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Finite Element Modeling of Tube Piercing and Creation of a Crack

Yvan Chastel[1], Aliou Diop[1], Silvio Fanini[2], P.O. Bouchard[1], Katia Mocellin[1]

[1]*Centre de Mise en Forme des Matériaux, CEMEF (ENSMP) – rue Claude Daunesse, 06904 Sophia-Antipolis, France*
URL: http://www-cemef.cma.fr *e-mail: yvan.chastel@ ensmp.fr*

[2]*DIMEG, University of Padova, Via Venezia 1 - 35131 Padova, Italy*

ABSTRACT: A 3D simulation of Mannesmann tube piercing is performed using the finite element software Forge 2005®. The sensitivity of the simulation results to numerical methods and physical parameters is discussed. Advanced numerical schemes and refined time discretizations are required to obtain correct descriptions of the material flow. In this study, one concentrates on the stress state and damage development before the material comes in contact with the plug. Indeed, the crack is to appear prior to the action of the plug. The description of the material behaviour is found to be a key information to predict the crack development. Predictions based on a modified Lemaitre damage law and a normalised Latham and Cockroft criterion are compared.

Key words: Tube piercing, Mannesmann effect, damage

1 INTRODUCTION

The Mannesmann tube piercing is a hot temperature process in which a solid bar is deformed in between two rotating bi-conical rolls. The process relies on the cyclic mechanical loading of the material caused by the conical shape of the rolls and their rotation. The material is pulled-in along a helical trajectory and a depressive mode causes a hole to form and develop in the billet (Figure 3).

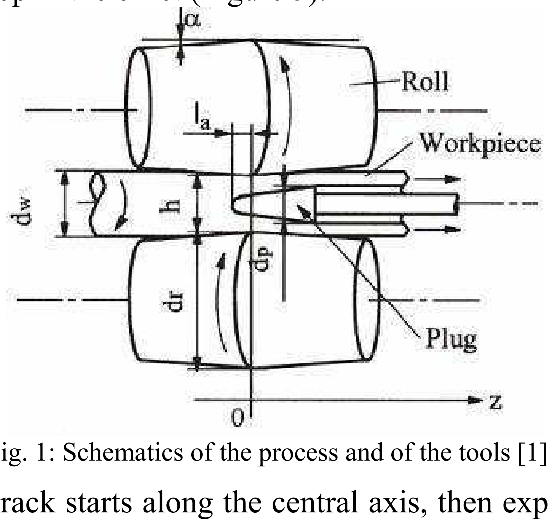

Fig. 1: Schematics of the process and of the tools [1]

The crack starts along the central axis, then expands and propagates. A plug is placed downstream to guide the material outward that a seamless tube can be produced.

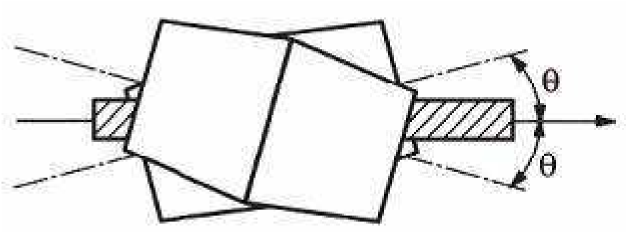

Fig. 2: Orientation of the rolls with respect to the billet [1]

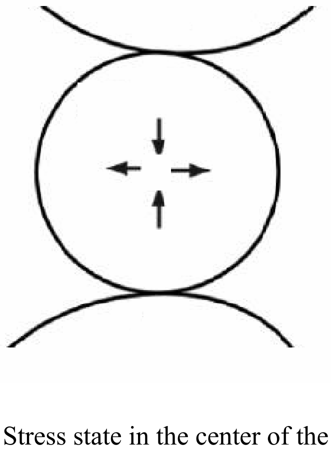

Fig. 3: Stress state in the center of the billet

The numerical simulation of this process is complex because of the kinematics of the rolls which forces the billet to rotate. A numerical model of the process is presented in this paper. The induced strains are very large. Shear, tensile and compressive modes are combined. One central phenomenon in the process is damage. Rheological models with damage have to be included to track the crack growth and to study the radial expansion which leads to the shaping of the tube. An optimal position is looked for which should take into account the oxidation of the billet material and the progressive wear of the plug (Figure 4). These features are not explicitly included in this paper.

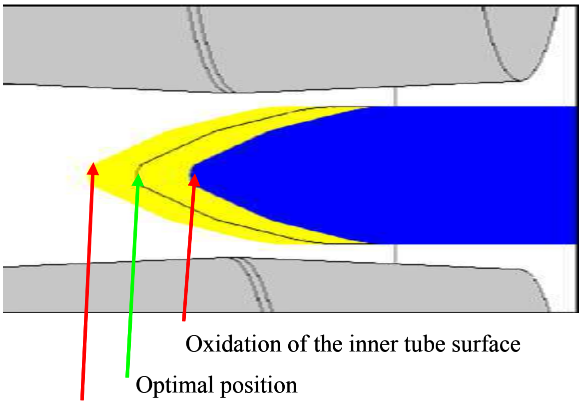

Fig. 4: Positions of the billet and of the plug

2 THE NUMERICAL MODEL

The software FORGE2005® is used as the basis for modelling the process. Six tools are included in the model: a pusher, two rolls, two guides and a plug, as depicted in Figure 5. The two rolls are rotating at 70 rotations/minute, and their axes form a 6° angle. The diameter of the billet is 200 mm and it is assumed to be at 1250°C as it enters the roll bite. At the beginning of the deformation, the temperature of the rolls is taken as 200 °C and the plug is 800°C. The constitutive law for the steel grade of interest writes:

$$\sigma = A \exp(T\, m_1)\, \varepsilon^{m_2}\, \dot{\varepsilon}^{m_3} \qquad (1)$$

The material parameters are obtained from experimental tests:
A = 10642 MPa. s^{m3}
m1 = -0.004 /°C
m2 = 0.164
m3 = 0.119

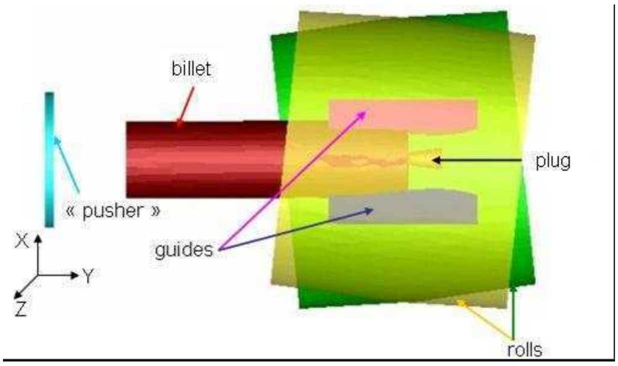

Fig. 5: Position of the tools in the numerical model

The contact with the billet and the rolls is assumed to be close to sticking friction. Sliding modes are applied to model the contacts between the billet and the guides.

3 NUMERICAL SENSITIVITY ANALYSES

3.1 *Time discretization*

The billet rotates all along the deformation stage. In updated Lagrangian formulations, large rotations are known to cause numerical volume increase which is artificial and leads to significant errors. The classical update, the explicit Euler scheme, can be written writes as in (2) for an update of the material position X moving at a velocity V over a time step dt :

$$X_{t+dt} = X_t + V_t \times dt \qquad (2)$$

For such processes, the second order Runge Kutta scheme as expressed with equations (3) and (4) proves better (see sketch in Figure 6) :

$$X_{t+\frac{dt}{2}} = X_t + V_t \times \frac{dt}{2} \qquad (3)$$

$$X_{t+dt} = X_{t+\frac{dt}{2}} + V_{t+\frac{dt}{2}} \times \frac{dt}{2} \qquad (4)$$

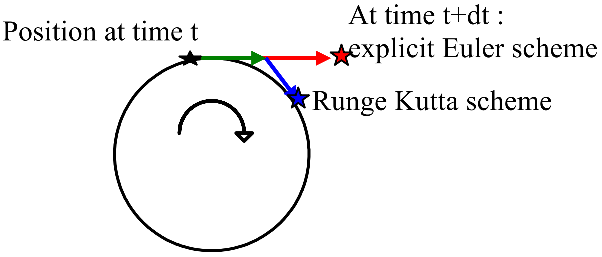

Fig. 6: Numerical update of the configuration over a time step

In the real tube piercing process, the total deformation time for each material volume is about 5 seconds. Even with a second order Runge Kutta integration scheme, some numerical volume increase is observed. Figure 7 shows a sensitivity study of this volume increase with the time step.

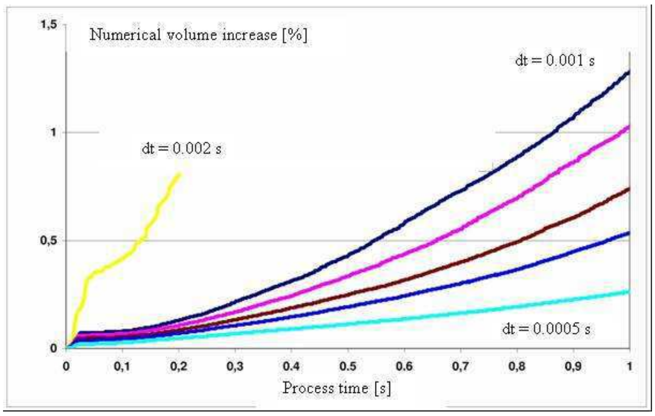

Fig. 7: Volume increase in the numerical simulation during the first second of the process for various time steps

An artificial and excessive shearing at the contact zone with the guiding tools can also be obtained in the numerical simulation at the outer surface of the billet (Figure 8).

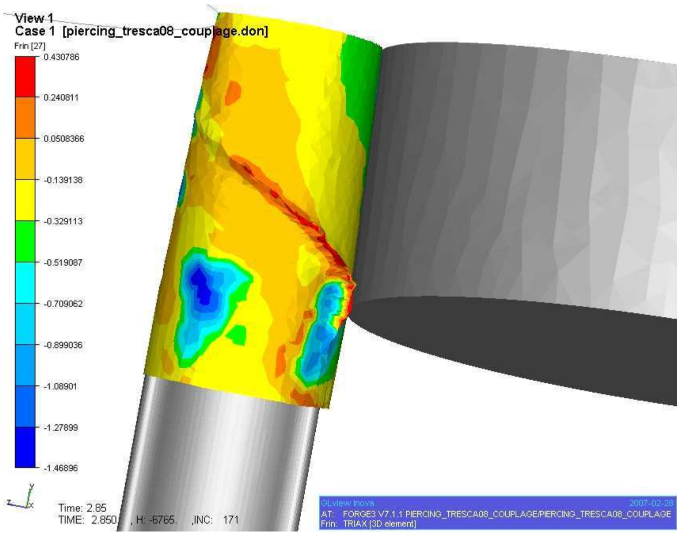

Fig. 8: Stress state in the center of the billet

A small time step can prevent these errors. But, reducing the time step leads to an increase in the required CPU time (Figure 9).

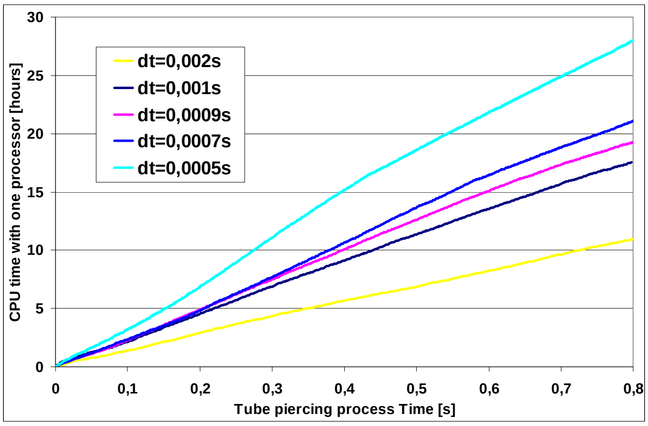

Fig. 9: CPU time required with one processor

3.2 *Stability of the process*

Given the kinematics of the rolls, the billet tends to twist. This is observed in practice. It makes the simulation very difficult since the position is then very sensitive to the friction model for instance. We concentrate on a configuration which would give a stable flow i.e. a flow with a fixed longitudinal axis of the billet as it goes into the roll bite. To enforce this stable motion of the billet in the numerical model, the shape of the two guiding tools is modified (Figure 10).

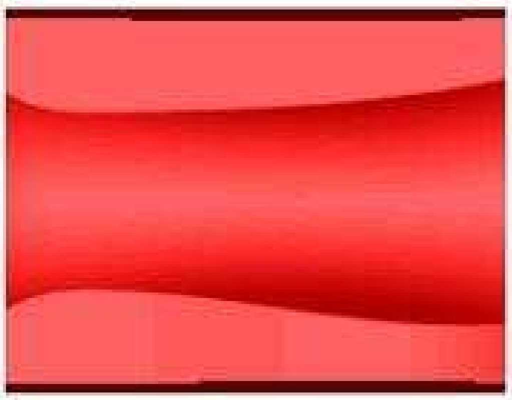

Fig. 10: Guiding tool used in the Finite Element model

4 MODELLING DAMAGE AND CRACKS

Two models were used to describe damage evolution during the process, a normalised Latham and Cockcroft and a modified Lemaitre model [2] which is updated incrementally (5):

$$dD = \begin{cases} 0 & \bar{\varepsilon}_p \le \varepsilon_D \\ \dfrac{D_C}{\varepsilon_R - \varepsilon_D}\left[\dfrac{2}{3}(1+\nu) + 3(1-2\nu)\left(\dfrac{\sigma_H}{\sigma_{eq}}\right)^2\right] d\bar{\varepsilon}_p & \bar{\varepsilon}_p > \varepsilon_D \end{cases} \tag{5}$$

where D is the damage variable, E the Young's modulus, ν the Poisson's ratio, σ_H the hydrostatic pressure, σ_{eq} the von Mises equivalent stress, ε_D the strain of damage onset, ε_R the strain at fracture, D_C the amount of damage at fracture.

This model is modified in order to take into account the loading in tensile on one hand, and in compressive modes on another hand [3]. This is necessary since a material volume of the billet experiences cyclic loading in the tube piercing process. Damage parameters are calibrated using tensile tests and micrographic analysis of the initial porosities in the material. As an example, a map of the damage intensity is shown in Figure 11.

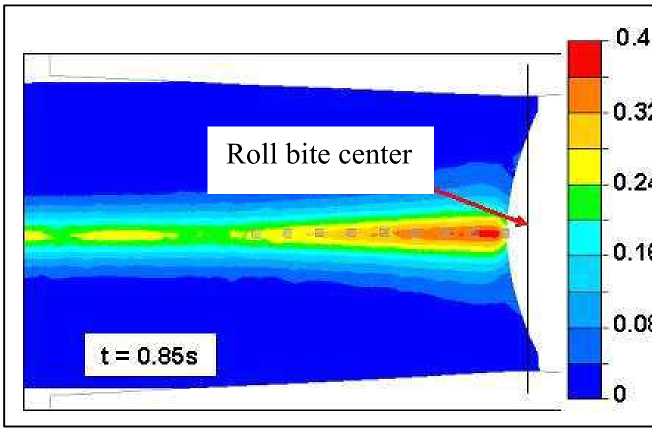

Fig.11: Damage values according to the modified Lemaitre model in a longitudinal cross section of the billet. The line shows the center of the roll bite i.e. the intersection between the central planes of the biconical rolls

The position of maximum damage is predicted along the central axis of the billet, and a critical damage value corresponding to the creation of a crack is found inside the billet, at about 14mm within the billet. As observed in the industrial products, the crack is created along the central axis upstream from the roll bite center. A kill element technique is coupled in Forge2005® to show and propagate the crack (Figure 11).

5 CONCLUSIONS AND PERSPECTIVES

The tube piercing starting from solid billets has been investigated and modelled using a 3D finite element code. Specific features of the code were used to prevent artificial volume increase and to describe the stable motion of the billet. Rheological and damage models were identified and used to estimate where and when crack is created.

The next step has been to describe the material flow thereafter, once the plug is in place.

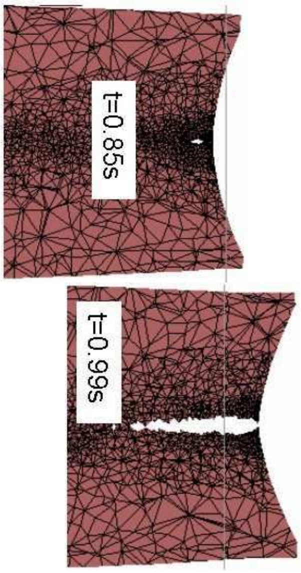

Fig. 12: Crack in the billet after 0.85 and 0.99 second.

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