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# NUMERICAL ANALYSIS OF THE FRICTION CONDITIONS INFLUENCE ON THE METAL TUBES EXTRUSION PROCESS

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***Abstract:*** *The aim of this study is to realize a numerical modelling study of the metal tubes extrusion process with the purpose of understanding how the material flows in the die and respectively how the friction parameters influence the plastic deformation evolve. The initial semi-finished part 34CrMo4 steel is a 24 mm in diameter and 15 mm long bar and undergoes a 3D complex extrusion process in a die consisting of an inferior die and a punch.*

***Key words****: metal tubes extrusion process, simulation, friction parameters*

## 1. INTRODUCTION

Extrusion is one of the main methods of forming in which materials are forced to fill through a die, to obtain a specific shape of constant cross section. Generally the extrusion process is used to produce cylindrical bars or hollow tubes or is used as a preparatory stage for drawn rod, or forged parts, in automobile, aircraft, construction and other industries. There are several categories of extrusion process including forward, backward and radial. The extrusion process has the advantage of producing complex components through one stage, but it has some limitations. During the extrusion process the metal flow is influence by the material flow properties, die-workpiece and container workpiece heat transfer and friction conditions and not on the least by the die geometry. One of the problems that can occur in extrusion process is due to the unsteady deformation zone which creates a different strain distribution through the extruded part.

In their recent publication Jamali et al. [1] mentioned that the radial forward extrusion is a suitable method for producing large diameter seamless tubes with superior properties from smaller cylindrical billets. They observed a good homogeneity of effective strain and micro- hardness in the longitudinal section while force requirement is dramatically reduced compared to the conventional extrusion. Shatermashhadi et al. [2] analyzed a backward extrusion process for a small diameter billet using a fix-punch and a moveable punch. Reducing the cross section of the initial billet, they found that by this method the load is reduced to about less than a quarter in comparison with the conventional backward extrusion process, imposing higher effective strain and a better strain homogeneity through the tube length. Bakhshi-Jooybari et al. [3] using the slab method and an iterative algorithm have reduced the deformation load in backward rod extrusion to optimize the die profile. One of the most applied methods for the analysis of the metal forming processes has become the finite element method (FEM). It is known that for the industry, the numerical simulation method is the most effective way to reduce the production cost. It is known that material flow properties, the profile of the die-assembly, heat transfer and friction conditions, all affect the metal flow [4].

The aim of this paper is to provide such information obtained by finite element analysis (FEA) in the case of metal tubes extrusion process with the purpose of understanding how the material flows in the die and respectively how the main parameters involved in the plastic deformation evolve.

## 2. FORMING PROCEDURE

The die setup used for the tubes extrusion process consists of two main parts of the punch and of the lower die. During the extrusion process the punch force the billet to fill the inferior die. The input parameters assigned to the deformed material are the initial

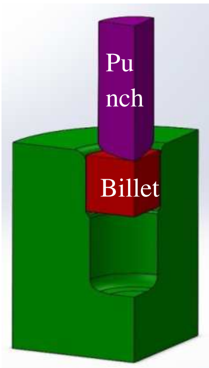



**Fig. 1** Schematic representation of the extrusion

temperature, the punch velocity (velocity at which the material enters in the mold), the friction coefficients and the parameters of the constitutive equations. The finite element code FORGE© allows different friction conditions to be entered in the calculation. The tube forming process was analyzed for three values of friction condition [6] corresponding to the friction parameters presented in Table 1.

The heat conduction transfer coefficient (between the dies and the slug) was considered homogeneous and equal to 20 kW/$m^2$K.

Table 1 Friction parameters used for simulation.

| **Friction conditions** | **μ** | **m** |
|---|---|---|
| High | 0.4 | 0.2 |
| Medium | 0.2 | 0.1 |
| Low (oil lubricant) | 0.1 | 0.05 |

### *2.1. Material and geometry of the filling device*

A 3D model able to predict most aspects of the forming process [5], such as the applied loading on the punch and thickness distribution was chosen to analyse the forming process. Fig. 1 shows a quarter of the 3D view of the filling system used in the study. The cylindrical billet made from 34CrMo4 steel is 24 mm diameter and 15 mm height. The composition of the 34CrMo4 steel is shown in Table 2. The billet undergoes an extrusion process in a die consisting of an inferior die and a punch. The characteristics of the billet material are: Young’s modulus = 200 GPa, density = 7.85 g/$cm^3$, Poisson’s ratio = 0.3.The filling tests were carried out considering the mechanical parameters of a 1000 kN hydraulic press. The punch speed was of 500 mm/s and the maximum displacement of the punch necessary to obtain the final extruded tube was 32 [mm] (see Fig. 2).

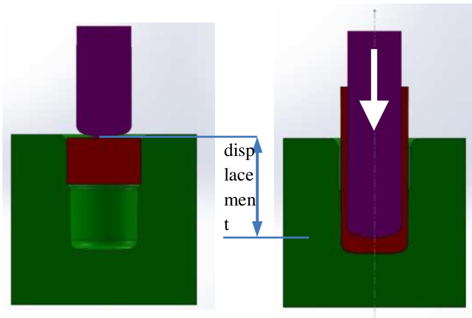



**Fig. 2**

Table 2 Chemical composition (%wt) of 34CrMo4 steel.

| 34CrMo4 Steel | % | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Cr | Mo |
| | 0.335 | 0.65 | 0.3 | 0.01 | 0.008 | 1 | 0.25 |

### *2.2. Mesh*

In this work, the finite element code FORGE® was used to perform the numerical simulations. As the mechanical problem is symmetric in the flow direction, only a quarter of the geometrical model (along the symmetrical planes) was meshed and considered for calculations. In this way, the computational time is significantly reduced. The mesh density should be high enough to capture all relevant flow aspects. Figure 3 illustrates the mesh used to analyse the deformation.

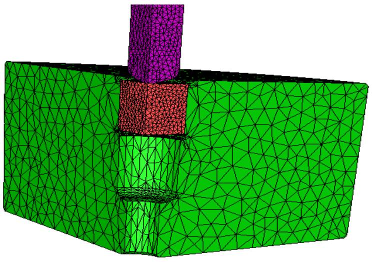


**Fig. 3** The initial meshed view of the geometric model.

The billet is divided into 18980 tetrahedral elements and 4063 nodes and has been defined as deformable object during all analyses. As the mesh quality is very important for deformable objects, the surface shape factor (SSF) was automatically checked by the GLPre Forge pre-processor using the relation:

$$SSF = \alpha \frac{\sqrt{A_{el}}}{P_{el}} \tag{1}$$

where $A_{el}$ - area element, $P_{el}$ - perimeter element α - factor such as better quality of surface element provides a form factor of 1. In our study's the surface shape factor correspond to 0.74 which is acceptable. The other parts of the geometrical model have coarser meshes. Assuming that the die and the punch do not undergo plastic deformation and their elastic deformations have a negligible effect on the deformation of the billet, their surface was defined as a non-deformable. The type of simulation was Lagrangian incremental and a global re-meshing was chosen.

## 3. RESULTS AND DISCUSSIONS

At this stage, a study on the flow of 34CrMo4 in the die during the plastic deformation by extrusion process was carried out. In order to model the friction at the tool workpiece interface the Coulomb friction model is used.

Figure 4 presents the effect of lubrication conditions on the flow of 34CrMo4 in the die cavity, after a 20 mm stroke of the punch. We must specify that for this study the die (punch and lower die) was considered rigid and the die temperature constant. At this intermediate stage, the flow of the material in the die is made by pressing it in the die cavity, but it can be noted that even before the material fills the inferior cavity of the die, the reverse flow through the die orifice starts (material displacement in the direction of minimum resistance). At this stage, the higher friction is, the more advanced is the flow in the direction of minimum resistance of the material. We can also notice a pronounced non-uniform temperature concentrated in the area where the semi-finished part is in contact with the lateral interior lower die wall, perhaps because to the friction and thermal conditions. Even if there is not a very big difference in terms of friction conditions, we can observe that the influence on the temperature's evolution on the semi-finished part is important. Thus, the higher the friction is on the contact areas, the higher the temperature in that area is. The duration of deformation up to this stage is 0.04 s and the maximum temperature reached in circumstances of high friction on the surfaces that get into contact is approximately 650°.

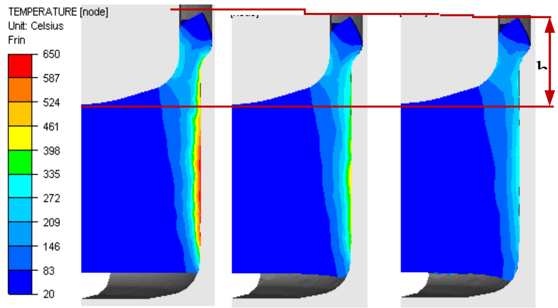



**Fig. 4** The effect of lubrication conditions on the flow of 34CrMo4 in the die cavity – Intermediate flow stage: a) high friction; b) average friction; c) low friction.

Figure 5 presents the effect of lubrication conditions on 34CrMo4 steel flow in the die cavity, after a complete punch stroke (32 mm). After the material is pressed into the die cavity (the lower area of the die cavity is full) and the material's reverse extrusion takes place (the shear zone is present). Considering different friction conditions at the high punch velocity (500 mm/s) we can observe here how the material flows on the punch during the reverse extrusion stage. At this process phase, we no longer detect an influence of the friction conditions on the flow length, but we do notice a distinct non-uniform temperature in the semi-finished part, caused by the increases of friction conditions. The non-uniform temperature is concentrated in the area where the semi-finished part is in contact with the lateral walls of the die/ punch, but also in the area where the semi-finished part is in contact with the tip of the punch (the area where the material is pressed).

Thus, higher the friction is on the surfaces in contact, higher the temperature in that area is. The maximum temperature reached in those circumstances is about 700°C.

Figure 6 shows the evolution of the force needed to extrude the metal tubes.

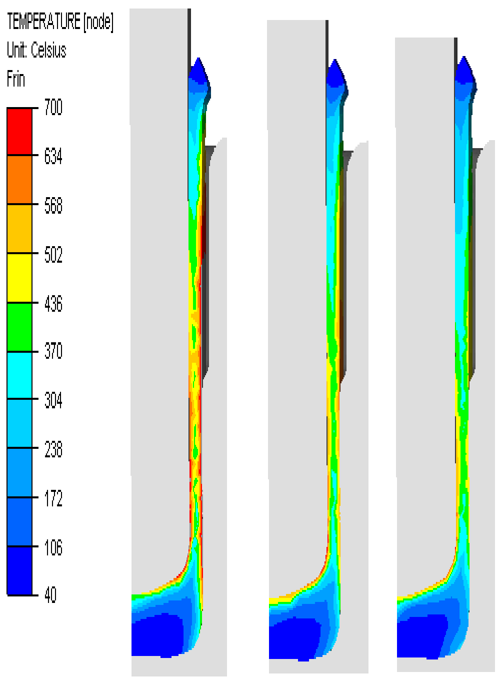



**Fig. 5** The effect of lubrication conditions on 34CrMo4 steel flow in the die cavity – Final flow stage: a) high friction; b) medium friction; c) low friction.

During the deformation process, the extrusion pressure, respectively the necessary force, slowly rises up to approximately 50 kN A slight force reduction can be noticed at 15-20 mm stroke, due to a slight backward flow of the material in the direction of minimum resistance.

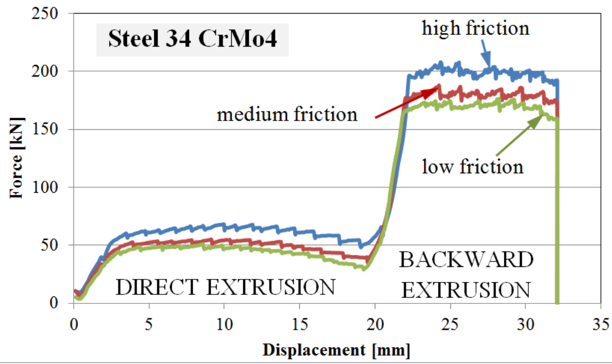



**Fig. 6** The effect of lubrication conditions on 34CrMo4 flow in the die cavity.

At the end of the pressing stage, the backward flow starts and the necessary force rises considerably (up to 4 times higher) and then, up to the end of the punch stroke the force's evolution remains approximately constant. The force needed for deformation has this kind of evolution because the pressure needed to maintain the flow rises, as friction forces increase when the length of contact between the material and the walls of the die/ punch grows. The sudden rise of the deformation force can be caused by the temperature rising up to values around 700°C in the backward deformation phase, which can lead to the growth of the coefficient of friction as a consequence of primary oxides appearing on the body surface. Fig. 6 allows us to notice that a reduction of the conditions of friction involves a decrease of the deformation force in the first stage, when the material is pressed and in the second stage of the deformation process, when the backward extrusion of the material takes place.

Figure 7 presents the distribution of the effective strain inside the billet at a final stage of tubes extrusion. We can observed, two zones of different deformation characteristics in the interior of the billet.

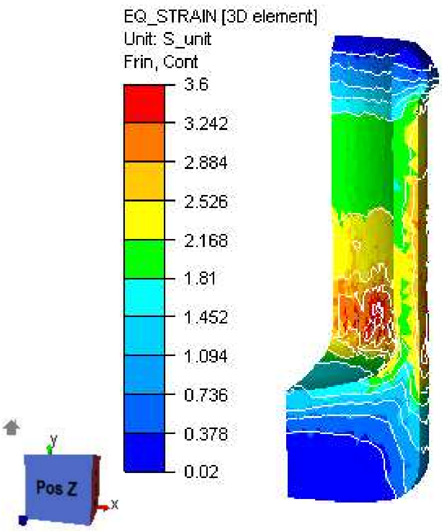
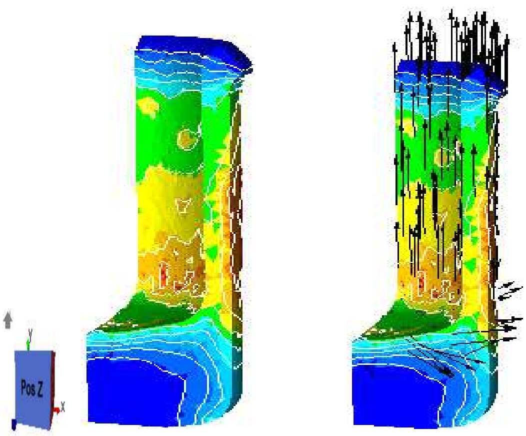



**Fig. 7** Effective strain distribution at a final stage of tubes extrusion

## 4. DETERMINING EQUIVALENT DEFORMATIONS

The metal tubes extrusion process involves high deformations and serious changes of the direction of deformation. Another aim of this study is to determine the distribution of equivalent deformations in the 34CrMo4 extruded tubes. Figure 8 presents the uneven distribution of deformations in the extruded tube after a 28 [mm] piston stroke, under the same lubrication circumstances (coefficient of friction μ = 0.2).

When analyzing the values of the equivalent deformation we can see that it is not even and that it has local maximum values.



b) c)

**Fig. 8** Deformation distribution in the extruded tube after a 28 [mm] piston stroke; b) and c) 34CrMo4.

The equivalent deformation records maximum values in the area of the outer vertical wall of the tube and respectively on the inner wall, above the connection radius (i.e. in the area where the punch first enters the material). As the punch advances, the travel on the y direction increases and the punch deforms also areas of undeformed material, areas where deformations are lower. In order to better understand how deformations are distributed during the tube extrusion process Fig. 8 c) presents vectorially the 34CrMo4 extruded tube.

## 5. CONCLUSIONS

This study has utilized three-dimensional finite element code FORGE® to examine the plastic deformation behaviour of 34CrMo4 steel billet during its axisymmetric extrusion. Although there is not a great difference in terms of friction conditions, we can notice that the influence on the evolution of the temperature in the semi-finished part is important.

Thus, the higher the friction on the contact surface, the higher the temperature gets in that area especially in the final flow stage. Reducing the friction conditions entails a decreasing of the deformation force in the first stage, when the material is pressed and also in the second stage of the deformation process, when the backward extrusion of the material takes place. It was observe 4 times higher force in the second part of deformation (backward extrusion) due to increasing of the length contact between the material and the walls of the die/ punch.

The effective strain, is small in the inferior part of the tube and on the upper edge (<2) and larger in the surface layer of the tube (>3.5), where the shear and friction effects are present. Manufacturing tubes by extrusion in low friction conditions process will reduce the forming load and energy and therefore, will increase the productivity of the production process.

In each of the cases presented in figure 8, the value of the equivalent deformation decreases on a radial direction, from the inner part of the tube towards its outer side. On the direction of the y-axis, the equivalent deformation is low in the upper part of the tube and at its bottom as well (the area where the material is pressed). The difference between the minimum and maximum equivalent deformation values is over 180%, which suggests increased anisotropy.

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**NUMERICAL ANALYSIS OF THE FRICTION CONDITIONS INFLUENCE ON THE METAL TUBES EXTRUSION PROCESS**

**Rezumat**: *Scopul acestui studiu constă în realizarea modelării numerice a procesului de extrudare a tuburilor metalice în vederea înţelegerii modului de curgere a materialului în matriţă şi respectiv a influentei parametrilor de frecare, în procesul de deformare plastică. Semifabricatul iniţial este din otel 34CrMo4 debitat din bară cu diametrul de 24 mm şi lungimea de 15 mm si este supus unui proces de extrudare complexa de tip 3D într-o matriţă, compusă din: matriţa inferioară şi poanson.*

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