TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 56, Issue I, March, 2013

MEANS FOR IMPROVING THE QUALITY OF LARGE DIAMETER BENT PIPES WITH NUMERICAL SIMULATION IN THE DEFORMATION PROCESS

Cristel MUREŞAN, Gheorghe ACHIMAŞ, Nicolae MIHĂILESCU

Abstract: *Finite Element Method (FEM) is the most common process of numerical analysis in engineering. The main advantages of FEM include: flexibility, possibility of modelling bodies which are physically not homogenous, as well as easy implementation in general calculus programs. The object of present paper is to extend the understanding of phenomena occurring in large diameter pipe bending using the mandrel. The object of present paper is to extend the understanding of phenomena occurring in large diameter pipe bending using the mandrel increased pulling speeds in order to reduce processing time, as well as to reduce manufacturing costs.*

Keywords: *bends, connections, bending, numerical simulation, finite elements.*

1. INTRODUCTION KNOWLEDGES

The most important goal in plastic deformation of metals is the manufacturing of defect-free parts, with the intended mechanical and micro-structural characteristics, which are achievable by proper design and adequate control of process parameters. As regards the thixomolding, the investigation of rheological behaviour of materials in semisolid state with the purpose of modelling is a domain of high interest. [9]

In the process of bending by mandrel pulling and induction heating is the most efficient method to manufacture bends at 45, 60, 90, 180° with a minimal energy consumption. The heating coil can be centred and adjusted both horizontally and vertically, the product has no ovalisation, the walls thickness is constant without thinning on the outer side or thickening on the inner side, and the minimum bending radius is of 1.5 D.

2. HOW TO SOLVE A PROBLEM USING THE FINITE ELEMENT METHOD (FEM)

The modelling of pipe bending process requires the preparation of a model for the system being studied in order to simplify the problem in question. Such simplification regards the geometry of tools, the behaviour of pipe material and the limits describing the interaction between tools and pipe product.[1]. Stages of pipe bending process modelling using Finite Element Method (FEM) are presented in image 1, there are:

Pre-processing: preparation of finite element model to be transferred to the solver. In this case, the main stages are:

-Prepare geometric model including the pipe product and pipe bending specific tools;

-Discretization of the pipe and tools into finite elements;

-Define product material;

-Define contact between tools and product;

-Determine loads and limits conditions.

Processing: automated (algorithmic) solving of the calculation model by the FORGE 2009 solver.

Post-processing: extract and process needed data, present results in graphic form, which is the most intuitive.

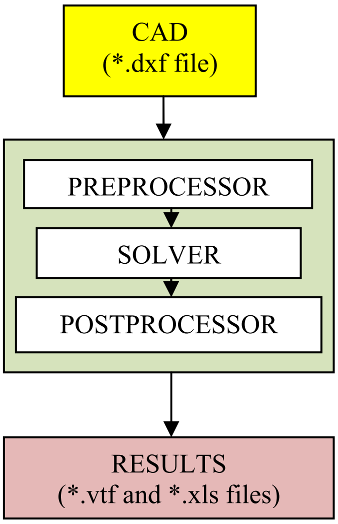


Fig. 1. Analysis procedure in Forge 2009;[5]

Geometric modelling begins with 3D designing in Solid Works [10] the mandrel, based on the original drawing of the German manufacturer Schmidt & Clemens GmbH as presented in figure 2. The drawing is used to perform bending of pipes with D_e 108 x 3.6 given the tube size D_e 96.1 x 3.6 and D_i 88.9, the other elements are designed such as to form an ensemble – in figure 3 and figure 4.

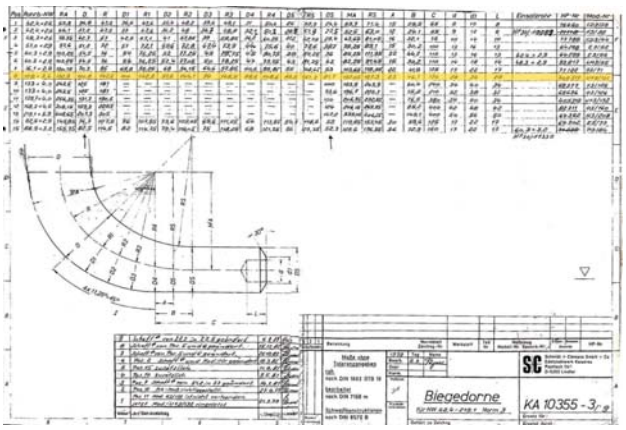


Fig. 2. Mandrel used for pipe bending by pulling and induction heating.

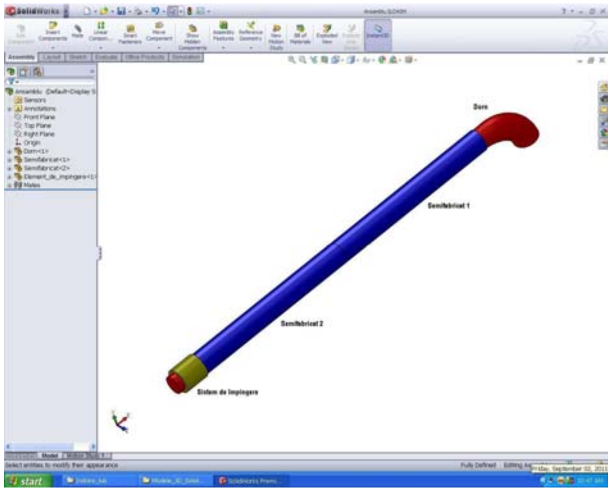
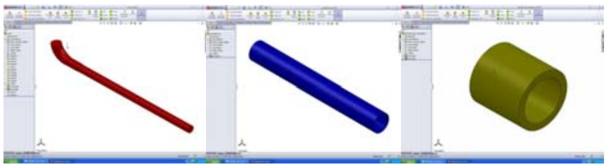


Fig 3. Ensemble of mandrel – blank product: 1- blank product; 2- pushing system.



a) b) c)

Fig. 4. Ensemble elements: a) mandrel; b) blank product; c) pushing system.

All these sub-assemblies, together with the general ensemble were imported in FORGE 2009 and, after selecting mandrel and blank product materials, the flat discretisation was performed, followed by volumetric discretisation. For the first stage, a coarse tetrahedral mesh has been used in order to speed up calculations.

Figure 5 and 6 present the discretisation mesh for the mandrel – blank product ensemble.

A file was prepared using a solid model based on a Norton – Hoff law (viscoplastic behaviour). [5]

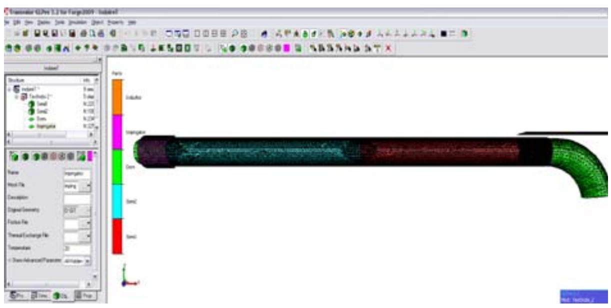


Fig. 5. Discretisation mesh for the mandrel – blank product ensemble, 1-blank product; 2-puscher

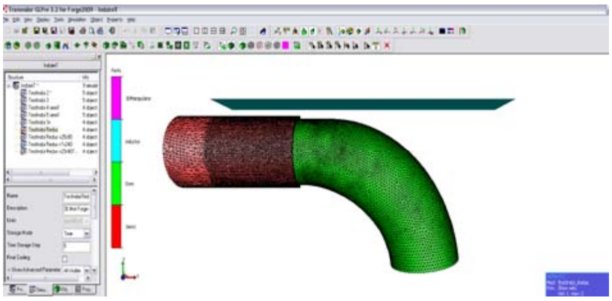


Fig. 6. Discretisation mesh for reduced ensemble of mandrel and blank product

3. THEORETICAL ASPECTS OF THE APPLIED MATERIAL MODEL

3.1 Modelling based on solid model

The Norton-Hoff model was selected for determining the parameters for the material behaviour law. Material consistency depends on thermal and mechanical conditions, which may vary, and the equation is: [5], [9]

$$A(T,\bar{\varepsilon}) = A_0 * (\bar{\varepsilon} + \bar{\varepsilon}_0)^n * e^{\frac{\beta}{T}} \tag{1}$$

where: A_0 constant; $\bar{\varepsilon}_0$ cold-hardening regularisation factor; n cold-hardening exponent; β temperature factor; T temperature, in Kelvin.

When such conditions are constant, the consistency may be defined with a constant value.

3.2 Input data used for the finite element analysis

Data regarding the deformation equipment (hydraulic pushing press), deformation mould (mandrel) and blank product (pipe), as well as the conditions of the testing are fed into FORGE 2009 calculation code, following standard procedure. In the rheological module a Hansel-Spittel evolution pattern shall be considered, defined by (2) [5], [9], [12]:

$$\sigma = A * e^{m_1 T} * T^{m9} * \varepsilon^{m2} * e^{m4/\varepsilon} * (1+\varepsilon)^{m5T} * e^{m7\varepsilon} * \dot{\varepsilon}^{m3} * \dot{\varepsilon}^{m8T} \tag{2}$$

where: A solid consistency [mm.Kg.s]; $\dot{\varepsilon}$ equivalent deformation velocity [s^{-1}]; ε equivalent deformation (total deformation); T [º] temperature; $m_{1...9}$ sensitivity parameters.

Modelling may use two types of variables:

- nodal variables or internal variables (e.g. temperature, pressure, pressing speed etc.);
- integration point variables or user variables (e.g. viscosity etc.).

4. FRICTION CONDITIONS

The software will use in the FEM the specific friction τ on the contact areas of the bodies, with equations [5], [9]:

$$\tau = \mu\sigma_n \ ; \quad \text{if} \quad \mu\sigma_n \le \bar{m}\frac{\sigma_0}{\sqrt{3}} \ , \tag{3}$$

$$\tau = \bar{m}\frac{\sigma_0}{\sqrt{3}} ; \quad \text{if} \quad \mu\sigma_n > \bar{m}\frac{\sigma_0}{\sqrt{3}} \ . \tag{4}$$

where μ - friction coefficient, $\bar{m}$ - Tresca's friction factor.

5. HEAT TRANSFER CONDITIONS

Heat module – regardless of the deformation tool – material interface, the energy dissipated by friction will be included in calculation, therefore the diffusion into the rigid tool (mandrel) shall be defined. For a heat exchanging interface, the value of a constant flow (if available) should be included for determining the conduction, as well as the transfer coefficient between tool and material, and the temperature of the tool. In the thermal-mechanical calculation, the environment interface will be included as a border where complex heat exchange processes may occur as conduction-convection, radiation and constant exchange. If initial exterior temperature is not constant, the following equation shall be used [5], [12]:

$$T = (\theta_o + 273) * \exp^{\frac{\beta}{t}} \ , \tag{5}$$

where: θ_0 constant; β time factor.

Thermal calculation is performed incrementally. Time step may be calculated automatically, according to variation of product's internal temperature. A maximum temperature increment may be defined, as well as a maximum time step. According to the product's internal temperature variation, the time step shall be adjusted in order to conform with the maximum temperature increment.

6. DISCRETISATION

For the first stage, a coarse tetrahedral mesh may be used, in order to perform fast calculation, as mentioned by other authors [2], [7], [8], [11]. Considering the fact that the mesh size may influence the simulation results, in cases of complex geometry, the effect of mesh size should be analysed, given the numerical problems that might occur.

Under the action of tools, the semisolid material is being deformed, as well as the discretisation mesh, since FORGE 2009 approaches the forging process as a Lagrange process (i.e. mesh volume is deemed to be equal with the material volume). The Lagrange formulation will consider the discretisation as being "material", since the mesh follows the material during its deformation (flow). Consequently, the quality of elements located in the highly deformed areas may degrade quickly. When the mesh would become too deformed, a new discretisation will be performed (automated discretisation). [5], [9], [12].

7. SIMULATION I

Working conditions (figure 7):

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 20 ˚C;
- heating time = 60 s;
- friction conditions – Coulomb's equation:

$\overline{m}$ = 0,15; μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^{2}K

diffusion coefficient = 11763,62 Wm^{-2}K^{-1}s$^{1/2}$

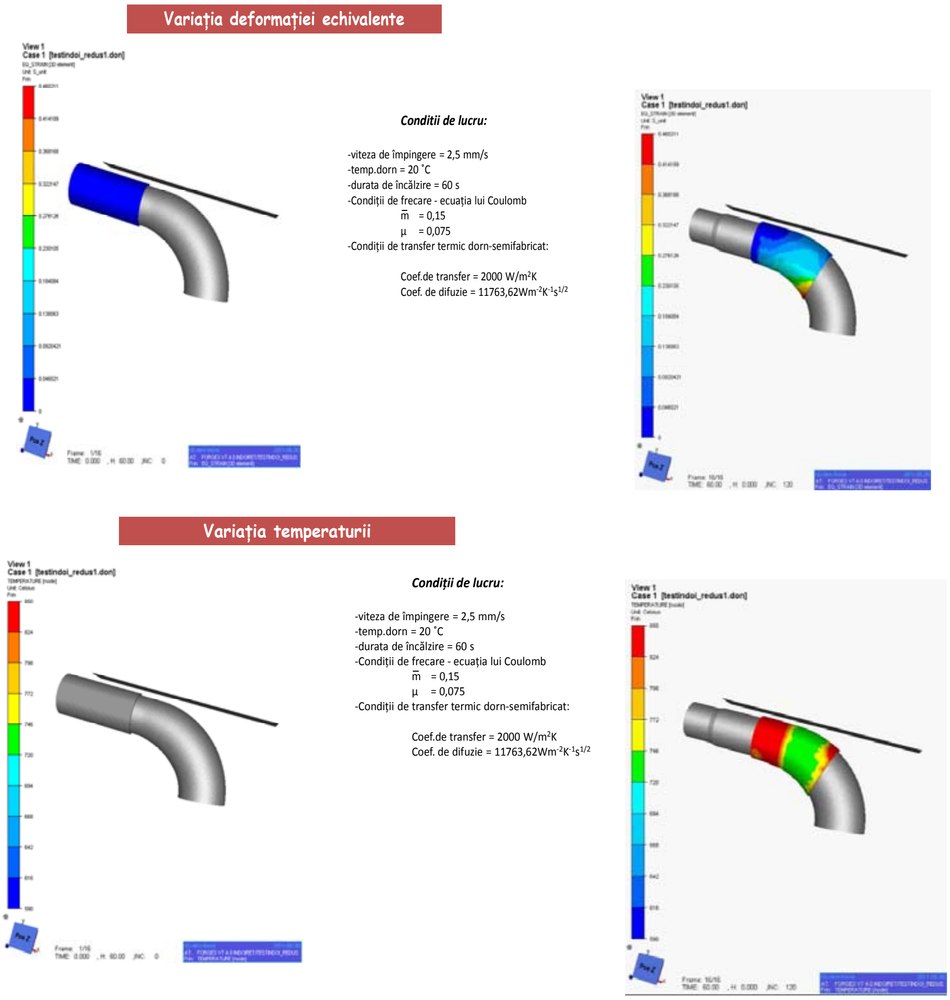


Fig. 7. Variation of equivalent deformation and temperature for Simulation I

8. SIMULATION II

Working conditions (Figure 8)

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 20 ˚C;
- heating time = 90 s;
- friction conditions – Coulomb's equation:

$\bar{m}$ = 0,15;
μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^{2}K
diffusion coefficient = 11763,62 Wm^{-2}K^{-1}s$^{1/2}$

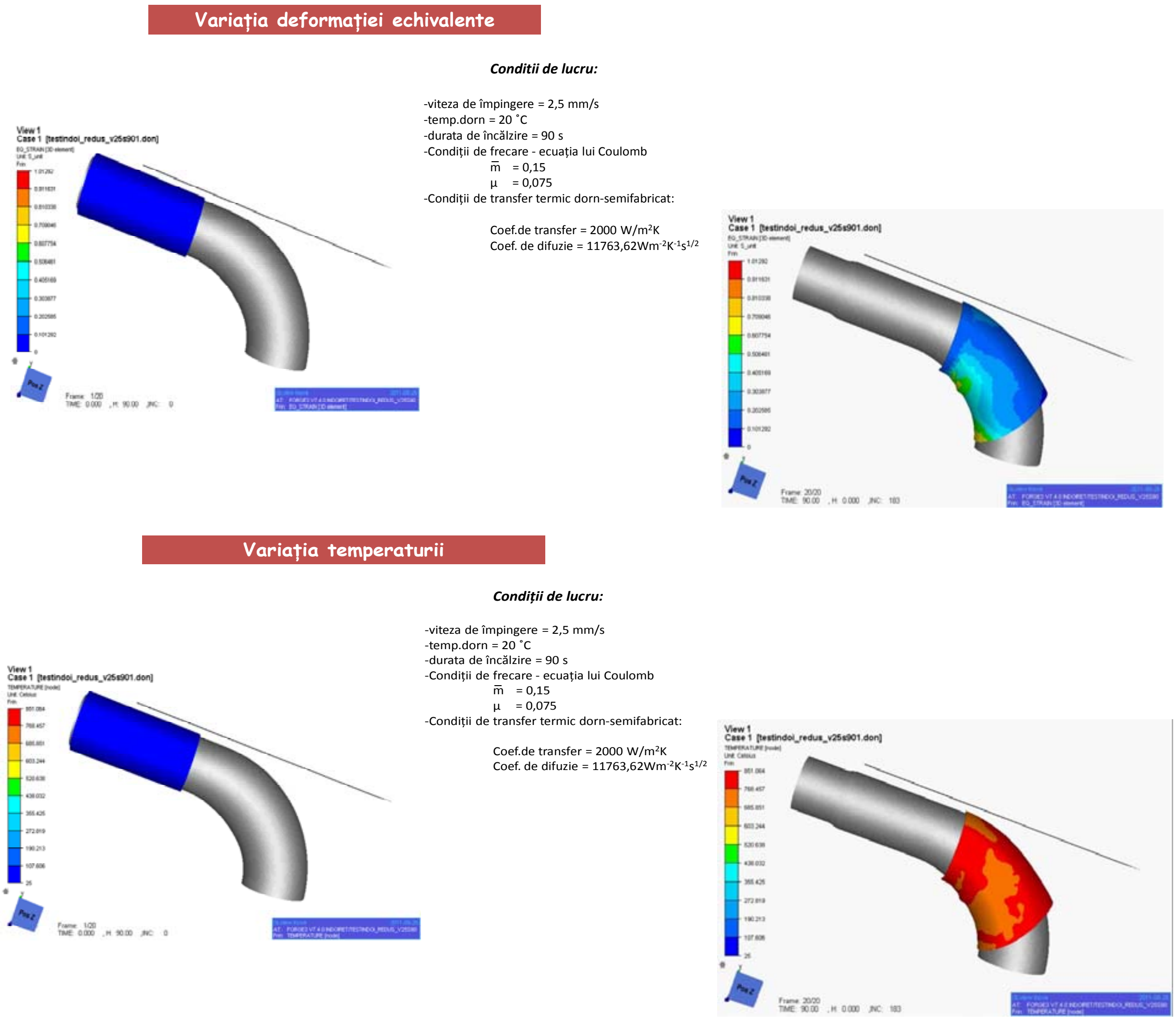


Fig. 8. Variation of equivalent deformation and temperature for Simulation II

9. SIMULATION III

Working conditions (Figure 9 and 10)

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 600 ˚C;
- heating time = 90 s;
- friction conditions – Coulomb's equation:

$\bar{m}$ = 0,15; μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^{2}K
diffusion coefficient = 11763,62 Wm^{-2}K^{-1}s$^{1/2}$

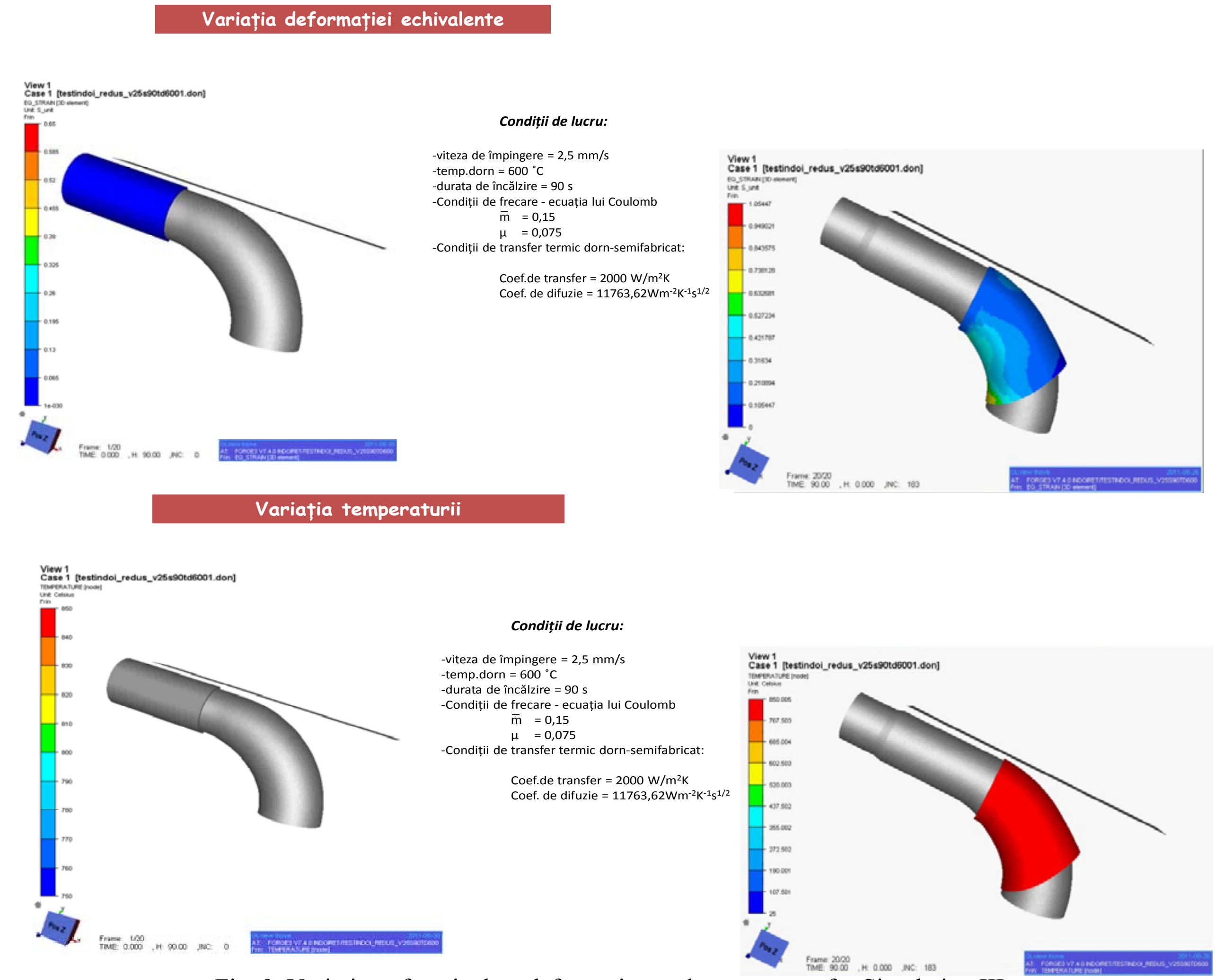


Fig. 9. Variation of equivalent deformation and temperature for Simulation III

10. VARIATION OF PIPE WALL THICKNESS FOR SIMULATION I, II and III (Fig. 10)

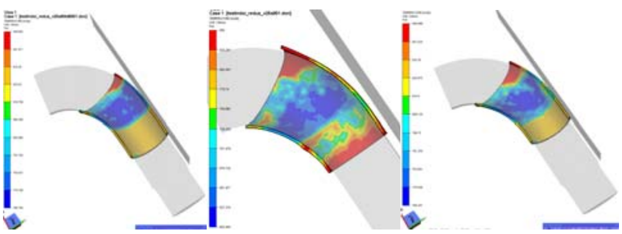


Fig. 10. Variation of pipe wall thickness

In order to show the constant thickness of walls in the blank product section, the following images present the sections related to the three simulations: figure 11 simulation I, figure 12 simulation II with the crease caused by insufficient heating of the mandrel, and figure 13 simulation III.

Simulation I

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 20 ˚C;
- heating time = 60 s;
- friction conditions – Coulomb's equation:

$\overline{m}$ = 0,15;
μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^{2}K
diffusion coefficient = 11763,62 Wm^{-2}K^{-1}s$^{1/2}$

Simulation II

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 20 ˚C;
- heating time = 90 s;
- friction conditions – Coulomb's equation:

$\overline{m}$ = 0,15;
μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^{2}K
diffusion coefficient = 11763,62 Wm^{-2}K^{-1}s$^{1/2}$

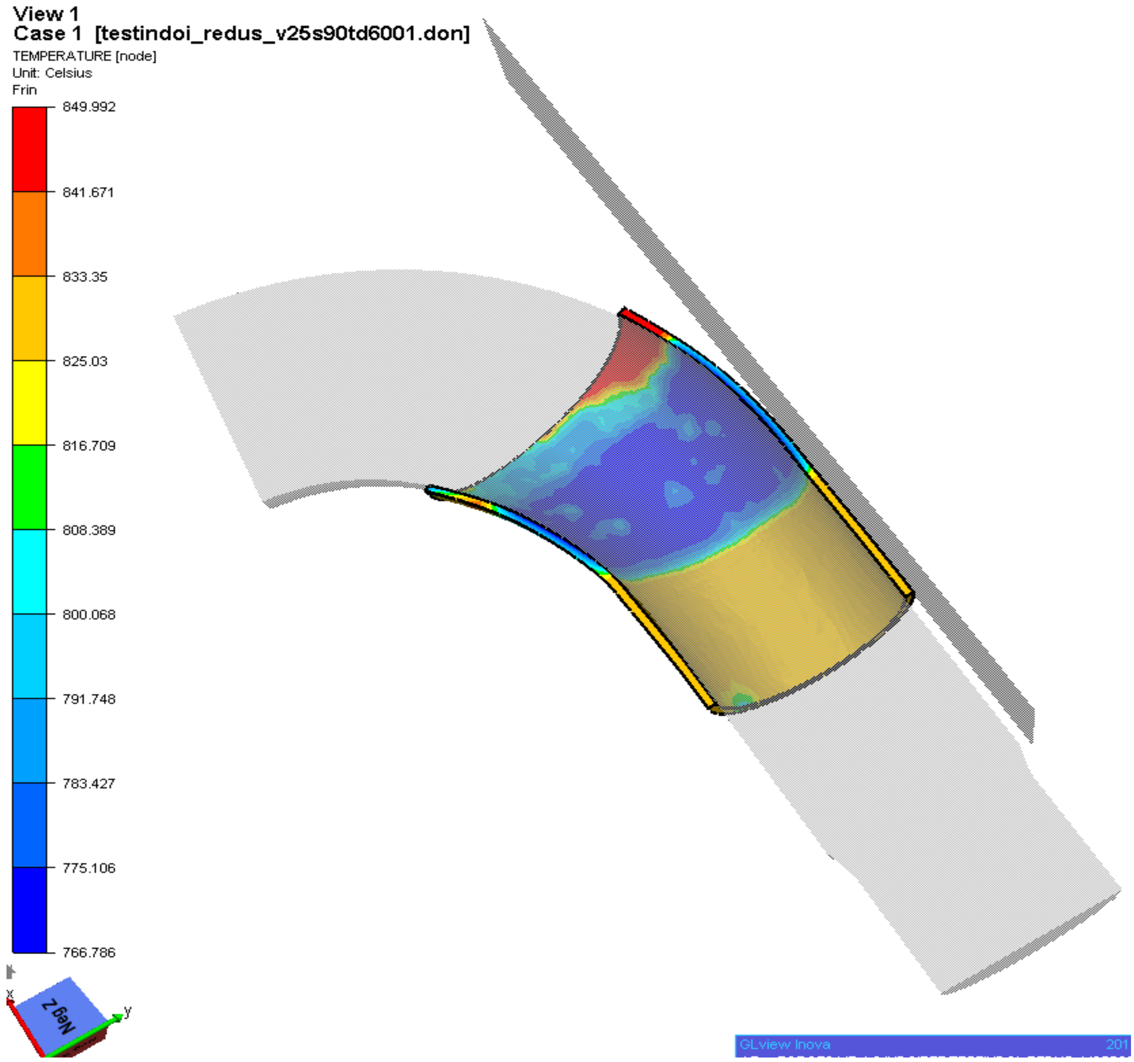


Fig. 11. Variation of wall thickness for simulation I.

Simulation III

- pushing velocity = 2.5 mm/s;
- mandrel temperature = 600 ˚C;
- heating time = 90 s;
- friction conditions – Coulomb's equation:

$\overline{m}$ = 0,15;

μ = 0,075;

- heat transfer conditions for mandrel – blank product:

transfer coefficient = 2000 W/m^2K

diffusion coefficient = 11763,62 $Wm^{-2}K^{-1}s^{1/2}$

11. CONCLUSIONS

Based on the concept formulated by Avitzur [3], who stated: "As regards the plastic deformation processes, models to provide an accurate description are not yet available, however approximations and simplifications of certain techniques may be applied", we have reduced the base model due to its size and consequently the estimated completion time; we have shortened the mandrel, shortened the blank product from 700 to 175 mm, the pushing system has been replaced with a pushing space not geometrically defined, and also the induction system has been replaced with a heating space. All such approximations allowed for achieving the objectives stated in the first part of the paper, namely to determine the mandrel temperature and to demonstrate the lack of variation in the thickness of blank product even after processing.

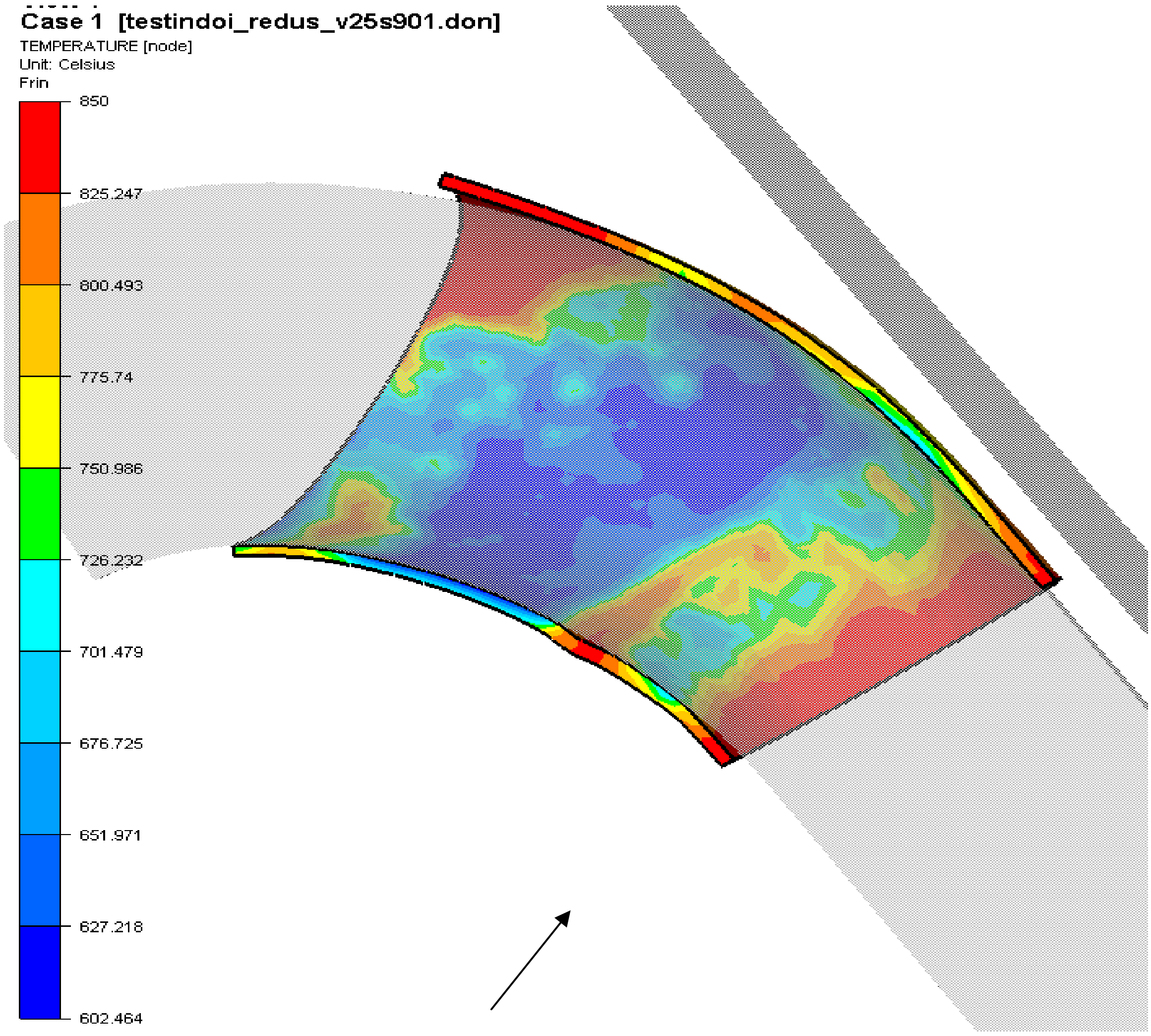


Fig. 12. Variation of wall thickness for simulation II.

The study was also continued in order to determine the best lubricant to reduce friction between blank product and mandrel; the movement of the blank product was intended to be continued until full exit from the mandrel, however due to the modifications made on the base model, namely replacing the pushing system with a pushing space, for which a complex motion law could not have been defined. On the X axis, when the blank product starts to bend and the pusher should follow the trajectory of the mandrel's symmetry axis (in real situations, the blank product is pushed by another blank product on the mandrel, from behind) the pushing motion is continued on X axis and the blank product is deforming towards the intrados until breaking.

In a real situation, the induction system generates heat which transfers to the blank product, in an uneven manner, and may be adjusted vertically, such as to create a difference in actual temperature between the extrados and intrados (approx. 50°C); for the shortened model, the geometrically undefined temperature space was not able to create the temperature difference, therefore a single value of 850°C has been used.

New research subjects and paths are available, and maybe in the future another, more complex, calculation software, would be able to solve the problems still unsolved. Maybe even Forge 2011 could provide the answers to such questions, however the Technical University of Cluj-Napoca has no such license.

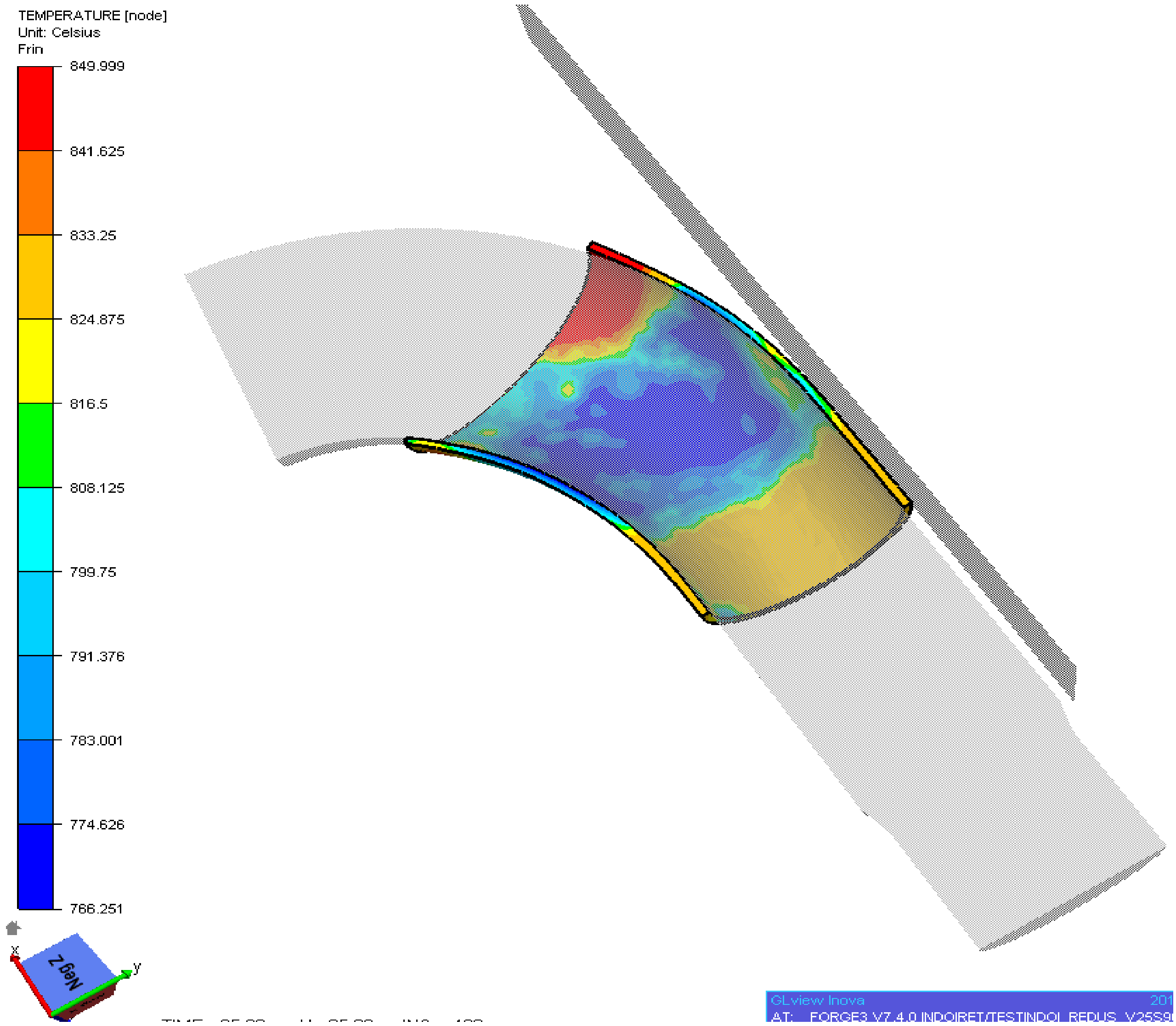


Fig. 13. Variation of wall thickness for simulation III.

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POSIBILITĂȚI DE CREȘTERE A CALITĂȚII TUBURILOR ÎNDOITE DE DIAMETRU MARE PRIN SIMULAREA NUMERICĂ A PROCESULUI DE DEFORMARE

Rezumat: Metoda Elementele Finite (MEF) este cel mai răspândit procedeu de rezolvare numerică a metodelor inginereşti. Principalele avantaje ale MEF sunt următoarele: flexibilitatea; posibilitatea de a modela corpuri neomogene din punct de vedere a proprietăților fizice şi uşurința implementării în programe de calcul generale. Scopul lucrării este: cunoaşterea mai aprofundată a fenomenelor care apar la îndoirea tuburilor de diametru mare folosind metoda tragerii pe dorn utilizând încălzirea cu curenți de inducție şi utilizarea unor intervale noi de temperatură, a unor noi game de viteze de tragere mai mari în vederea reducerii timpului tehnologic de lucru, respectiv de reducere a costurilor de fabricație.

Cristel MUREŞAN, Phd. Student Eng., Technical University of Cluj-Napoca, Department of Manufacturing Engineering, Muncii Boulevard 103-105, Cluj-Napoca, ROMANIA, e-mail: cristelmuresan@yahoo.com; Gherla 405300, Str. Mihai Viteazu no. 25, Județ Cluj, 0264 243129, 0744 604794.

Gheorghe ACHIMAŞ, Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Manufacturing Engineering, Muncii Boulevard 103-105, Cluj-Napoca, ROMANIA, e-mail: Gheorghe.Achimas@tcm.utcluj.ro; Cluj-Napoca 400537, St. Clăbucet no. 1/38, Județ Cluj 0720 054863.

Nicolae MIHĂILESCU, Phd. Student Eng., Technical University of Cluj-Napoca, Department of Manufacturing Engineering, Muncii Boulevard 103-105, Cluj-Napoca, ROMANIA, e-mail: mihailescunic@yahoo.com; Cugir 515600, Str. Tineretului no. 7/16, Județ Alba, 0735 403270.