MODELLING PLASTIC DEFORMATION OF STAINLESS STEEL PIPES

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Abstract
Plastic deformation is the most common technique adopted to manufacture complex shape pieces in the most efficient way. Even higher requirements need to be faced in the different applications. In order to target such requirement quality and compliance tests are carried out aimed to guarantee that these standards are faced; this often means a waste of material and economic resources. A far as concerns welded stainless steel pipes many criticises affecting the general trend of subsequent machining need to be considered. In this paper, the effects of different process parameters and geometrical constrain on austenitic stainless steel pipe forming are studied by Finite Elements Method (FEM) simulations. The model sensitivity to input parameters is reported. The feasibility of the simulated process is evaluated through the use of Forming Limit Diagrams (FLD).

Keywords: stainless steel, plastic deformation, mechanical properties

1 Introduction

Stainless steels are today quite appealing materials both for scientific and commercial matters, based on to their excellent strength/ductility combination coupled to corrosion resistance [1-6]. Such materials are applied in all these fields facing with corrosion resistance requirements coupled with the capacity to be cold worked into complex shapes [7-8]. Plastic deformation is the most common technique adopted to manufacture complex shapes in the most efficient way [9]. In order to target such requirement quality and compliance, tests are carried out aimed to guarantee that these standards are faced; this often means a waste of material and economic resources. Plastic processing of stainless steel pipes is characterized by a poor behavior homogeneity [10]. This implies a considerable percentage of tests unreliability, performed on random specimens, following the steel intrinsic nature itself. Therefore, such tests, usually performed in terms of tensile tests according to specifications, are not considered enough to guarantee the requirements. Many types of research are facing on such item by predictive simulations based on Finite Element Method (FEM) numerical analysis [11-13] approach. Such works are aimed to predict the behavior of various shapes in different processing areas, such as hydroforming and bending, or cold metal forming of steel sheets. Many relevant industrial applications where a proper procedure of pipe bending and a correct simulation of pipe yielding after bending turns out to be critical are found in the literature (e.g. [14-17]). All these applications are based on the analysis of the steel mechanical behavior, both at the macroscopic level and at the crystalline structure and grain levels, such as stress-strain curves and hardening [18] caused by the plastic processing leading to the final required geometry. Concerning pipes manufactured from rolled stainless steel sheets, many critical points affecting the general trend

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of subsequent machining need to be considered, in particular regarding high strength materials for application in the structural field. Just as an example, the geometry of the pipe itself or the plastic processing procedure (e.g. speed and bending angle) are known to strongly affect the final result of the plastic deformation process. In this framework, the aim of the paper is to study the effects of different process parameters and geometrical characteristics on various austenitic stainless steels.

2 Test material and methods

The following materials and pipe geometries are considered:

- AISI 304
  - Diameter: 35 – 40 – 50 – 60 mm
  - Thickness: 1.0 – 1.2 – 1.5 mm
- AISI 316
  - Diameter: 35 – 40 – 50 – 60 mm
  - Thickness: 1.0 – 1.2 – 1.5 mm

All the considered materials were assessed for each combination of diameter and thickness in terms of tensile properties, according to the UNI EN ISO 6892 specification. The Formability Limit Diagram (FLD) is also used to describe the sample deformation paths. This plot contains the Formability Limit Curve (FLC) showing the maximum capacity of a material to be deformed, calculated by carrying out repeated Nakazima tests and measuring the deformation along the two perpendicular directions.
A commercial software package was adopted for numerical calculation. Such software allows adopting the Hill 48' yield function [19-20]. Such a function is known to be ideal for small-sized tubular geometries [12] as a constitutive equation for stainless steels behaviour taking into account the following parameters in order to simulate the bending process:

- Bending radius
- Bending angle
- Rotational speed

Based on the above assumptions/inputs the pipe bending behaviour is simulated.
Simulation outputs are analysed by mapping the calculated values (such as internal stress, thinning and deformation). Based on such maps it is possible to obtain the desired information for the case study.

3 Results and discussion

The input parameters effect on simulation results is reported below.

3.1 Pipe diameter

In the following a R/D=1 ratio is considered, being such values typical of what usually happens in the industrial applications. In **Fig.1** stress mapping for smaller and larger diameter sizes is reported as an example for the AISI 304 stainless steel. The stresses values reached for single diameter sizes are shown in **Fig. 2**.
Results show a variation of the maximum stresses in a range between -2% and 3% as a function of pipe diameter if R/D ratio is kept constant. Such variation can be considered negligible. Moreover, it is also clear that the internal stresses distribution is not strongly modified as the pipe diameter increases.

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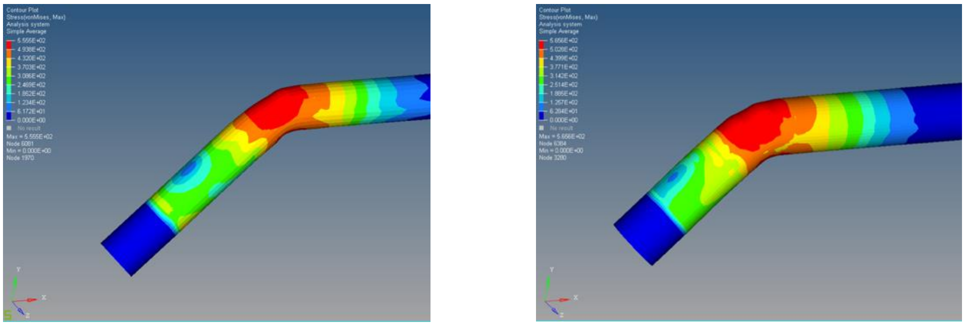
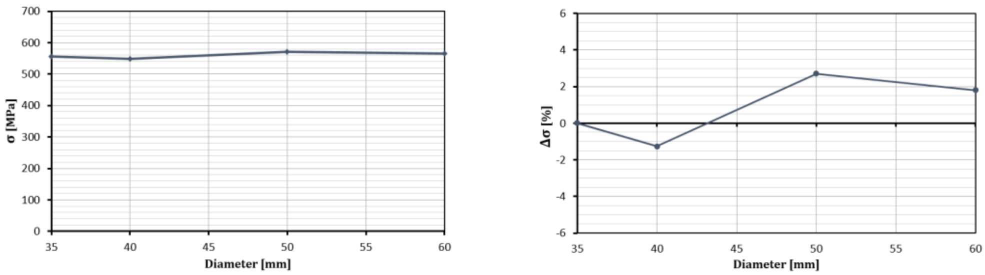
In order to evaluate the deformation capacity of the various samples, the FLD diagrams were compared. **Fig. 3** shows the extreme cases of the analyzed range of AISI 304 stainless steel (35 and 60 mm diameter sizes). FLD diagrams confirm that the deformation path of the various elements of the geometry is not affected by this parameter.



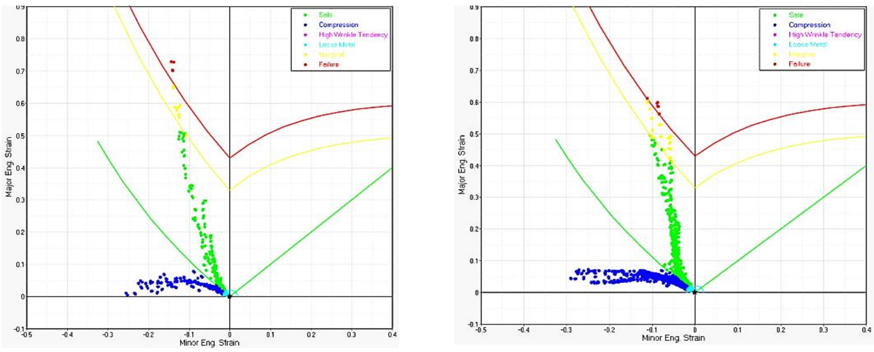
(**a**) (**b**)

Fig. 1 Stress mapping for: D=35 mm (a); D=60 mm (b) (AISI 304 steel - 1.5 mm thickness)



a b

Fig. 2 Mean maximum stress behavior as a function of diameter size (AISI 304 steel - 1.5 mm thickness) (a); Mean maximum stress variation as a function of diameter size (for AISI 304 - 1.5 mm thickness) (b)



a b

Fig. 3 FLD diagrams for AISI 304 stainless steel pipe (1.5 mm thickness). 35 mm (a); 60 mm (b)

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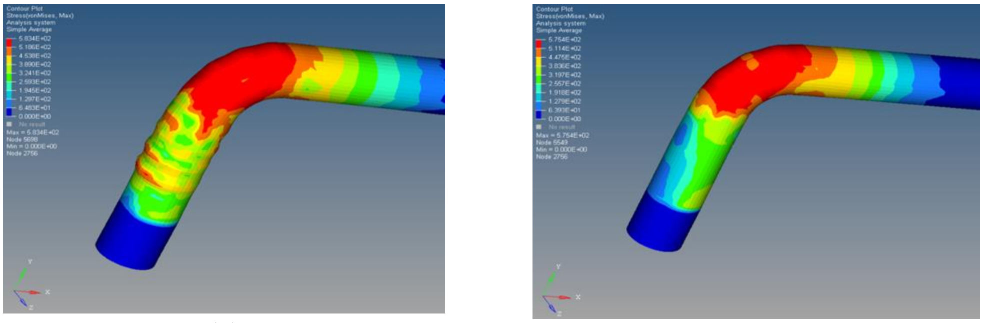
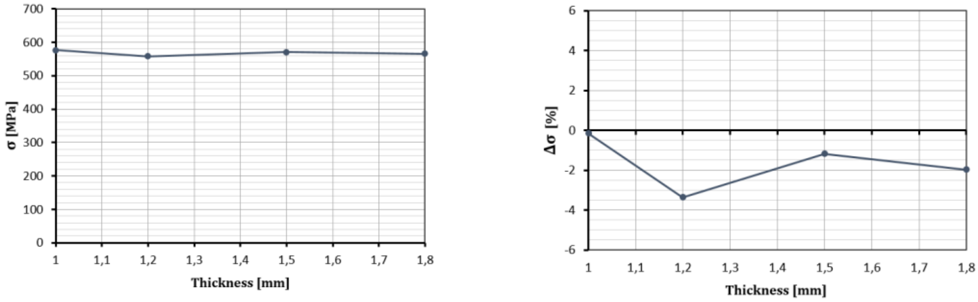
3.2 Pipe thickness

Same cases as above were considered to analyze the effect of pipe thickness (R/D=1). **Fig. 4** shows stress mapping for smaller and larger thickness and Fig.5 their distribution as before.



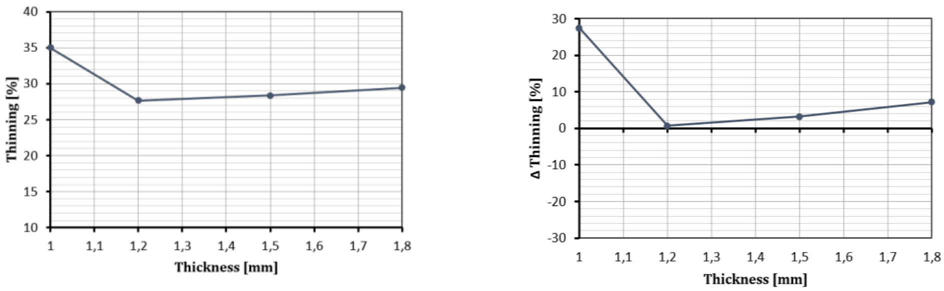
(**a**) (**b**)

Fig. 4 Stress mapping for: thickness=1.0 mm (a); thickness=1.8 mm (b) (AISI 304 steel - 50 mm diameter)



a b

Fig. 5 Mean maximum stress behavior as a function pipe thickness (AISI 304 steel - 50 mm diameter) (a); Mean maximum stress variation as a function pipe thickness (50 mm diameter) (b)



a b

Fig. 6 Maximum thinning behavior as a function pipe thickness (AISI 304 steel - 50 mm diameter) (a); Mean maximum stress variation as a function pipe thickness (50 mm diameter) (b)

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Even if not strong differences are found in **Fig. 5** results, **Fig. 4** shows a processing failure for 1.0 millimeter thickness. Therefore, to go deeper into the analysis, the thinning caused by the working on the tube geometry was considered, as shown in **Fig. 6**. From these graphs, it is more evident how the initial thickness of the geometry has a strong impact on the success of the bending process. In fact, a decreasing trend is reported, confirming the above results.

Conclusions

In this paper, the bending process of stainless steel pipes has been studied. Simulations highlighted the effect of process parameters on the final results.

In particular, it has been observed that the pipe diameter does not prove to be a decisive parameter for the success of the working process, while the pipe thickness appears to be a determinant factor for failure and/or unwanted deformation of the formed piece.

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