Journal for Technology of Plasticity, Vol. 29 (2004), Number 1-2

FEM ANALYSIS FOR THE EXTRUSION PROCESS OF TUBES USING PORTHOLE DIES

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ABSTRACT

This paper deals with FEM simulation of porthole-die extrusion process in order to gain insight in design and control process parameters. In this study, dies with two, four and six porthole with different length of the bridge were used in order to observe the material split flow and the impact on bridge deformation. For these purposes, PAK software was used for elasto-plastic analysis of bridge loading and deflection. In order to obtain the boundary conditions for this analysis, the numerical simulation of the hot aluminum extrusion process was also performed, using FEM software CAMPform 2D. It is shown that this approach can be a very efficient way to separate numerical studies about the aluminum flow from calculations of die deformation. Moreover, it has made it possible that the complex three-dimensional flow through the extrusion die can be studied by means of two-dimensional plane strain calculation, in representative sections. Through investigating elasto-plastic deformation of porthole-die, it is also possible to estimate the porthole-die failure behaviour.

1. INTRODUCTION

Porthole die extrusion has a great advantage in the manufacture of hollow section products, which are difficult to produce by conventional extrusion with a mandrel on the stem. The billet in the container flows through the portholes and welds by high pressure in the welding chamber. Aluminium and its alloy are effective for this kind of extrusion, due to strong welding possibility. Many papers refer about direct extrusion through porthole die [1-12, 18].

Die designer experience has shown that very small changes in the die shape imply large effects on the profiles shape and accuracy. Moreover, material flow through porthole-die is so complicated that its systematic design is strictly required. On the other hand, failure of hollow extruded products mostly occurs along one of weld lines, when the products are subjected to severe internal pressure or expansion during their service life. At the same time, strongly pronounced temperature and dynamic load on the bridge of porthole die, brings about excessive wear and fatigue cracking of the die. Therefore, it is very important to properly design the process through an extensive use of FEM simulation.

The objective of this study is to analyse bridge deformation for dies with two, four and six porthole with different length of the bridge. CAMPform 2D rigid-viscoplastic simulation of hot aluminium extrusion has been used to observe the material split flow in order to determine boundary conditions on the bridge for further PAK elasto-plastic FEM analysis of die deformation. The complex three-dimensional flow through the extrusion die has been studied by means of two-dimensional plane strain calculation, in representative sections. It is a very efficient to separate the material flow and die deformation calculations, by application of two FEM software.

2. PROBLEM STATEMENT

In order to investigate the influence of geometry and position of bridge in its elastic deformation, the model of extrusion die with two, four and six porthole was made, as shown in Fig. 1. These models are different from true industrial tools (see Fig. 2), but they correspond to established objectives of investigation. Fig. 1 also shows cross section of the bridge.

Whereas Mooi at all [12] had shown that two-dimensional flow calculations give very reasonable estimates of the real three-dimensional stress state and deformations, 2D FEM analysis of material flow were performed, at representative sections A-A and B-B.

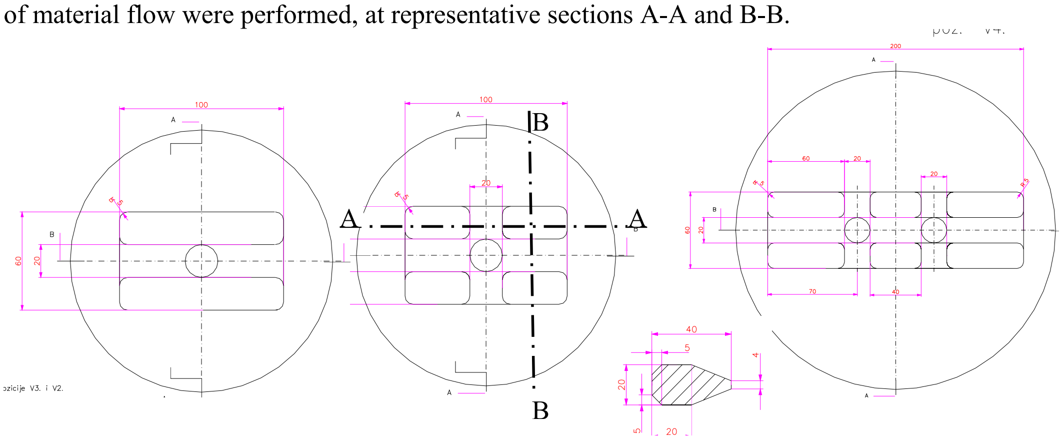


Figure 1 - The model of extrusion die with two, four and six portholes and different position and lenght of bridges

Figure 2 - Extrusion tool with one bridge

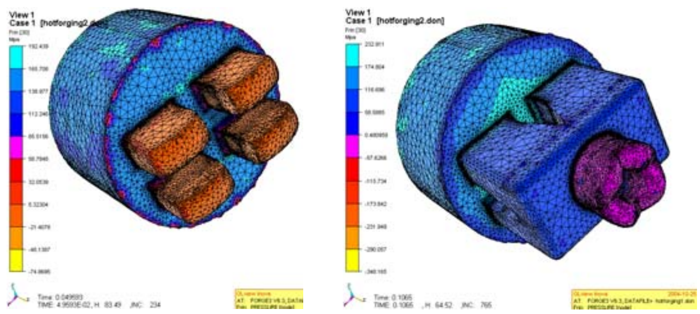


Figure 3 - FORGE3 simulation of porthole die extrusion (Courtesy from DIMEG, University of Padova, Italy)

Fig. 3 shows some results of FORGE3 simulation of aluminium porthole die simulation, through model on Fig. 1, that was supported by DIMEG, University of Padova. In order to avoid too large 3D calculations, two-dimesional plane strain calculations of aluminium flow were performed.

3. CAMPform 2D FLOW CALCULATIONS

CAMPform 2D software was used for two-dimensional approximate FE analysis of aluminium tube extrusion process with porthole die. The programme was developed in KAIST institute [13]. The programme package contains the solver, graphic user's interface (GUI), which consists of pre-processor and post-processor, and AMG module for automatic generation of mesh and remeshing. Solver is based on the finite element method with thermo-rigid-viscoplastic approach developed by Kobayashi and others [14]. Basically, this approach is a coupled procedure of solving equilibrium and energy equations, in which rigid-viscoplastic constitutive model was used, with Mises's yield criterion.

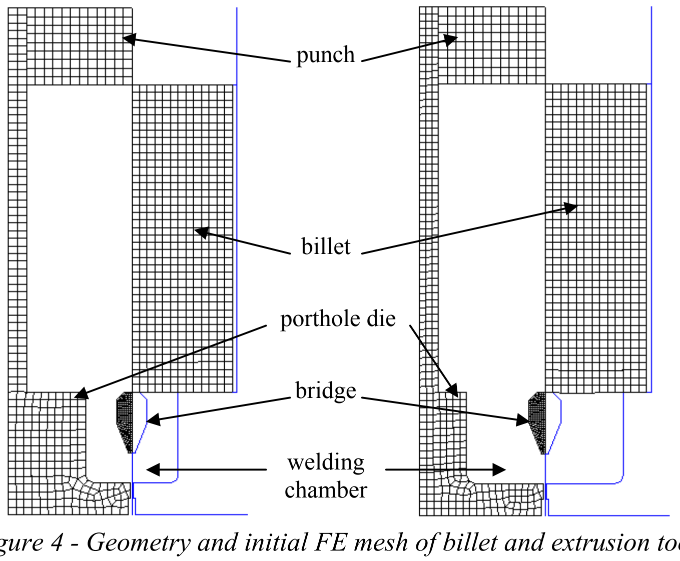
Fig. 4 shows geometry and initial FE mesh of the porthole die that was used in two-dimensional (plane-strain) approximate analysis. Quadrilateral elements were employed. Also, billet geometry and initial FE mesh are shown at the same figure, in CAMPform pre-processor editor. Half geometry was considered due to symmetry and the portion of the axis after the bridge was the considered line of welding.

The deforming material is AA 6060, aluminium alloy for hot extrusion, with constitutive equation considered as follows [16]:

$$\sigma = 29.15\varepsilon^{-0.0425}\dot{\varepsilon}^{0.18}, MPa \tag{1}$$

The temperature of billet and die were 480°C and 420°C, respectively. The ram speed was 330mm/s. The friction factor is assumed to be a constant of 0.6, that is used in common non-lubrication aluminium extrusion processes. The die material is AISI H13 hot work steel. It was assumed that die is perfectly rigid.

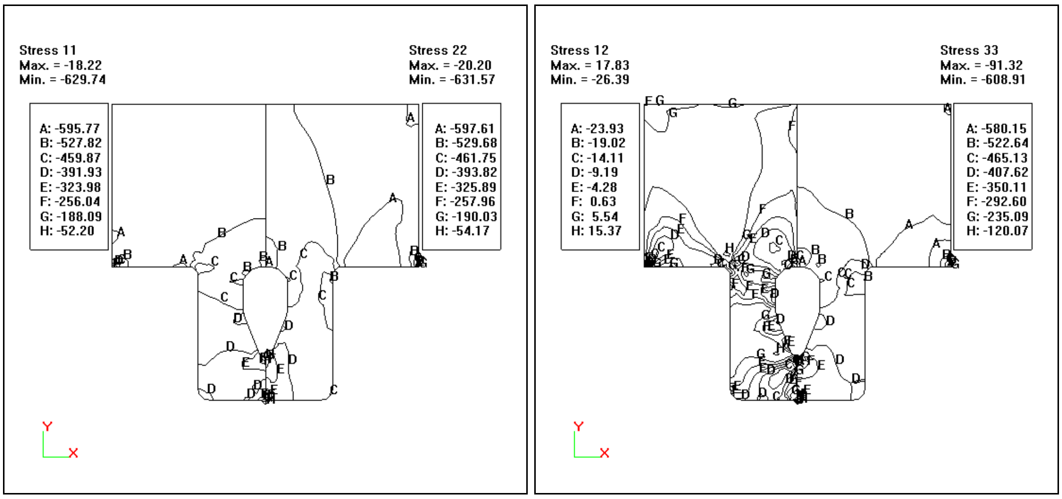
a)



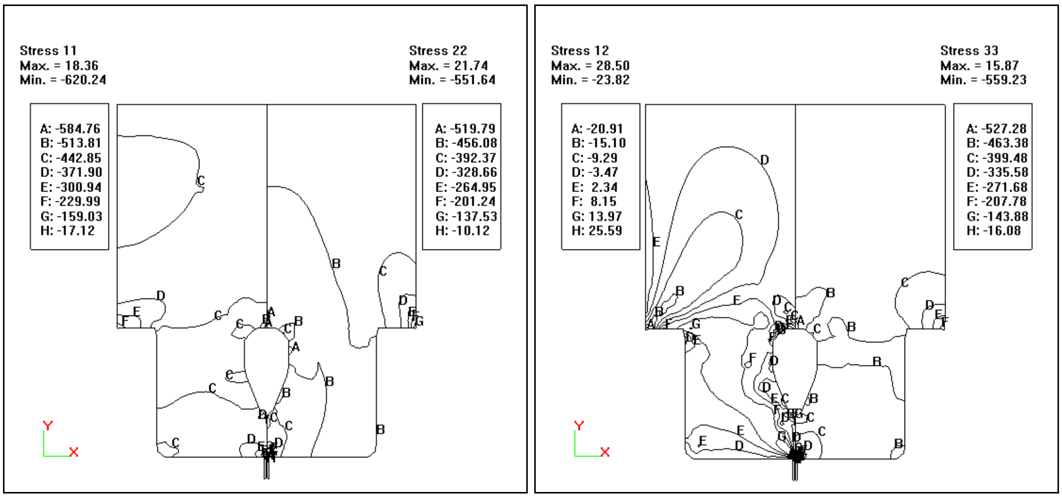
b)

Figure 4 - Geometry and initial FE mesh of billet and extrusion tool:
a) section A-A b) section B-B

Since the pressure on the core causes the largest part of the deformation of the die, it is very important to determine the distribution of pressure at deformed material during extrusion, especialy at forming stage of extrusion when extrusion load is steady-state. Pressure value, as boundary conditions for elasto-plastic FE analysis of die deformation, was determined as mean value of stress components (σ_{xx}, σ_{yy}, σ_{zz}). Accordingly, distributions of stress components, at forming stage of porthole die extrusion of aluminium tube, were shown in Fig. 5 and analyzed.



a) Section A-A



b) Section B-B

Figure 5 - Distributions of stress component σ_{xx} (Stress 11), σ_{yy} (Stress22), σ_{xy} (Stress 12) and σ_{zz} (Stress33)

4. PAK ELASTO-PLASTIC TOOL ANALYSIS

In order to complete FEM analysis on the extrusion of the tube, the three-dimensional deformation calculations of the extrusion tool, precisely of the tool bridge, are treated also. For that purpose, PAK software was used. Programme package was developed at Mechanical Engineering Faculty in Kragujevac, in Laboratory for Engineering Software [17], [18]. PAK programs are intended for linear and nonlinear structural analysis, heat conduction, fluid mechanics with heat transfer, coupled problems, biomechanics, fracture mechanics etc.

Because of symmetry, only one quarter of bridge has to be modelled. The three-dimensional mesh with boundary conditions (displacement and pressure) is shown in Fig. 6.

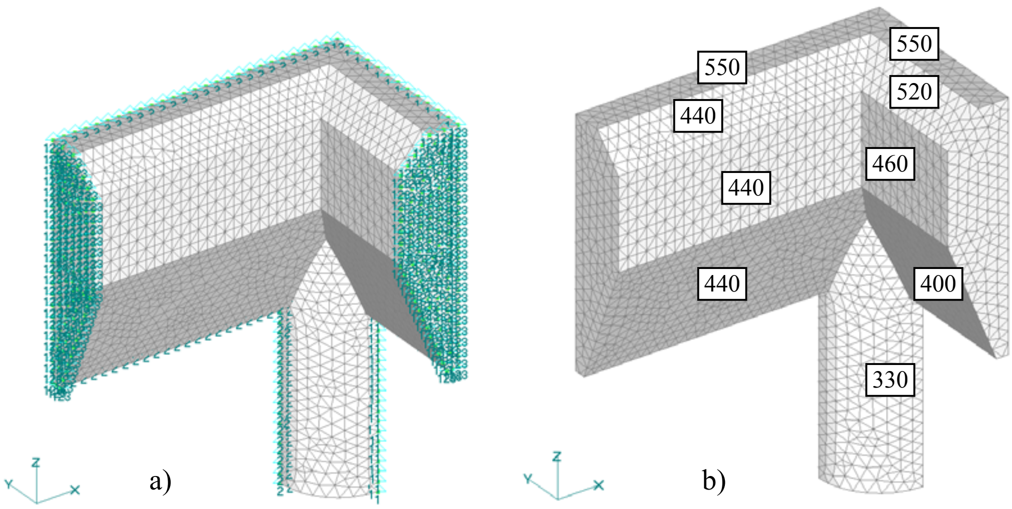


Figure 6 - Three-dimensional FE mesh of the bridge and boundary conditions:
a) displacement, b) pressure (MPa)

The material parameters at 420°C for the bridge are follows: elastic modulus E=176000 MPa, Poissons ratio ν=0.3 and the yield strenght $\sigma_{y,0}$=850MPa. PAK simulation of bridge loading during extrusion process was performed. In order to check whether the bridge deformations are plastic, the Von Mises stress distribution is analysed (see Fig. 7, 8 and 9).

Since the yield strenght of tool material is higher then Von Mises stresses for all models of bridge in porthole die, there is no plastic deformations in this part of tool. However, if thermal loads are added or the loads are increased, plastic deformation might be possible. The worst case of geometry is a model of extrusion die with six porthole, for extrusion of two tubes together. In this case there is a maximum value of Von Mises stress at ends of the bridge. Besides, elastic deformations of bridge are considerable, especially mandrel deflection, as shown in Fig. 9.

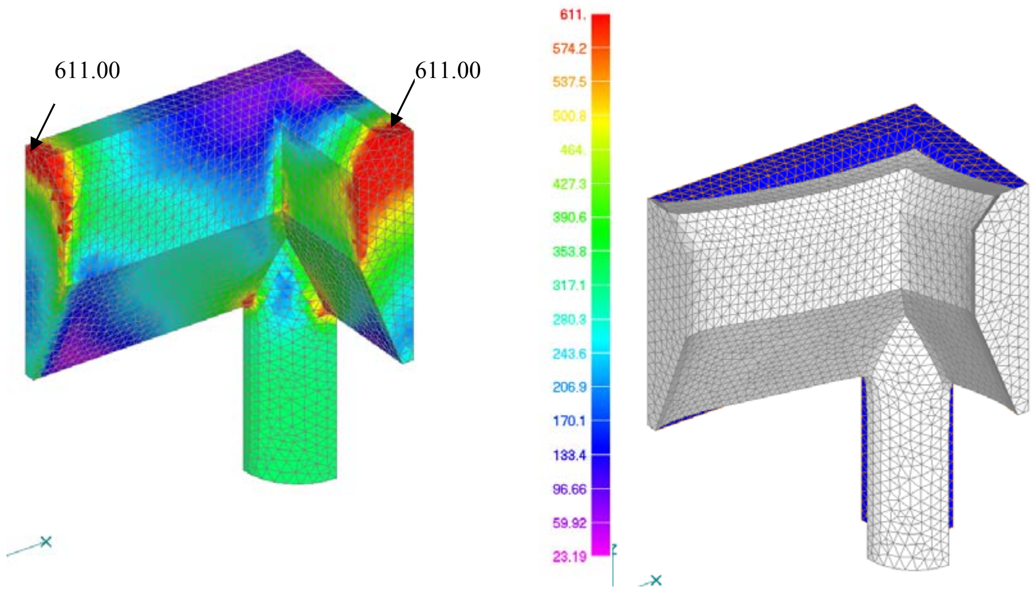


Figure 7 - Results of PAK analysis for extrusion die with four porthole: a) distribution of Von Mises stress (max. 611.0MPa), b) deformed and undeformed model - scale factor 5

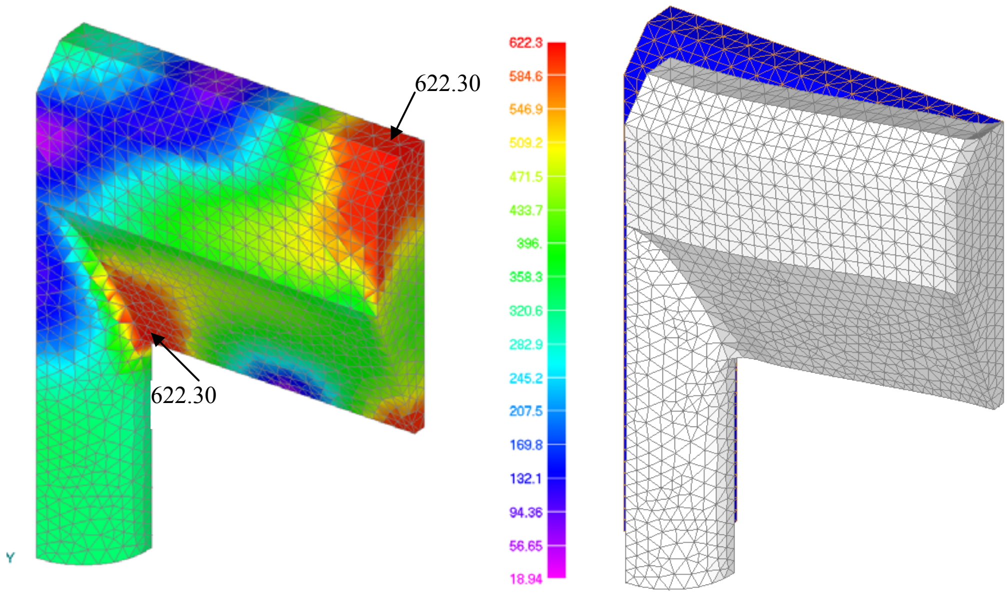


Figure 8 - Results of PAK analysis for extrusion die with two porthole: a) distribution of Von Mises stress (max. 622.3MPa), b) deformed and undeformed model - scale factor 5

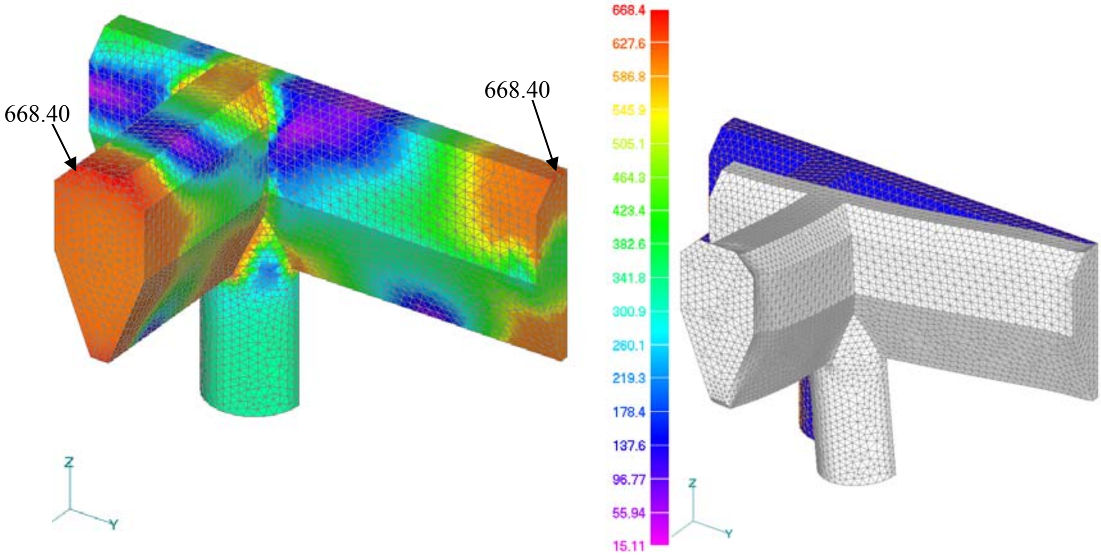


Figure 9- Results of PAK analysis for extrusion die with six porthole: a) distribution of Von Mises stress (max. 668.4MPa), b) deformed and undeformed model - scale factor 5

5. CONCLUSIONS

This paper studied the influence of shape of porthole extrusion die with different number of portholes and bridge lenghts, on die deformations and mandrel deflection. It is shown that separete FEM analysis of material flow and tool deformation is a very efficient way for this purpose. Boundary conditions, as loads on the bridge, can be obtained through two-dimensional plane strain FE simulation of split material flow during extrusion process, i.e. through the distribution of the pressure on the core.

Elasto-plastic FEM analysis has shown that all examined porthole dies are deformed elasticaly. The worst geometry is extrusion die with six portholes because of mandrel deflection. In this manner it is possible to analyse other process parameters, such as: welding pressure, the cross section of bridge, geometry of welding chamber etc.

6. REFERENCES

[1] H.H. Jo, S.K. Lee, S.B. Lee, B.M. Kim, Prediction of welding pressure in the non-steady state porthole die extrusion of Al7003 tubes, Inter. Journal of Machine & Tolls Manufacture 22 (2002), 753-759.

[2] K.J. Kim, C.H. Lee, D.Y. Yang, Investigation into the improvement of welding strength in three-dimensional extrusion of tubes using porthole dies, Journal of Materials Processing Technology 130–131 (2002) 426–431.

[3] T. H. J. Vaneker, Development of an integrated Design Tool for Aluminum Extrusion Dies, Ph.D. Thesis, University Twente, 2001, Netherlands.

[4] L. Donati, L. Tomesani, Analysis of material flow and welding in aluminum extrusion of hollow sections, V AITEM Conference, Bari, September 2001, 678-688.

[5] L. Donati, L. Tomesani, Simulation of welding conditions in porthole die extrusion,Proc. Adv. Manuf. Systems and Technology (AMST), Udine, July 2002, n. 437.

[6] L. Donati, L. Tomesani, V. Giacomelli,Evaluation Of A New FEM Criterion For Seam Welds Quality Prediction In Aluminum Extruded Profiles, ET 2004, The Conference for Innovations in Aluminum Extrusion, Extrusion Technology Seminar, (Orlando U.S.A.) 221-235 vol.II.

[7] L. Donati, L. Tomesani, Determining the quality of longitudinal welds in aluminum extruded profiles, The Sixth Conference AITeM (Gaeta) September 2003, 49-50.

[8] Y/T. Kim, K.Ikeda, T. Murakami, Metal flow in porthole die extrusion of aluminium, Journal of Materials Processing Technology 121 (2002) 102-115.

[9] J. Lof, Y. Blokhuins, FEM simulation of the extrusion of complex thin-walled aluminium sections, Journal of Materials Processing Technology 122 (2002) 344-354.

[10] J. Lof, Elasto-viskoplastic FEM simulations of the aluminium flow in the bearing area for extrusion of thin-walled sections, Jour. of Materials Processing Technology 114 (2001) 174-183.

[11] H.H. Jo, C.S. Jeong, S.B. Lee, B.M. Kim, Determination of welding pressure in the non-steady-state porthole die extrusion of improved AL7003 hollow section tubes, Journal of Materials Processing Technology 139 (2003) 428-433.

[12] H.G. Mooi, P.T.G. Koenis, J. Hue´tink, An effective split of flow and die deformation calculations of aluminium extrusion, Jour. of Materials Processing Technology 88 (1999) 67–76.

[13] Y.T.Im, A computer-aided-design system for forming processes, Journal of Materials Processing Technology, 89-90 (1999), 1-7.

[14] S. Kobayashi, S-I Oh, T. Altan, Metal Forming and the Finite-Element Methods, Oxford University Press, New York, 1989.

[15] V. Mandic: Physical modelling and numerical simulation as basis of new concept in die design of hot bulk forming processes, Ph.D. Thesis (in serbian), Faculty of Mechanical Engineering, in Kragujevac, December 2002.

[16] T. Marinković, Influence of the configuration and position of the bridge in die for manufacture Al and Al-alloy profile by the direct extrusion process on the quality of welding area, Master Thesis (in serbian), Mechanical Engineering Faculty, Nis, 1994.

[17] Kojić M., Živković M., Slavković R., Grujović N., PAK - Finite Element Program for Linear and Nonlinear Structiral Analysis and Heat Transfer, Faculty of Mechanical Engineering, University of Kragujevac, Yugoslavia, 1996.

[18] Kojić M., Živković M., Slavković R., Grujović N., Vlastelica I., A Procedure for Large strain Elastic-plastic Analysis of shells, Computational Methods for Shell and Spatial Structures, IASS-IACM 2000, Athens, Greece 2000.

FEM ANALIZA PROCESA ISTISKIVANJA CEVI KORIŠĆENJEM KOMORNIH MATRICA

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REZIME

U radu se prezentiraju rezultati FEM simulacije procesa istiskivanja šupljih aluminijumskih profila, odnosno cevi, u cilju sveobuhvatnijeg i preciznijeg proučavanja i kontrole parametara procesa pri njegovom projektovanju. Korišćene su tri vrste matrica, sa dva, četiri i šest otvora u cilju praćenja podeljenog tečenja materijala i uticaja na deformisanja mosta matrice. U tu svrhu, korišćen je PAK softver za elasto-plastičnu analizu opterećenja mosta i njegove deformacije. YZa dobijanje graničnih uslovaza ovu analizu, izvedena je numerička simulacija procesa toplog istiskivanja aluminijuma, korišćenjem FEM softvera CAMPform 2D. Pokazano je da pristup sa parcijalnom numeričkom simulacijom tečenja materijala i deformacija alata može biti veoma efikasan način ya ovakve vrste analiya. Pored toga, moguće je da se složeni tro-dimenzionalni problemi tečenja kroz matricu za istiskivanje mogu proučavati posredstvom dvo-dimenzionalne numeričke simulacije u uslovima ravnskog deformacionog stanja, u reprezentativnim presecima. Preko izučavanja elasto-plastičnog deformisanja komorne matrice, odnosno mosta matrice, moguće je poboljšati vek alata i predupredití njegov lom.