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THEORETICAL AND EXPERIMENTAL CUTTING FORCE PARAMETER STUDY

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Abstract

Cutting force is a very important parameter, which can be used to determine tool geometry and its interaction with the workpiece. This work presents some orthogonal cutting AISI 4340 hardened steel workpiece. Comparison with experimental results are also carried out. The simulation considers the thermal effect caused by material deforming and friction between tool, workpiece and chips. The main parameters changed during the simulations are the cutting speed and the feed rate. As results, the simulated cutting forces showed an error around 5% and the simulated feed forces about 27% when compared to the experimental values.

Keywords: Machining/ cutting force/thermal effect/ FEM/ cutting simulation.

Résumé

La force de coupe est un paramètre très important qui peut être utilisé pour déterminer la géométrie de l'outil et son interaction avec la pièce à usiner. Ce travail présente la coupe orthogonale d'une pièce en acier durcie AISI 4340. La comparaison avec les résultats expérimentaux est également effectuée. La simulation considère l'effet thermique causé par la déformation du matériau et de la friction entre l'outil, la pièce et les copeaux. Les principaux paramètres modifiés pendant les simulations sont la vitesse de coupe et la vitesse d'avance. Comme résultats, les forces de coupe simulées ont montré une erreur d'environ 5% et les forces d'avance simulées environ 27% par rapport aux valeurs expérimentales.

1. INTRODUCTION

According to Childs [1], the machining process is the most widely used in mechanical manufacturing industry to obtain metallic pieces.
Machining is a term that covers a vast amount of manufacturing processes where there is the removal of material from the raw material in the form of chips for the part design specifications are met, such as shape and size.
According Altintas [2], machining processes can be divided between the tools using well-defined geometry to remove material such as turning, a planning, drilling, milling and broaching, and those in which no tool presents a well-defined geometry, such as grinding and other abrasive processes.
Until the early 1980s, parts of hardened materials - including steel AISI 4340, currently the type of steel more applicable due to its mechanical properties and its machinability [3] needed to be rectified to their shape and dimensional tolerances could be achieved [4].
It is estimated that in the United States the amount spent annually in machining processes exceeds the $ 100 billion [5], which demonstrates the importance that these processes have on the economy and of itself justify the studies aimed at improving of machining processes. According Belhadi [6], most research always aimed to improve material removal rate and lower manufacturing costs. Therefore, stronger and more powerful machines were developed.
The way the chip is formed affects the stresses suffered by the piece, which determine the residual stresses in the machined surface, cutting forces and also the cutting temperatures [7], and directly influence the life of the cutting tool [8] and also vibrations which may occur during the machining process [9]. The experimental approach to study the chip formation in machining processes is an expensive task and time-consuming when considering the vast amount of parameters involved [10]. Faced with these difficulties, many researchers began looking for analytical and numerical models that could be able to provide

satisfactory answers to such study [8]. Among these models, stands out most recently the finite element method (FEM) due to their ability to solve nonlinear problems [11] and representing the material properties as a function of temperature, pressure and shear rate [7].
Childs [1] state that pioneered the use of MEF facing the simulation of machining processes were Zienkiewicz and Kakino, both in 1971. Since then, many researchers have been looking for models that can represent more reliably and accurately processes machining.
The proposed work aims to:
1- Simulate through the finite element method, the process of chip formation in steel AISI 4340 during orthogonal cutting operation in turning with carbide inserts
2. Get the shear forces resulting from such operation.
3- Check the temperature distribution in the piece, the chip and the tool through the developed model.
The simulation will be developed in Abaqus, a tool capable of solving nonlinear problems, using the Lagrangian formulation and criterion of rupture of the material developed by Johnson and Cook [12].
Cutting forces obtained in these simulations will be compared with those acquired in experimental trials, which will be performed with the same simulation machining parameters.

2. EXPERIMENTAL STUDIES ON ORTHOGONAL CUTTING

Orthogonal cutting tests were made by means turning to obtain the cutting forces. The test specimens used are made of hardened steel AISI 4340 with a hardness from 27 to 30 Rockwell C, and the geometry is the outside diameter 55mm, internal diameter 44mm, thickness 2.2mm.
The geometry of the cutting edge, obtained by using a profilometer Taylor Robson model, in which it is clear that the cutting edge does not have a sharp edge, but a chamfer of approximately 0.074 mm and angle of 45 ° with respect to the output surface.
In order to obtain the orthogonal cutting, the support was modified such that the cutting edge is parallel with the machine axis of rotation. Thus, the support was cut and then welded with an

angular displacement from 15° to lead the angle tool passed from its original 75° to 90°.
Cutting parameters of testing are cutting speed and advancement.
The dynamometer used in the acquisition forces is a Kistler 9121, which functions as a tool holder. The signals from dynamometer passed per one Kistler amplifier 5019. The amplified signals were received by an input module and signal output by the Model BNC-2120 and sent to the Analog / Digital acquisition board (A / D) NI PCI-6040E installed in a personal computer. Finally, the signals are captured by an application developed.

3. NUMERICAL STUDIES ON THE CUT ORTHOGONAL

According to Childs [1] and Athavale [13], the Eulerian formulation elements are fixed in space and the material flows through them, functioning as a volume control, more suitable for the study of flow of the material [14]. The advantages Pantalé [8] state that this type of approach avoids major distortions in the fabric, Vaz [15] point to the fact that the material can undergo large deformations without causing numerical problems, [16] reports that the simulation of machining can be easily performed because it requires few elements, causing, according Özel [17] the simulation time is reduced. Moreover, this formulation requires that the study of chips from occurring in the state of regime permanent. Because the shape of the chip should be defined in advance, acting as a simulation model of the input data [14] [2] [15] [17] [16] [8], implying the previous definition of the shear angle [17] and the length of the contact area between the workpiece and the tool [15]. Furthermore, the elasticity of the material and is neglected in this approach prevents the study of residual stresses in the machined surface [14] [2].
The numerical simulations were carried out in commercial finite element ABAQUS with the aim of replicating the experimental tests.

3.1. Numerical model

In figure 1 we can see that the top the piece - where there will be removal of material - has a much more refined mesh to the bottom and the part. The use of a coarser mesh in areas where there will be little or no deformation is a strategy to reduce the number of nodes

and elements and consequently reduce the computational time. The length and width of the upper part of the elements are 0,012mm. The total height of the simulated piece is 0.3 mm and the length of 2 mm, except for the simulation to the cutting condition with vc = 150m / min f = 0.15 mm / rev, for in that case the length used was 3 mm and a height of 0.5 mm so that there was enough material for the simulation.
The boundary restrictions of the piece are setting in the underside and a region located on the left side of the lower part with a length of 0.15 mm in cases where the part of the height is 0.30 mm or 0.25 mm when the piece is 0.5 mm height. On the tool, restrictions were imposed that allow only move in the horizontal direction to apply the shear rate (X axis or the axis 1).

3.2. *Modeling of materials and failure criteria*

The material behavior of piece (AISI 4340) followed the Johnson-Cook plasticity model [12]

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

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.

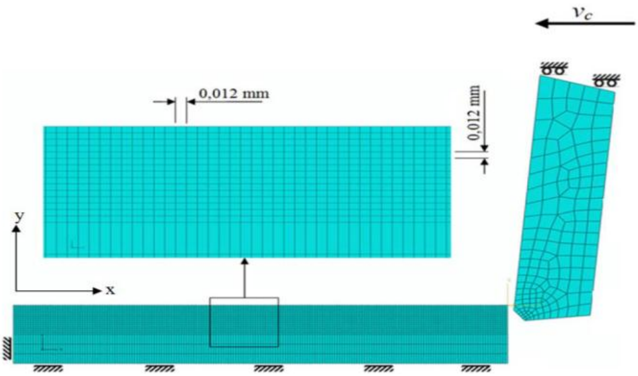


Figure 1: finite element model

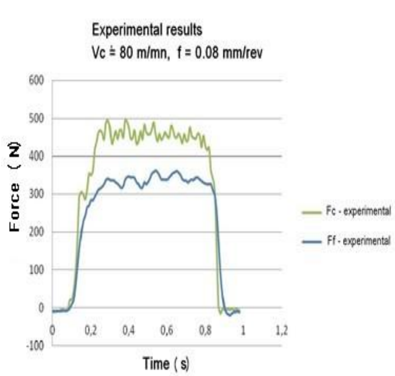
The created simulation model assumes that the tool undergoes only elastic deformation, so it makes sense to use the JC model to describe the behavior of your material. The failure criterion adopted for the workpiece material was to Johnson-Cook [12].
All references surveyed there is no value reported on how the material is deformed until their elimination from the finite element model. The underlying assumption in this work, that the element is deleted when some of its dimensions deform more than 2.5 (two and a half) times the original size.

4. RESULTS AND DISCUSSION

4.1. Experimental results

Three assays were performed for each set of cutting parameters proposed and the average value of these tests are related graphics in Figure 2 to Figure 6.

Experimental results of test 1-5: Fc = cutting force and Ff = Feed Force.



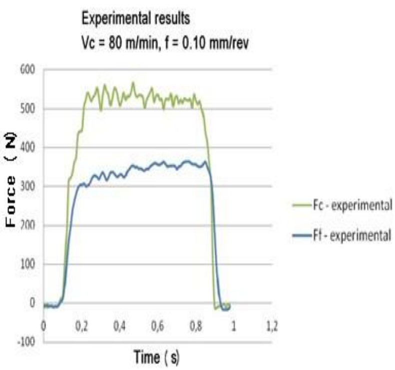
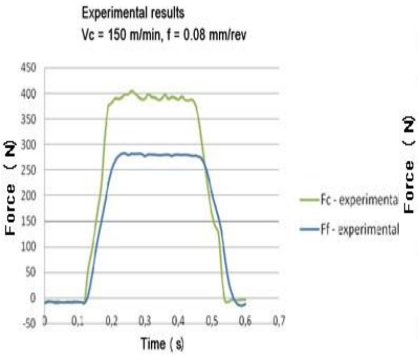


Figure 2: Vc = 80 m/min **Figure 3:** Vc = 80 m/min
f = 0.08 mm/rev.f = 0.10 mm/rev.



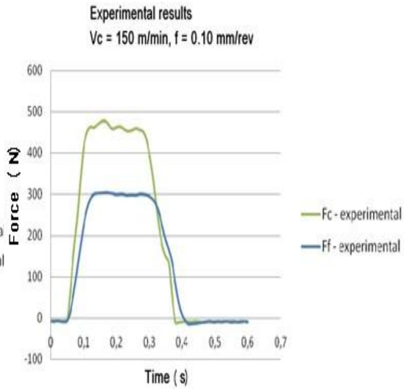
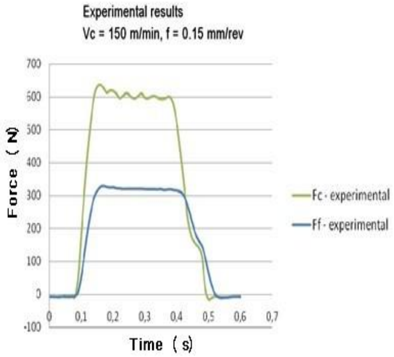


Figure 4: Vc = 150 m/min **Figure 5:** Vc = 150 m/min
f = 0.08 mm/rev.f = 0.10 mm/rev.

It is observed that the forces grow from zero to a relatively stable value. The edge touches the workpiece and begins the cutting with increasing section thickness up to establish aconstant value after a back piece, since, due to rotating movements of the workpiece and tool if the straight establishes a "Spiral of Archimedes ". Thus, the



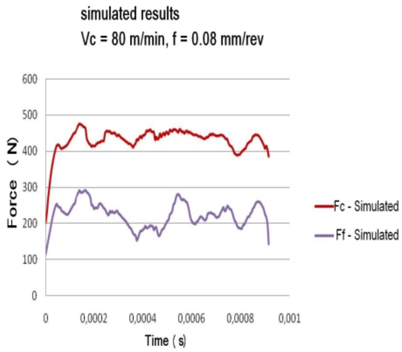


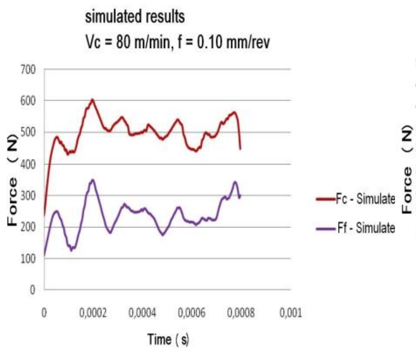
Figure 6: Vc = 150 m/min,**Figure 7 - Simulated results:**
f = 0.15 mm/rev.Vc = 80m/min, f = 0.08 mm/rev

cutting force values and advance stabilize after a different time for each situation, depending on the piece turnover time. The stable value will be the one used to compare with the simulation by FEM. After reaching the constant value of section thickness there is still some oscillation of forces which has its origin in mechanical

vibrations of the machine-tool- workpiece system, imperfections in the chip due to adhesion processes, inclusions in the workpiece material , curvature of the chip and contact with the part to break, edge wear, etc. In this case, it can be said that the oscillations are unstable due to adhesions on the exit surface,possibly due to the use of uncoated edge, with additional dynamic instability own orthogonal plunge cutting, and also the crystalline structure of the material , polycrystalline and heterogeneous. Additionally, there are oscillations caused by rupture, which occurs randomly, sometimes the front edge, causing forces to oscillate.
The values for the coefficient of friction are in the same range of values found by [19], whose values were used for numerical simulation.

4.2. *Numerical results: simulation (FEM)*

The results of feed and cutting forces obtained in the simulation are from Figure 7 through Figure 11.
The forces advancing and cutting are the sum of the reaction forces acting on each of the nodes contained in the tool. The reaction force in the X direction, or 1, corresponding to the cutting force and the reaction force in the Y direction, or 2 corresponds to the feed force.
Strength charts are the result of a moving average of 7 terms of the original values, which have oscillations that perhaps could be written off by the use of damping coefficients in the model.
Figure 12 to Figure 16 we can see the development of chip formation and the temperature gradient corresponding to each cutting condition in Kelvin. Furthermore, the shear angle is easily identifiable.



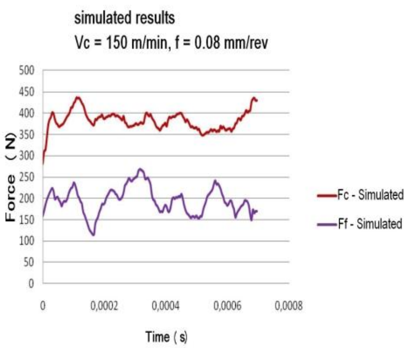
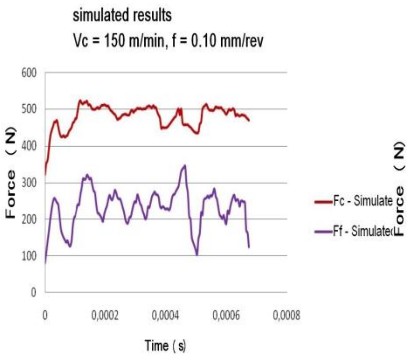


Figure 8 - Simulated results:Figure 9 - Simulated results: Vc = 150 m/min, f = 0.08 mm/rev.Vc = 80 m/min, f = 0.10 mm/rev



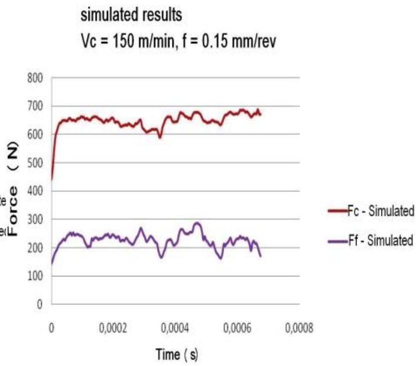


Figure 10 - Simulated results:Figure 11 - Simulated results:
Vc = 150 m/min, f = 0.10 mm/rev.   Vc = 150 m/min, f = 0.15 mm/rev.

5. CONCLUSIONS

Results obtained in this work can reach the followingconclusions:

- The orthogonal turning cutting process can be simulated by a finite element program (FEM), using classical models and frangible material, with results strength and temperature.
- The simulated results for the cutting forces and advance compared to the experimental produced average errors of 5.36% and 27.02%, respectively. These errors may be related to the material data, which were taken from literature. A testing machine would be desirable for these errors could be minimized.
- The friction model on the output surface of the tool, as well as the friction coefficient values also have fundamental importance for a better agreement between the simulated and experimental values.
- The shapes of chips obtained in the simulation were similar to thoseobserved in the experiments.
- The angle found for the shear plane in the simulations diverged that is calculated using equations obtained through analytical models classics. Experimental measurements were not possible in this work, and analytical calculations performed by measuring the thickness of the chips obtained.

• A more detailed evaluation of the temperatures involved in the process becomes impossible since there is no reference experimental and simulation times are very short.

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