Mechanical Characterization of Stainless Steel Tubes thanks to a Tube Bulging Test - Validation of analytical models.

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CONTEXT

A complete mechanical characterization of stainless steel tubes is often complicated, even impossible, through usual normal tensile tests. The appraisal of the impact of the forming process and the welding step (figure 1) on the true mechanical properties and forming ability of the tube is therefore most of the time underestimated, leading to a critical or detrimental use of the tubes. Moreover, the hardening dependency to the loading history is also mistakenly neglected as the presence of a welding join. The present approach is dealing with the final wish to create analytical models which could help to characterize the effective mechanical properties of the tubes taking into account their metallurgical path. This paper constitutes the first part of the global approach and concerns the validation phase of different analytical models considering isotropic and homogeneous tubes.

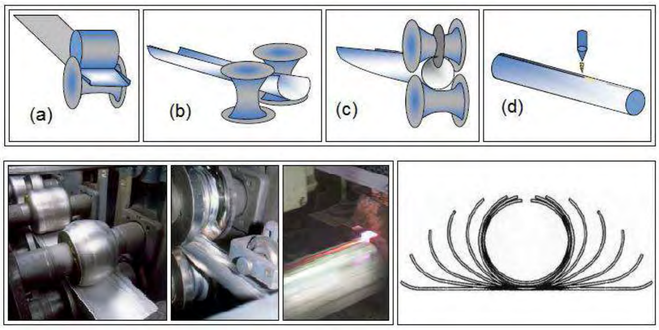

Figure 1: Illustration of the forming process leading to a rolled-welded tube and resulting “Flower” forming characteristic – a complex metallurgical history/path.

A GLOBAL APPROACH

A more complex mechanical test compared to single tensile tests usually carried out on tubes (rolling direction only) has to be performed to well appreciate the forming ability of the tubes: a bulging test (figure 2-a). This test, corresponding to a biaxial expansion of the tube thanks to an internal pressure, is more representative of any hydroforming process. This process presents great industrial interests because complex hollow shaped parts can be produced with a reduced number of welding spots and a higher structural quality. Nevertheless, the good ability of a bulging test to predict tube formability is mainly counterbalanced by the complexity of getting back to the experimental stress-strain curves.

Indeed, the evaluation of the stresses and strains in this experimental test is not immediate and requires the development of analytical models and appropriate experimental procedures. Thus the present paper compares different analytical models which have been developed in order to rebuild these stress-strain curves thanks to experimental data. The Y.M. Hwang model [1] and the N. Boudeau model [2] are two of them.

Figure 2-b illustrates the two experimental parameters which have been currently used in the literature to getting back this curve representative of the material behaviour: the applied internal pressure (P) and the maximal bulging height (h).

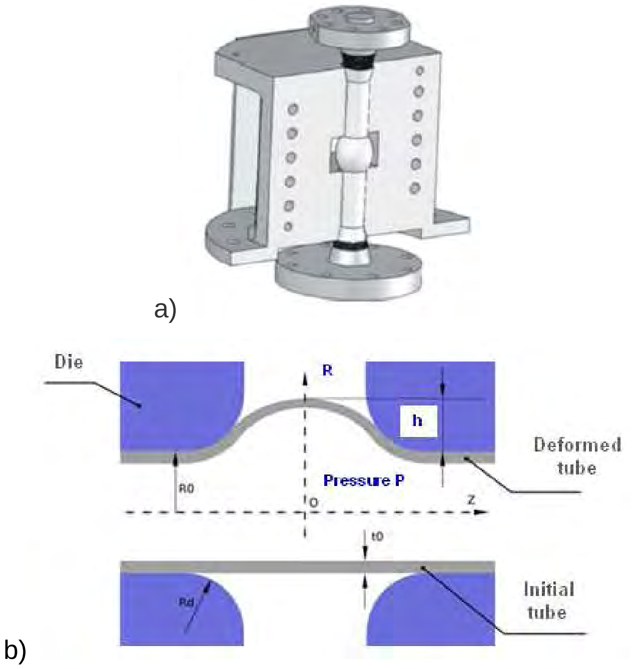

Figure 2: a) Schema of the bulging test machine – b) Identification of the experimental parameters required by the different analytical models.

The different models mainly differ from one to another by the geometric hypothesis made on the bulged part. When the Y.M. Hwang model [1] considers an elliptical profile of the bulged part, the Boudeau-Malecot model [2] opts for a circular profile, easier to modelize. Furthermore, according to the model, the die edges can also be taken into account to predict as accurately as possible the geometry of the bulged part (Y. Hwang and optimized Boudeau-Malecot models). The influence of this parameter has been clearly highlighted once again by the present study.

To compare all these different analytical models together, an iterative approach combining a finite element model (LS-DYNA software) and the different analytical models has been firstly adopted. Figure 3 illustrates this systemic approach and the different validation steps. It has been secondly completed by experimental tests (bulging tests) using a 3D Digital Image Correlation (DIC - ARAMIS) system allowing to quantify the displacement fields (more especially the displacement field) and the equivalent deformation at the surface of the bulged tube. The acquisition of these data has been trigged with the experimental device and the internal pressure applied on the tube (P).

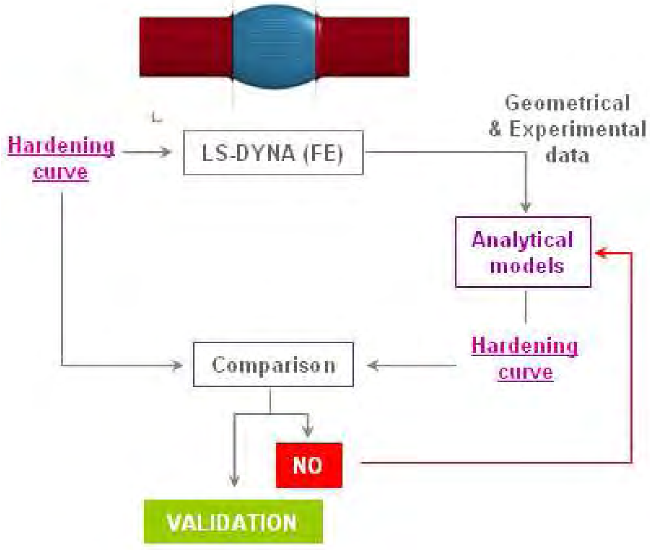

Figure 3: Diagram representing the systemic approach used to validate the different analytical models

MATERIAL DATA

All the experimental characterizations have been carried out on two different stainless steel grades: a 1.4401-316L austenitic one (1.5mm thick) with final annealing treatment after the forming step and a 1.4510-430Ti ferritic one without thermal treatment. These two grades have been respectively welded thanks to TIG and laser techniques. So they initially differ from each other by their crystallographic structure, their final hardening state after the tube's forming process and by the nature of the welding joins. In order to erase the influence of these different metallurgical paths, some final annealing thermal treatments adapted to the different grades have been done to finally work on recristallized microstructures. It has been wished in order to firstly appreciate the robustness of the global approach combining analytical models and experimental bulging tests.

RESULTS

As examples of the different results, figure 4 compares the evolution of the bulged profile (radial position) and the current thickness along the tube (axial position) for the three different models. All seems to give identical tube profiles (figure 4.a). The comparison with FE simulation results and experimental measures is very satisfying concerning this geometric parameter.

Concerning the thickness repartition along the bulged tube at the end of the tube bulge test (Figure 4.b), it can be observed that Hwang's model overestimates the pole thickness and tends to be equal to the one evaluated from Boudeau & Malécot's model near the die radius. It seems that the Boudeau & Velasco's model is the best compared to the experimental measures.

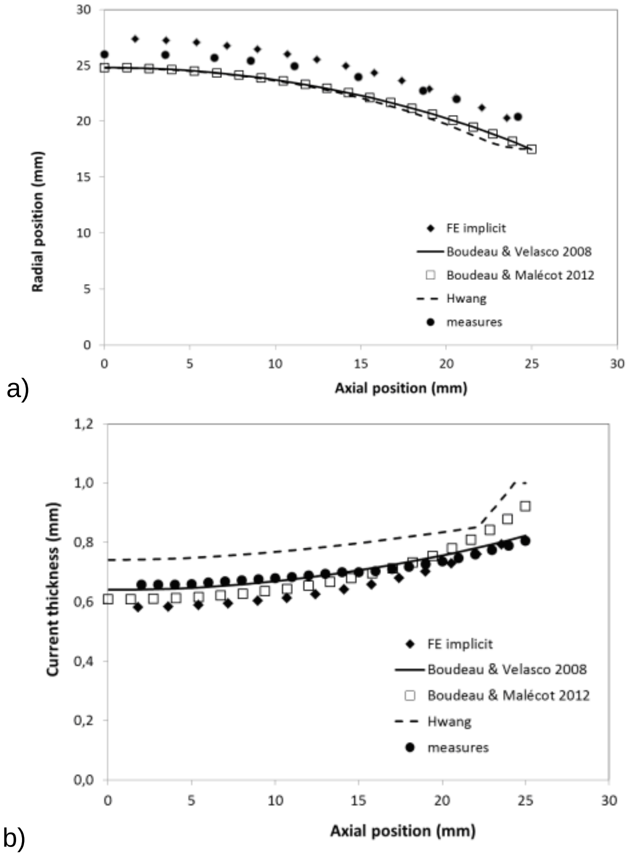

Figure 4: Global comparisons of tube profile (a) and thickness repartition along the bulged tube (b) at the end of the bulging test.

Thanks to these parametric data, the iterative approach carried out to validate the different analytical models has been validated, opening the way to the next step.

BIBLIOGRAPHY

[1] Y-M Hwang & Al - Evaluation of tubular materials by a hydraulic bulge test - Machine Tools & Manufacture - 2007 - vol 47 - p 343-351

[2] N. Boudeau & Al - A simplified analytical model for post-processing experimental results from tube bulging test: Theory, experimentations, simulations - International Journal of Mechanical Sciences - 2012 - vol 65 - p 1-11