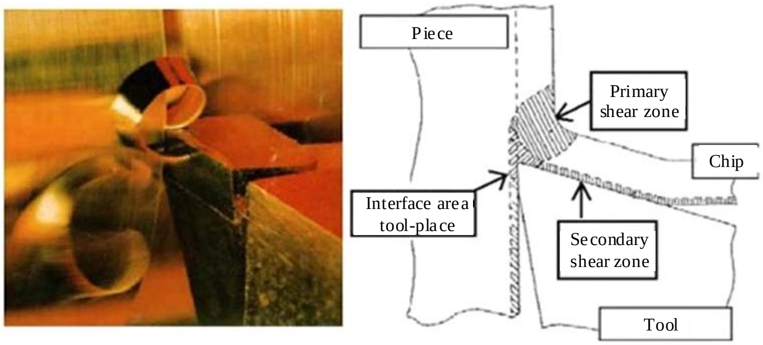

Fig. 1: Areas of the heat generating in the machining

temperature distribution is very important because it affects the maximum cutting speed while affecting the economics of the operation. Thermal energy is one of the main factors that affect the accuracy during the process for the induction of thermal expansion of the tool and the workpiece. The effect of thermal influence on the accuracy is one of the largest sources of error, which affects the size and accuracy of form of the piece. According to Zhou *et al*. (2004), thermal effects contribute more than 50% of the total error of the workpiece.

Da Silva and Wallbank (1999), Abukhshim *et al*. (2006), Saglam *et al*. (2006) and O'Sullivan and Cotterell (2001), stated that the heat generated in the cutting zone is affected by many factors, namely:

- Cutting conditions (cutting speed, feed rate and depth of cut) and soda
- The thermal properties of tool and workpiece (thermal conductivity)
- The mechanical properties (material resistance)
- Tribological conditions and the time of contact between tool/chip

O'Sullivan and Cotterell (2001) and Grzesik *et al*. (2005), stated that the temperature generated in the primary shear zone affects the mechanical properties of the material chip/body-of-piece materials and the interfaces tool/chip and tool/body-of-piece influences the tool wear, mainly on the output and duty surfaces. The heat generated in the secondary shear zone is the most responsible for the supply temperature of the cutting tool.

The temperature of the tool cannot be considered as a major problem in machining of soft materials and of low melting point. Such as aluminum and magnesium but becomes the factor controller removal rate of material, when the machining of hard materials and of high melting point, such as cast iron, steel, nickel alloys and titanium alloys (Machado and Silva, 2004; Abukhshim *et al*., 2006).

For non-abrasive solid metal chips formed during machining average cutting speed is assumed to between 20 and 35% of the heat in the primary zone (Tay *et al*., 1976; Wright and Trent, 1974). Vernaza *et al*. (2002) reported that 17% of the heat generated in the primary zone flows into piece. For very low metal removal rate, the amount of heat that is always high of 50%. Moriwaki *et al*. (1993) assumed that half of the heat generated due to friction between the tool and workpiece is supplied to piece and the other half is as tool for heat flow. Thus, 10-30% of the heat generated enters the tool Takeuchi *et al*. (1982).

Machado and Silva (2004), O'Sullivan and Cotterell (2001), Abukhshim *et al*. (2006), Da Silva and Wallbank (1999) claimed that the chip dissipates much of this "Generated heat", a small percentage is dissipated by another piece and the environment. The remainder goes to tool cutting. Although this represents only remaining small percentage (8-10%), the temperature rise associated with this heat is significant, reaching in some cases, 1100°C, which compromises heavily the resistance tool.

Mechanisms of formation of the chip: The study of the formation of the chip in various machining processes is of paramount importance (Ferraresi, 1977; Wright and Trent, 1974; Lucas *et al*., 2005; Diniz *et al*., 1999). Since the formation of the chip influences on many factors related to machining, such as tool wear, cutting forces, heat generated, built up edge cut, workpiece surface finish, chip breaks, vibration, force behavior machining, temperatures and penetration of the cutting fluid. Therefore, the process of chip formation involves many factors such as use of the machine tool, operator safety, product quality, economic etc. The first studies to explain the mechanism of formation of the chip, made in the late 19th century, considered that the phenomenon occurs by the fracture of the material ahead of the tool cutting edge. However, the shear plane theory (Lucas *et al*., 2005) promptly replaced this assumption. According to Lucas *et al*. (2005), Piispanen published important research results and are considered today the first detailed analysis of the mechanism of formation of the chip. The deformation of the material in the orthogonal cutting was analyzed qualitatively and proposed a model in which the deformation occurred by shearing the chip (neat) over successive inclined planes in relation to the cutting direction.

The chip deformation mechanism can be explained considering the volume of metal moving toward the cutting wedge (Machado and Silva, 2004). The action tool represses the volume. At this point, the metal begins to undergo elastic deformation. With the continuation of the process, the yield strength is overcome and the material starts to deform plastically. Plastic deformations keep happening until tensions are no longer sufficient to maintain this regime. A primary shear zone is well defined and to facilitate the study, it is represented by a single plane.

After the material undergoes plastic regime, advancing the tool causes the voltages exceed the endurance limit of the material still in the primary shear zone, promoting breakage, which begins with the opening of a crack and it can extend. The extent of crack propagation, which mainly depends on the ductility or brittleness of the workpiece material will determine the class chip, i.e. continuous or discontinuous.

After passing through the primary region of shear, the volume of material can only move over the tool’s output surface and leave as a component or lamella chips. However, across the primary zone of shear it deforms plastically to a new format. Understanding the conditions of these chip-tool interfaces is of fundamental importance for analysis of the cutting process.

Interface chip/tool: The formation of the chip is a process periodic, with each cycle in four distinct stages, namely: repression or elastic deformation, plastic deformation, breaking and moving or slipping on the output surface of the tool (Machado and Silva, 2004). The conditions under which this happens slip (slipping of the chip over the rake surface of the tool) have remarkable influences on the entire process. Particularly, in the proper chip formation mechanism, the strength of machining, the heat generated during cutting and thus the cutting temperature, the mechanisms and rate of wear of cutting tools and therefore the life of the tools. It is therefore necessary to understand how to process the chip movement along the tool's output surface. As Komanduri and Hou (2001), the maximum temperature at the exit surface or the clearance surface of a cutting tool determines the maximum material removal rate. Thus, the optimization of machining conditions, especially the cutting speed depends on the temperature tool of resistance.

The tribological phenomenon in chip-tool interface controls the formation of the chip and affect the wear of the tool (Gekonde and Subramania, 2002; Moufki *et al*., 2004). In the tool/chip interface friction important condition is affected by heat induced by the large values of pressure and shear rate. The classical concept of friction based on the laws Coulomb and Amonton (the frictional force F is proportional to the normal force N, i.e. $F = \mu N$; where, μ is the friction coefficient) is not suitable for the cutting of metals. Where the normal pressure to the tool output surfaces are very high (can reach 3.5 GN m^{-2}, in the machining of some steels). The conditions of the tool-chip interface are therefore one of the most important areas of study machining. Doing so, however, has been a major challenge, because few conclusions that can be drawn from direct observations during cutting. Most theories available studies was derived from this interface after the cut has been stopped (using quick-stops) and measurements of strain and temperature in that region.

Method: The method used is of FEM simulation, orthogonal cutting compared with tests experimental oblique cut, the study of temperature, strength and plastic deformation.

Compared with the experimental test measured temperature in (Aneiro *et al*., 2008).

Finite element method model for temperature distribution in the cutting zone: The finite element method is a powerful tool that allows the estimation process variables where it is difficult to obtain data by experimental methods. Several programs are able to solve the problem coupled between efforts and temperature. The explicit method is more suitable for simulations that have nonlinear deformations in large strain rate and temperature there is generated in the contact between tool surfaces/chip and tool/workpiece during the formation of the chip. The simulation of chip formation can be performed using several models, each with its special features, which make them more suitable for certain situations.

The problem is solved in 3 steps distinct and essential for the use of the finite element method: preprocessing step, simulation and post-processing step.

Pre-processing: This is the preparation of the physical problem to fix it later. It is the step that makes the modeling, defining geometry of the workpiece and the tool, properties of the workpiece and tool materials, cutting conditions, boundary conditions, load, type of mesh element, the grid density and the choice of adaptive mesh (mesh adaptative), etc.

The parameters used for the modeling are shown in Table 1.

Table 2 shows the values used for the simulation parameters tool with some other values of employees angles.

The formation of the chip is modeled as shown below Fig. 2.

- Model 1, vc = 150 m min^{-1} f = 0.07 mm rev^{-1}, b = 0.2 mm
- WC coated with TiN in AISI 4340
- Model 3, vc = 200 m min^{-1} f = 0.07 mm rev^{-1}, b = 0.2 mm
- WC coated with TiN in AISI 4340

Fig. 2: Geometries of the tool and the workpiece

Table 1: Parameters used for modeling

V_c (m min^{-1})	f (mm rev^{-1})	a_p (mm)	Piece (AISI)	Substratum	Coverage
150	0.07	0.2	4340	WC	TiN
150	0.17	0.2	4340	WC	TiN
200	0.07	0.2	4340	WC	TiN
200	0.17	0.2	4340	WC	TiN

Table 2: Tool geometry

Parameters	Values
Angle of inclination (°)	-6
Clearance angle (°)	6
Approach angle (°)	95
Tool tip radius (mm)	0.8

Table 3: Thermal parameters of the workpiece, tool and coverage

Thermal parameters	WC	AISI 4340	TiN
Density, r (kg m^{-3})	14950.00	7850.00	5220.00
Thermal conductivity l (W/m°C)	20.00	44.50	19.00
Young's modulus E (GPa)	400.00	205.00	600.00
Poisson's coefficient v	0.21	0.30	0.25
Specific heat C_P (J/kg°C)	210.00	475.00	-
Thermal diffusivity ad ($\times10^{-6}$ m^2 sec^{-1})	-	11.93	-
Thermal expansion (μm/m°C)	-	13.70	9.40
T_{melt} (°C)	-	1710.00	-
T_{room} (°C)	35.00	35.00	35.00

The tool has been modeled as elastic materials with isotropic conductivity, density, specific heat, Poissons ratio, Young's modulus, thermal diffusivity, thermal expansion, melting temperature (T melt) and temperature (Troom). Table 3 shows the values with units (SI) corresponding to each property.

The physical properties of the workpiece material are of fundamental importance for the correct simulation of chip formation. The chip is free to flow or break, according to their physical properties, which depend on the stresses, deformations and temperature. The material model proposed by Johnson-Cook is one of the most convenient and one that produces excellent results in describing the material behavior in the formation of the chip (Coelho *et al*., 2007). The workpiece material was modeled as isotropic elasto-plastic-term follow Johnson-Cook curve according to the following equation:

$$\bar{\sigma} = \left(A + B\bar{\varepsilon}^n\right)\left[1 + C\ln\left(\frac{\dot{\bar{\varepsilon}}}{\dot{\bar{\varepsilon}}_0}\right)\right]\left[1 - \left(\frac{T - T_{room}}{T_{melt} - T_{room}}\right)^m\right]$$

where, $\bar{\sigma}$ is the equivalent stress, $\bar{\varepsilon}$ is the equivalent plastic strain, $\dot{\bar{\varepsilon}}$ is the plastic strain ratio, $\dot{\bar{\varepsilon}}_0$ is the rate of deformation related (1.0 s^{-1}), T_{room} is the ambient temperature, T_{melt} is the melting temperature, A is the equivalent shear stress (MPa), B is hardening module; n is the exponent of cold work, C is the coefficient of shear rate dependence of strength (MPa), m is thermal coefficient.

The interactions between tool/workpiece and chip/tool are quite complex involving friction and tribological phenomena, whose theories are not fully consolidated. The contact between tool and workpiece and the friction plays an important role in metal cutting, they determine the quality of the machined surface and the energy generated during the process. In this study, the contact surfaces between algorithms (surface-to-surface) are employed based on Coulomb friction law (the shear stress τ is proportional to the normal tension σ, that is:

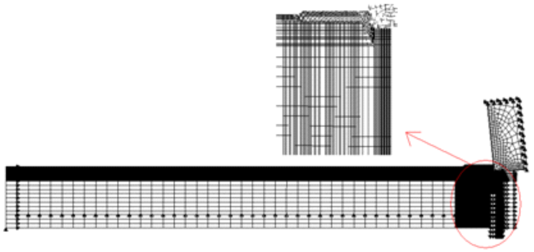

Fig. 3: Initial mesh and the condition of the contour for model training analyzed chips

$$\tau = \mu\sigma$$

where, μ is the friction coefficient. The Coulomb friction is recognized as valid in cases where the normal stress is small compared to the shear stress of the materials involved. In the case of chip formation, the normal stresses can reach very high values and in this case, the proportion between them may not be constant. Therefore, the stress τ is equal to an upper limit less shear stress between the friction materials. Moreover, the friction coefficient may vary with temperature, since the cover is oxidized by changing the surface properties at high temperatures. The values used in each model are listed as μ = 0.65. This was considered good second Coelho's work (Coelho *et al*., 2007).

The mesh is an important step in the process of simulation by finite element because it determines the accuracy of the result. Additionally, where the materials are subject to large deformations, as may be the case of certain materials in chip formation, the mesh may be deformed excessively compromising the results. You must have finer mesh in critical areas where the gradients can be very large. Moreover, the use of uniform and very fine mesh in the region leads to a very high number of elements which results in longer times for resolution. In this study, an adaptive mesh is used with a Eulerian formulation for some nodes to a mixed Lagrangian formulation in others. It is called Adaptive Lagrangean-Eulerian method (ALE), since both reference systems are used to mesh. In the case of Abaqus® program the command "Adaptive Mesh Constraint" was used to restrict the movement of the nodes near the root of the chip, making them Eulerian. This feature is only compatible with the explicit method. Thus, these remained fixed while the workpiece material flowed by thereof. In this method the material is not broken and behaves like a "Fluid" high viscosity. This model best suited to the study of the formation of continuous chip when the process is already established. Turning continuous processes are the best examples to application of four types of models. Figure 3 shows the initial mesh tool and workpiece.

In the black region of Fig. 3, there are many small elements. The tool is fixed in both directions and the part is fixed in the y direction. The piece is moving against the speed with tool 150 or 200 m min^{-1} in plane strain state (plane strain).

In this study, this energy will be 98% transformed into heat, although that percentage can be changed in the simulation.

RESULTS AND DISCUSSION

Distribution of temperature in the cutting zone: Figure 4 shows the temperature distribution at t = 0.8 ms for the 4 conditions cutting.

In general, numerical simulations of the heat partitioning in the cutting zone including the tool and the chip were carried out for variable cutting parameters cutting, i.e., speed of 150 and 200 m min^{-1}, feed rate of 0.07 and 0.17 mm rev^{-1} and depth of cut of 0.2 mm.

In addition, an analytical model for heat transfer in the cutting tool and its partitioning, proposed by Grzesik and Nieslony (2003, 2004) was employed to generate the input data to computations of the tool-chip interface temperature.

Observing Fig. 4, it can be noted that there is no disruption of the workpiece material, which is uniformly requested, allowing greater deformations and therefore greater energy is converted into heat. In all cases, the friction is also contributes to increase the energy being converted into heat. This finding agrees qualitatively with finite difference analysis predictions study of Grzesik *et al*. (2004). It was also observed that the heat rate increases in the vicinity of the cutting edge and changes for the cutting tool materials used (Grzesik *et al*., 2005; Grzesik, 2006).

The maximum temperature in the cutting area for four conditions after the elapsed time of 0.8 ms, are shown in Table 4.

All these values in Table 4 are higher in the interface tool/chip than in the primary shear zone due to additional heat during sliding the chip, the plastic work and friction between tool/chip; by analyzing the figures temperature, it is clear that the advancement has an important role with respect to the generation of temperature during machining. The increase of this parameter f = 0.07 mm rev^{-1} for f = 0.17 mm rev^{-1} causes a significant rise in temperature in the cutting zone.

Forces in cutting tool: Figure 5 shows the directions of the forces x and y. Figure 6a shows the forces Tool averages in function of time in the x direction (Fx) and y (Fy) by Abaqus simulation program and Fig. 6b for Fx and Fy by experiments, measured with the dynamometer.

For both the simulated and for experimental, by increasing the cutting speed, the cutting force tends to decrease due to the increased heat generation. This increase causes a decrease of the mechanical properties of the workpiece material, to facilitate chip formation.

Table 4: Maximum temperatures for each cutting conditions

Maximum temperature (° C)	Vc (m min^{-1})	b (mm)	f (mm rev^{-1})
829	150	0.2	0.07
949	150	0.2	0.17
868	200	0.2	0.07
982	200	0.2	0.17

Regarding the progress of machining, an increase in this parameter f = 0.07 mm rev^{-1} for f = 0.17 mm rev^{-1} causes a rise in the areas of plans of shear primary and secondary leading to an increase in cutting force and thus the energy required to shear the material, which translates into an increase in temperature.

Comparing the 2 results, it can be seen that the shear force diagram of the four simulated models using finite element is approximated to the actual experiments. The forces of actual experiments are larger than those due to the simulation tests are done in three dimensions and simulation oblique cut in two orthogonal dimensions in the cutting and the friction coefficients of the interface chip/tool and the tool/workpiece between tests and simulations are different. The three dimensional cut has larger areas of tool-chip contact and ask the material deforms in 3 dimensions leading to a higher value of machining force. In conclusion, that any progress in the prediction ability of the metal cutting theory cannot be achieved if the single-shear plane model is still in the very core of this theory (Astakhov, 2005).

Temperatures in the shear plane: Three points along the shear plane are collected in function of time, to analyze the behavior of the temperature. One is positioned in the central region B and the other at each end of the plane (A and C regions), as shown in Fig. 7. It was relatively difficult to find always the same points on the shear plane due to the configuration of the nodes, which will change as the chip is formed. Thus, the location of these points is approximated, but would be equivalent to the temperature measurement along the shear plane for chip formation.

Figure 8 shows the results of measurements made in the shear plane as the chip were formed. Points of yellow color corresponds to region A that are close to the tool. The points of pink color corresponds to region B which points were located in the middle of the shear plane and the blue color that corresponds to the region C that are located the other end of the plane.

Through an analysis of the selected temperature in the shear plane over time points, one can observe that:

- In all simulations, the four cutting conditions during the first few seconds the temperature increases rapidly. After the temperature increase is slower presenting a smaller gradient. Temperatures near the cutting edge of the tool, for the four models, increase with time and cutting are higher during chip formation, itself. The temperatures of the points that are located on the primary shear plane are between 100 and 400°C. A sudden change in the temperature rise on either side of the shear band heat

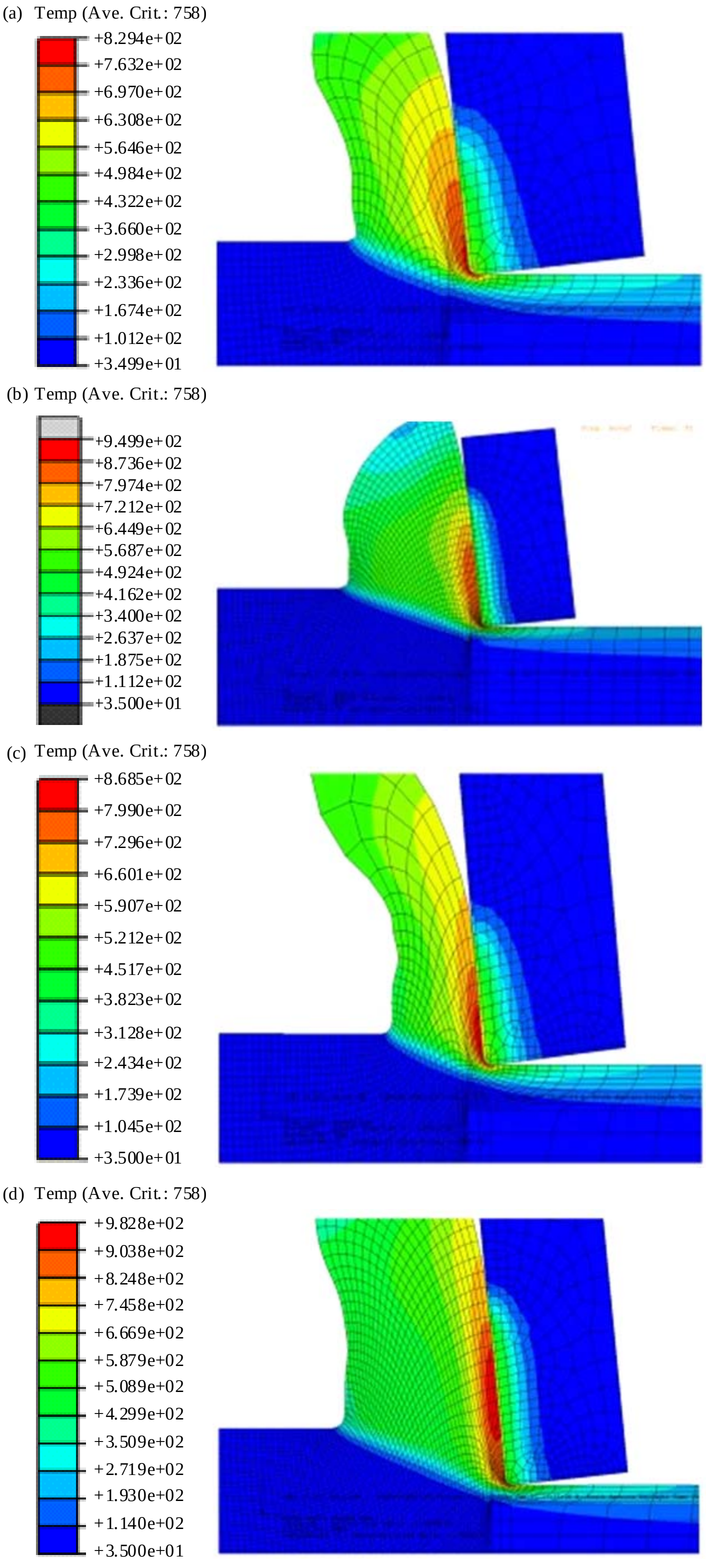

Fig. 4(a-d): Distribution of temperature in the cutting zone at t = 0.8 ms, (a) Condition 1, vc = 150 m min^{-1}, f = 0.07 mm rev^{-1}, b = 0.2 mm, WC coated with TiN with AISI 4340, (b) Condition 2, vc = 150 m min^{-1}, f = 0.17 mm rev^{-1}, b = 0.2 mm, WC coated with TiN with AISI 4340, (c) Condition 3, vc = 200 m min^{-1}, f = 0.07 mm rev^{-1}, b = 0.2 mm, WC coated with TiN with AISI 4340 and (d) Condition 4, vc = 200 m min^{-1}, f = 0.17 mm rev^{-1}, b = 0.2 mm, WC coated with TiN with AISI 4340

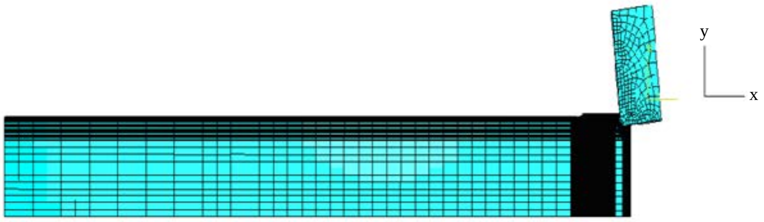

Fig. 5: Directions x and y of forces (Fx and Fy)

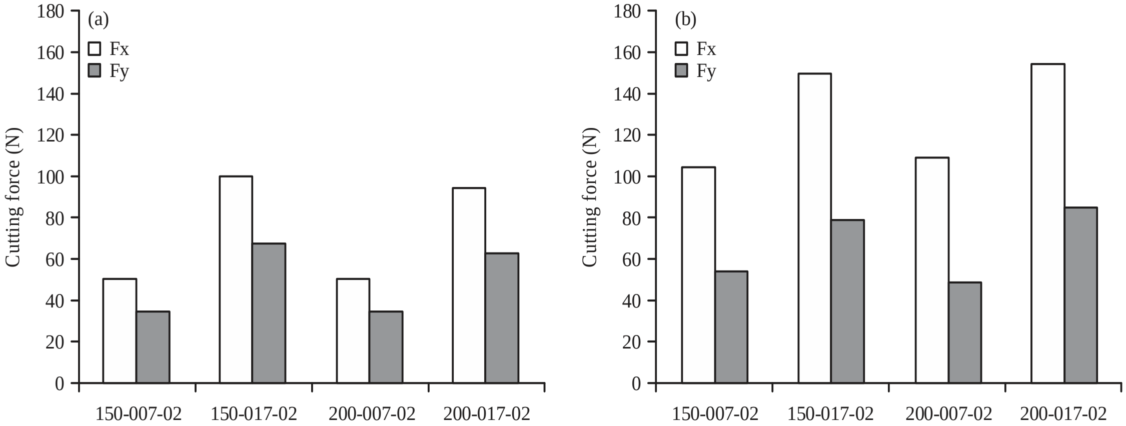

Fig. 6(a-b): Average cutting force in function of time for 4 cutting conditions obtained by (a) FEM simulation and (b) Experiments

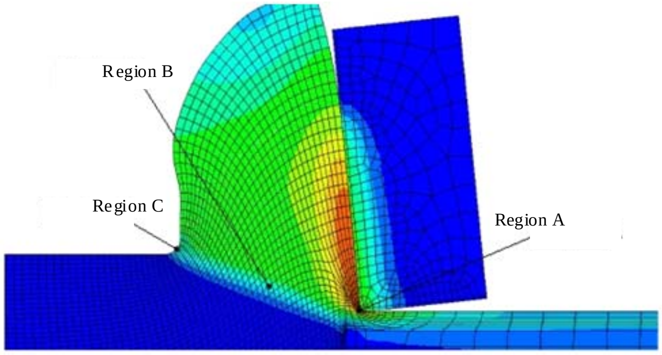

Fig. 7: Location of the three regions A, B and C in the shear plane

source. This is because the shear plane is assumed as a line instead of a zone. It may be pointed out that these models assume the temperature rise at the chip-tool interface to be nearly uniform and equals the average temperature rise in this volume, as (Komanduri and Hou, 2000) concluded

- It is observed that the temperature at the shear plane increases when the carbide tool coated with TiN comes into contact with the workpiece AISI 4340 until reaching a relatively stable conditions for 4 cutting condition.
- The effect of feed leads to an increase in temperature of the shear plane irrespective of the position in the measuring
- The temperature rise in the primary shear plane is not much influenced by the cutting speed, which apparently contradicts the current theory on these variables. However, the speed increase was very small and the values are already relatively high, which may explain this slight increase in temperature as a function of shear rate

Deformations on machined surfaces: Figure 9 shows the maximum and minimum deformation on machined surfaces.

One of the main sources of heat in the process of formation of the chip is due to plastic deformation of the chip in the shear region (primary shear zone). It can be seen that the

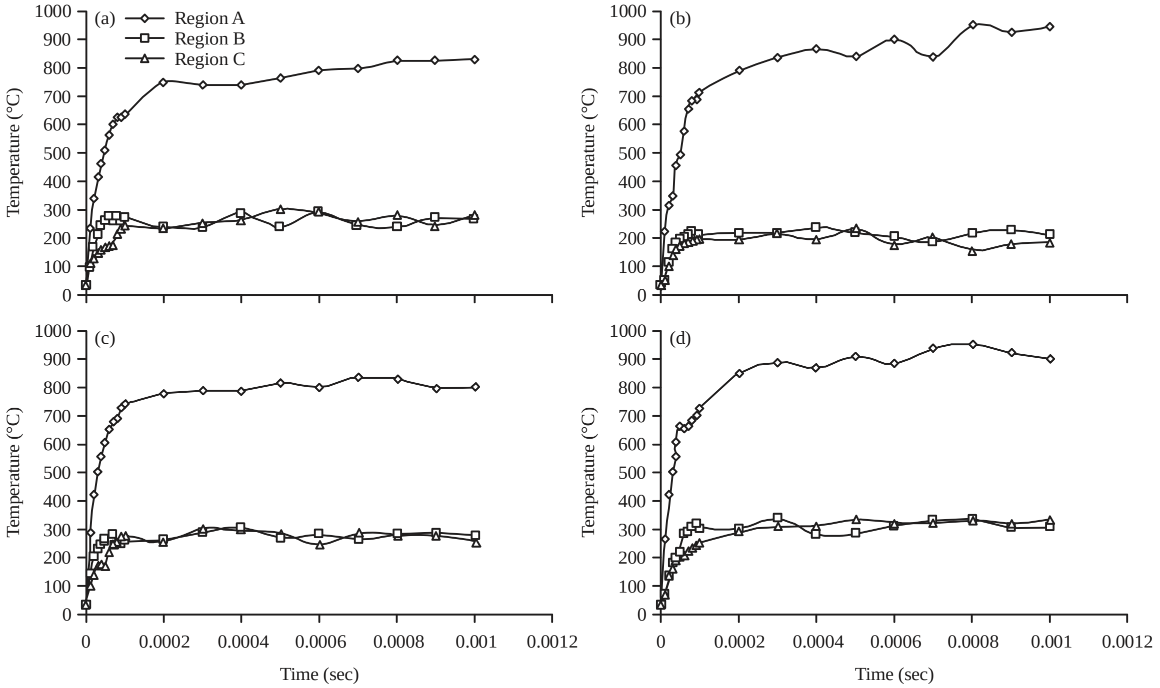

Fig. 8(a-d): Temperatures of the various points in the shear plane, (a) Condition 1, vc = 150 m min^{-1}, f = 0.07 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340, (b) Condition 2, vc = 150 m min^{-1}, f = 0.17 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340, (c) Condition 3, vc = 200 m min^{-1}, f = 0.07 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340 and (d) Condition 4, vc = 200 m min^{-1}, f = 0.17 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340

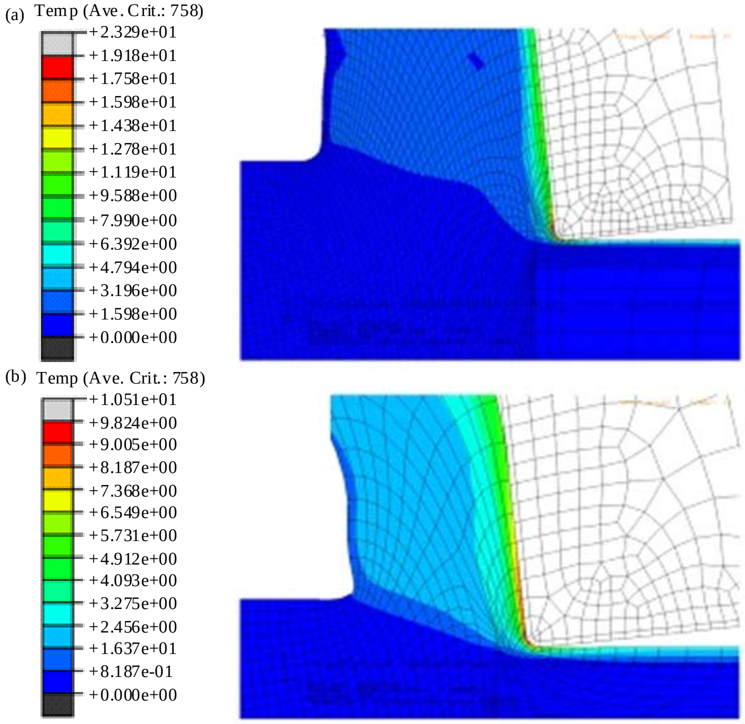

Fig. 9(a-b): Deformations in the machined surfaces t = 0.008 sec, (a) Condition 4, vc = 200 m min^{-1}, f = 0.17 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340 and (b) Condition 1, vc = 150 m min^{-1}, f = 0.07 mm rev^{-1}, b = 0.2 mm WC coated with TiN with AISI 4340 maximum deformation occurs in condition 4 due to machining conditions and the advance speed, which is maximal for this experiment. In this case, the tool used has a radius of 0.8 mm and the minimum cutting depth of 0.2 mm was applied, which is smaller than the radius of the tool tip and the cutting area two arcs of circumference. The process of plastic deformation during the formation of chip is very close to the cutting edge due to the small value of the cut section (f and a_p). In addition, the active cutting edge of the tool is increased due to increased a_p. With this increases the amount of heat that acts on the tool causing increased temperature. On the contrary, if the radius of the tool tip is less than the active part of the cutting edge of the tool the temperature is lower.

With increasing shear rate for vc = 200 m min^{-1} and feed f = 0.17 mm rev^{-1} in the condition 4, the thermal aspects of the court could affect the dimensional accuracy (in the form of thermal expansion) of machining. The effect of thermal influence on the accuracy is one of the largest sources of errors that affect the size and accuracy of the piece.

CONCLUSION

The models obtained by FEM have several qualities, including the economy of material and time relative to actual experiments and may estimate the distribution of temperature, stress and strain in the shear zone and the interfaces during the turning process. The model shows that the highest temperature is generate at the interface tool/chip than in the primary shear zone due to the additional heat during the sliding of the chip.

The forward, the cutting depth and the cutting speed machining play important roles, for influencing the generation of heat in the interface tool/chip and the tool/body-test piece and the primary shear zone, the shear plane.

The simulation is do in two dimensions, orthogonal cutting, so it is difficult to measure the temperature in the primary shear zone, because there is not always node in this region and therefore, an oscillation in temperature occurs. In the future, it can be sought better ways, for example, placing more elements in this region to find the temperatures in the primary shear plane.

In future work, other training models of the chip can be developed to study and investigate the effect of microstructure on machining using FEM. The finite element method is not ideal but may help understand the mechanisms of the process of chip formation. The temperature can also be used to provide micro-structural changes in the machined material, which can lead to damage in the surface layer of the part.

The application of suggested topics to other manufacturing processes for machining, such as milling, drilling, grinding and using FEM, seeking a correlation between phenomena observed in different processes can be an important issue for many future research.

Although, still early in its development the simulation of chip formation already producing important results. In the future, more studies and data from the behavior of the materials in chip forming conditions are required. Likewise, the rupturing under the same conditions criteria are required. Studies by JOHNSON-COOK already produced useful and applicable results, but only exist for a limited group of materials.

ACKNOWLEDGMENT

The authors would like to acknowledge the “Ministry of Higher Education and Scientific Research” Project CNEPRU J0301920120029, for the financial support of this study.

REFERENCES

Abukhshim, N.A., P.T. Mativenga and M.A. Sheikh, 2006. Heat generation and temperature prediction in metal cutting: A review and implications for high speed machining. Int. J. Machine Tools Manuf. 46: 782-800.

Aneiro, F.M., R.T. Coelho and L.C. Brandao, 2008. Turning hardened steel using coated carbide at high cutting speeds. J. Braz. Soc. Mech. Sci. Eng., 30: 104-109.

Astakhov, V.P., 2005. On the inadequacy of the single-shear plane model of chip formation. Int. J. Mech. Sci., 47: 1649-1672.

Ay, H. and W.J. Yang, 1998. Heat transfer and life of metal cutting tools in turning. Int. J. Heat Mass Trans., 41: 613-623.

Borelli, J.E., C.A. Franca, G.C.F. Medeiros and A. Gonzaga, 2001. [Temperature analysis in the contact region between the workpiece and the tool]. Revista Maquinas Metais, 423: 114-125, (In Portuguese).

Coelho, R.T., E.G. Ng and M.A. Elbestawi, 2007. Tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions. Int. J. Mach. Tools Manuf., 47: 263-272.

Da Silva, M.B. and J. Wallbank, 1999. Cutting temperature: Prediction and measurement methods: A review. J. Mater. Process. Technol., 88: 195-202.

Dhar, N.R., M.W. Islam, S. Islam and M.A.H. Mithu, 2006. The influence of Minimum Quantity of Lubrication (MQL) on cutting temperature, chip and dimensional accuracy in turning AISI-1040 steel. J. Mater. Process. Technol., 171: 93-99.

Diniz, A.E., F.C. Marcondes and N.L. Coppini, 1999. Machining materials technology. Mmedit., Sao Paulo, Brazil.

Ducloux, R., 2014. Improvement of part or tooling life prediction through simulation of whole manufacturing process. Procedia Eng., 81: 504-509.

El-Wardany, T.I., E. Mohammed and M.A. Elbestawi, 1996. Cutting temperature of ceramic tools in high speed machining of difficult-to-cut materials. Int. J. Mach. Tools Manuf., 36: 611-634.

Ferraresi, D., 1977. Fundamentals of Machining of Metals. 9th Edn., Edgard Publisher, Sao Paulo, Brazil.

Gekonde, H.O. and S.V. Subramanian, 2002. Tribology of tool-chip interface and tool wear mechanisms. Surf. Coatings Technol., 149: 151-160.

Grzesik, W. and P. Nieslony, 2003. A computational approach to evaluate temperature and heat partition in machining with multilayer coated tools. Int. J. Mach. Tools Manuf., 43: 1311-1317.

Grzesik, W. and P. Nieslony, 2004. Physics based modelling of interface temperatures in machining with multilayer coated tools at moderate cutting speeds. Int. J. Mach. Tools Manuf., 44: 889-901.

Grzesik, W., M. Bartoszuk and P. Nieslony, 2004. Finite difference analysis of the thermal behaviour of coated tools in orthogonal cutting of steels. Int. J. Mach. Tools Manuf., 44: 1451-1462.

Grzesik, W., M. Bartoszuk and P. Nieslony, 2005. Finite element modelling of temperature distribution in the cutting zone in turning processes with differently coated tools. J. Mater. Process. Technol., 164-165: 1204-1211.

Grzesik, W., 2006. Determination of temperature distribution in the cutting zone using hybrid analytical-FEM technique. Int. J. Mach. Tools Manuf., 46: 651-658.

Hajmohammadi, M.S., M.R. Movahhedy and H. Moradi, 2014. Investigation of thermal effects on machining chatter based on FEM simulation of chip formation. CIRP J. Manuf. Sci. Technol., 7: 1-10.

Komanduri, R. and Z.B. Hou, 2000. Thermal modeling of the metal cutting process: Part I-Temperature rise distribution due to shear plane heat source. Int. J. Mech. Sci., 42: 1715-1752.

Komanduri, R. and Z.B. Hou, 2001. A review of the experimental techniques for the measurement of heat and temperatures generated in some manufacturing processes and tribology. Tribol. Int., 34: 653-682.

Longbottom, J.M. and J.D. Lanham, 2006. A review of research related to Salomon's hypothesis on cutting speeds and temperatures. Int. J. Machine Tools Manufac., 46: 1740-1747.

Lucas, E.O., W.L. Weingaertner and P.N.A. Bernardini, 2005. As the chip is formed in the turning of ferritic nodular cast iron]. Maquinas Metais, 477: 152-163, (In Portuguese).

Machado, R. and R. Alisson, 1988. The evolution of materials for cutting tools. Mach. Metals, 268: 92-98.

Machado, R. and M.B. Silva, 2004. Machining of Metals. 8th Edn., Federal University of Uberlandia, Uberlandia, Brazil.

Mahnama, M. and M.R. Movahhedy, 2012. Application of FEM simulation of chip formation to stability analysis in orthogonal cutting process. J. Manuf. Process., 14: 188-194.

Moriwaki, T., S. Sugimura and S. Luan, 1993. Combined stress, material flow and heat analysis of orthogonal micromachining of copper. CIRP Ann. Manuf. Technol., 42: 75-78.

Moufki, A., A. Devillez, D. Dudzinski and A. Molinari, 2004. Thermomechanical modelling of oblique cutting and experimental validation. Int. J. Mach. Tools Manuf., 44: 971-989.

O'Sullivan, D. and M. Cotterell, 2001. Temperature measurement in single point turning. J. Master. Process. Technol., 118: 301-308.

Rech, J., J.L. Battaglia and A. Moisan, 2005. Thermal influence of cutting tool coatings. J. Mater. Process. Technol., 159: 119-124.

Ren, X.J., Q.X. Yang, R.D. James and L. Wang, 2004. Cutting temperatures in hard turning chromium hardfacings with PCBN tooling. J. Mater. Process. Technol., 147: 38-44.

Saglam, H., F. Unsacar and S. Yaldiz, 2006. Investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature. Int. J. Mach. Tools Manuf., 46: 132-141.

Saglam, H., S. Yaldiz and F. Unsacar, 2007. The effect of tool geometry and cutting speed on main cutting force and tool tip temperature. Mater. Design, 28: 101-111.

Singamneni, S.B., 2005. A mixed solution for the three-dimensional temperature distribution in turning inserts using finite and boundary element techniques. J. Mater. Process. Technol., 166: 98-106.

Takeuchi, Y., M. Sakamoto and T. Sata, 1982. Improvement in the working accuracy of an NC lathe by compensating for thermal expansion. Precision Eng., 4: 19-24.

Tay, A.O., M.G. Stevenson, G. de Vahl Davis and P.L.B. Oxley, 1976. A numerical method for calculating temperature distributions in machining, from force and shear angle measurements. Int. J. Mach. Tool Design Res., 16: 335-349.

Trent, E.M., 1991. Metal Cutting. 3rd Edn., Buterworth-Heinemenn, Oxford, UK., ISBN-13: 9780750610681, Pages: 273.

Vernaza-Pena, K.M., J.J. Mason and M. Li, 2002. Experimental study of the temperature field generated during orthogonal machining of an aluminum alloy. Exp. Mech., 42: 221-229.

Villeta, M., E.M. Rubio, J.L. Valencia and M.A. Sebastian, 2012. Integrating the continuous improvement of measurement systems into the statistical quality control of manufacturing processes: A novel link. CIRP Ann. Manuf. Technol., 61: 507-510.

Wright, P.K. and E.M. Trent, 1974. Metallurgical appraisal of wear mechanisms and processes on high-speed-steel cutting tools. Metals Technol., 1: 13-23.

Zhou, J.M., M. Andersson and J.E. Stahl, 2004. Identification of cutting errors in precision hard turning process. J. Mater. Process. Technol., 153-154: 746-750.