LAGRANGIAN AND ALE APPROACH FOR PREDICTING RESIDUAL STRESSES IN ORTHOGONAL CUTTING

N.C. Marín, M.H. Miguélez, J.A. Canteli, J.L. Cantero
Department of Mechanical Engineering, Universidad Carlos III, Madrid, Spain

1. Introduction

Machining is a complex process involving very large strains and strain-rates, which cause large temperature increase. Improvement of tool performance and quality surface requires good understanding of the process. Since most process variables are difficult to measure, analytical and numerical modelling of chip formation are versatile and reliable approaches to obtain information on some local variables of the workpiece and the cutting tool [1,2]. Finite element analysis has provided an insight look at what is going on during cutting, which is difficult to achieve by experimental or analytical methods. Eulerian, Lagrangian and Arbitrary Lagrangian-Eulerian (A.L.E.) techniques have been used to simulate orthogonal cutting. [3,4]. In Lagrangian analysis, the computational grid deforms with the material whereas in Eulerian analysis it is fixed in space. The Lagrangian calculation embeds a computational mesh in the material domain and solves for the position of the mesh at discrete points in time. Two distinct methods, the implicit and explicit time integration techniques, could be used to implement these analyses. A.L.E. is a relatively new modelling technique in machining, including a combination of the Lagrangian and Eulerian approaches without having their drawbacks. It was firstly introduced to model the cutting process by the end of the last decade. This approach became popular due to its implementation in commercial finite element codes. Explicit dynamic A.L.E. formulation is very efficient for simulating highly non-linear problems involving large localized strains.

The residual stress field in a machined surface is one of the most important factors influencing the surface quality. In fact, residual stress distribution can affect the workpiece material behaviour during service loading (fatigue, fracture, stress corrosion) [5]. Residual stresses are produced by mechanical and thermal phenomena associated with the process of chip formation. The nature of residual stresses depends not only on machining parameters such as cutting speed, feed rate, depth of cut, but also on the tool geometry and the lubrication conditions.

In this work, orthogonal cutting is modelled with ALE approach (ABAQUS/Explicit code) and Lagrangian approach (DEFORM-2D™ code). The aim of this paper is predicting residual stresses after orthogonal cutting, comparing general and specific codes. The study is focused on AISI 316L a difficult-to-machine material, because of high strain hardening effects and low thermal conductivity [6]. Advantages and drawbacks of both codes are analyzed.

2. Numerical models

A plane strain A.L.E. model was developed in ABAQUS/Explicit. A thermo-mechanical coupled analysis was developed, with CPE4RT element type (see ABAQUS manual). These are plane strain, quadrilateral, linearly interpolated, and thermally coupled elements with automatic hourglass control and reduced integration, for A.L.E. formulation. In DEFORM-2D™, the workpiece was initially meshed with 10000 isoparametric quadrilateral elements. The tool was modeled as rigid and meshed with 6000 elements.

For both models, the cutting velocity is 120 m/min and the feed used was 0.1 mm. The clearance angle, rake angle and the edge radius are 10º, 0º and 0.02, respectively. Analysis was carried out in two steps. In the first step, cutting was modelled at constant cutting speed and steady state conditions were reached. In the second step, the workpiece was unloaded and cooled. The residual stress distribution was obtained in a section of the workpiece corresponding to stationary conditions during cutting. The workpiece material was modelled using the Johnson-Cook (JC) constitutive model [7].

3. Results

Fields of residual stress in direction x (the direction of cutting speed) after unload and cooling obtained with DEFORM-2D, is shown in figure 1(a). Residual stress is tensile in machined surface, the level is around 900 MPa. Distribution of residual stress in depth into workpiece obtained with ABAQUS/Explicit is shown in figure 1 (b). The level of tensile residual stress in machined surface is higher with this code.

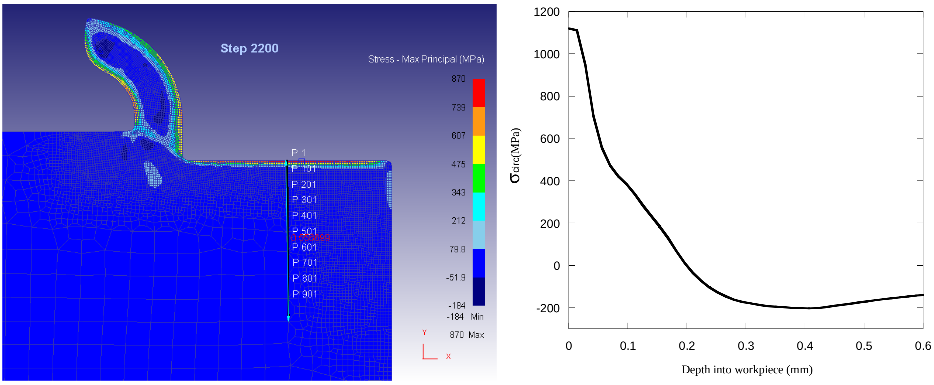

Figure 1. (a) Fields of residual stress (circumferential) obtained with DEFORM-2D. Circumferential stress obtained in depth in workpiece with ABAQUS/Explicit.

In Lagrangian formulation using DEFORM-2D^{TM}, the mesh should be very fine around the tool tip, this fact increases the computational cost of the simulation. In the ALE model a specific mesh should be defined for a given tool geometry, being necessary to make some iterations to obtain the initial geometry of the chip able to deform to the final shape of the chip. Changes in tool geometry imply the development of a new initial geometry for the chip.

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5. References

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