TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 60, Issue II, June, 2017

NUMERICAL SIMULATION OF TOOL WEARING IN REVERSE COLD EXTRUSION PROCESSES

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Abstract: *Numerical simulation of the wearing processes allows the optimization of the shape and properties of extrusion tools before their manufacturing. As a result the costs for redesigning caused by the die incomplete filling, material overlapping and unacceptable wear of the tools can be avoided. The wear of the punch and extrusion die should be assessed both through the specific wear, this means the wear that corresponds to 1000 extruded parts and the parameters of the wearing region.*

Key words*: reverse extrusion, tool wearing, extrusion dies, heat distribution in reverse extrusion.*

1. INTRODUCTION

The technological process of cold reverse extrusion of low carbon steels is applied with maximum efficiency to small parts produced in large batches using specialized manufacturing equipment.

The interest shown by specialists for the cold extrusion of concave steel products having a small diameter has constantly increased, the proof being the large number of papers dealing with this topic published in scientific magazines.

The quality of the tubular parts with small diameter manufactured through extrusion must be assessed bot through the dimensional accuracy and the deviation from the ideal configuration. One cannot neglect the roughness of the inner and outer surfaces achieved after the extrusion process and the modification of the mechanical properties of the workpiece material as a result of the hardening induced during the cold extrusion process.

2. EXTRUSION OF A STEEL TUBULAR PART. CASE STUDY

The shape and the dimensions of the part whose extrusion technology is the object of the case study are presented in Fig. 1. The manufacturing documentation specifies that the part is to be produced from a low carbon steel having the properties of a C15 steel (according to SR EN 10277-2: 2008). Due to its relative low content of carbon, the C15 steel is characterized by a very good formability, even in the conditions of cold extrusion process. In fact, this material is widely used in the domain of cold extrusion.

The part in Fig. 1 can be manufactured through reverse extrusion. The dimensions of the cylindrical workpiece being extruded were established using the equivalent mass method. For verifying the cold extrusion possibility the process of plastic deformation was numerically simulated. Thee finite element analysis program DEFORM-2D [1] was used for this purpose.

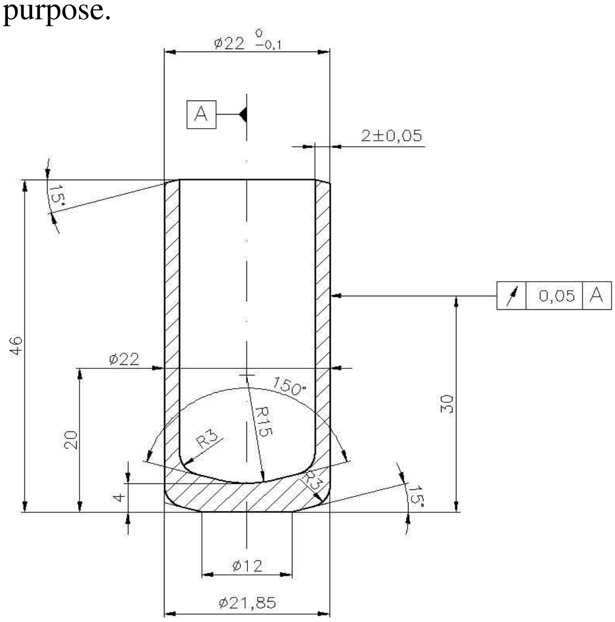


Fig. 1. Configuration and the dimensions of the part that is the object of the case study (material: steel C15 SR EN 10277-2: 2008; mass: 53.27 grams)

DEFORM-2D is widely used in the domain of computer-aided design in the case of volumetric deformation technologies (forging, extrusion, rolling etc.). This program is capable to simulate processes that take place at ambient or warm temperature. Among the most important facilities that DEFORM-2D can provide, are the following:

- Possibility of modelling tools with a complex geometry
- Automatic generation of the finite element mesh
- Adaptive regeneration of the finite element mesh for obtaining accurate results
- Simplified description of the deformation process that is the object of the simulation (automatic positioning of the tools relative to the workpiece, defining the movement direction of the mobile components of the extrusion die, identification of the contact surfaces between the workpiece and the tools, easy specification of the parameters that describe the frictional interaction, etc.)
- Libraries containing the mechanical parameters of the materials frequently used in various metal forming processes (ferrous and non-ferrous alloys)
- Realistic modelling of heat phenomena and tool wearing processes that take place in the same time with the workpiece deformation
- Graphical representation of the simulation results in the form of diagrams easily interpretable the user.

3. DEVELOPING THE FINITE ELEMENT MODEL OF THE COLD REVERSE EXTRUSION PROCESS

The DEFORM-2D program provides the users with a graphical preprocessing module, through which the parameters of the metal forming process to be simulated can be easily specified. In what follows, the stages in developing the finite element model of the cold reverse extrusion process will be presented.

- Defining some general characteristics of the process that is the object of the simulation: process type (in this case, a process with axial symmetry consisting of plastic deformation accompanied by heat generation due to friction), etc.
- Defining the control parameters for the simulation steps: number of the steps (174), number of the steps after which the data will be saved in the output files (5), the displacement increment of the mobile tool (punch) corresponding to a simulation step (0.1 mm)
- Defining the parameter that will determine the simulation to stop (see Fig. 2): the vertical displacement of the mobile tool (punch) equal to 174 mm

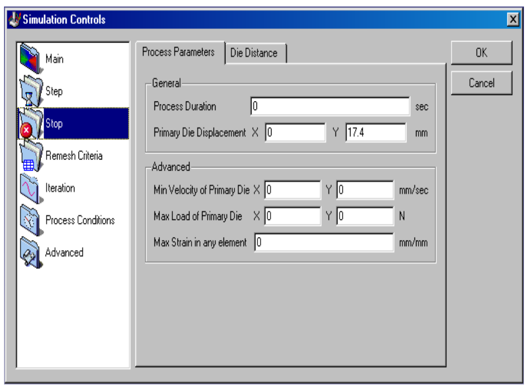


Fig. 2. Defining of the parameter that will stop the numerical simulation

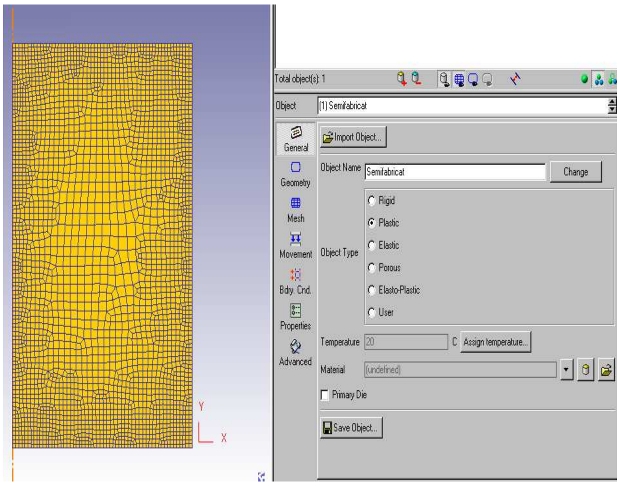


Fig. 3. Import of the geometrical model of the workpiece, its finite element meshing and specification of the associated mechanical model

- The import of the geometrical model of the workpiece, its finite element meshing and specification of associated mechanical models (see Fig. 3). Due to the cylindrical symmetry of the extrusion process, the geometries of the workpiece and tools that produce the deformation are described by means of axial sections. These sections were modelled using the AutoCAD design program and transferred to the DEFORM-2D program as DXF files. The workpiece was meshed into about 3000 finite elements, DEFORM-2D being allowed to refine the mesh during the simulation if needed. The mechanical model associated to the workpiece is of elastoplastic type.
- Specifying the kinematic restrictions for the finite element mesh associated to the workpiece: locking the radial translations of the nodes situated on the vertical symmetry axis of the extrusion process.
- Import of the geometrical model of the tools, their meshing into finite elements and specifying the associated mechanical model. The tools were meshed into about 1000 finite elements, a mesh that DEFORM-2D program is not allowed to refine during the simulation. The mechanical model associated to the tools is of rigid type.
- Specifying the control parameters of the punch motion: direction of motion (the negative direction of axis Y) and the translation speed (17.4 mm/sec)
- Locking the extrusion die movement.
- Specifying the material being extruded, in this case, C15 steel selected from the library of the DEFORM-2D program
- Specifying the material of the punch and the extrusion die: toolmaking steel DIN-D5 selected from the library of the DEFORM-2D program. DIN-D5 steel is widely used for the cold extrusion dies [2, 3, 4]. After heat treatment this material achieves a hardness of about 55 HRC.
- Specifying the boundaries along which there is heat exchange between the workpiece and tools, the workpiece and environment and the tools and environment. The heat transfer determines significant variations of the workpiece and tools temperature having important influences on the intensity of the wearing phenomena.
- Specifying the heat transfer coefficient – average value selected according to the recommendations of the DEFORM-2D preprocessor.
- Specifying the parameters that define the frictional contact model between the workpiece and tools.
- Specifying the parameters that define the tool wearing process model. For the numerical simulation of the cold deformation processes, the DEFORM-2D [1] program documentation recommends using the Archard wearing model. In its more general variant, this model defines the volume of material W lost by a tool by wear in the time interval $[0,T]$ the formula

$$W = \int_0^T K \frac{p^a v^b}{H^c} \mathrm{d}t \qquad (1)$$

where p is the pressure on the contact surface, v is the relative sliding speed of the workpiece 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. For the couple of materials steel-steel, the DEFORM-2D [1] documentation recommends using of the following values: $K = 10^{-9}, a = 1, b = 1$, and $c = 1$.

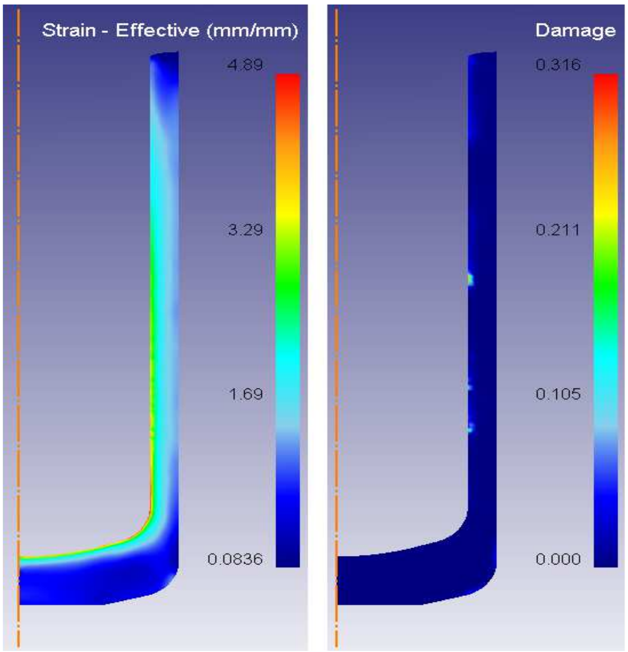
- Specifying the Rockwell hardness of the tool material: 55 HRC, value achieved by the steel DIN-D5 after heat treatment.

4. SIMULATION RESULTS

To facilitate the interpretation of the numerical results DEFORM-2D provides the users with a graphical postprocessor. Generally, the simulation results are presented as colored maps accompanied by a legend that associates each color field a value range of the analyzed result. Among the most useful information items provided by DEFORM-2D the following ones can be mentioned:

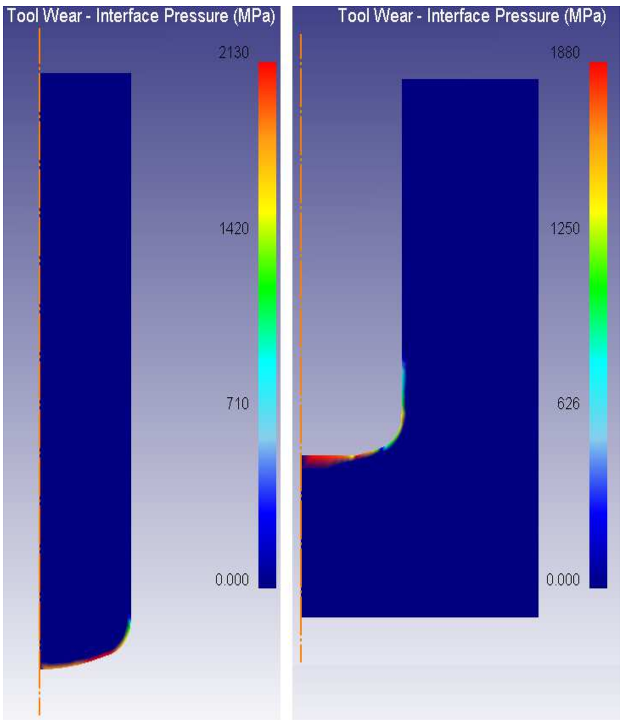
- Distribution of the equivalent plastic strain accumulated in the workpiece during the extrusion process (Fig. 4.a)
- Distribution of the damage risk indicator in the final stage of the extrusion (Fig. 4.b)
- Distribution of the contact pressure on the work surfaces of the punch (Fig. 5.a), and die (Fig. 5.b) in the final stage of the extrusion process
- Distribution of the temperature in the axial section of the workpiece (Fic. 6.a), punch (Fic. 6.b), and die (Fig. 6.c) in the final stage of the extrusion process
- Thickness of the material layer lost due to wearing by the punch (Fig. 7.a), and die (Fig. 7.b) for each extruded part (estimation given by Archard's law)
- Diagram showing the evolution of the vertical force developed by the punch during the extrusion process (Fig. 8).

The equivalent plastic strain reflects the level of the strain hardening of the material. The diagram in picture 4.a presents the distribution of this value in the final stage of the extrusion process. As it can be observed in the diagram legend, the maximum value of the equivalent plastic strain is 4.9, being found in the region where the workpiece suffers the strongest distortion (at the joint between the cylindrical wall and the bottom area of the part). It can be also observed that the equivalent plastic strain



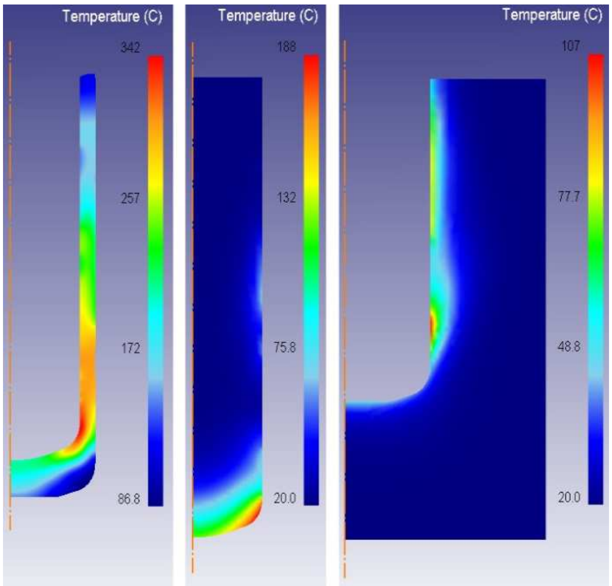
(a) (b)

Fig. 4. Distribution of the equivalent plastic strain (a) and damage indicator that highlights the exceeded value of the forming capability of the workpiece (b) in the final stage of the extrusion process



(a) (b)

Fig.5. Distribution of the contact pressure on the work surfaces of the punch (a), and extrusion die (b) in the final stage of the forming process



(a) (b) (c)

Fig.6. Distribution of the temperature in the axial section of the workpiece (a), punch (b), and extrusion die (c) in the final stage of the forming process

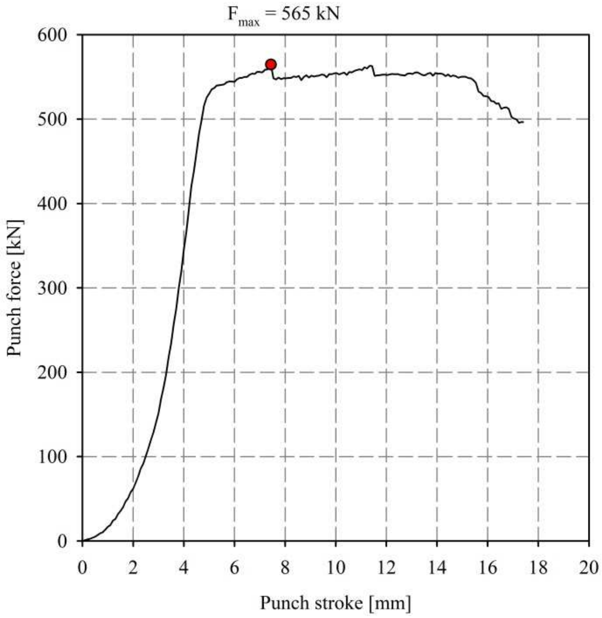


Fig. 8. Evolution of the vertical force developed by the punch during the extrusion process

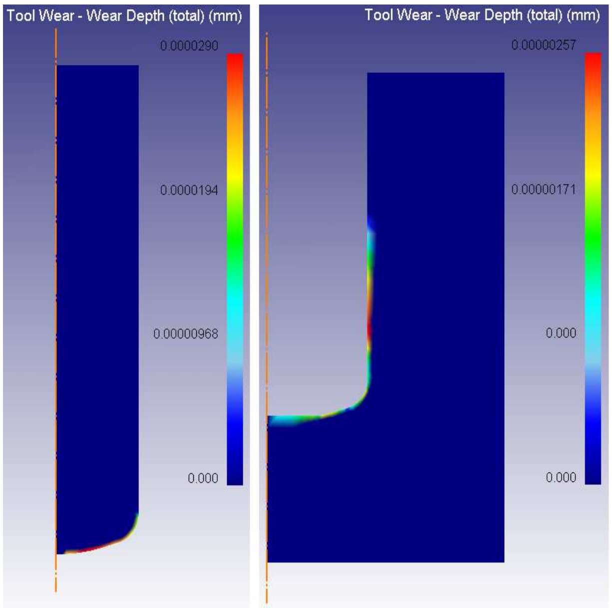


Fig.7. Thickness of the material layer lost due to wearing by the punch (a) and die (b) for each extruded part (estimation given by Archar's law)

has large values on the frontal side of the punch, and also on the inner part of the cylindrical wall. This situation is the consequence of the strain gradually accumulated during the deformation of the workpiece by the punch and material compression against the cylindrical wall. Although the level of the plastic strain is high, it is still in the admissible range for the C15 steel. This fact results from the diagram shown in Fig 4.b, according to which the risk indicator reaches nowhere in the axial section of the extruded part values larger than one.

5. CONCLUSIONS

As previously mentioned, the wear of the extrusion tools is highly influenced by the pressure level on the contact surfaces with the workpiece, and also by the temperature. The diagrams in Fig. 5 show the distribution of the contact pressure on the active surfaces of the punch and die at the end of the extrusion process. It can be noticed the extremely high pressure levels both on the frontal side of the punch (a maximum of 2130 MPa), and on the bottom side of the die cavity (a maximum of 1880 MPa). The temperature also registers a significant growth during the extrusion process. According to the diagrams in Fig. 6, the workpiece suffers the strongest heating (a maximum of 342 °C). On the second place is the punch whose temperature reaches a maximum of 188 °C at the joint of the cylindrical wall with the frontal side. The element that suffers the less heating is the extrusion die whose maximum temperature is 107 °C. It can be deduced that the wear of the punch will be more aggressive. This fact is confirmed by the diagrams in Fig. 7, that show the thickness of the material layer lost due to wearing by the punch and die for each extruded part. One may also notice that the areas where the wear is more aggressive are the same with those where the mechanical and heat loads acting on tools are higher.

The diagram in Fig. 8 presents the evolution of the vertical force developed by the punch during the extrusion process. The vertical force acting on the die has a similar evolution, because, according to the principle of reciprocal actions, it is equal in absolute value and of opposite sign to the force developed by the punch. The diagram in Fig. 8 highlights a quite fast growing of the force to a maximum level of 565 kN, after which the force remains practically unchanged. The evolution up to the maximum value corresponds to the incipient stage of the extrusion process and continues until the cylindrical wall of the part begins to take shape. The horizontal level in the diagram in Fig. 8 corresponds to a stable phase of the extrusion process, when the cylindrical wall continues its growing in the space between the punch and the die.

6. REFERENCES

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Simularea numerică a uzurii matrițelor de extrudare inversă la rece

Rezumat: Simularea numerică a proceselor de deformare plastică permite optimizarea formei și proprietăților sculelor de extrudare, înainte ca acestea să fie realizate. Ca urmare, costurile reproiectării cauzate de umplerea incompletă a matrițelor, suprapunerilor de material și uzura inacceptabilă a elementelor active pot fi evitate. Uzura poansonului și plăcii active este util să fie apreciată prin uzarea specifică, adică uzarea ce revine la 1000 de piese extrudate, cât și prin parametrii zonei de uzură.

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