

PIPE DIAMETER AND PIPE THICKNESS EFFECT ON THE PLASTIC DEFORMATION BEHAVIOUR OF AUSTENITIC STAINLESS STEELS

Received – Primljeno: 2018-11-15

Accepted – Prihvaćeno: 2019-02-28

Original Scientific Paper – Izvorni znanstveni rad

The high quality standards required for metal forming call for compliance tests aimed to guarantee that such standards are faced. Such tests often implies a waste of time and of economic resources. In particular, if stainless steel pipe forming is considered, many factors need to be taken into account. Scope of the work presented in this paper is to analyse the effect of different process parameters and geometrical constrains on the cold forming of austenitic stainless steel pipes by Finite Element Method (FEM). Results of such analysis will allow to map the effect of different parameters.

Key words: stainless steel, forming, pipe, FEM, diameter/thickness

INTRODUCTION

Stainless steel components are increasingly used in many applications. Among the different stainless steel families austenitic and duplex stainless steels show the most interesting in terms of strength/ductility/fatigue combination together with corrosion resistance [1-5]. Following to such properties stainless steels have been indispensable for the technological progress during the last century and their annual consumption increased with a rate of 5% during the last 20 years, faster than other materials [6]. Their applications affect all these fields where good corrosion resistance together with ability to be worked into complex geometries are required [7-10]. Aimed to manufacture even complex geometries, metal forming is widely used. Moreover, following to the strong technological progress concerning the different application fields, higher and even more stringent requirements and quality standards are foreseen. In order to target such standards, quality and compliance tests are usually performed, with a consequent increase of costs, both due waste of personnel and time. Focusing on the case of plastic forming of stainless steel welded pipes, the plastic processing is characterized by a poor homogeneity as far as concerns the plastic behavior [11]. on specimens, due to the nature of the steel itself. As a consequence it comes out that such tests, usually carried out by means of tensile tests based on specifications, are not enough to guarantee the required standards. Aimed to predict the behavior of several pipes geometries in different processing areas (such as hydroforming and bending, or cold metal forming of steel sheets) attempts are now performed by many peo-

ple aimed to face such topic by means of predictive simulation by Finite Element Method (FEM) numerical analysis. Concerning pipes manufactured starting from rolled and welded steel plates, many critical issues relating to the general trend machining operations need to be taken into account, especially regarding high strength steels for application in the structural field. For example, the pipe geometry or the operating parameters driving during the plastic process (e.g. speed and bending angle), show to strongly affect the final process result outcome. In this framework, aim of the paper is to study the effects of different process parameters and geometrical characteristics on various types of austenitic stainless steel.

MATERIALS AND METHODS

The following steels grades and pipe geometries are considered:

- AISI 304 - AISI 316 (austenitic stainless steel)
 - Diameter: 30 – 40 – 50 – 60 mm
 - Thickness: 1,0 – 1,2 – 1,5 mm

The considered steels were assessed in terms of σ - ϵ curve calculated, according to UNI EN ISO 6892 specification regarding tensile tests on pipes, for each diameter/ thickness combination. A commercial software package integrated with its own solver, commonly used by automotive engineers, was adopted for numerical calculation. Outputs of modelling are internal stress, pipe thinning and deformation. In particular, the equivalent stress is considered calculated by the solver on the basis of the Hill criterion. The Hill 48' yield function was adopted since this is known to be ideal for small-sized tubular geometries as a constitutive equation for stainless steels behavior [12]. Bending radius, bending

A. Di Schino, Università di Perugia, Dipartimento di Ingegneria, Perugia, Italy, andrea.dischino@unipg.it

angle and rotational speed are considered aimed to reproduce the pipe bending process.

RESULTS AND DISCUSSION

The effect of process parameters on the deformation behavior of stainless steel pipes is reported below.

Pipe diameter effect

Typical curvature radius / pipe diameter ratio (R/D) values adopted in industrial application are in 1,0 and 1,5. range. Based on this observation, $R/D = 1$ has been adopted so to reproduce examples of deformation to be considered representative of a realistic industrial processes. Figure 1 and Figure 2 report stress mapping and behavior as function of pipe diameter size respectively. Results show that a variation of the diameter size (within the constrain $R/D = 1$) implies a negligible variation of the maximum stress (- 2 % / - 3 %).

Moreover, results also show that the internal stresses distribution is not affected by the diameter size variation.

Pipe thickness effect

The effect of pipe thickness is reported below. $R/D = 1$ has been considered as a constant value. Stress mapping for 1,0 mm and 1,8 mm pipe thickness are reported in Figure 3 a and b respectively. Results of mapping are summarized in Figure 4. A processing failure id detected in Figure 3 in the case of the thinner pipe, even if

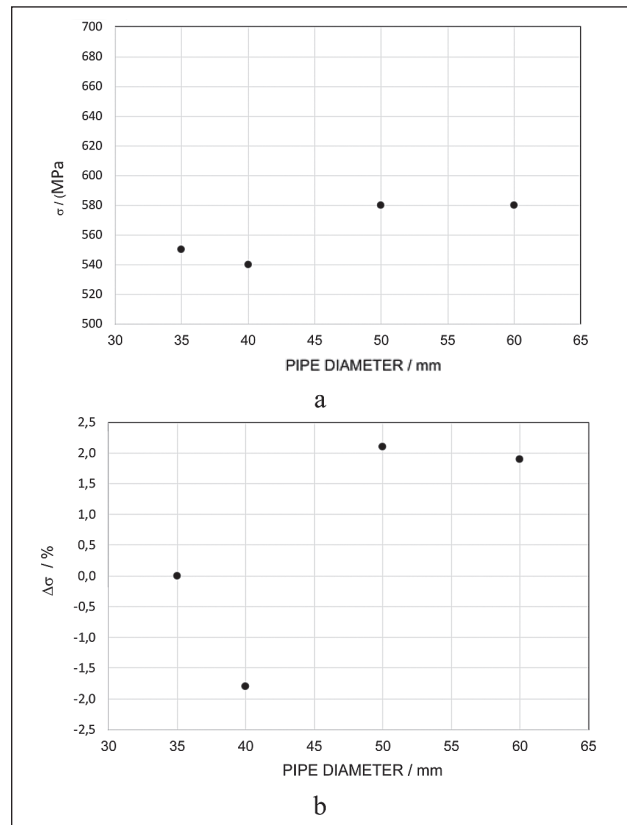


Figure 2 Maximum equivalent stress (a) and Maximum equivalent stress percentage (b) behavior as a function of pipe diameter size (AISI 304 – 1,5 mm thickness).

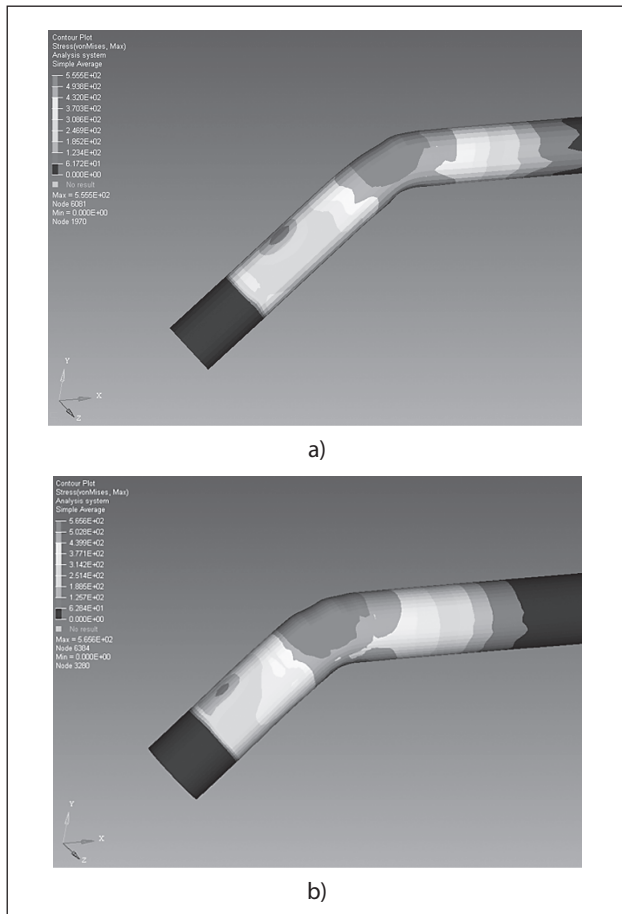


Figure 1 Equivalent stress mapping for AISI 304 steel. Thickness = 1,5 mm. Diameter size 35 mm (a) 60 mm (b).

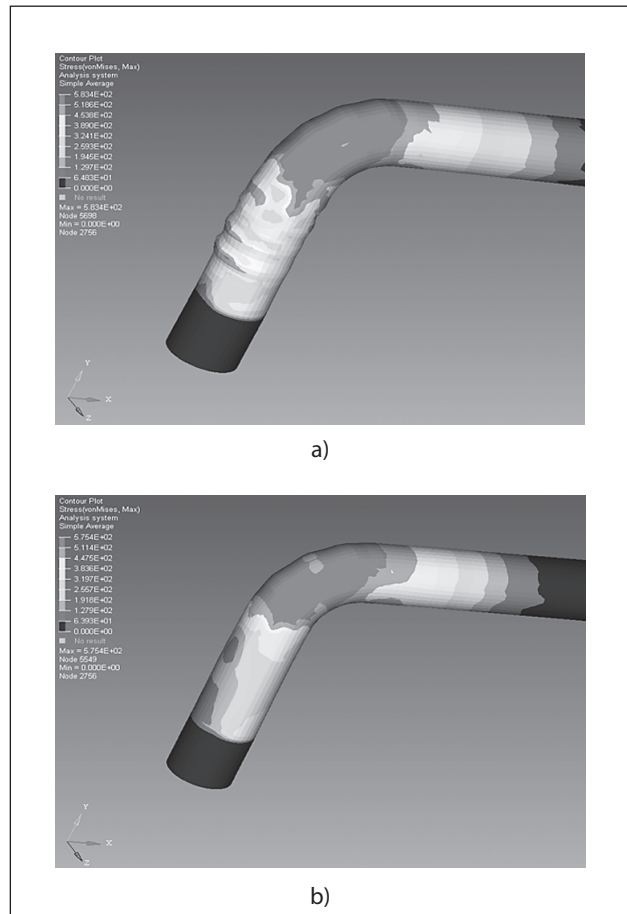


Figure 3 Equivalent stress mapping for for a) 1,0 mm b) 1,8 mm thickness AISI 304 (50 mm diameter).

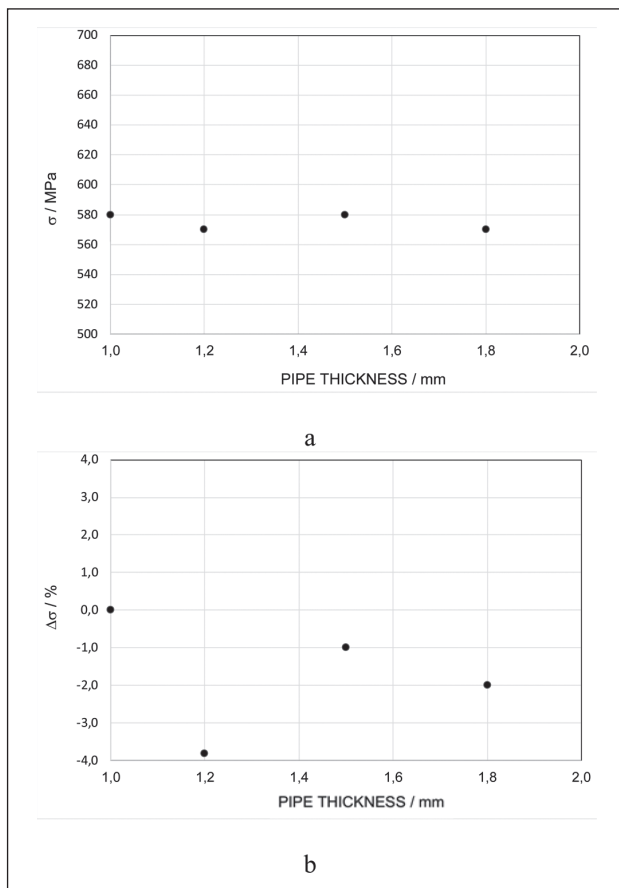


Figure 4 Maximum equivalent stress dependence in pipe thickness; b) maximum equivalent stress variation behavior (AISI 304 - 50 mm diameter).

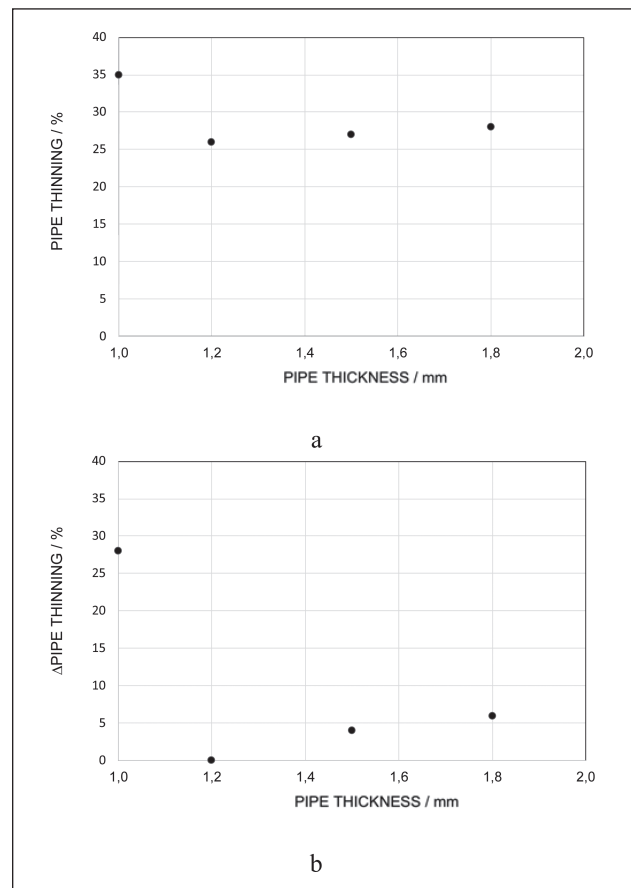


Figure 5 a) Maximum thinning dependence in pipe thickness; b) maximum thinning variation behavior (AISI 304 - 50 mm diameter).

such failure is not clearly put in evidence in Figure 4. In order to go deeper in such analysis the thinning caused by the working on the tube geometry was considered, as shown in Figure 5. Figure 5 better put in evidence how the initial pipe thickness has a strong impact on the success of the bending process. In fact, a decreasing trend is reported confirming the variation that this parameter involves. In particular a 30 % difference in the final thickness of the most stressed area is reported.

CONCLUSIONS

In this paper the bending process of austenitic stainless steel pipes has been studied. Simulations highlighted the pipe diameter and thickness on the final results. In particular, it is reported 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.

REFERENCES

- [1] P. Marshall P., Austenitic stainless steels, 1984, Springer Netherlands, ISBN: 978-0-85334-277-9
- [2] A. Di Schino, and P.E. Di Nunzio, "Effect of Nb microalloying in the heat affected zone microstructure of girth welded joints", *Materials Letters* 186 (2017), 86-89.
- [3] A. Di Schino, M. Longobardo, G. Porcu, G.L. Turconi and L. Scoppio, *Metallurgical design and development of C125*

grade for mild sour application", NACE-International Corrosion Conference Series (2006), pp. 061251-0612514.

- [4] A. Di Schino, Analysis of the heat treatment effect on microstructural features evolution in micro-alloyed martensitic steels, *Acta Metallurgica Slovaca* 22 (2016), 266-270.
- [5] I. Calliari, K. Brunelli, M. Dabala, E. Ramous, Measuring secondary phases in duplex stainless steels, *JOM* 61 (2009), 80-83.
- [6] N.R. Badoo, Stainless steel in construction: A review of research, applications, challenges and opportunities", *Journal of Constructional Steel Research* 64 (2008), 1199-1206.
- [7] K.H. Lo, C.H. Shek, K.L. Lai, Recent development in stainless steels, *Materials Science and Engineering R* 65 (2009), 39-104.
- [8] L. Gardner, "The use of stainless steel in structures", *Progress in Structural Engineering and Materials* 7(2005)4, 5-52.
- [9] H.J. Bong, F. Barlat, M. Lee and G. Ahn, The forming limit diagram of ferritic stainless steel sheets: Experiments and modeling, *International Journal of Mechanical Sciences* 64 (2012), 1-10.
- [10] T.B. Yang, Z.Q. Yu, C.B. Xu and S.H. Li, Numerical analysis for forming limit of welded tube in hydroforming, *J. Shanghai Jiaotong Univ.* 45 (2011), 6-10.
- [11] M. Zhan, M. Guo, H. Yang, Advances and trends in plastic forming technologies for welded tubes, *Chinese Journal of Aeronautics* 29 (2016), 305-315.
- [12] H. Zhang, Y. Liu, The inverse parameter identification of Hill'48 yield function for small-sized tube combining response surface methodology and three-point bending", *Journal of Materials Research* 32 (2017), 2343-2351.

Note: The responsible for English language is: Elisabetta Petricci, Italy