SIMULATION OF CUTTING PROCESS IN TURNING POLYAMIDE PA 66

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Abstract: This paper presents simulation of cutting process by turning of polyamide PA 66, the simulation based on approach Arbitrary Lagrangian Eulerian, ALE. Was taken into account a tool knife CNMA from Coromant. The flow stress of the workpiece is modeled as function of strain, strain rate and temperature, so as to reflect its dynamic changes in physical properties. In this way, the influences of depth of cut, feed rate and cutting velocity on the force cutting are analyzed by FE simulation.

1. Introduction

The phenomenon of chip formation is essential in the cutting process. This represents the basis for researches regarding such physical phenomena as: the cutting force, the temperature, the tool's wear etc.

According to a study made by CIRP Working Group on Modelling of Machining Operations between 1996 and 1997 [1], among 55 modelling research centres, 43% work with empirical modelling, 32% with analytical modelling and 18% with numerical modelling, and the finite element modelling techniques are the dominant tools. In the past few years, the applications of the finite element in metal cutting developed very much due to their advantages and to the progress of powerful computers [2, 3].

The method of the finite element was used to simulate the cutting process by Klamecki [4], Okushima [5] and Tay and others [6] since the beginning of the 70's. Along with the development of fast processors with high memory, the limits of the model and the processing difficulties have been somehow overcome. In addition, many programmes simulating chip formation with the help of the finite element have appeared, such as: NIKE2™ [7], ABAQUS/Standard™ [8], MARC™ [9], DEFORM 2D™ [10], [11], FORGE™ [12], [13], ALGOR™, FLUENT™, ABAQUS/Explicit™ [14] and LS DYNA™ [15].

Great progress was achieved in this field of research: the Lagrangian approach is used to simulate the cutting process, the incipient stage of chip formation is included [16], the segmental chip formation is modelled in order to simulate the cutting process at high speed [17, 18, 19] or at high negative values of the angle of departure [20], the 3D simulation is made in order to analyse the oblique cut [21], [4], [22], [23], etc.

The main types of cutting processes simulated are: lathing [24], milling [25], drilling [20]. The orthogonal cut is the most frequent simulated cutting process [26].

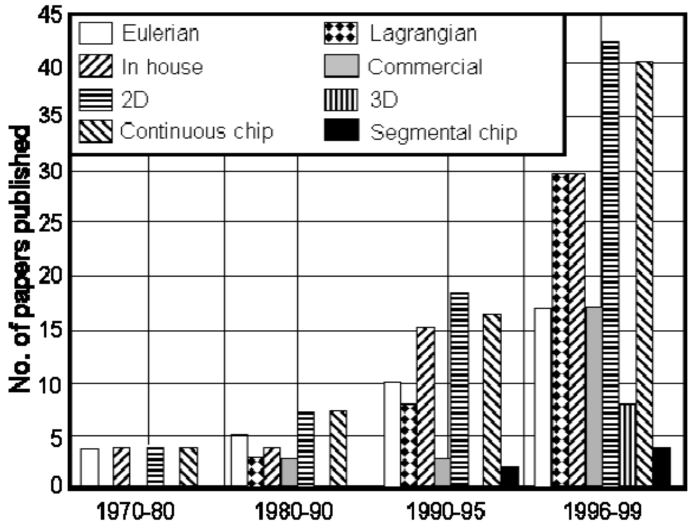

Fig.1 Research trends in finite element modelling [26]

2. Numerical aspects regarding material simulation

The implementation of simulating the cutting process is based on numerical and technical theory. Their development helps the improvement of the simulation capacity.

For the numerical simulation there are several methods: Lagrangian, Eulerian and Arbitrary Langrangian Eulerian (ALE).

In the Eulerian method, the mesh, as well as the flux of material, are fixed. The Eulerian method is adequate to analyse the state of equilibrium of the cutting process, without including the action of moving from the equilibrium state to the cutting process state, by varying the cutting depth at lathing or the segmental chips at high speed cutting the free surface conditions cannot be simulated. The analysis of the cutting process using the Eulerian method takes less time to calculate because the model of the semi-product (the working part) is made of fewer elements. This is the reason why before 1995 the applications of the Eulerian method in the analysis of chip formation overtook those of the Lagrangian method. But experimental activity is most of the time needed in order to determine the geometry of the chip and the shearing angle, which are an inevitable part of geometrical modelling.

In the model proposed by the Lagrangian method, the mesh follows the material. Since the deformation of the free surface of the chip can be treated automatical as an elastic-plastic deformation, the Lagrangian method can be used to simulate the action of moving from the initial state to the cutting process state. But, in order to expand the cutting period to the state of equilibrium we need more time to model the part geometrically, this modelling increases the time to calculate. In order to divide the chip we have to take into consideration the criteria and method of dividing the chip.

The ALE method combines the characteristics of both the Lagrangian and the Eulerian methods, the mesh can move independent of the material. The improvement of the quality of the mesh is an efficient tool in the analysis of high deformations. Many FE programmes introduce ALE methods to adjust the mesh based on its adaptability.

The adaptive technique of discretization in ABAQUS/Explicit is part of the ALE method. This can be used to analyse both Lagrangian and Eulerian problems. Through the adequate control of the mesh parameters, the entire process, from the initial to the equilibrium state, can be simulated without using the criterion of dividing the chip or other data about the geometry of the chip obtained through experiments. This is why the time to calculate is not high.

The precision of the finite element analysis depends very much on the accuracy of the mechanical properties of the material.

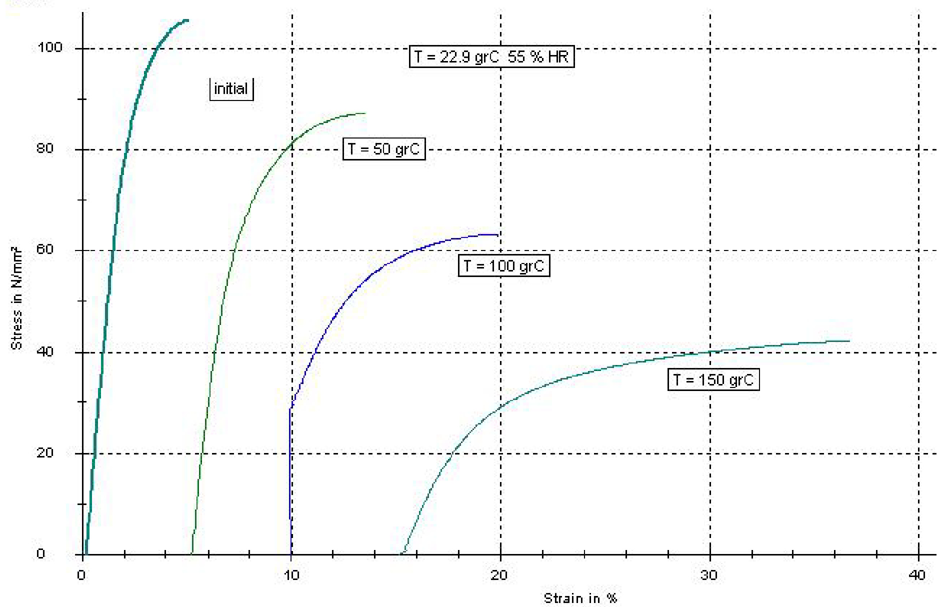

Fig.2 The curve of the properties of PA 66 material

The influence of the properties of the material on the factors

Experiments have shown that the properties of the material, the relation stress-deformation, are affected by the rate of deformation and the temperature during the plastic deformation process of materials. For the same value of deformation, the stress is higher at a higher deformation rate due to the viscous aspect during the plastic deformation at lower and higher temperatures, and to the softening of materials, as presented in fig. 2.

This over-pressure due to the effect of the deformation rate is more accentuated with the increase of temperature [27]. During the cutting process of metals, the temperature, the deformation and the rate of deformation are very high. The thermo-viscous-plastic model of the material is needed for the finite element analysis at metal cutting.

3. Simulating the work of PA 66 polyamide by lathing

In order to describe the material, some models are specified in the technical literature, among which: Hollomon, Ludwik, Bergström, Johnson – Cook, Zerrili-Armstrong, Poulachon, Cowper – Symond, Huh and Kang and others. A part of these models resemble and most of them contain the deformation, the deformation rate and the temperature.

In this case the material was defined following Johnson – Cook model, equation 1:

$$\sigma = (A + B \cdot \varepsilon_p^n) \cdot \left[1 + C \cdot \ln\left(\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_0}\right)\right] \cdot \left[1 - \left(\frac{T - T_0}{T_m - T_0}\right)^m\right] \quad (1)$$

where:

- A, B, C, m, n – coefficients that define the material;
- T – temperature [^{0}C];
- T_0 – reference temperature [^{0}C];
- T_m – flowing temperature [^{0}C];

- ε – deformation [mm];
- $\dot{\varepsilon}$ - deformation rate [s^{-1}]

Generally speaking, at all defining models $A = \sigma_{0,2}$.

Based on this material simulation was made under the following conditions: lathe plate CNMG 08 12 04 (K15), side cutting edge angle 10^0, back rake angle (inclination angle) -5^0, side rake angle (normal rake angle) -5^0, working feed f = 0.1 and 0.4 rot/min, cutting depth a_p = 0.5 and 2 and cutting speed v = 58.875 and 235.5 m/min.

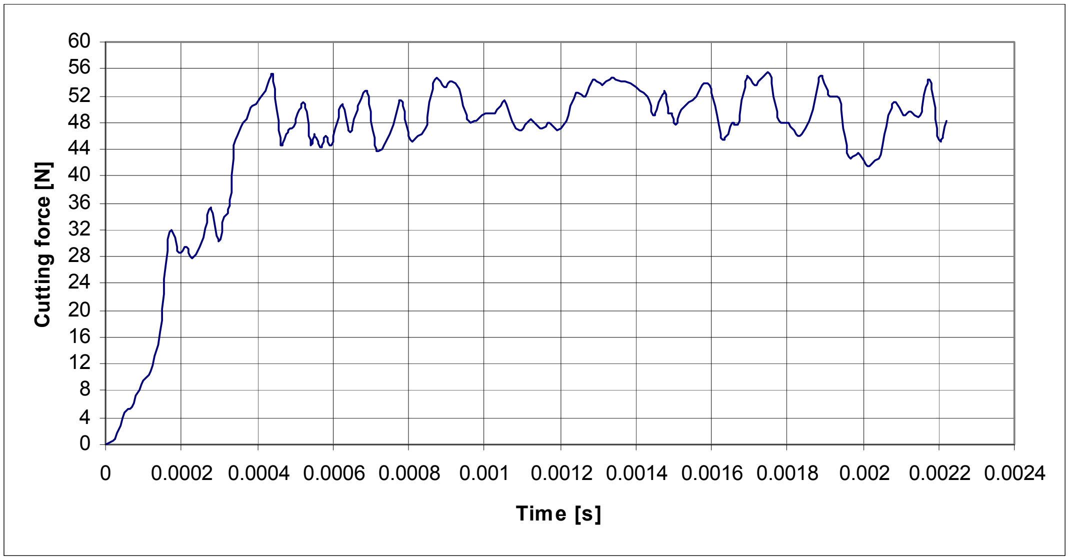

Fig. 3 The cutting force F_z - a_p = 0,5 mm, f = 0,1 mm/rev, v = 58,875 m/min

Figures 3 and 4 present both the influence of the parameters of the cutting regime on the force of cut, F_Z, and the comparison of the results obtained after simulation with the experimental results [MOT 10].

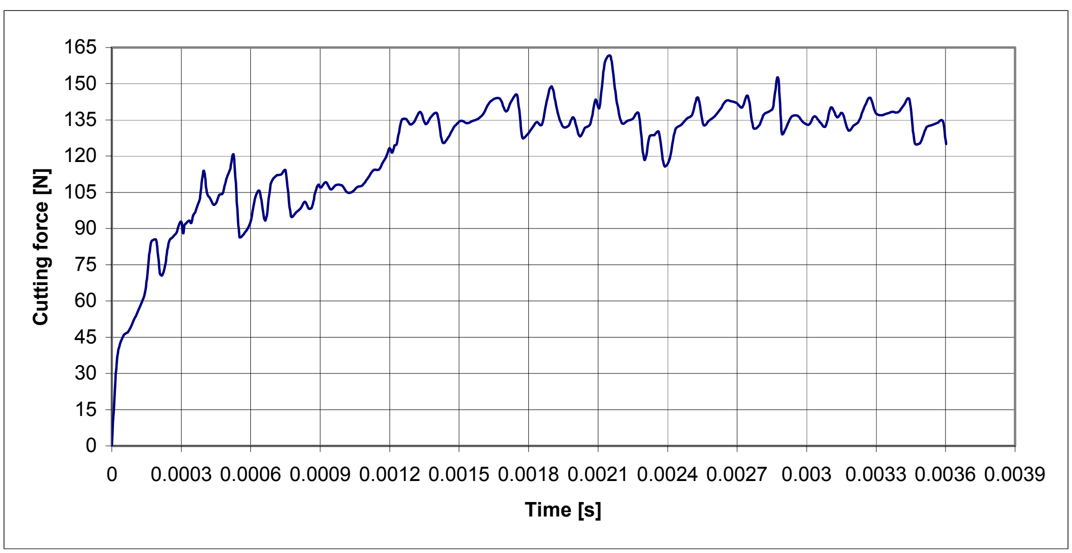

Fig. 4 The cutting force F_z - a_p = 2 mm, f = 0,4 mm/rev, v = 235 m/min

4. Conclusion

We notice that between the results obtained based on simulation and the experimental results, there is a slight difference, but, since this difference is under 10% we may consider that they can be used as such. Based on these results and since simulation is far less expensive than experimental research, we can consider the fact that we can use the finite element method in the case of plastic materials, as well as in the case of metallic materials, in order to determine some parameters of the cutting process, no matter what type.

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