SELECTED ASPECTS IN NUMERICAL ANALYSIS OF COLD EXTRUSION OF TUBES USING CAE SYSTEM

Grzegorz Skorulski, Andrzej Lukaszewicz
Bialystok University of Technology, Poland
g.skorulski@pb.edu.pl, a.lukaszewicz@pb.edu.pl

Abstract. The present paper deals with the numerical analysis of the process of cold extrusion of tubes. The analysis was carried out for a specific technological problem in which the principal objective was to reduce the outer tube diameter in a segment within a given length. Assumptions were made as to initial and boundary conditions, and the punch speed was preselected. In particular, the influence of the friction coefficient between the die and workpiece has been analyzed. As a result, using the CAD/CAE system, the diagrams of pressure distribution for each node in the CAD model of the die in several time steps have been obtained and presented. The results of the numerical analysis are of great importance, as they make it possible to (approximately) estimate the die load. Though the actual extrusion process is accomplished within split second, the setting up of a workpice equipped with all required measurement sensors to register the die load poses a very complicated problem and often requires significant outlays. Additionaly, the numerical result of the obtained diameter of the tube has been presented.

Keywords: cold extrusion, tubes, friction, contact stresses distribution, CAx, DEFORM 3D.

1. Introduction

Cold extrusion is defined as a compressive forming process (push-through), in which the source material is billet (slug), and the process is carried out at the room temperature [1-2]. The design and manufacture of dies and the selection of die materials are very important in the production of discrete parts by means of metal-forming processes [3-6]. CAx [7-11] – computer aided techniques, like CAD [12-15], CAM [16-18], CAE [19-24] tools are used in many engineering fields. The flow stress is a function of temperature, strain, strain rate and structure. It is, therefore, determined by the billet material, billet preheat temperature, container and die temperatures, extrusion ratio and extrusion speed. Thus, the calculated flow stress value can be used for estimating the extrusion pressures for other extrusion ratios and shapes [25-26]. A review of theoretical methods and experimental studies reveals that the extrusion pressure at the end of the extrusion stroke (i.e. without container friction) is a nearly linear function of the homogeneous extrusion strain [27]. The loads have an impact on numerous engineering processes described in [28-40]. In the present work a tube extrusion process has been scrutinized. In particular, a solution of the pressure problem by means of a computer simulation in the above process has been discussed below. Also, a method of obtaining the contact stresses distribution during extrusion has been shown.

2. Die design in CAD/CAM Systems

The basic objectives of applying CAD techniques to extrusion are described in [30-32]. The model of the die has been created using Deform 3D CAD/CAE system (Fig. 1.).

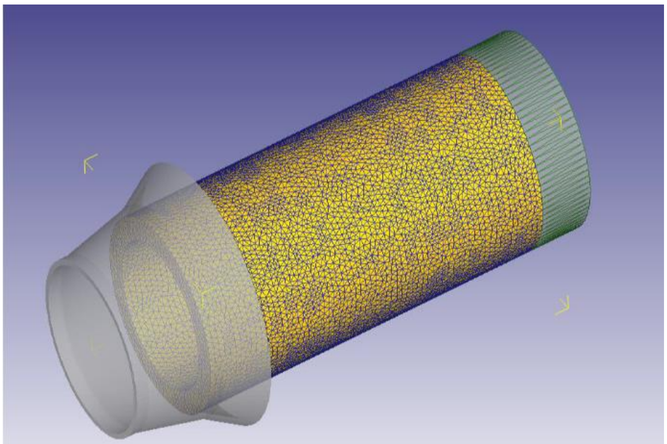

Fig. 1. **Die, workpiece (tube) and punch designed in CAD/CAE system**

The mesh of this model is available within this system. This means that the model of the die has been divided into rectangular pattern of finite elements [28; 30]. This kind of models can be also imported by the system when they are saved as possible file format.

3. Preparing the simulation

Before commencing the simulation of the extrusion process, a number of conditions have to be fulfilled. It is necessary to check if all the required files and date are available [29; 33]. The punch data comprised the following information:

- density: 7.8E-09 kg·mm^3
- Young Modulus: 2.1E+05 MPa
- Poisson ratio: 0.3
- velocity of the punch: 10000 mm·s^{-1}.

The specified dimensions of the die and workpiece geometry are presented in Fig. 2.

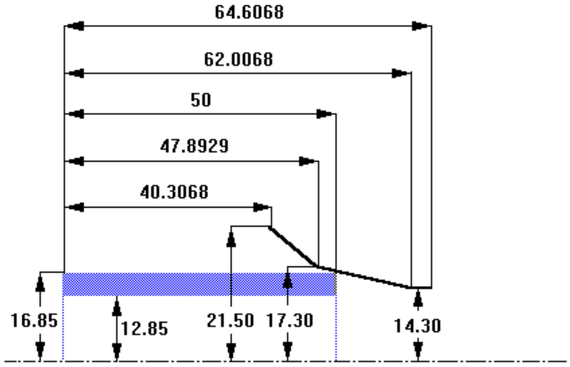

Fig. 2. **Geometry of the tool and workpiece**

Usually, in the included model the tool is a rigid body. In this case, however, the pressure solution for the tool is completely disabled. Therefore, it has become necessary to re-create the tool material as elastic for the purpose of the simulation (if possible).

4. Discussion of the results

There were three different friction coefficients used in each simulation. The values were as follows [31; 33]: $\mu = 0.15$ (for example uncoated steel), $\mu = 0.2$ (zinc-coated steel in metal forming), $\mu = 0.05$ (lubricated extrusion). The property of the workpiece can be compared with steel containing 0.35% C. Below, in Fig. 3, the cross-section of the tool is presented. Point numbers from 1 to 8 correspond to the numbers of the nodes in the finite element model. The corresponding points are described in Fig. 3.

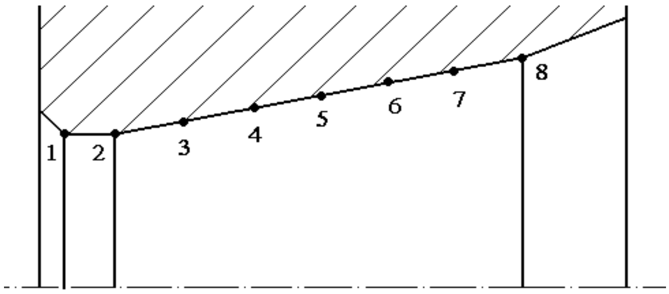

Fig. 3. **Characteristic point numbers on the die surface: radial plane cross-section**

To recognize the possible load of the press during the extrusion process, which is significant to planning, the analysis was created using DEFORM 3D system for this simulation. As the results, the distribution of effective stress can be presented. Accurate contact type with the coefficient of friction equal to 0.12 was set, such as really the production condition during cold extrusion of steel tubes. Numerical simulation in Fig. 4. (initial state of extrusion), Fig. 5. (advanced phase of extrusion) and Fig. 6. (end of the process) is presented below.

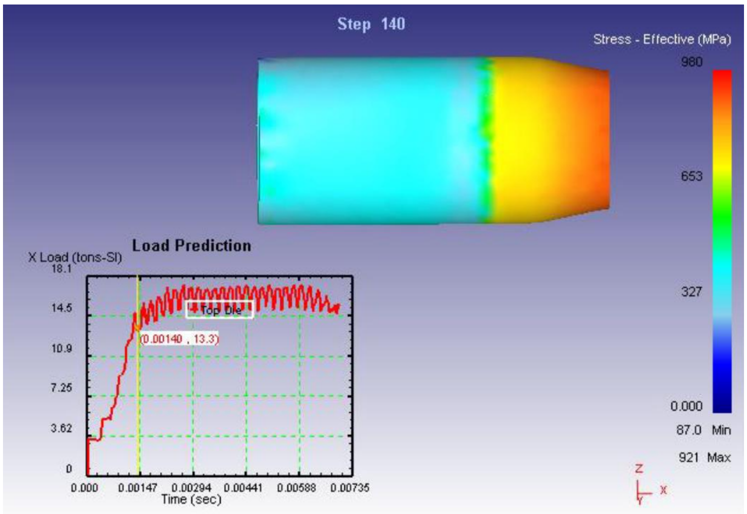

Fig. 4. **Effective stress during cold tube extrusion – initial phase of the process**

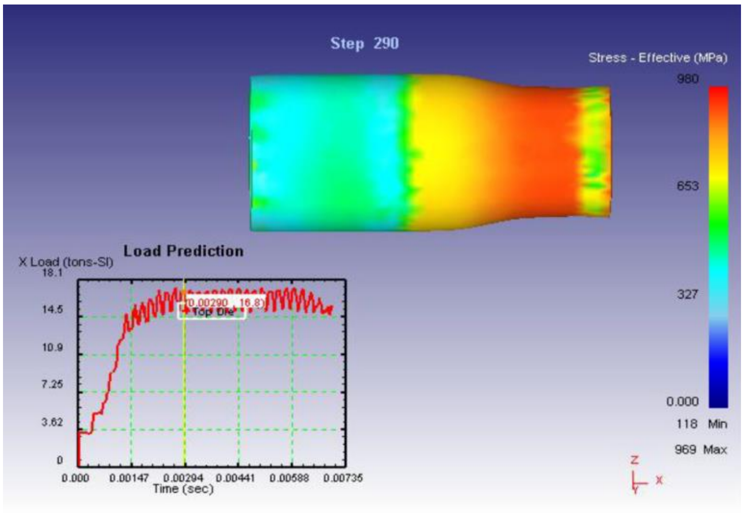

Fig. 5. **Effective stress during cold tube extrusion – advanced phase of the process**

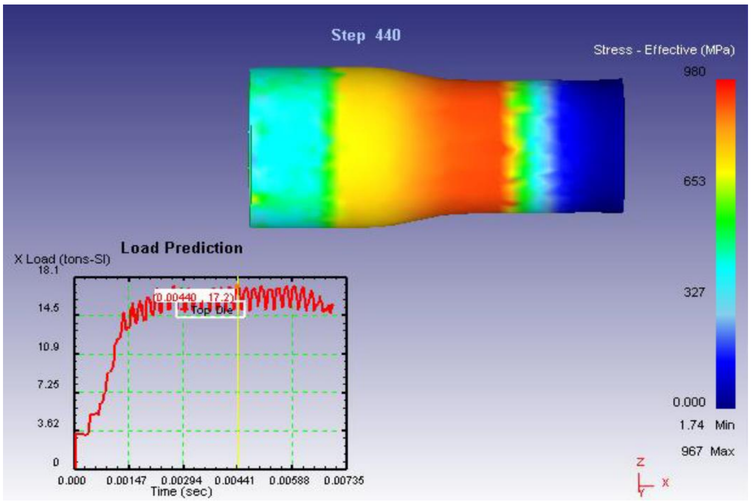

Fig. 6. **Effective stress during cold tube extrusion – end of the process**

The technical problem of the tube extrusion is almost always the final diameter of the product. It is possible to obtain this kind of results from numerical simulation. They are shown in Fig. 7.

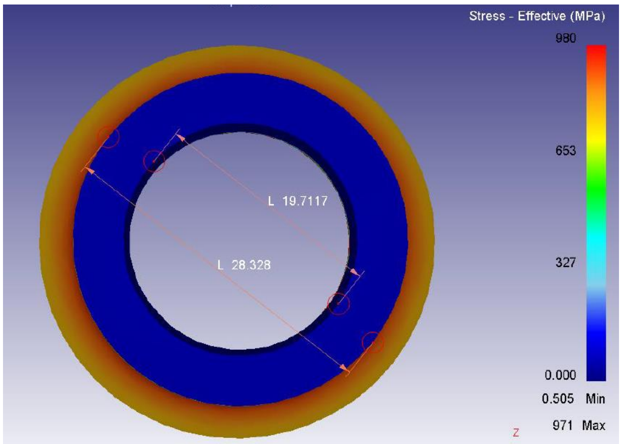

Fig. 7. **Final diameters of the extruded tube**

In the course of the simulation, obtaining of the distributions of pressure on the die surface is more difficult, but not impossible. The MS Excel tool has been used to get and analyze the pressure distribution diagrams. They are shown in Fig. 8-10. "Seria" is treated here as a distribution of pressure in each time step in a numerical solution. On the whole, 21 time steps (each 0.005 s) have been used. The significant points have been described above (Fig. 3).

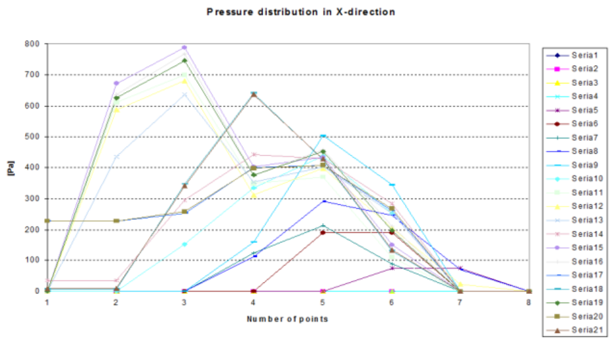

Fig. 8. **Pressure distribution (radial direction) in analyzed points during the process with μ = 0.05**

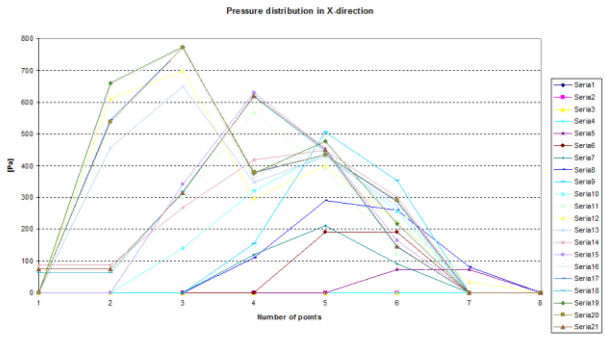

Fig. 9. **Pressure distribution (radial direction) in analyzed points during the process with μ = 0.15**

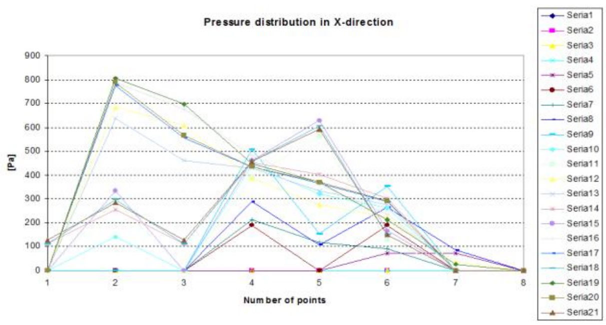

Fig. 10. **Pressure distribution (radial direction) in analyzed points during the process with μ = 0.2**

5. Conclusions

The most important information resulting from the obtained numerical simulation is as follows:

1. The basic research work and experiments have confirmed that the value of the friction coefficient is changing during extrusion. This conclusion is confirmed in Fig. 8-10. The friction coefficient ranges from 0.05 to 0.15. Comparing Figs. 8, 9 with Fig. 10 (friction coefficient $\mu = 0.2$), it can be seen that there is also a change in the nature and distribution of the die loads.
2. The influence of the friction coefficient is very important, different distributions of pressure have been obtained which depend on the friction conditions on the contact surface. This way of analysis allows to determine desirable properties of the die material and facilitates optimization of the extrusion process. The numerical simulation is also helpful to design optimal die so as to obtain diameters of the tube correctly.
3. It seems to be impossible to obtain the results of contact stresses using the DFORM 3D system only (with all functional constrains). Some kind of results is disabled, because the material of the tool is defined as a rigid body of necessity. Thus, only the solution described below has been worked out.
4. During the test, the friction coefficient $\mu = 0.12$ was assumed as a recommended parameter to extrusion of steel tubes. The results of effective stress (Fig. 4, 5, 6.) have shown also the possible load of the punch. The extreme value of this range is 18 tons.
5. This is preliminary, approximate information, which kind of press should be used. Additionally, the computer simulation allows to check the possible inner and outer diameter of the extruded tube. It is shown in Fig. 7.
6. So, the computer simulation of the described extrusion process may be very useful to define the precision load of the die. Using even similar, theoretical or experimental methods, obtaining this data may be most complex. The results of the numerical analysis, then, are of great importance, as they make it possible to (approximately) estimate the die load. Though the actual extrusion process is accomplished within split second, the setting up of a workplace equipped with all required measurement sensors to register the die load poses a very complicated problem and often requires significant outlays.

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Conceptualization, G.S. and A.Ł.; methodology, G.S. and A.Ł.; software, G.S.; validation, G.S.; writing – original draft preparation, G.S.; writing – review and editing, G.S. and A.Ł.; funding acquisition, A.Ł. All authors have read and agreed to the published version of the manuscript.

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