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OPPORTUNITIES TO INCREASE THE QUALITY OF SMALL DIAMETER TUBULAR PARTS OBTAINED BY REVERSE EXTRUSION, BY NUMERICAL SIMULATION OF THE DEFORMATION PROCESS

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Abstract: The reverse extrusion process that makes the subject of this paper focuses on plastic deformation, which operates on a cylindrical tablet of 20 mm in diameter and 29.8 mm in length. Due to the complexity and nonlinear nature of the phenomena related to the active plate wear, the program DEFORM-2D [DFM 2008a] was used to analyze this process. Currently, DEFORM-2D is used in computer-aided design of the technologies for volume deformation. This program is able to simulate processes taking place at room temperature or warm temperature. The program provides a graphic processing module, through which one can specify the parameters of the analyzed deformation process.
The paper will present the model development stages of reverse extrusion operation.
Keywords: reverse extrusion, simulation, finite elements, volume deformation

1. INTRODUCTION

The mark whose technology is the subject of this paper is a metal tube (fig. 1.). Drawing C-01 provides the achievement of this piece out of brass, whose mechanical properties are shown in table 1.

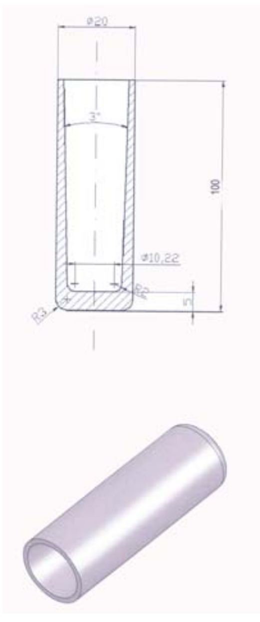


Figure 1. Geometrical configuration of the mark „Tube"

This material is largely used in the field of cold extrusion. As related to the price, it is one of the cheapest materials used for the processing by plastic deformation.

Table 1.
Mechanical properties of brass

Flow limit $R_{P0,2}$	Tensile strength R_m	Breaking alongation A_{50}	Brinell HB hardness
Min. 20 N/mm^2 Max. 35 N/mm^2	Min. 65 N/mm^2 Max. 80N/mm^2	Min. 35 N/mm^2 Max. 42N/mm^2	Min.20N/mm^2 Max.21N/mm^2

In terms of technology, the extrusion of mark "tube" does not pose difficult problems. Both wall thickness (2 mm at the top, respectively 3.5 mm in the lower collar) and gauge dimensions (inner / outer diameter, respectively lengths) are in the field of economic processing. Also, the limits provided in the drawing are easily achieved by extrusion, without the need for calibration.

The success of processing by plastic deformation, especially those taking place by cold processing is conditioned by not exceeding the limit of deformation, which the material allows. This plays a decisive role in determining the technological route of the parts, especially the number of operations and intermediate configurations. To achieve a milestone under economic conditions it is desirable to achieve a minimum number of such operations, which leads to lower costs of production preparation.

2. TECHNOLOGICAL ASPECTS RELATED TO THE ACHIEVEMENT OF THE „TUBE" PRODUCT

In case of extrusion, the degrees of deformation suffered by the blank are usually determined by means of one of the [Tap 1986] relations:

$$\varphi_A = \ln\frac{A_0}{A} \quad , \tag{1}$$

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

The first formula expresses the so-called "logarithmic degree of deformation". The second formula, more commonly used in practice, defines a percentage deformation.

The cross-section area of the blank (A_0), respectively the area of a representative section of the extruded part (A) intervene in both relations. As required, the above formulas may be applied to several sections of the part. Thus, the degrees of deformation tolerated by the blank may be checked in various areas. The sizes calculated using the above relations must not exceed the limit values accepted by the material subject to extrusion. In the case of brass, literature [Tap1986] states the following acceptable values:

$$\varphi_A \leq 2{,}5...4{,}6 \tag{3}$$

$$\varepsilon_A \leq 95...99\% \tag{4}$$

To control the maximum level of deformations, it is essential to establish the shape and size of the blank on which the plastic deformation is based. The shape and size of the "tube" mark recommends its performance by reverse extrusion (figure 2).

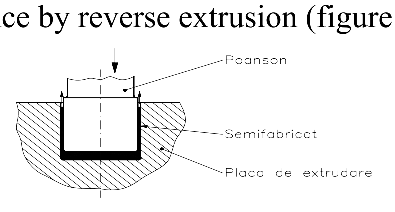


Figure 2. Performance of the "tube" mark by reverse extrusion

The starter blank is shaped like a pill, all pill sizes were set based on technological criteria (figure 3).

Figure 3. Configuration of the blank used for the extrusion of the mark "tube"

To analyze the limit deformation of the mark "tube", we will take into account two specific areas (see figure 2)

a) The superior tubular section

In this area of the part, the following values of the limit deformations result from the relations (1) and (2):

$$\varphi_A = 1{,}833 \text{ and } \varepsilon_A = 84\% \tag{5}$$

We may notice that both measures are below the acceptable limits specific to brass (see rel. (3) and (4)).

b) The inferior tubular section

The following values of the limit deformations result from relations (1) and (2):

$$\varphi_A = 1{,}984 \text{ and } \varepsilon_A = 86{,}25\% \tag{6}$$

In conclusion, the maximum deformations are not dangerous for any of the two specific areas of part. Therefore, the piece may be prepared in a single operation. Based on the aspects analyzed above, the technological route of the mark "tube" has been developed.

3. WEAR ANALYSIS OF THE ELEMENTS USED FOR REVERSE EXTRUSION OF A TUBULAR MARK

The reverse extrusion process that is the subject of this analysis is outlined in Figure 4. It is noticed that the plastic deformation operates on a cylindrical tablet of 20 mm in diameter and 29.8 mm in length. The blank results from cutting a steel AISI-1010 bar on the lathe (carbon steel with OLC 10 in terms of composition and mechanical properties). The plastic deformation takes place under the action of a mandrel performing a vertical run of 24,8 mm.

In the case of reverse extrusion process, the wear is concentrated mainly at the level of the mandrel and the cavity of the active plate.

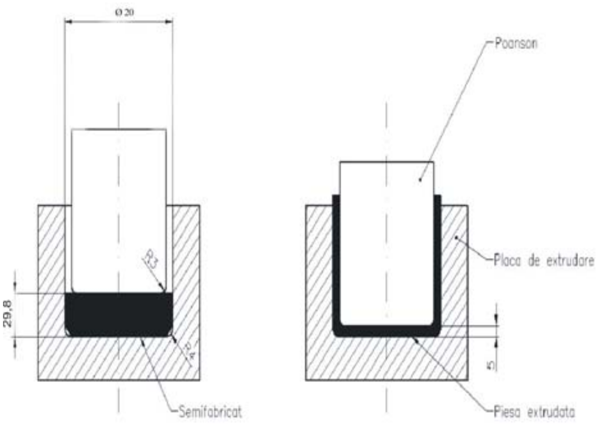


Figure 4. Design of the reverse extrusion process that makes the subject of the analysis

The intensity of this phenomenon is under the influence of the following factors:

- the nature of the blank;
- the material of the active plate and its hardness obtained after heat treatments;
- the level of friction between the blank and tools;
- heat elimination accompanying the plastic deformation process and frictional interactions.

DEFORM-2D program provides a graphical preprocessing module, through which one may specify the parameters of the deformation process analyzed. Next, we will present the development phases of the model with finite elements of the reverse extrusion operation presented in Figure 4

During the reverse extrusion process, the wear affects almost equally both the mandrel and the active board. This situation is a consequence of the mechanics of the deformation process, characterized by an important dislocation of the material, not only in the gap between the plate and the mandrel, but also on the frontal surface of the mandrel.

In this case, for the analysis of the tool wear, we used DEFORM-2D program [DFM2008a]. Next, we will present the development stages of the finite element model of the reverse extrusion process:

- Running of the preprocessor DEFORM-2D;
- Definition of generic parameters of the process that is the subject of the numerical simulation;
- The process type analyzed (process with cylindrical symmetry), the system of measurement units (SI), respectively the model that will be adopted (plastic deformation accompanied by thermal effects);
- The criterion that will be used to detect the final stage of the process analyzed;
- The impact of the geometrical design of the blank, its digitization in finite elements and the determination of the associated mechanical model (figure 5);

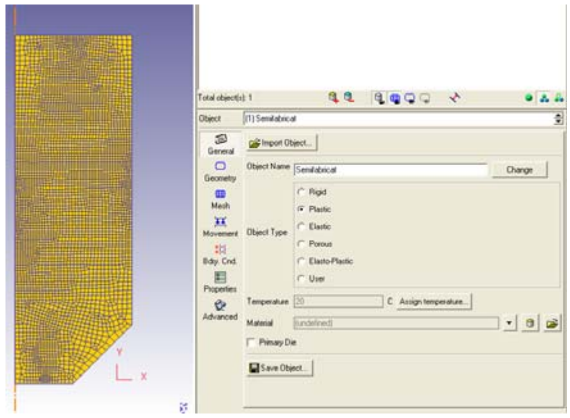


Figure 5. Import of the geometrical model of the blank, its discretization in finite elements and specification of associated mechanical model

- Import of the geometrical model of the mandrel; Import of the geometrical model of the active card; Specification of the material subject to extrusion; Specification of the material of which the active elements of the matrix are made; Definition of blank movement restrictions; Specification of the borders where heat exchange occurs; Specification of the friction component parameters of the contact interactions between the blank and tools.

For the numerical simulation of the deformation processes characterized by very high pressure at the contact surfaces between the blank and tools, the literature [Lan2008] and program documentation DEFORM-2D [DFM2008b, DFM2008c] recommend the use of a principle

$$\tau_f = m\tau_c \tag{7}$$

where τ_f is the tangential stress associated to friction, τ_c is the flow limit for the pure shearing of the plastically deformed material (a size that evolves under the control of a cold hardening principle), and m is a dimensionless coefficient that depends on the type of the materials in contact and the lubricant. For the pair steel - steel, given a very good lubrication with a suspension of molybdenum bisulphuret, the documentation of DEFORM-D2 program [DFM2008b, DFM2008c] recommends a coefficient m = *0.08*

- Specification of the parameters associated to the thermal part of the contact interactions between the blank and the tools - similar to the situation shown in Figure 6.

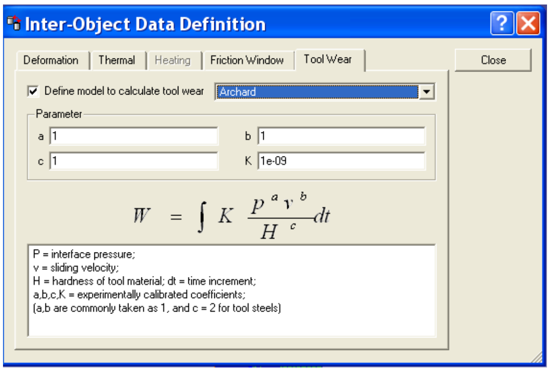


Figure 6. Specification of the parameters that intervene in the structure of the Archard wear model

Note: For the numerical simulation of the cold deformation processes, the documentation of the DEFORM-2D program [DFM2008b, DFM2008c] recommends the Archard wear model [ASM1992]. In its most general version, this model defines the volume of material W lost by a tool through wear during the period $[0,T]$ through formula:

$$W = \int_0^T K \frac{p^a v^b}{H^c} dt \,, \tag{8}$$

where p is the pressure at the interface of contact with the blank, v is the relative sliding speed of the blank on the tool surface, H is the Rockwell hardness of the tool, and K, a, b and c are constants that depend on the couple of materials in contact, as well as the conditions the process investigated is performed (example, the quality of lubrication). For the case of steel cold deforming processes, the documentation of DEFORM-2D program and recommends the use of values $K = 10^{-5}$, $a = 1$, $b = 1$ şi $c = 1$ – see Figure 6.

- The running the program that performs the numerical simulation of the extrusion process
- The interpretation of the results by means of graphical postprocessor DEFORM-2D.

4. SIMULATION RESULTS

Next, we will analyze the most relevant results in terms of wear phenomena. In general, the simulation results are presented as color maps accompanied by a legend that associates each color field with a value interval for the size analyzed. Among the most useful information, which the DEFORM-2D postprocessor supplies, we may mention the following:

- distribution of equivalent plastic deformation accumulated by the blank during the process shown in figure 7;

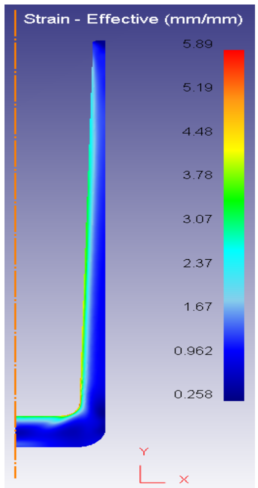


Figure 7. Distribution of the equivalent plastic deformation accumulated by the blank during the extrusion process

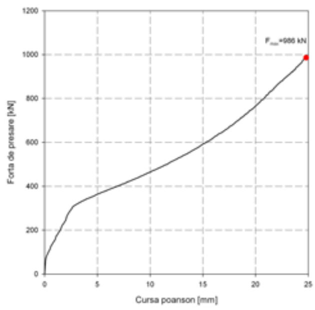


Figure 8. Variation chart of the vertical force that the mandrel develops

• the chart of the variation of the force developed by the mandrel during the deformation process – figure 8;

• Distribution of temperature in the blank associated section – figure 9.

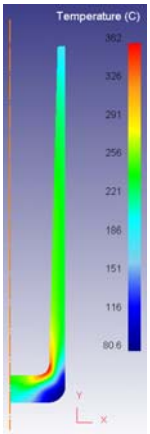
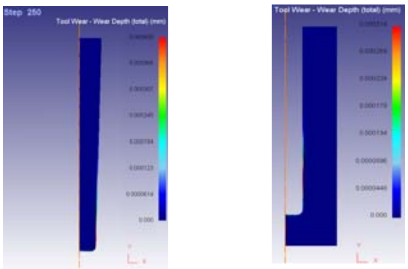


Figure 9. Temperature distribution in the auxiliary section of the blank at the end of the extrusion process

• Depth of the layer lost by the tools by wear layer - figures 10 and 11.



Figures 10 and 11. Estimation of the depth of material lost by the mandrel by wear (estimate given by Archard's principle).

The diagram in figure 12, shows the distribution of the equivalent plastic deformation of the blank in the final phase of the extrusion process.

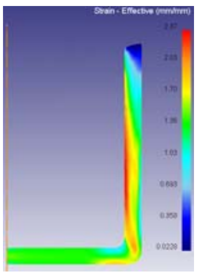


Figure 12. Distribution of the equivalent plastic deformation accumulated by the blank during the extrusion process

As we may notice in the chart legend, the maximum value of this size is 2.37 and it is located on the cylindrical inside wall of the part (area strongly thinned after passing through the gap between the plate and the mandrel). Although it corresponds to a high level of cold hardening, the plastic deformation does not exceed the limits allowed for steel-DIN-D5. The temperature influences tool wear; the diagram in figure 13 shows the temperature distribution at the end of the extrusion process.

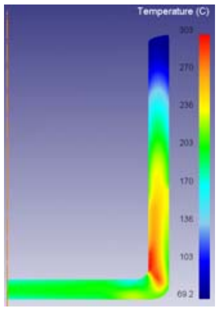


Figure 13. Temperature distribution in the auxiliary section of the blank at the end of the extrusion process

The diagrams in figures 14 and 15 show the estimations of the DEFORM-2D about the depth of the layer lost by wear by mandrel, respectively plate.

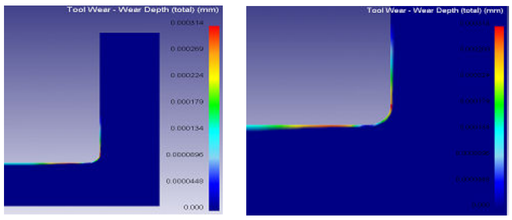


Figure 14. Estimation of the depth of the material layer lost by mandrel by wear (estimate given by Archard's principle).

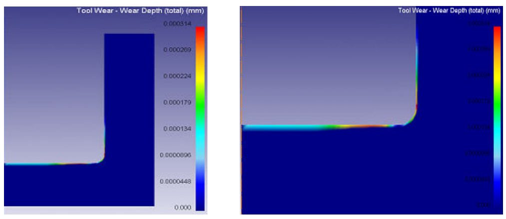


Figure 15. Estimation of the depth of the material layer lost by mandrel by wear (estimate given by Archard's principle).

5. CONCLUSIONS

First, we have to notice the extremely high value of the contact pressure. In fact, the press is very high on the entire surfaces of the mandrel. In the case of the plate, the pressure is slightly lower (1720 MPa), the maximum being almost evenly distributed on the bottom surface of the cylindrical seat. These distributions are indicative of quasi-hydrostatic blank request in the space below the mandrel.

The temperature also records an important increase during reverse extrusion (figure 13). We may notice a stronger heating of the mandrel than that of the heating plate (maximum temperatures of 221^{o}C, 168^{o}C respectively).

Not surprisingly, the temperature peaks are located in the areas where the highest plastic deformation of the blank and contact pressure occur. In fact, heat dissipation sources are the deformation process and the frictions with working surfaces of the tools.

Temperature peaks are found in the same areas and on the surface of the extruded mark (figure 13). We may notice that the connection area at the base of the cylinder wall (the localization of major plastic deformations) is very strongly heated (up to 303°C). We may notice at the level of the mandrel, the maximum depth of wear is 0.0004 mm and it corresponds to the connection area (where the highest contact pressures are). The wear may be also noticed on the front surface, but its intensity is slightly reduced. In the case of the plate, the wear is almost similar in distribution (with a maximum of 0.0003 mm, also located at the bottom connection area of the seat with the cylindrical wall), shown in figures 14 and 15. The finite element analysis programs available on the market today relieve the user of the unpleasant task of manual discretization, transferring it to specialized modules that automate this operation.

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POSIBILITĂȚI DE CREȘTERE A CALITĂȚII PIESELOR TUBULARE DE DIAMETRU MIC EXECUTATE PRIN EXTRUDARE INVERSĂ, PRIN SIMULAREA NUMERICĂ A PROCESULUI DE DEFORMARE

Rezumat: Procesul de extrudare inversă care face obiectul analizei din această lucrare se concentrează pe deformarea plastică care operează asupra unei pastile cilindrice având diametrul de 20 mm şi lungimea de 29,8 mm. Datorită complexității şi caracterului neliniar al fenomenelor care au legătură cu uzura plăcii active, pentru analiza acestui proces a fost utilizat programul DEFORM-2D [DFM 2008a]. La ora actuală, DEFORM-2D este folosit în domeniul proiectării asistate de calculator a tehnologiilor de deformare volumică. Acest program este capabil să simuleze procese care se desfăşoară la temperatură ambiantă sau la cald. Programul pune la dispoziție un modul de procesare grafică, prin intermediul căruia pot fi precizați parametrii procesului de deformare analizat. În lucrare vor fi prezentate etapele elaborării modelului cu elemente finite ale operației de extrudare inversă.

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