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MODELING OF ELECTRO RESISTANCE WELDING TUBE FORMING PROCESS.

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Abstract. During the forming process in an electro resistance welding (ERW) forming line, a flat skelp evolves from a flat surface to a round shape, enforced by a series of roll stages. The formed round shape determines, together with welding parameters, the obtained weld and tube quality. In order to improve the process and achieve a better understanding of the skelp evolution towards the welding station, a finite element model has been developed. The process has been usually studied with analytical techniques and "trial and error" plant testing, while the use of finite element in modeling this type of process is quite recent. Process complexity imposes great computing efforts and heavy pre and post processing work.

A finite element model has been proposed to predict the skelp behavior along the critical stages of the forming line. Large displacement, contact algorithms and J2 material models have been used in the problem description. Agreement with plant measurements, computational speed and robustness are the main achieved goals.

1 INTRODUCTION.

During the forming process in an electro resistance welding (ERW) tube forming line, a flat skelp evolves from a flat surface to a round shape, enforced by a series of roll stages. In the first stages (breakdown, edge press and cage roller) initial rounding and edge forming is achieved. The next stages are those called fin pass roll-stands, in which the rounding process is finished and the skelp edges are forced into contact. When the edges reach contact, at the welding station, electric current is induced in order to melt skelp edges, and pressure rolls squeeze the melted edges together to form a fusion weld (see Figure 1).

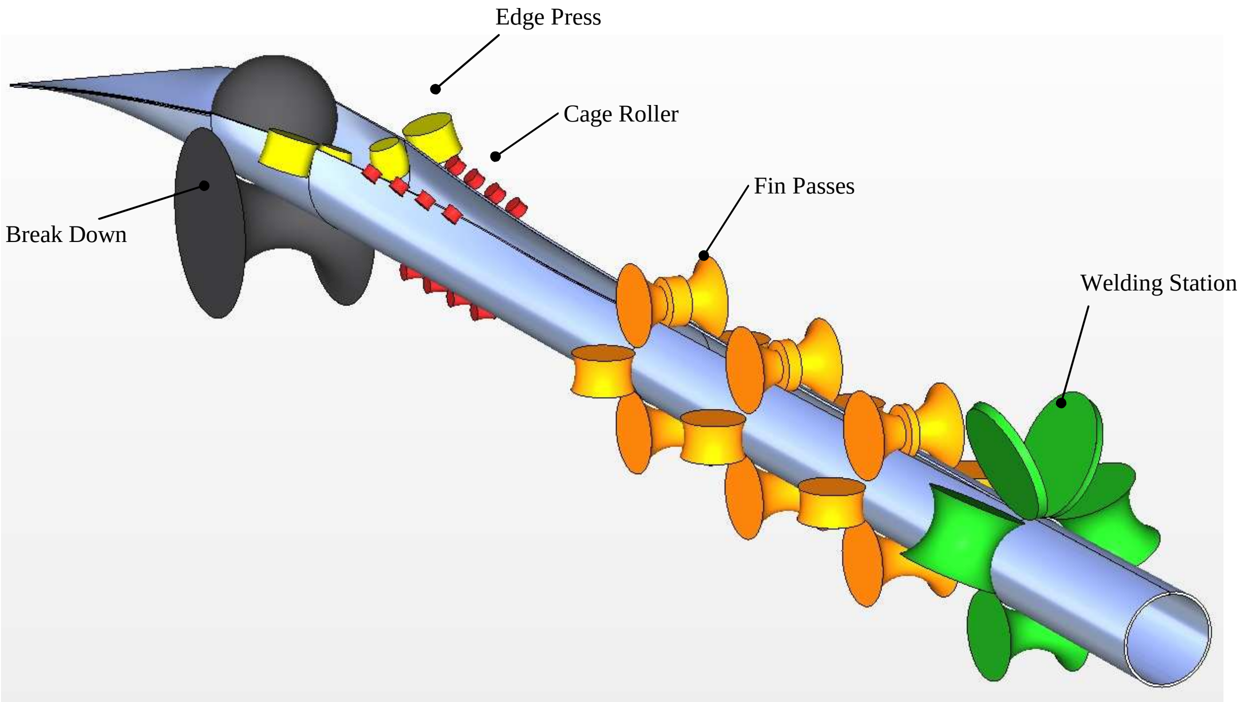
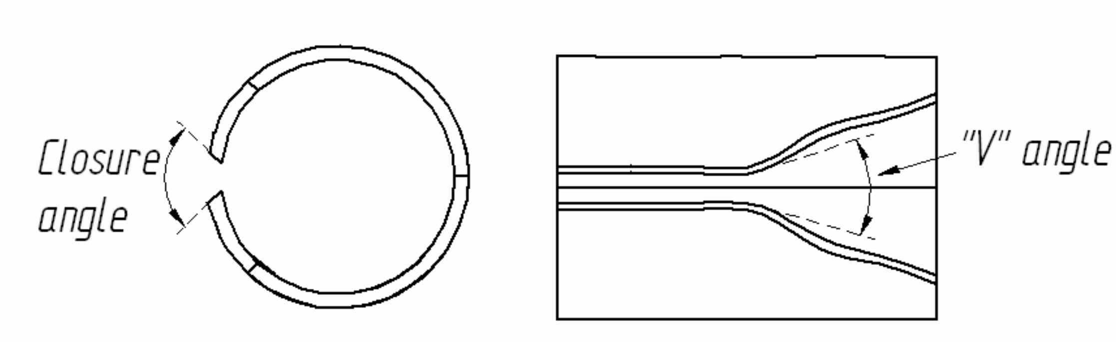


Figure 1: Schematic diagram of an ERW line.

Weld quality is determined to a great extent by the angles at which skelp edges come into contact, namely closure and “V” angles (see Figure 2), which in term depend on the forming process carried out by the fin pass rolls. This is a highly coupled process, because the contact geometry imposes boundary conditions to the current flow, the current flow determines the thermo-mechanical properties of the melted material and the boundary of the heated yet un-melted skelp, and this boundary affects the contact conditions.



a) Front view b) Top view

Figure 2: Closure and "V" angles.

1.1 Background.

Several authors have dealt with the problem of predicting the deformed geometry of the skelp in this tube forming process, using analytical, empirical and numerical methods. Walker and Pick (1990-1991), proposed a geometric model based on mill set up parameters to assess the strain state in the deformed skelp, aiming at model buckling of thin walled tubes. It was shown that skelp geometry can be predicted considering only the roll-stand geometries, but this is not sufficient to capture the strain state, and experimentally based corrections are needed. Wen and Pick (1994) developed a finite element model to study buckling instabilities caused by bending in breakdown and subsequent roll forming stages, for roll stands were skelp is confined between two opposing rolls to impose geometry. Brunet et al. (1998), proposed an elastic-plastic finite element based model for strain analysis and roll design optimization, based on a 2D cross section FEA combined with a 3D analysis between rolls for open sections. Nefussi et al (1993, 1998, 1999), in successive works, developed an analytical method based on the use of Coons patch as geometry descriptor, enhanced to attain isotropic plasticity and spring back effects on skelp forming. Kim et al. (2003), presented the modeling of the tube forming process via a rigid-plastic FEM, oriented to edge shape prediction and optimization.

1.2 Objectives.

Plant main objective is to increase process repeatability and develop technically oriented decision criteria for the welding process parameters, through an agile and robust calculation tool. For this purpose an elastic-plastic finite element model to predict the skelp behavior reaching the welding station is developed. The input for the proposed finite element model is taken from production line set up and allows a wide variety of roll stand adjustments to completely emulate it. For line and roll design purposes, the inclusion of new tooling is available along with the output of product trends to assess configuration effectiveness.

The model is focused on the fin pass stands and welding station, and pursues to model the geometry close to the welding point. Several results of practical interest are obtained from the model, such as the developments at critical sections, border angles, distribution of equivalent strain and stress and the evolution of the skelp edge position.

The paper is ordered as follows: model is described in section 2, study cases and plant validation are shown in section 3 and conclusions and future work are presented in section 4.

2 MODEL DESCRIPTION.

2.1 Initial geometry.

The press section to be modeled is taken between Cage Roller exit and the welding station. Tools included in the analysis are the three fin pass roll stands (fin pass 1, fin pass 2 and fin pass 3) and the squeeze roll stand at the welding station. The input skelp geometry is adopted as the one resulting from the Break Down and the Edge Forming press processes, immediately after Cage Roller exit, determined using analytical calculations. This initial geometry is generated by the imposition of two mayor radii to the skelp previous to any tooling action (see Figure 3). This initial geometry is loaded with the plastic history corresponding to a cylindrical bending process.

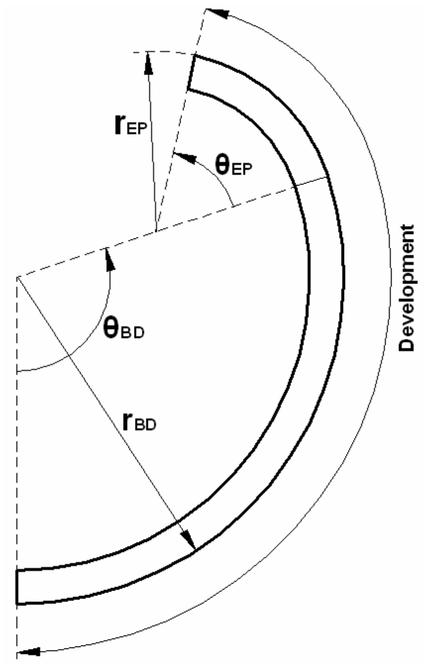


Figure 3: Initial skelp geometry.

2.2 Tooling action.

In a Lagrangian geometrical description, the obvious model is to move the skelp along the roll stands from an input section to the exit, following the plastic and deformation history. This would imply dealing with sliding contact conditions between the skelp surface and the forming rolls through out the forming process. This approach would also imply having to deal with initial conditions and passing enough skelp length so as to reach a constant deformation response. The extremely high computational cost and lack of robustness are major drawbacks for this approach.

To avoid these drawbacks, successive application of tools reproducing the deformation history and preserving plasticity is devised. Tooling action is simulated through a series of radial closures and openings seeking to preserve elastoplastic history. Though radial tool approach is not the physical one, it is preferred because it increases numerical scheme robustness and computing speed. With this hypothesis at hand, contact conditions can be enforced only beneath the tools thus allowing the use of a coarse mesh elsewhere.

The boundary conditions include longitudinal symmetry assumed along the model, and the imposition to input and output sections to remain in a plane normal to the longitudinal axis in order to model skelp continuity.

2.3 Welding process.

Welding is modeled by enforcing the skelp to remain closed after squeeze. The material loss by melting is attained introducing a volume at skelp edge of a constant width that behaves elastoplastically during tool actions from fin pass 1 to fin pass 3 but does not participate during squeeze, allowing the not melted material to build up stresses induced by compression. See Figure 4.

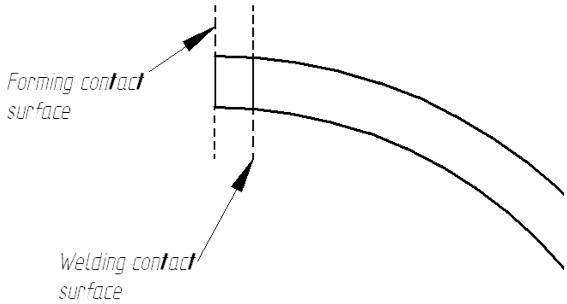


Figure 4: Forming and welding contact surfaces.

2.4 Finite element model.

The model is developed using finite elements in ADINA software (www.adina.com). The skelp is modeled via 3D 27 node mixed elements (Bathe, 1995) and the tooling is modeled with rigid parabolic frictionless contact elements, see Bathe and Chaudhary (1995). Large displacements and small deformations are adopted. A bilinear elastoplastic model is adopted for the skelp material.

3 STUDY CASES.

Several configurations were studied to assess model capabilities:

- Validation Configuration.
- Fin pass 3 vertical displacement.
- Sensibility to material strain hardening.

3.1 Validation Configuration.

To validate model results, measurements were carried out over a 16” diameter and 8.7mm thickness tube. Simulation results on skelp development between tools compared to plant measurements are presented in Table 1. Simulation results show good agreement with plant measurements.

	Parameter	Discrepancy
Developments	**Between cage roller and FP1**	0.14%
	Between FP1 and FP2	0.05%
	Between FP2 and FP3	0.07%
	Between FP3 and SQZ	-0.11%
	After welding	0.15%

Table 1: Model validation.

The longitudinal stresses are shown in Figure 5 and Figure 6, and equivalent plastic strains are shown in Figure 7 and Figure 8.

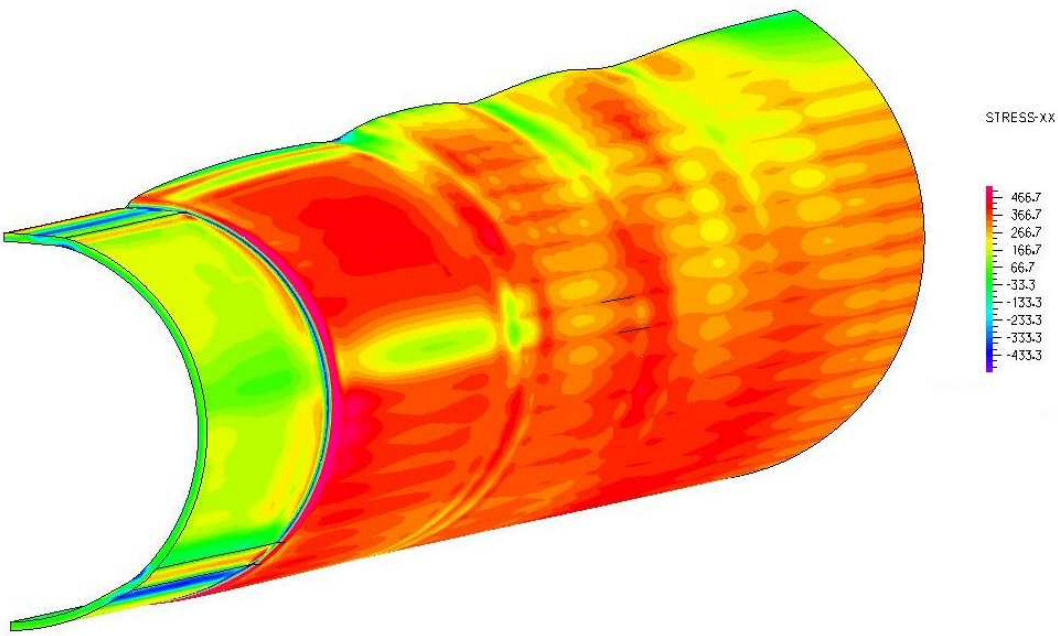


Figure 5: Axial stress, external view.

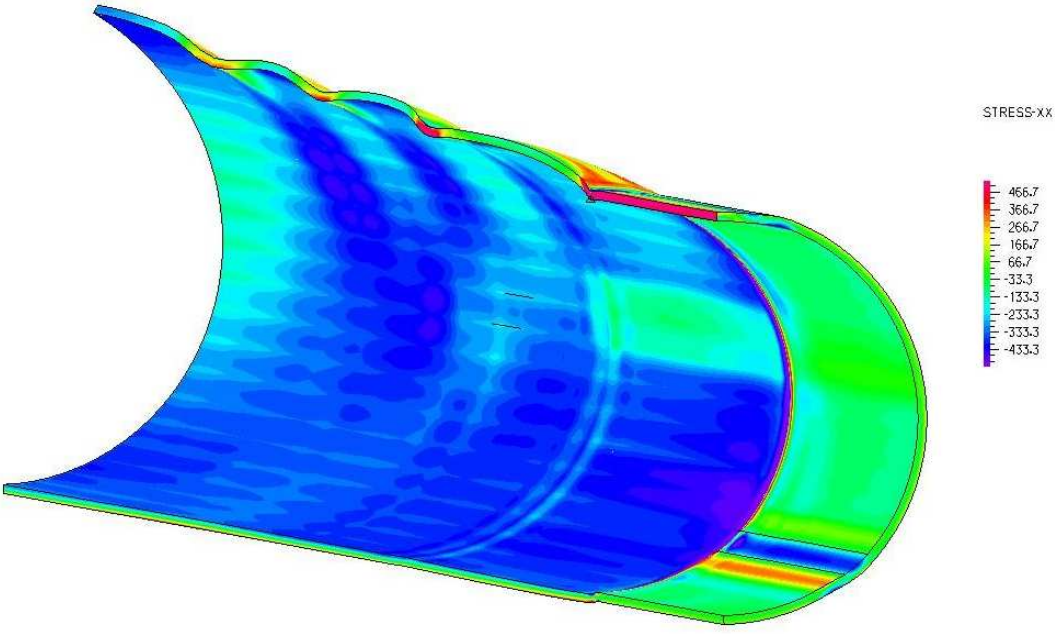


Figure 6: Axial stress, internal view.

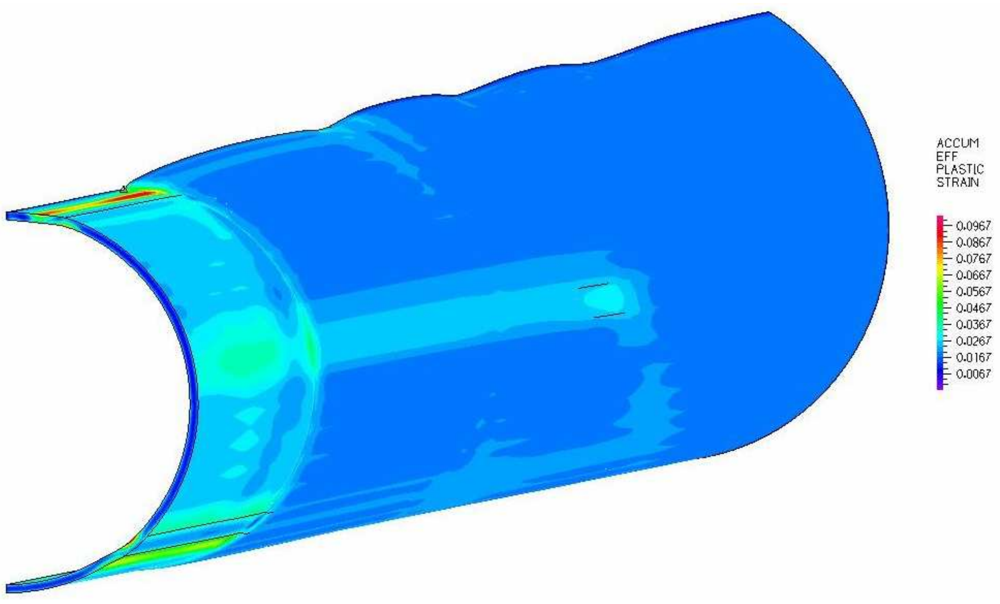


Figure 7: Accumulated effective plastic strain, external view.

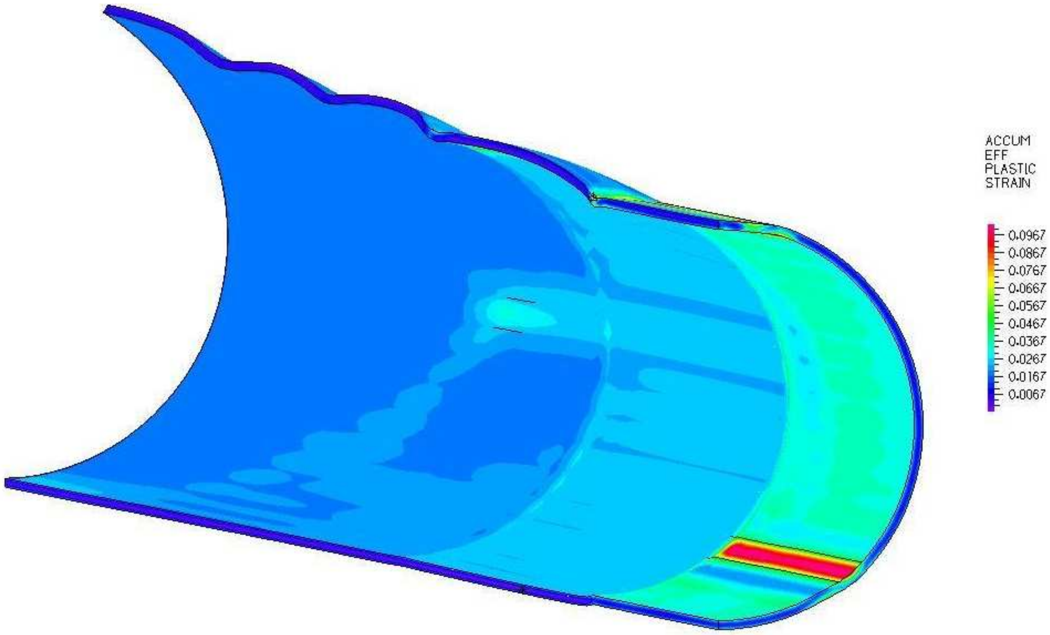


Figure 8: Accumulated effective plastic strain, internal view.

3.2 Fin pass 3 vertical displacement.

Using the same geometry as in the previous case, fin pass 3 stand rolls were moved rigidly 3 mm vertically upwards to verify model behavior. Results are compared to the previous case, named “reference”. Comparative lateral and top views are shown in Figure 9, closure and "V" angles are shown in Figure 10. No significant difference is observed due to this tooling change, though the model response is physically correct.

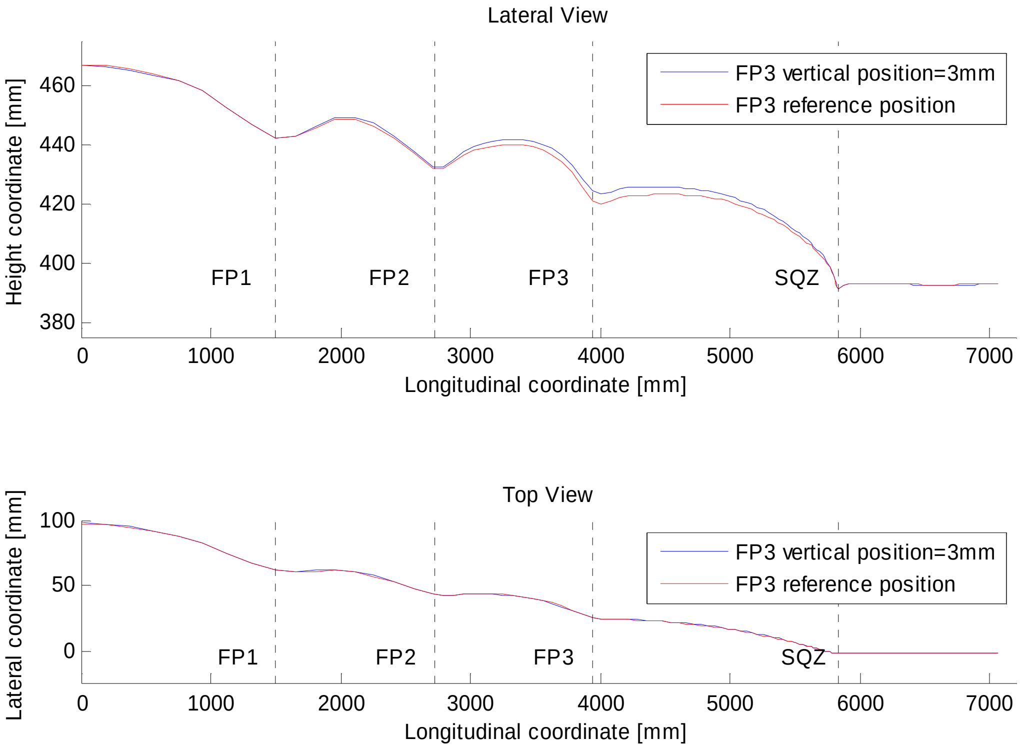


Figure 9: Skelp edge position. Lateral and top views.

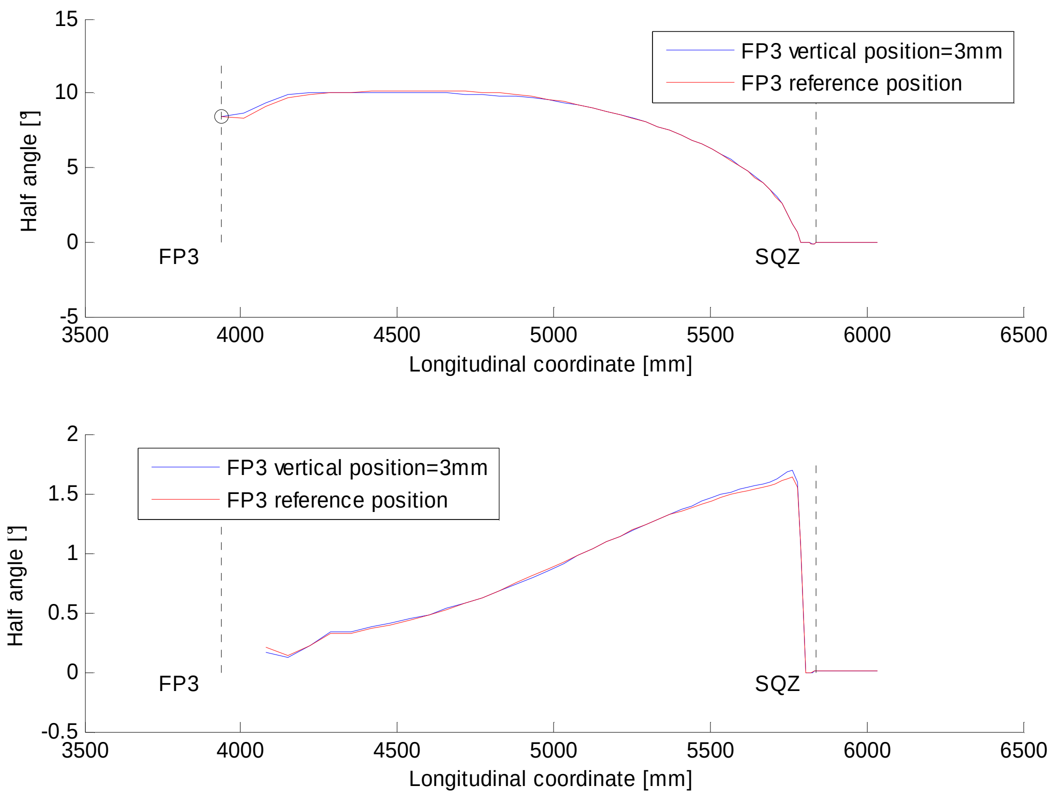


Figure 10: Closure and "V" angles.

3.3 Sensibility to material strain hardening.

To analyze model dependency on material strain hardening two reference cases were simulated: no hardening and hardening ratio equal to 1% of elastic modulus. Comparative lateral and top views are shown in Figure 11, closure and "V" angles are shown in Figure 12. It can be seen that hardening has no effect on welding angles but does modify the spring back geometry, as expected.

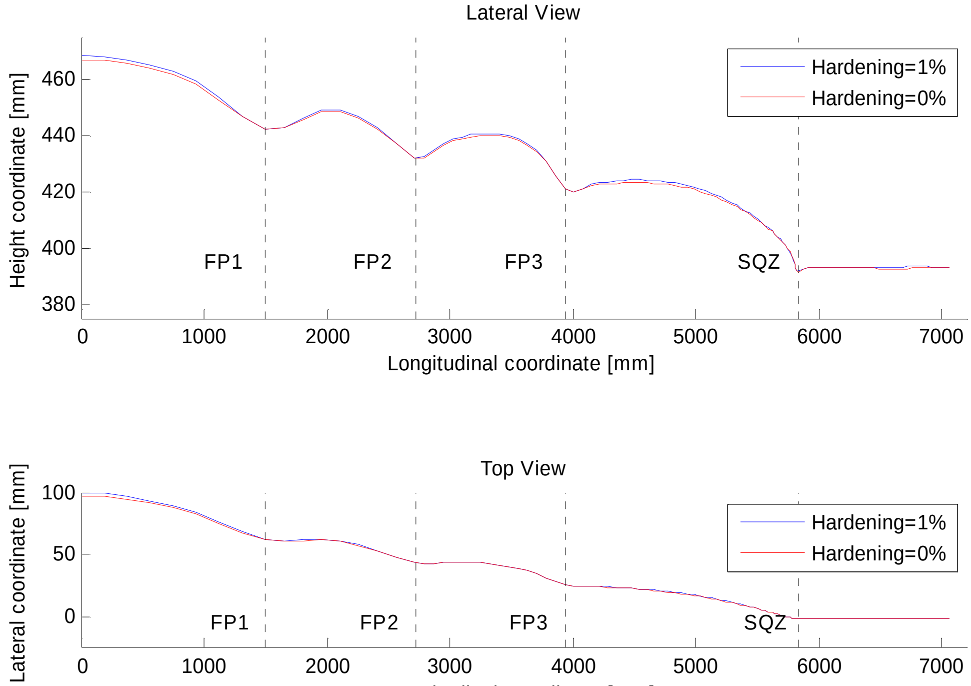


Figure 11: Skelp edge position. Lateral and top view.

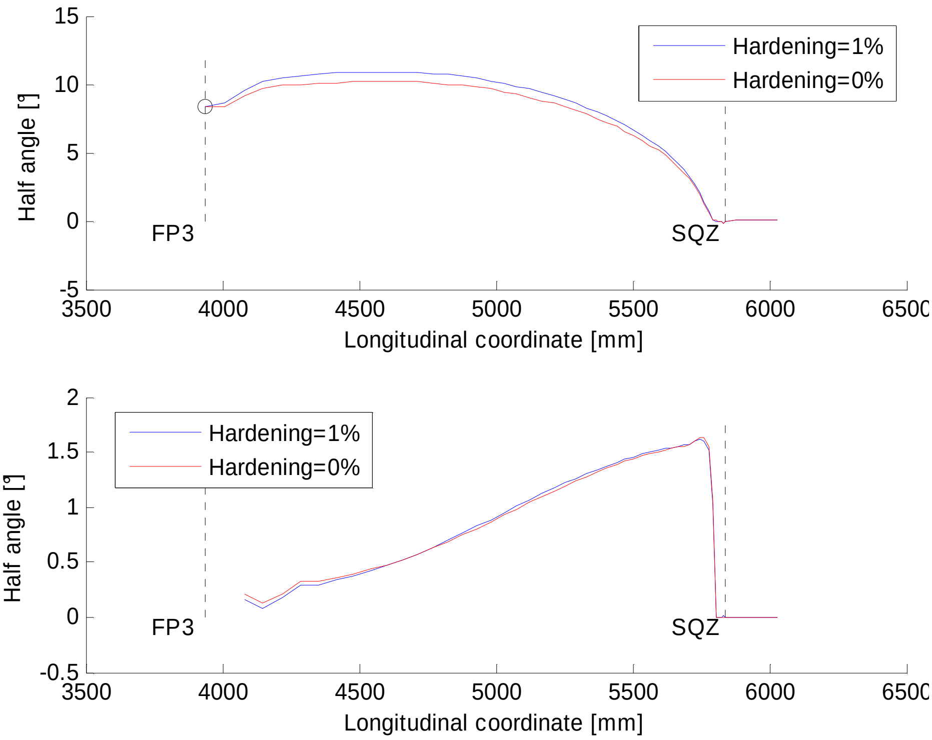


Figure 12: Closure and "V" angles.

4 COMPUTATIONAL ASPECTS

To facilitate interaction between the numerical model and process engineers, a graphical user interface has been implemented where sensitive variables are made accessible for numerical testing. The preprocess task involves the definition of roll stands geometry and setup of the initial geometry. All mesh parameters and tooling displacements are fully automated. The post processing main task is to predict the skelp approaching angles near the welding stand. In addition the contact stress distribution and resulting roll loads are made available, to be used as guiding variables for process setup and rolls design. Results from different forming line setups can be compared in order provide more accurate decision criteria and benchmarking trends.

The computational effort required to run the proposed model is estimated to be around 90 times faster in CPU time than a full sliding contact model, while it preserves satisfactory results.

5 CONCLUSIONS.

A robust finite element model capable of predicting tube geometry, strains and stresses at an acceptable computational cost for steady state conditions has been developed. Pre and post processing automated tasks have been developed to allow plant users without training in finite elements to interact with the model.

The modeling strategy adopted, even though strong hypothesis were chosen, is satisfactorily validated against plant results and the response to line setup changes agrees with plant experience. The model allows to evaluate the influence of plant set up parameters on the forming process.

The future work is to include more tube dimensions and line set up configurations in the testing and to enhance the model to take into account the previous forming stages.

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