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NUMERICAL SIMULATION OF THE FORMING PROCESS BY REVERSE EXTRUSION OF SMALL DIAMETER TUBES

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Abstract: *As compared with other processes, the reverse extrusion ensures high productivity, high material utilization and reducing workload. The finished part presents superior mechanical characteristics due to the cold hardening of the extruded material.*
In order to determine the parameters of the inverse extrusion operation of the "tube", the numerical simulation of the forming process was carried out. For this purpose, the finite element analysis program Deform-2D was used [2]. Deform-2D provides a graphical user interface for preparing the model, through which the parameters of the forming process can be easily specified. This paper presents the steps performed in order to develop the finite element model of a reverse cold extrusion operation. ***Key words:*** *reverse extrusion, small diameter tubes, and finite element simulation.*

1. INTRODUCTION

Product whose technology is the subject of this paper is a small diameter tube (Φ 20). The technical documentation prescribes the execution of this part from brass. This material is widely used in cold extrusion. The shape and size (Fig. 1), and the series production of the part (about 10 000 parts / year) recommend its manufacturing through reverse cold extrusion.

A possible alternative would be the execution through cutting technologies. However, choosing this option would be uneconomic because of the metal losses in the form of chips.

In terms of the forming technology, the "tube" extrusion does not pose particularly difficult problems. Both the wall thickness (2 mm at the top and 3.5 mm at the bottom) and the overall dimensions (inner diameter and height, respectively) are in the field of economic workability.

The execution tolerances provided by the drawings are easily achieved by extrusion, without the need of calibration.

The success of the metal forming processes, especially those taking place at room temperature, is conditioned by not exceeding the maximum straining that is allowed by the material.

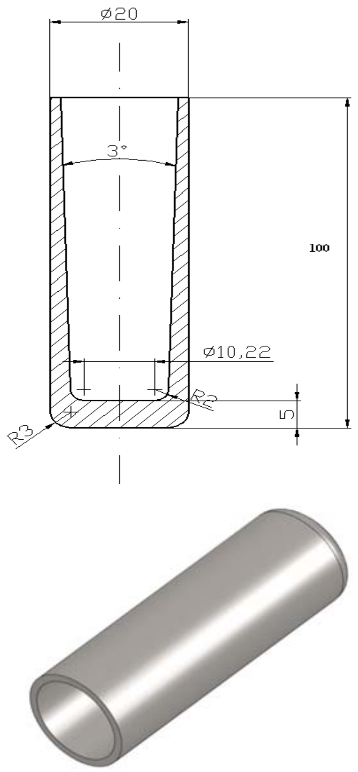


Fig. 1 Geometric configuration of the tubular part

This condition has a decisive role in determining the technological route of the parts, especially the number of forming operations and the intermediate configurations. To achieve a part in economic conditions, it is desirable to achieve a minimum number of such operations, which leads to lower leading costs.

In the case of the cold extrusion, the straining degrees can be evaluated using one of the following relations [9]:

$$\varphi_A = \ln \frac{A_0}{A} \quad (1)$$

$$\varepsilon_A = \frac{A_0 - A}{A_0} \cdot 100 \quad [\%] \quad (2)$$

The first formula expresses the so-called "logarithmic strain." The second one, more frequently used in practice, defines a percent strain. Both relationships involve the cross-sectional area of the blank and the area of representative sections of the extruded part.

The above formulas can be applied across several sections of the tube, where it is necessary. Thus, the degree of deformation can be checked in various regions of the finished part.

The calculated sizes using the above relations must not exceed the limit values allowed by the material subjected to extrusion. In the case of brass, the literature [9] mentions the following allowable values:

$$\varphi_A \le 2{,}5 \ldots 4{,}6 \quad (3)$$

$$\varepsilon_A \le 95 \ldots 99\,\% \quad (4)$$

The principle of the reverse extrusion is shown in Fig. 2.

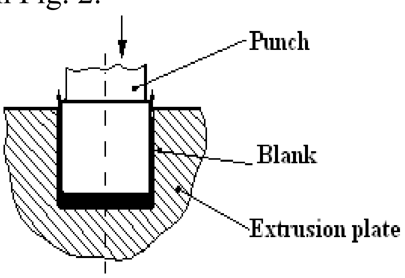


Fig. 2 Execution of the tubular part through reverse extrusion

The operations used to prepare the metallic materials for the cold reverse extrusion do not require the use of a complex equipment.

2. TECHNOLOGICAL ELEMENTS USED FOR THE TUBE MANUFACTURING

The workpiece is cut on a lathe from a cylindrical bar. Its shape and dimensions are presented in Fig. 3. With the exception of the height, all the other sizes were established on the basis of technological criteria. To facilitate the blank placement in the mold, the outer diameter, D = 20 mm, was chosen slightly smaller than the cavity diameter of the extrusion die, while an inside 3 % tapering must be provided.

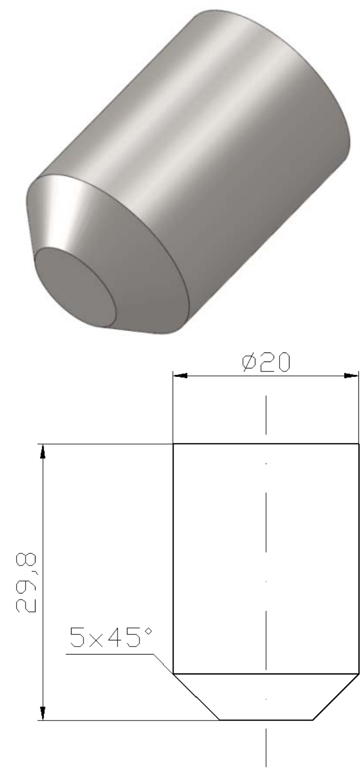


Fig. 3 Configuration of the workpiece

The only dimension that remains to be determined is the height. For its determination, the volume conservation method has been used [9]. For that matter, the condition that the material volume included in the workpiece is to be found in the finished part has been imposed. Given that the upper wall height of the extruded part forms freely, the finished part volume was supplemented with an addendum, which has to be removed by the trimming operation. This processing will be done on the lathe.

By the numerical simulation of the extrusion process (see §3), a cutting addendum of h = 5 mm height was established.

The condition of the material volume conservation is expressed by the equality:

$$V_{sf}=V_{pf}+V_{adaos} \qquad (5)$$

where the V_{sf} is the volume of the workpiece, V_{pf} is the volume of the finished part and V_{adaos} is the addendum volume required by the further cutting of the upper edges. Volume set with the addition of 5 mm was determined by direct measurement of the part on the 3D model created using SolidWorks.

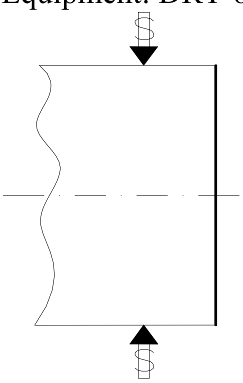
Thus, a total volume $V_{pf} + V_{adaos} = 8704.52$ mm^3 has been obtained. The V_{sf} volume can be determined by analytical calculation. It is noted that, from the geometrically point of view, the workpiece form which the extrusion starts is a cylinder provided at one end with 45° chamfer at the bottom end (Fig. 3). Given this, we can write:

$$H = h + \frac{4(V_{pf}+V_{adaos})^2}{\pi D^2} - \frac{h}{3D^2}\left[D^2 + D(D - 2h)^2\right] \qquad (6)$$

Performing the numerical replacements in the above relation, we obtain the value H = 29.791 mm, which will be rounded at H = 29.8 mm. On the basis of the issues discussed above, the following technological flowchart of the tube was devised:

1. Workpiece preparation

Equipment: DRT-80 lathe.



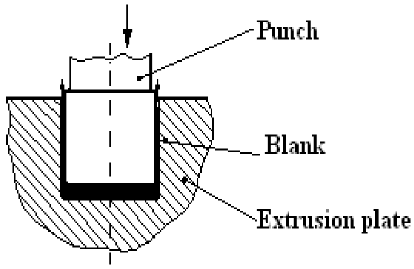
2. Heat treatment (quenching)

Equipment: heat treatment oven

3. Cold extrusion

Equipment: Hydraulic Press PH-40, reverse extrusion die

Note: Before the extrusion, the workpiece is lubricated with molybdenum disulfide powder.



4. Intermediate control

Note: Check the aspect of the extruded parts.

5. Trimming

Equipment: SN-320 lathe

6. Final control

Note: Check all the dimensions specified in the technical documentation of the product.

3. NUMERICAL SIMULATION OF THE COLD EXTRUSION OPERATION

The numerical procedure almost exclusively used nowadays for the simulation of the metal forming processes is the finite element method. This is frequently used not only in research but also in the industry. For a more precise analysis of the cold extrusion operation of the tub, the numerical simulation of the forming process was carried out.

For this purpose the finite element analysis program Deform-2D was used [2]. Deform-2D is used widely in the computer-aided design for bulk forming technologies (forging, extrusion, rolling etc.). This program is able to simulate the processes taking place at room temperature or warm. Among the facilities offered by Deform-2D, the most important are:

• The possibility of modeling tools with complex geometry;
• Automatic generation of the finite element meshes;
• Adaptive regeneration of the finite element mesh in order to obtain accurate results;
• Simplified description of the forming process (automatic tool positioning in relation to the

blank, defining the direction of movement of mobile elements of the die, identification the contact surfaces between workpiece and tools, simple specification of the parameters that describe the frictional interactions, etc.);

• Libraries containing the mechanical parameters of materials widely used in industry (ferrous and non-ferrous alloys);

• Graphical representation of the simulation results as diagrams easily interpreted by users.

3.1. Developing the finite element model of the cold extrusion process

Deform-2D provides users with a graphical preprocessing module, through which can be easily specify the deformation process parameters that ought to be simulated. Further on, steps taken to develop the finite element model of cold extrusion operation were presented, as follows:

• Define the general type of the process (in this case, a process with axial symmetry) and the unit system adopted in the simulation;

• Establish a name for the numerically simulated operation;

• Specify the temperature range in which the forming process analysis was carried out (in this case, the ambient temperature);

• Specifying the complexity of the workpiece and the tool shapes, as well as the precision requirements of the numerical simulation;

Note: DEFORM-2D needs this information to adjust the density of the finite element mesh. In this case, the geometric complexity of the blank and tool is average and the accuracy requirements are moderate.

• Specify the number of active components of the die (in this case, two components namely the extrusion plate and the punch);

• Defining the workpiece as the first component of the process model;

• Loading the geometric model of the workpiece (Fig. 4);

Note: Due to the cylindrical symmetry of the extrusion process, not only the blank geometry, but also the active elements that produce the deformation are described by their axial sections. These sections were modeled using AutoCAD and transferred to Deform-2D via DXF files.

• Meshing the axial section of the workpiece subjected to the extrusion (Figure 5);

Note: The meshing is automatically performed; the user must specify only the total number of finite elements (4000, in this case).

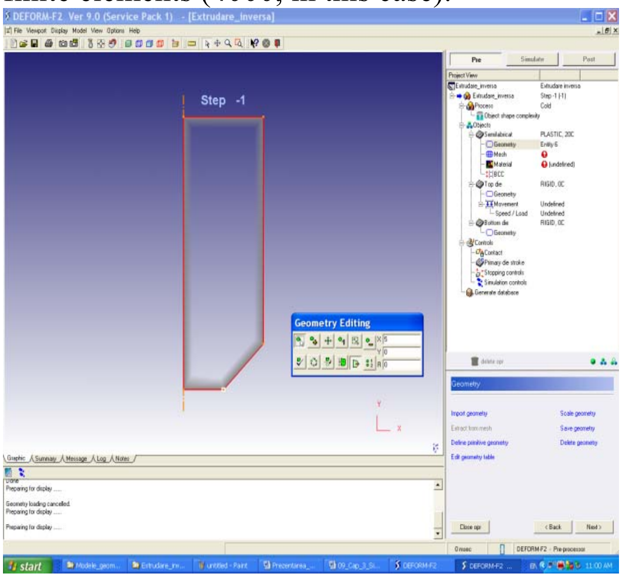


Fig. 4. Loading the geometrical model of the workpiece

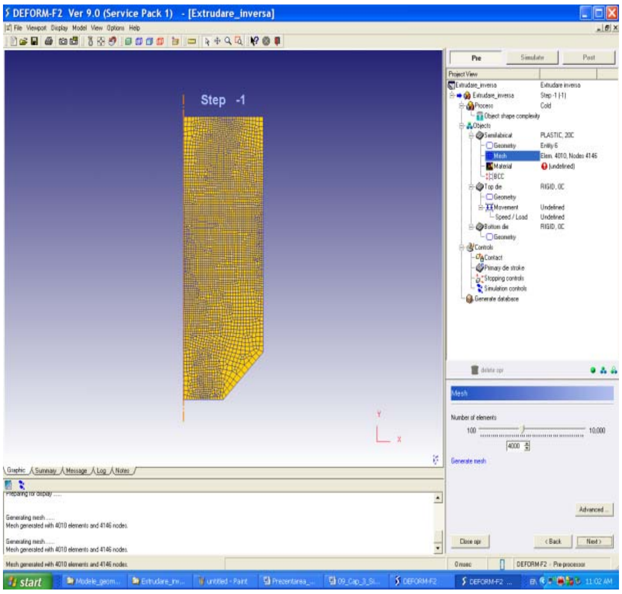


Fig. 5. Meshing the axial section of the workpiece

• The mechanical parameters of the brass were imported from the material library. The main characteristics are the following ones:

- o Name: CARTRIDGE BRASS (ISO 426 / 1);
- o Composition: 70% Copper and 30% zinc;
- o Density: 8.53 g/cm^3 at 20 ° C;
- o Stiffness: 4200 kg/mm2;
- o Elasticity: 11.200 kg/mm2

• Loading the geometric models of the active elements, defining their motion and control parameters (Fig. 6).

Note: In the case of the tubular part under analysis, the active elements have the following status:

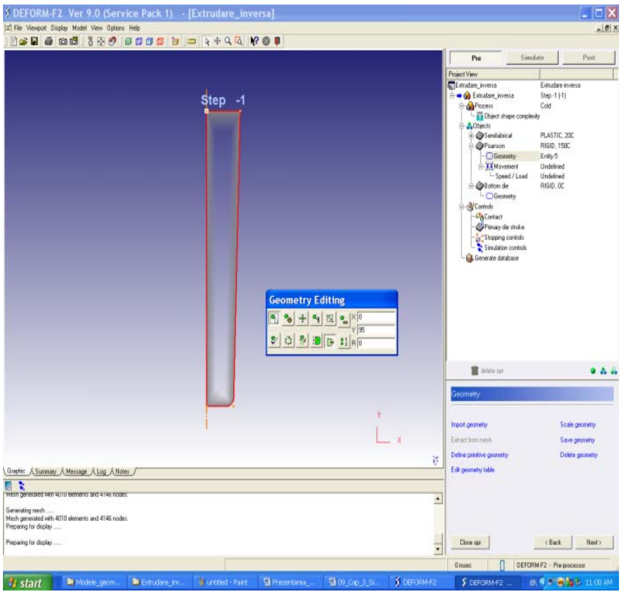


Fig. 6 Loading the geometric model of punching

• Punch makes a downward movement along the Y axis of the coordinate system used by DEFORM-2D along a distance of 24.8 mm (calculated as the difference between the workpiece height and the thickness of the bottom region of the finished part). Adopting a conventional duration of one second of the extrusion process, we obtain a speed of 24.8 mm/s of the punch;

• The extrusion plate is a fixed element of the die.

• Positioning of the active elements in relation with the workpiece;

Note: DEFORM-2D automatically performs this operation, taking into account the status of active elements (fixed or mobile).

• Specifying the friction coefficient, μ, associated to the contact surfaces between the workpiece and the active elements;

Note: The value μ=0.2 was adopted taking into account the recommendations from the literature for brass extrusion at room temperature [3].

• Specification of punch vertical stroke (in this case 24.8 mm);

• Define the stopping conditions for the extrusion process simulation (achieving the lower dead point of punching down stroke);

• Specification of the number of temporal increments that have to be made during the simulation, namely the number of increments between two consecutive savings of the output data (Fig. 7);

• Checking the design and execution of simulation programs.

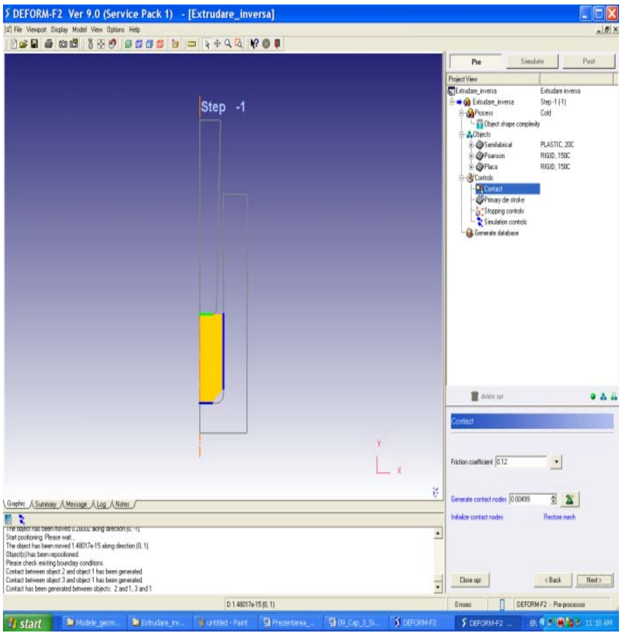


Fig. 7 The specification of the friction coefficient associated to the contact surfaces between the workpiece and the active elements of the die

3.2. Analysis of the simulation results

To facilitate the interpretation of the numerical results, DEFORM-2D provides users with a graphical postprocessor. In general, the simulation results are presented as color maps accompanied by a legend that associates each color field a size range of the analyzed values.

Among the most useful information that DEFORM-2D program provides, the following items are included:

• Distribution of the equivalent plastic strain and equivalent stress in the axial section;

• Variation diagrams of the forces taken from the die active elements during the simulated forming process.

The equivalent plastic strain reflects the level of the material cold hardening. Figure 8 shows the distribution of this quantity in the final stage of the extrusion process.

As shown in the legend of the diagram, the maximum equivalent strain is localized in the area where the blank undergoes the largest plastic distortions (at the connection between the upper cylindrical wall and the bottom area of the part). It may be noticed that the equivalent strain has also high values along the inner surface of the upper cylindrical wall (Fig. 9).

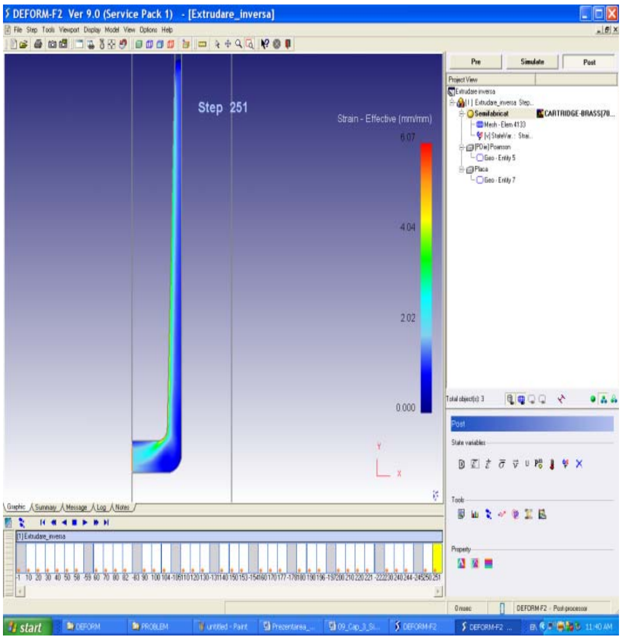


Fig. 8 Distribution of the equivalent plastic strain in the final stage of the reverse extrusion process

This fact is the result of a gradually accumulated hardening during the wall extrusion.

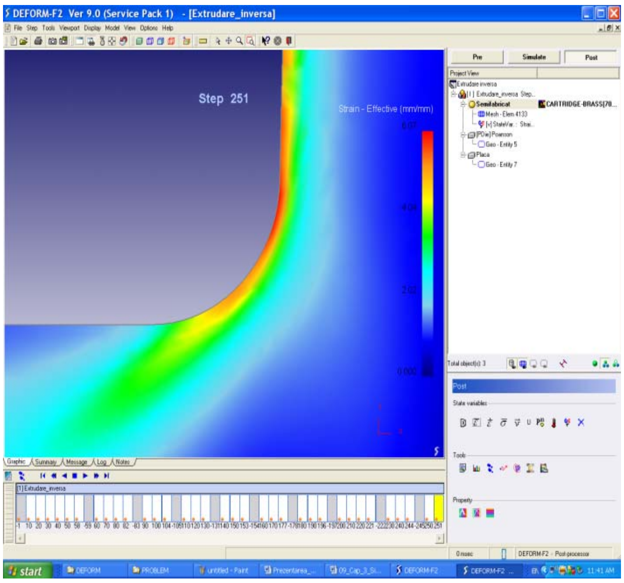


Fig. 9 Distribution of the equivalent plastic strain in the final stage of the extrusion process (the detail is limited to the region where the maximum values occur)

The plastic equivalent strain can be also seen on the outside of cylindrical wall located at the bottom of the part (Fig. 9).

The values are still lower than those obtained in the upper zone because the plastic distortion of the workpiece is less pronounced.

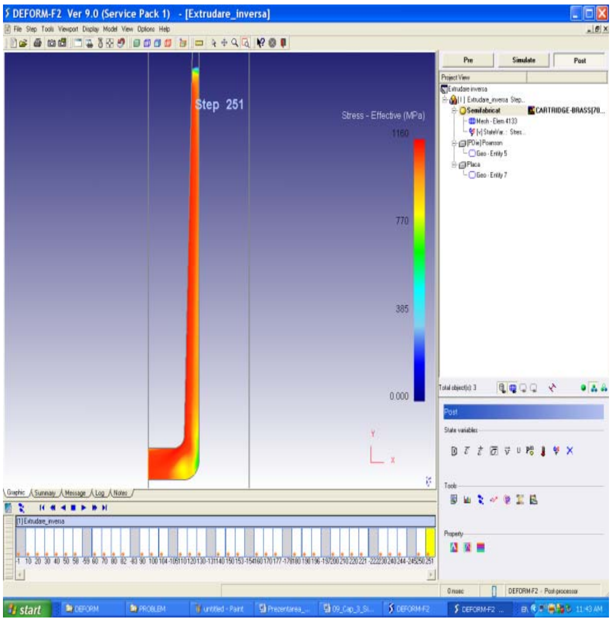


Fig. 10 Equivalent von Mises stress distribution in the final stage of the reverse cold extrusion process

Figure 10 shows the distribution of the equivalent von Mises in the final stage of the extrusion process.

This amount reflects the mechanical strength of the hardened material.

As it is shown on the chart, the maximum equivalent tensile is also located in the connection zone of the upper cylindrical wall with the bottom of the part, where the highest values of the equivalent strain appear.

Figure 11 presents the variation of the vertical forces developed by the active elements of the die during a downward stroke of the ram.

It is noticeable that the punch develops the most important load (the maximum force is about 1676 kN).

This situation is normal, because the punch is the driving element of the forming process.

The maximum load values determined through numerical simulation will be used for the selection of the press on which the die will be installed, and for the strength calculations of the die components (punch, extrusion plate, counter-punch, ejecting springs etc.).

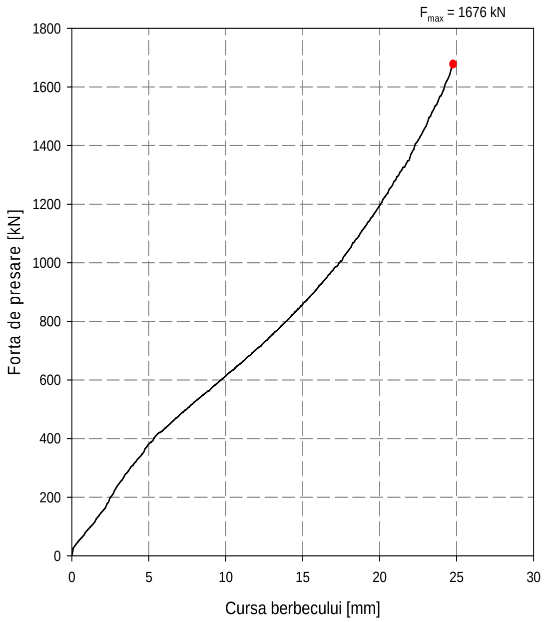


Fig. 11 Variation diagram of the vertical force developed by the press ram

4. CONCLUSION

The main objective of this work was the numerical simulation of the extrusion operation of a tubular part. The reduced thickness of the wall part (2 ÷ 3.5 mm) and the extrusion depth require a detailed analysis of the forming process.

For this purpose, in order to validate the technological solutions obtained by classical methodology it was used the numerical simulation of the extrusion operation.

At the moment, the numerical simulation is a tool widely used in the technological design of cold forming operations.

In the process of the tooling design, numerical simulation plays an essential role. This is the consequence of the important role played by the plasticity properties of the raw material, as well as by the contact interactions between the workpiece and tools during the forming process.

Using numerical simulation it is possible to adjust the blank geometry or the configuration of the tools at an early stage of technological design without the need for repeating the adjustment steps that describe the traditional design.

Thus, a reduction of costs involved in the tooling design and production is obtained. In addition, a better sizing of the workpiece usually has the effect of improving the value of the material utilization coefficient.

It should be noted that the numerical simulation software provides very useful additional information for engineers: evolution in time of the pressing force, and also the contact loads at which the die active elements are subjected.

In order to simulate the cold extrusion operation, the finite element analysis program Deform-2D was used. Following the numerical simulation has revealed the following information:

• distribution of the equivalent plastic strain and the equivalent stress in the axial section of the workpiece;
• the variation diagram of the forces developed by the active elements of the die during the forming process.

The predictions provided by DEFORM-2D have validated the accuracy of the preliminary results obtained by using conventional methodologies.

5. REFERENCES

[1] Comşa, D. S. Metoda elementelor finite. Curs introductive Cluj-Napoca. Editura U.T. Press, 2007.

[2] http://www.deform.com/products/deform-2d/2d-brochure.pdf

[3] Lange, K., Kammerer, M., Pöhlandt, K., Schöck, J. *Fließpressen. Wirtschaftliche Fertigung metallischer Präzisionswerkstücke*. Berlin: Springer, 2008.

[4] Paquin, J.R., Crowley, R.E. *Die Design Fundamentals*. New York: Industrial Press, 1987.

[5] Schuler Gmbh (ed.) Metal Forming Handbook. Berlin: Springer, 1998.
[6] Skrzypek, J.J. Plasticity and Creep. Theory, Examples, and Problems. Boca Raton: CRC Press, 1993.
[7] Smith, D.A. (ed.) Die Design Handbook. Dearborn: Society of Manufacturing Engineers, 1990.,
[8] Suchy, I. Handbook of Die Design. New York: McGraw-Hill, 2006.
[9] Tăpălagă, I., Berce, P., Achimaş, Gh. *Extrudarea metalelor la rece*. Cluj-Napoca: Editura Dacia, 1986.
[10] Vermeşan, G. *Tratamente termice*. Cluj-Napoca: Editura Dacia, 1987.

SIMULAREA NUMERICĂ A PROCESULUI DE DEFORMARE A METALELOR PRIN EXTRUDARE INVERSĂ A TUBURILOR DE DIAMETRU MIC

Rezumat: Comparativ cu alte procedee, prelucrarea prin extrudare inversă asigură o productivitate ridicată, un grad înalt de utilizare a materialului şi reducerea volumului de muncă. De asemenea, datorită ecruisării materialului extrudat piesele realizate prezintă caracteristici mecanice superioare.
Pentru determinarea parametrilor operației de extrudare inversă a produsului „tub", a fost efectuată simularea numerică a procesului de deformare plastică. În acest scop a fost utilizat programul de analiză cu elemente finite DEFORM-2D [2].
Programul DEFORM-2D pune la dispoziția utilizatorilor un model de preprocesare grafică, prin intermediul căruia pot fi precizați cu uşurință parametrii procesului de deformare ce urmează a fi simulat. În lucrare vor fi prezentate etapele parcurse în vederea elaborării modelului cu elemente finite ale operației de extrudare inversă la rece.

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