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A technique for the identification of friction at tool/chip interface during machining

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Numerical simulation of chip formation during high speed machining requires knowing the friction at tool/chip interface. This parameter is hardly identified and generally the loadings (temperature, force) during the identification are not similar to those encountered during machining. Thus, Coulomb friction identified with pin-on-disc device is often used to conduct numerical simulation. The used of this technique cannot leads to good numerical results of chip formation compared to the experimental tests especially in the case of low uncut chip thickness.

In this contribution, we propose a new method to evaluate the friction at tool/chip interface. In fact several Coulomb friction parameters are identified corresponding to several parts of the cutting tool. Experimental tests have been conducted allowed us to determinate both the level and the distribution of the Coulomb friction. Experimental results are also compared to the results of orthogonal cutting simulation. We show that this technique allows predicting accuracy results of chip formation.

Keywords: Friction identification, Numerical cutting modeling

1. INTRODUCTION

Metal cutting modelling provides understanding and prediction of machining process variables as temperature, stress, strain, and cutting forces.... Several approaches can be employed [1-3], but in all the cases, if a "fine" numerical description of the cutting process and an accurate prediction of these variables is needed, a detailed input data will be required for: (i) material flow characteristics at high temperature, strain-rate and strain as encountered during cutting process, (ii) a tool-chip contact friction.

The friction parameters at the tool-chip contact are hardly identified. Only few methods are available and, in all cases, experiments conditions are not conducted in similar conditions as encountered in cutting process. Pion-on disc friction tests allow light pressure (< 1Mpa) and temperature. Moreover, the working surface is not refreshed such as cutting process. So, the value obtained by this means is usually overestimated. The modified pin-on-disk device proposed by Olsson [4], allows refreshing the working material such as the cutting process. However, the pressures applied on the pin-on-disk device are still low regarding to the mechanical conditions during machining. In the test proposed by Joyot [5], even if the loading system is high enough to impose a high pressure, the temperature at the interface between the frictional tool and the working material are not similar in regards to those supposed during cutting process. As a result of that, the chemical diffusion at tool-chip interface is not taken into account.

A different approach is to use machining tests to obtain an approximation of Coulomb friction coefficient from a macroscopic point of view. An example of this idea is Albrecht's method [6], which will be explained later in this paper. However, when applying this experimental coefficient friction as a constant value over all the rake face, including the cutting edge area, differences are found between numerical and experimental results, which can be very important in the case of very low uncut chip thickness.

The aim of this paper is to present a new approach to model friction effects over the rake face in order to reduce differences between numerical and experimental results regarding the cutting and feed forces.

First of all, the method to obtain a Coulomb friction at the tool-chip interface will be presented. In a second point, comparisons between experimental and numerical results will be showed. Then, the basic idea of the method will be explained and results will be detailed. Finally conclusions are pointed out.

2. COULOMB FRICTION COEFFICIENT IDENTIFICATION

In order to identify a Coulomb friction coefficient at the tool-chip interface, we have used an analysis based on Albrecht's works [6-8]. Thus, the cutting tool is not considered such as a perfectly sharp but has a cutting edge. According to the orthogonal cutting scheme, Figure 1 shows the forces decomposition proposed by Albrecht. The resultant of the cutting force is the sum of two parts. One part represents the force (P) resulting from localised phenomena close to the cutting edge (rubbing, forcing back). The second part represents the force (Q) applied on the rake face. These last forces can be split into normal and tangential contributions, thus defining a Coulomb tool-chip contact friction.

For a critical uncut chip thickness, Albrecht assumes that the force (P) reaches a stable and constant value. It's the major drawback of the method. On the other hand, he assumes that for uncut chip thickness greater than the critical uncut chip thickness, the evolution of the two components of cutting forces (Fc, Ff) with the uncut chip thickness is obtained by the sum of the two vectors (P) and (Q).

So, for each uncut chip thickness, we can plot a point in the (Fc, Ff) plane. We obtain a curve make up of a linear part and a non-linear part. The linear part of the curve gives an approximation of the Coulomb friction (μ) at tool-chip interface, while the non-linear part gives the critical uncut chip thickness.

3. EXPERIMENTAL AND NUMERICAL RESULTS

Coulomb friction coefficient of $\mu = 0.23$ is usually found when machining AISI 4140 steel with cemented carbides grade P. [7]. In a first step this value will be the input data,

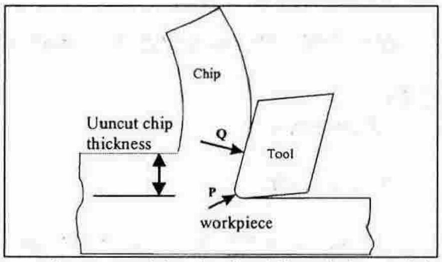

Fig. 1 Forces decomposition in the Albrecht's model.

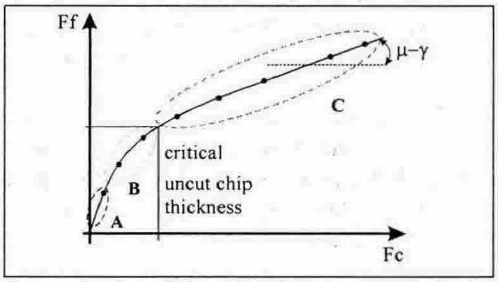

Fig. 2 Determination of the critical feed rate. μ is the Coulomb friction parameter, while γ represents the rake angle of the cutting tool.

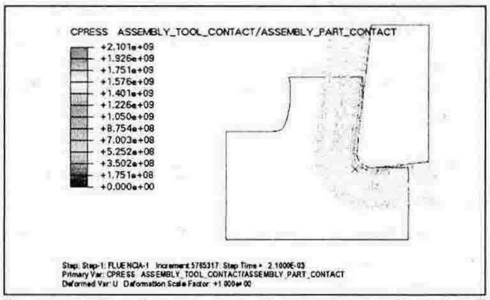

Fig. 3 Pressure distribution over the tool-rake face for 0.2 feed rate.

as a friction coefficient, in a 2D numerical that has been set up in Abaqus, using an Arbitrairian Lagrangian Eulerian approach [3]. Several numerical tests were carried out with different uncut chip thickness in order to compare them with experimental ones carried out by Grolleau [7], regarding the cutting and feed forces. In Figure 4, Ff-Fv results are plotted for experimental and numerical tests. A shift in the numerical curve is observed, giving lower cutting forces, but above all feed ones.

It is observed as well that the critical uncut chip thickness in numerical tests is much lower that in experimental ones.

These differences in numerical Ff-Fv graphic can be due to several reasons: cutting edge radius effect is not taken into account properly, material deposition observed in experimental tests is not modeled in numerical tests, friction coefficient can depends in pressure, temperature...and besides that it could not be a constant value over all the tool-chip interface. In fact, an increase of friction coefficient could lead to an increase of material deposition, thus a modification of the actual cutting edge radius when machining.

4. NEW APPROACH

In order to match better, numerical, we propose to use a variable Coulomb friction value over the rake surface area applied from the end of cutting edge radius to the tool-chip contact length corresponding to the experimental critical uncut chip thickness found experimentally.

From the Ff-Fv graphic, it is observed that the critical uncut chip thickness is higher than the cutting edge radius. Between these values the Ff-Fv graphic slope decreases continuously from "0" the uncut chip thickness to the critical uncut chip thickness. Adjusting the Ff-Fv points allows us to obtain a continuous curve. Thus, deriving it allows having a Coulomb friction value for each feed, after equation 1:

$$\mu = \tan\left[\arctan\left(\frac{dF_f}{dF_c}\right) + \gamma\right] \qquad (1)$$

Tool-chip contact length can be measured for each experimental test. Thus, a Coulomb friction coefficient-undeformed chip thickness can be obtained. Three zones are distinguish: (C) rake surface area where a constant value of μ = 0.23 is applied (B) rake surface area where a variable of μ is applied and (A) rake surface-cutting edge area where a constant value equal to the B zone close to it is applied.

Figure 3 shows numerical results obtained when using this variable friction coefficient over the rake surface. As can be observed a good correlation is reached.

5. CONCLUSIONS

Using a variable friction coefficient obtained from experimental results allows obtaining a good correlation regarding the cutting forces, especially important in the case of low uncut chip thickness. More than the result itself, this contribution show the importance of friction effects and the necessity to corectelly evaluate it as a function of temperature, pressure,...

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