

On the modeling of the Mannesmann piercing process

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Abstract

With the hypothesis of rigid-viscoplastic material model we have simulated the Mannesmann piercing process. The model has been developed using our finite element code METFOR which is based on the flow formulation and the pseudo-concentrations technique. Since the results of the Mannesmann piercing model are highly dependent on the contact boundary conditions, an improved methodology for dealing with this conditions was implemented. The numerical results were validated by comparing them with experimental determinations; therefore, the model constitutes a valuable engineering tool for analyzing the effect of different operational set-ups.

Keywords: Mannesmann piercing process; METFOR; Pseudo-concentration technique

1. Introduction

The flow formulation, based on the hypothesis of rigid-viscoplastic material behavior has been widely adopted for modeling bulk metal forming processes [1]. An Eulerian implementation of the flow formulation, the pseudo-concentrations technique, has been presented in [2,3].

At the Center for Industrial Research we have implemented, in our finite element code METFOR, the flow formulation via the pseudo-concentrations technique and we have used it to analyze manufacturing processes related to the steel industry (see [4–13]). A summary of this implementation is presented in the second section of this paper.

For manufacturing seamless steel pipes the most standard route is:

- Continuous casting of round bars.
- Piercing of the round bars to get hollows (Mannesmann process).
- Rolling of the hollows to produce the pipes.

A scheme of the Mannesmann process is presented in Fig. 1.

Observations:

- The central hole is not pierced by the plug: it is formed at the bar center where the material is

weakened by the rotating system of orthogonal tensile/compressive stresses induced by the rolling in the convergent zone of the bi-conical rolls (Mannesmann effect) [14]. A pipe can be produced even without the plug; but, in this case, the central hole will have an irregular star-like shape rather than the desirable smooth round one. The plug functions are to guide the material after the Mannesmann effect and to prevent the oxidation of the formed inner surface.

- The plug is conveniently located in advance of the section where the Mannesmann effect produces the first macroscopic hole in the bar center. The objective is to prevent a spontaneous (not guided) hole from developing; however, if the plug would be located too much in advance it would be rapidly worn by the incoming bar not yet centrally weakened.
- The bar is heated at approximately 1200 °C before entering the piercing process, it is extremely important that the center of the bar is as close as possible to the hottest (weakest) point because the hole is going to be localized at this weakest point and it is important to reduce the hollow bar eccentricity as much as possible.

In the third section of this paper we present a METFOR simulation of the Mannesmann piercing process [15,16]. The validation of our finite element results is performed by comparing them with the results of

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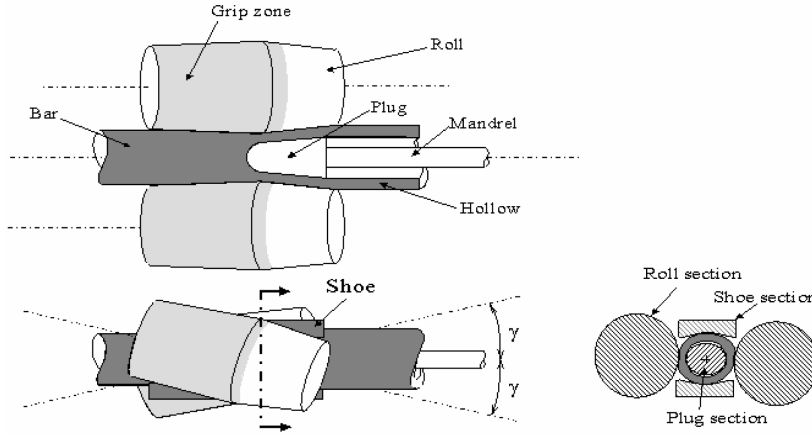


Fig. 1. Scheme of the Mannesmann piercing process.

industrial measurements developed at the plant of TenarisDalmine where steel seamless pipes are manufactured.

2. The flow formulation via the pseudo-concentrations technique

For modeling bulk metal forming processes we implemented an Eulerian formulation in which we use a fixed mesh with the material moving inside it; at each point interior to the mesh we define a variable named *pseudo-concentration* (c):

$f_1 \leq c \leq f_2 \iff$ there is material at the point,

$f_1 \geq c$ or $c \geq f_2 \iff$ there is no material at the point.

Being (\underline{u}) the velocity field inside the mesh, the c -distribution fulfills the following equations:

$$\underline{u} \cdot \nabla c = 0 \quad (\text{stationary problems}) \quad (1a)$$

$$\frac{\partial c}{\partial t} + \underline{u} \cdot \nabla c = 0 \quad (\text{transient problems}) \quad (1b)$$

For modeling the material behavior we use a rigid-viscoplastic constitutive relation [17]; the material flow is described via a viscoplastic associated von Mises model; hence, the material flow is incompressible. In our finite element formulation we impose the incompressibility constraint via an augmented Lagrangian procedure [11].

The equivalent viscoplastic strain is also obtained using transport equations ($\bar{\epsilon}$ -transport equations) [12].

An iterative algorithm coupling the c -transport equations, the $\bar{\epsilon}$ -transport equations and the equilibrium equations was developed in our previous publications.

Since in our Eulerian formulation the material moves inside a fixed mesh:

- The formulation provides the free surfaces in stationary and transient problems without any special free surface algorithm.
- The formulation does not require a remeshing algorithm, usually needed when using Lagrangian or Eulerian-Lagrangian formulations.

The modeling of the contact problem between the blank and the forming tools is discussed in our references [11–13]. For modeling the friction between the blank and the forming tools we use either a constant friction law or a Coulomb friction law [18] and we apply friction loads only at the points of the tools-blank interface where the contacts are established and actual material is present ($f_1 \leq c \leq f_2$).

The material viscosity for the regions where no material is present ($f_1 \geq c$ or $f_2 \leq c$) is low enough so as not to influence the actual material flow and not so low as to incorporate conditioning problems [12,13].

2.1 Constitutive relations

When modeling hot metal forming processes using rigid-viscoplastic material models we use an associate viscoplastic flow rule with von Mises yield function [17]. Also an isotropic hardening law is normally used to relate the instantaneous yield stress (σ_y) with the equivalent viscoplastic strain ($\bar{\epsilon}$), the equivalent viscoplastic strain rate ($\dot{\bar{\epsilon}}$) and the temperature (T),

$$\sigma_y = \sigma_y(\bar{\epsilon}, \dot{\bar{\epsilon}}, T) \quad (2)$$

In our research on hot metal forming processes we have used three constitutive laws:

- *The Fields-Backofen model*
- $$\sigma_y = A(T) \bar{\epsilon}^{m(T)} \dot{\bar{\epsilon}}^{n(T)} \quad (3)$$

- Exponential-power law 1

$$\sigma_y = [A(T) e^{-B(T)\bar{\epsilon}} (\bar{\epsilon} + \bar{\epsilon}_o)^{n(T)} + C(T) (1 - e^{-B(T)\bar{\epsilon}})] \dot{\bar{\epsilon}}^m(T) \quad (4)$$

- Exponential-power law 2

$$\sigma_y = [A(T) e^{-B(T)\bar{\epsilon}} \sqrt{1 - e^{-n(T)(\bar{\epsilon} + \bar{\epsilon}_o)}} + C(T) (1 - e^{-B(T)\bar{\epsilon}})] \dot{\bar{\epsilon}}^m(T) \quad (5)$$

An algorithm for identifying the material parameters from the results of a simple test (e.g. the torsion test) is discussed in [4].

3. Modeling of the Mannesmann process

The results of this model are highly dependent on the correct modeling of the contact area between the tools (rolls, shoes and plug) and the blank. The algorithm implemented in METFOR for this problem is discussed in [13]; now we will just present some preliminary results that we obtained simulating two cases rolled at TenarisDalmine.

It is important to indicate that for the reported analyses we did not use damage criteria for simulating the Mannesmann effect but we just approximately introduced a ‘damaged area’; however the numerical results indicate that the model sensitivity to the extension of this ‘damaged area’, within reasonable bounds, is quite low.

Table 1 Comparison between numerical and experimental results

Plug profile	μ_{rolls}	μ_{shoes}	μ_{plug}	$L_{Mannesmann}$	FEA-pith	Exp. pitch
1	0.2	0.2	0.35	λ_1	1054 mm	1195 mm
1	0.5	0.2	0.35	λ_1	1252 mm	1195 mm
1	0.2	0.2	0.35	$2\lambda_1$	1158 mm	1195 mm
2	0.2	0.2	0.35	λ_3	695 mm	790 mm
2	0.5	0.2	0.35	λ_3	899 mm	790 mm
2	0.2	0.2	0.35	$2\lambda_3$	714 mm	790 mm

3.1. Model validation

A very sensitive parameter for comparing the numerical and industrial results is the pitch of the helix where the points initially on a straight generatrix get located; this helix pitch is a measure of the torsion imposed to the material by the process.

In Table 1 we compare the numerical and experimental results for two plug profiles. Considering the uncertainty introduced by the unknown value of the friction coefficients (Coulomb friction was used for these analyses) and the above commented approximation to the Mannesmann effect, the agreement between experimental and numerical results looks very promising.

In Figs. 2 and 3 we display the equivalent viscoplastic strains that are introduced by the first plug design and the equivalent viscoplastic strain rates for the case of the second plug design.

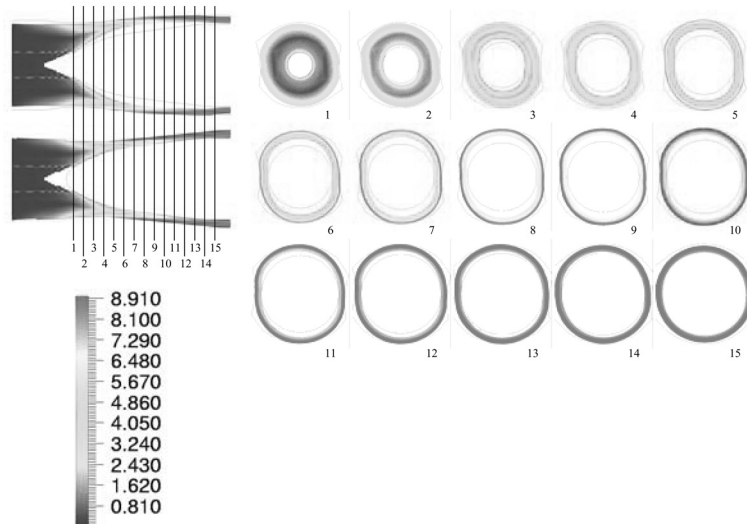


Fig. 2. Accumulated effective plastic strain for plug design #1. The two axial sections are: (a) top one through the shoes; (b) bottom one through the rolls.

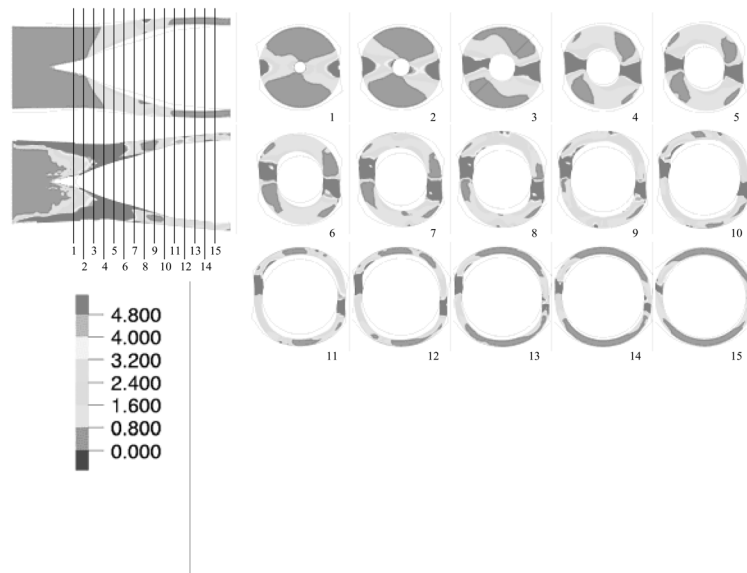


Fig. 3. Viscoplastic strain rates for plug design #2. The two axial sections are: (a) top one through the shoes; (b) bottom one through the rolls.

4. Conclusions

The modeling of the Mannesmann piercing process is quite involved because the problem is 3D with no obvious symmetry simplifications and the results are highly dependent on the correct definition of the contact areas between the blank and the tools.

In the present paper we discussed the validation of a model that we developed using the flow formulation implemented via the pseudo-concentrations technique.

A future task is the correct characterization of the Mannesmann effect, even though from the preliminary results reported in this paper we see that the solution has a low geometrical sensitivity to the definition of the 'damaged area'.

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