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FEM ANALYSIS OF UPSETTING PROCESS BY CYLLINDRICAL DIES WITH EXPERIMENTAL VERIFICATION

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ABSTRACT

This paper reviews results of analysis of the upsetting process for prismatic and cyllindrical specimens by cyllindrical dies. The results were obtained using various methods. The upsetting of prismatic specimens was analysed using the Slab method and FEM, while FEM solely was used for the analysis of upsetting of cyllindrical specimens. FEM analysis was performed with CAMPform and verified experimentally using diagram of the upsetting force.

***Key words**: Upsetting process, FEM Analysiss*

1. INTRODUCTION

Upsetting processes play an important role in the technology of warm and cold bulk forming. For the upsetting of prismatic or cyllindrical parts, flat slabs are most often used, although upsetting methods exist which utilise tools of various geometries [8, 9, 10, 11] usually in preforming operations in forging.

Given in [8] is the classification of methods for prismatic part upsetting with tools which have working surfaces generated by a combination of a flat slab, cyllindrically-concave and cyllindrically-convex tool, thus allowing six models of upsetting. One of those six models is upsetting by cyllindrical dies (Fig. 1a). Substitution of prismatic specimen with the cyllindrical one, results in the method shown in Figure 1b.

Various modes of upsetting of prismatic and cyllindrical specimens [10] find their application in the analysis of formabillity of materials, due to a range of possibilities in creating various stress conditions.

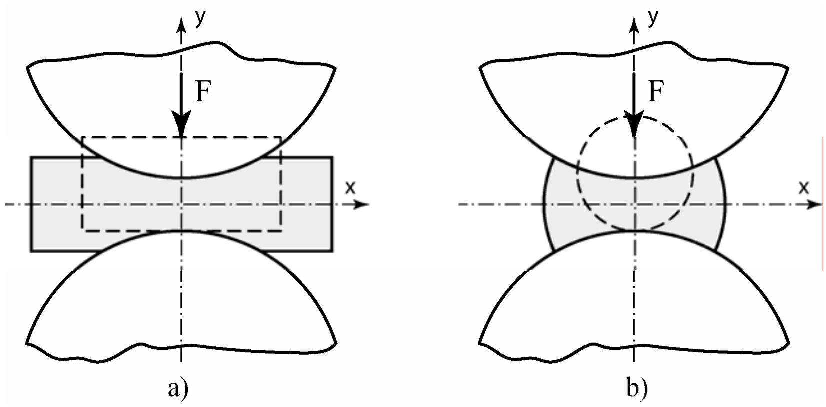


Fig. 1 Upsetting by cyllindrical dies
a) upsetting of prismatic specimen b) upsetting of cyllindrical specimen

This paper presents the results of FEM and Slab method analysis of the stress-strain state and process parameters in upsetting by cyllindrical dies, with experimental verification.

2. UPSETTING OF PRISMATIC PART BY CYLLINDRICAL DIES

2.1. THEORETICAL SOLLUTION BASED ON THE SLAB METHOD [8]

Presupposing the plane strain condition, and taking into consideration the variable flow stress along x-axis direction, as well as the presumtion that the tangential contact stress can be defined by the Coulombe relation ($\tau_k = \mu \cdot \sigma_m$), based on the stress scheme in Fig.2, we have the following differential equation of equilibrium:

$$\frac{d\sigma_x}{d\alpha} + \sigma_x \frac{\mu \cdot \cos\alpha}{a - \cos\alpha} + 1.15K \frac{\sin\alpha - \mu\cos\alpha}{a - \cos\alpha} = 0 \qquad (1)$$

where:

K is flow stress which is the function of effective strain (φ_e)

$a = \frac{h}{R} + 1$ is the geometric factor

μ is the friction coefficient

The effective strain along x-axis of the specimen is:

$$\varphi_e = 1.15 \ln \frac{H}{y} = 1.15 \ln \frac{H}{R(a - \cos\alpha)} \qquad (2)$$

The stress component σ_n follows from the plasticity equation:

$$\sigma_n = 1.15K + \sigma_x \qquad (3)$$

The forming load is derived by integration of contact stresses:

$$F = 2B \cdot R \int_0^{\alpha_B} \sigma_n \left(\cos\alpha + \mu \sin\alpha\right) d\alpha \qquad (4)$$

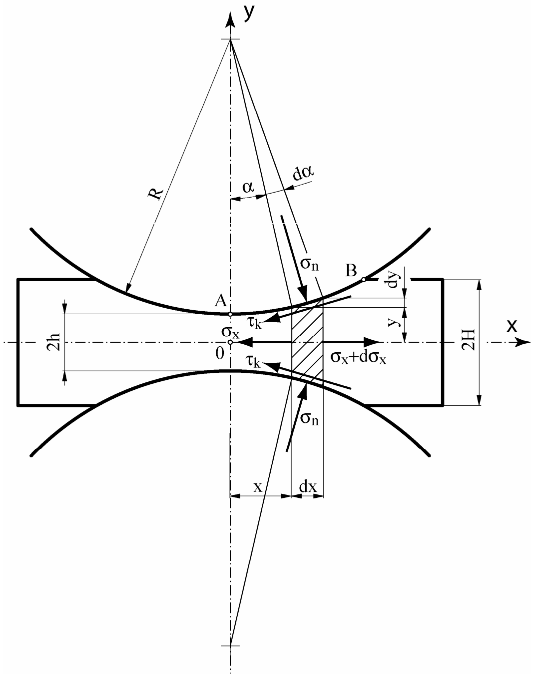


Fig. 2 Stress components

Figures 3 and 4 illustrate the distribution of contact stresses for specimens SP–100 (material Č.1221) and specimens SP–300 (material Č.1431)

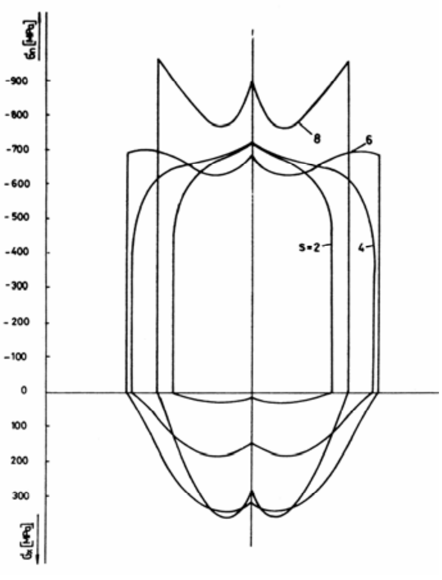


Fig. 3 Contact stresses for specimens SP–100 (Č.1221)

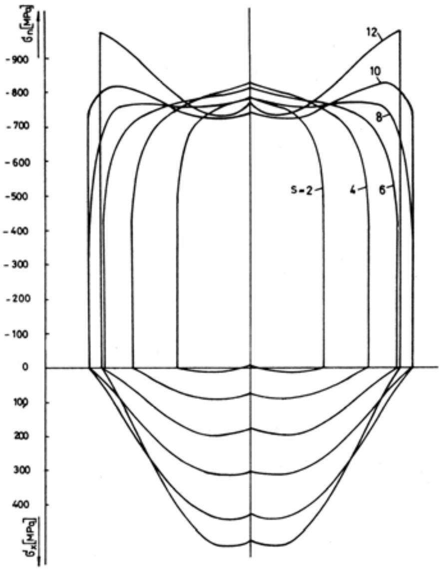


Fig. 4 Contact stresses for specimens SP–300 (Č.1431)

2.2. NUMERICAL CAMPFORM SIMULATION OF THE FREE UPSETTING PROCESS

Numerical simulation of the processes was performed using CAMPform 2D software, which is used for FEM analysis of warm and cold volumetric forming. The software was developed at the KAIST Institute (*1999*). It comprises module for numerical analysis, graphical user interface (GUI) which FEMtures a pre- and a post-processor, and AMG module for automated mesh generation and regeneration.

Numerical module is based on FEM, with thermo-rigid-visco-plastic elements, which were developed by Kobayashi et al. (*Rebelo 1980, Oh 1991*). In essence, this approach unifies methods for solving equlibrium and energy equations using rigid-visco-plastic constituent model with the Von Mises flow criterium. The temperature field distribution in the specimen is influenced by the level of plastic forming and friction energy, which can be determined by strain analysis, for any point i time. This temperature field is an important parameter in determining the flow stress, which influences all other characteristics of material flow. Thus, the strain analysis was unified with the analysis of heat transfer using the rigid-visco-plastic approach for problem solving.

AMG module for automated mesh generation and regeneration, is part of CAMPform 2D. For automated generation of quadrilateral mesh elements, "paving" and "looping" algorithms are used, which are described in more detail, in *Blacker 1991* and *Talbert 1990*. The procedure for mesh regeneration consists of three steps:

1. Deciding when the *remeshing* is necessary;
2. Automated mesh regeneration;
3. Mapping the state of all variables from the previous meshing system to the new one.

CAMPform 2D uses two criteria for the beginning of *remeshing*. It uses either the level of deformation of the quadrilateral elements, defined by the maximum angle inside the quadrilateral (e.g. 160°), or checks the interference of FE mesh nodes with the tool, which depends on the nature of the process examined. The user interactively defines the starting condition for *remeshing* and the maximum number or the approximate size of elements in the new mesh.

CAMPform pre-processor allows two basic functions: input of data defining conditions of analysis and analysis control. O*nline monitoring* is also provided during analysis, which allows flow of analysis and graphical output of results to be monitored. Pre-processor has a built-in editor which allows review of input data. Tool and specimen geometry can be defined either in a built-in CAMform editor or using CADInterface module for CAD geometry transfer from external systems (e.g. AutoCAD, Mechanical Desktop, CATIA, etc.).

The post-processor generates graphical images of output functions, creating coloured renderings, contour line and vectorial or tensor renderings. Output information from simulation are: deformed shape of specimen, flownet line, strain distribution, strain velocity, stress, structural tool-strain, tool and specimen temperatures, forming load diagram, material plastic yield factors and tool wear characteristics. The post-processor can also generate bitmap (BMP) and AVI files, for animated process simulation in the user-defined form: 2D or 3D image, with or without tool path generation, coloured rendering or meshed rendering, etc.

Material flow stress is input as the function of strain velocity and plastic forming, while the structural deformations are neglected. Mathematical model can be described as:

$$\sigma = \mathrm{A_t}\, \bar{\varepsilon}^{\mathrm{n}} \dot{\bar{\varepsilon}}^{\mathrm{m}} \text{, Mpa} \tag{5}$$

CAMPform has a built-in friction model which is based on constant friction:

$$\tau = m\,\mathrm{k} \tag{6}$$

because this law applies mostly to the processes of volumetric metal forming, in which high working pressures occur.
Boundary values for determination of conditions of plastic yield, i.e. yield coefficients, are defined using two criteria, plastic work hypothesis, proposed in 1950 by Freudenthal, and Cocroft & Latham hypothesis, from 1968 (*Kim 1999*).
FEM analysis and simulation of the free upsetting of quadar and radial upsetting of cyllinder were performed using this software. Material flow curves for two kinds of materials, Č1220 and Č1431, which were used in exepriments, were given in the following form:

$$\sigma = 862.447\ \bar{\varepsilon}^{0.179}\text{, MPa (Č1220)} \tag{7}$$

$$\sigma = 1042.887\ \bar{\varepsilon}^{0.184}\text{, MPa (Č1431)} \tag{8}$$

Specimen and tool geometry, and strain velocity were given based on the experimental investigation, presented in previous section of this paper. Friction factor m=0.155 was given, which is equivallent to friction coefficient μ=0.09. FEM analysis was conducted based on conditions of plane strain state.
Tool and specimen geometry and the initial FE mesh, used in simulation of the quadar upsetting (experiment coded SP100), are shown in Figure 5.

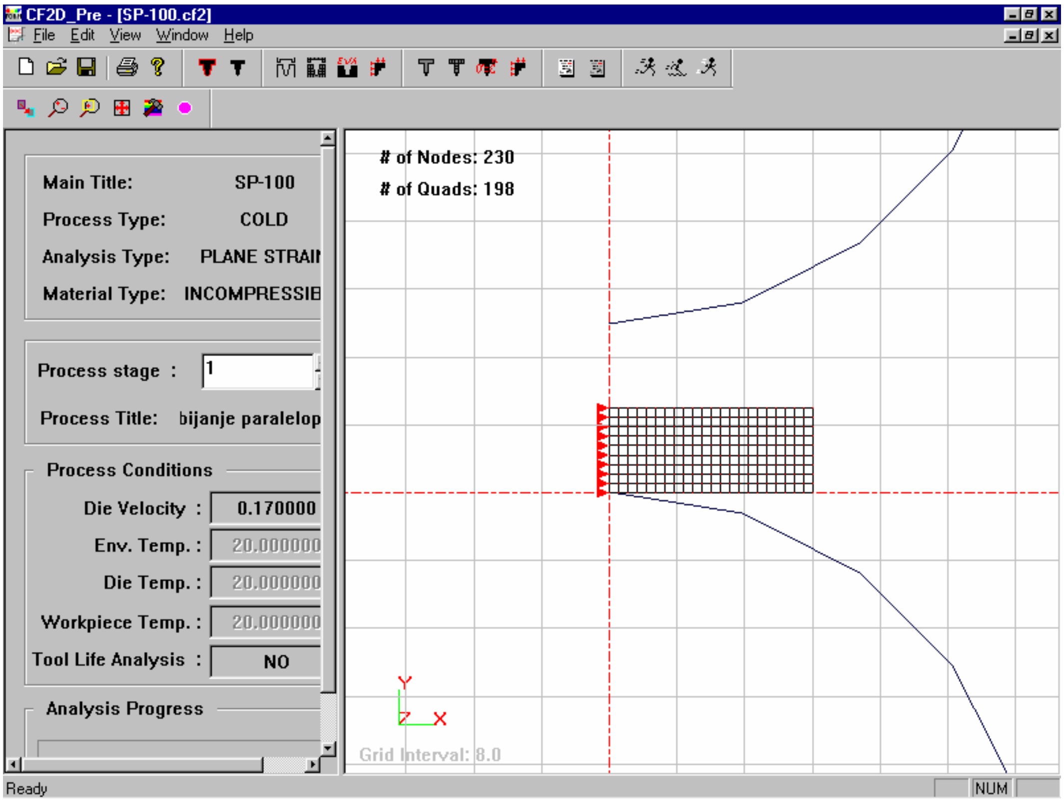


Fig. 5 Initial FE mesh of specimen and tool geometry in CAMPform 2D editor, process SP100

Since complete FEM analysis of the process was performed, deformation, stress and velocity fields were obtained for the entire duration of the process. In order to facilitate comparison of results with experimental investigations and results of other methods applied, only partial results are presented here. Shown in Figure 6 are stress distributions of σ_x and σ_y, through process phases which correspond to the results obtained by Slab method.

The same process with the unchanged specimen geometry and material type, results in different values of stress fields. Shown in Figure 7 is the initial FE mesh of specimen for this simulation (experiment coded SP300).

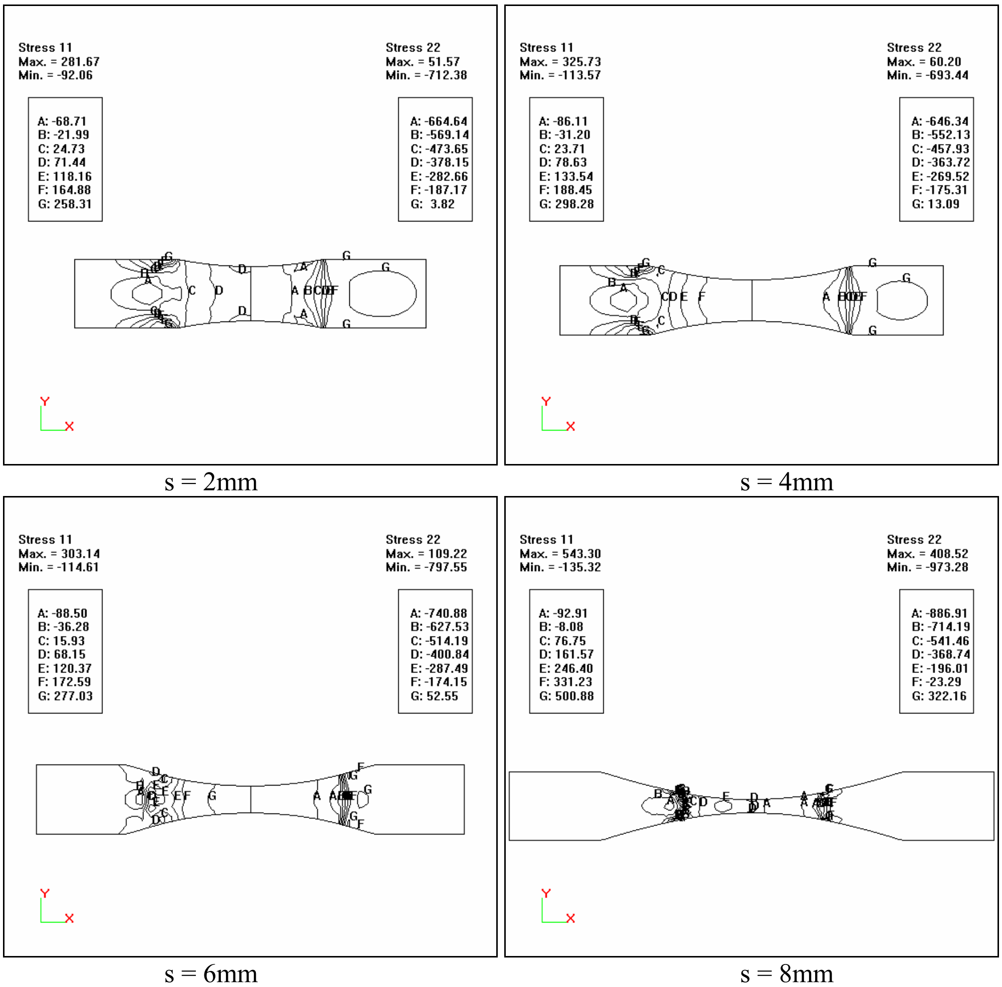


Fig. 6 Distribution of stress components σ_x (left) and σ_y (right) through different phases of process SP100

Within experimental investigation, the method of viscoplasticity was used. This allowed material flow, stress and strain fields to be monitored through several phases, using coordinate mesh applied onto the specimen. For the purpose of qualitative comparison of material flows in the reference plane of the specimen, in experimental investigation and FEM analysis, it is convenient to show FEM approximation of material flow in the form of coordinate mesh. CAMPform software allows this to be done in its *flownet* option, where the user enters the number of horizontal and vertical lines of the coordinate mesh. Shown in Figure 8 is the approximation of FAE coordinate mesh on the specimen, during the phases of the process which correspond to the experiment.

Stress fields for this model of process derived by FEM analysis, are presented in Figure 9.

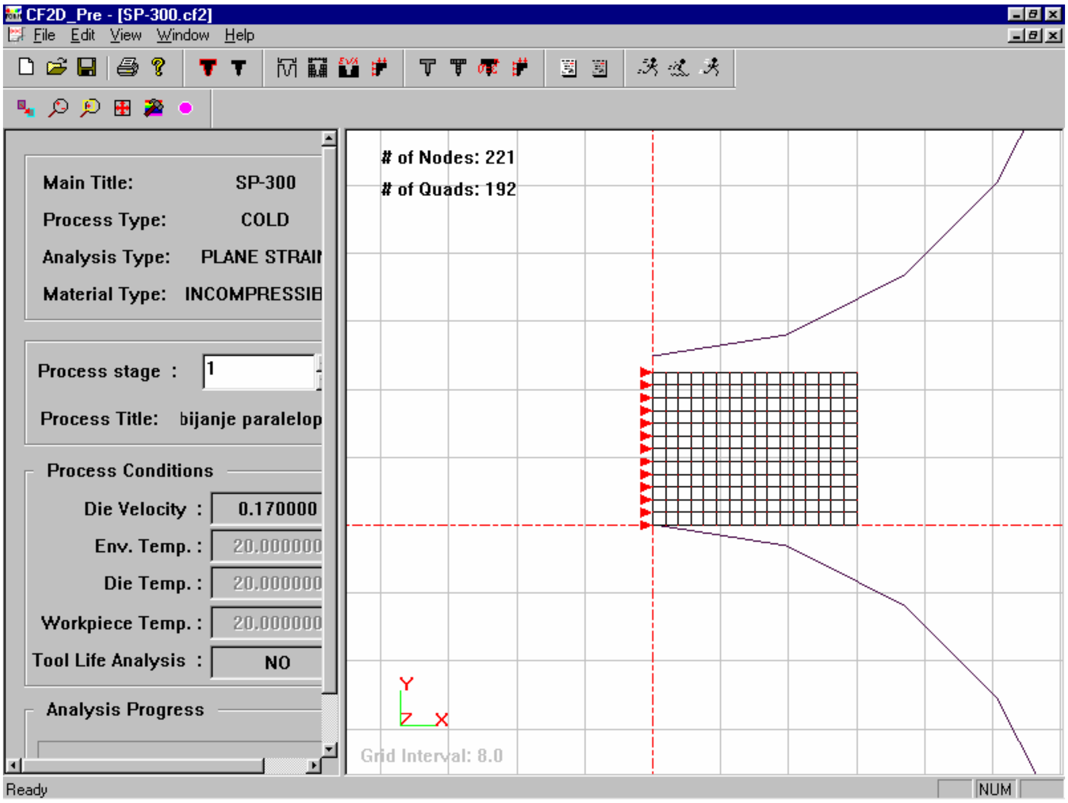


Fig. 7 Initial FE mesh of specimen and tool geometry in CAMPform 2D editor, process SP300

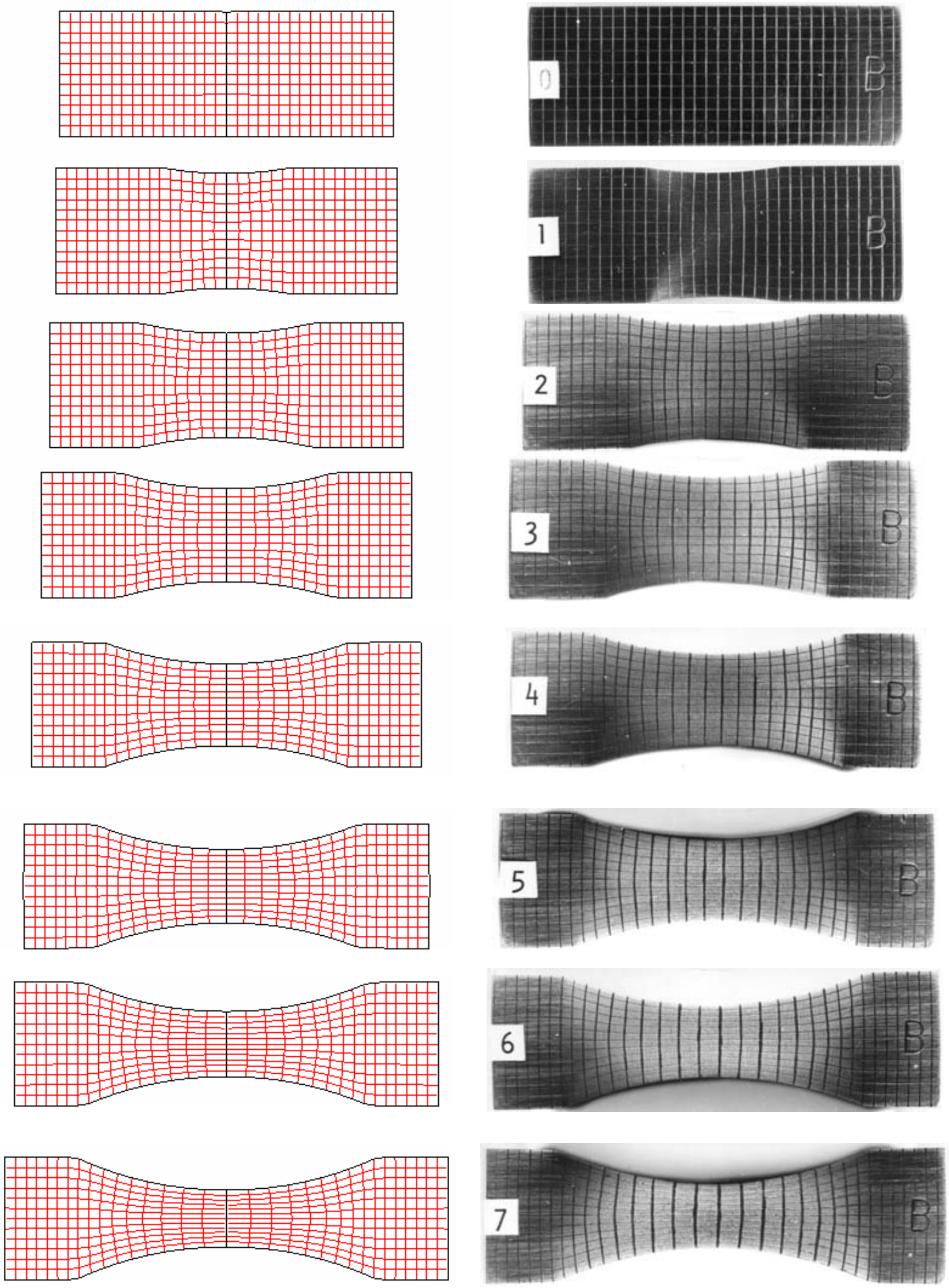


Fig.8 Phases of upset specimen SP-300

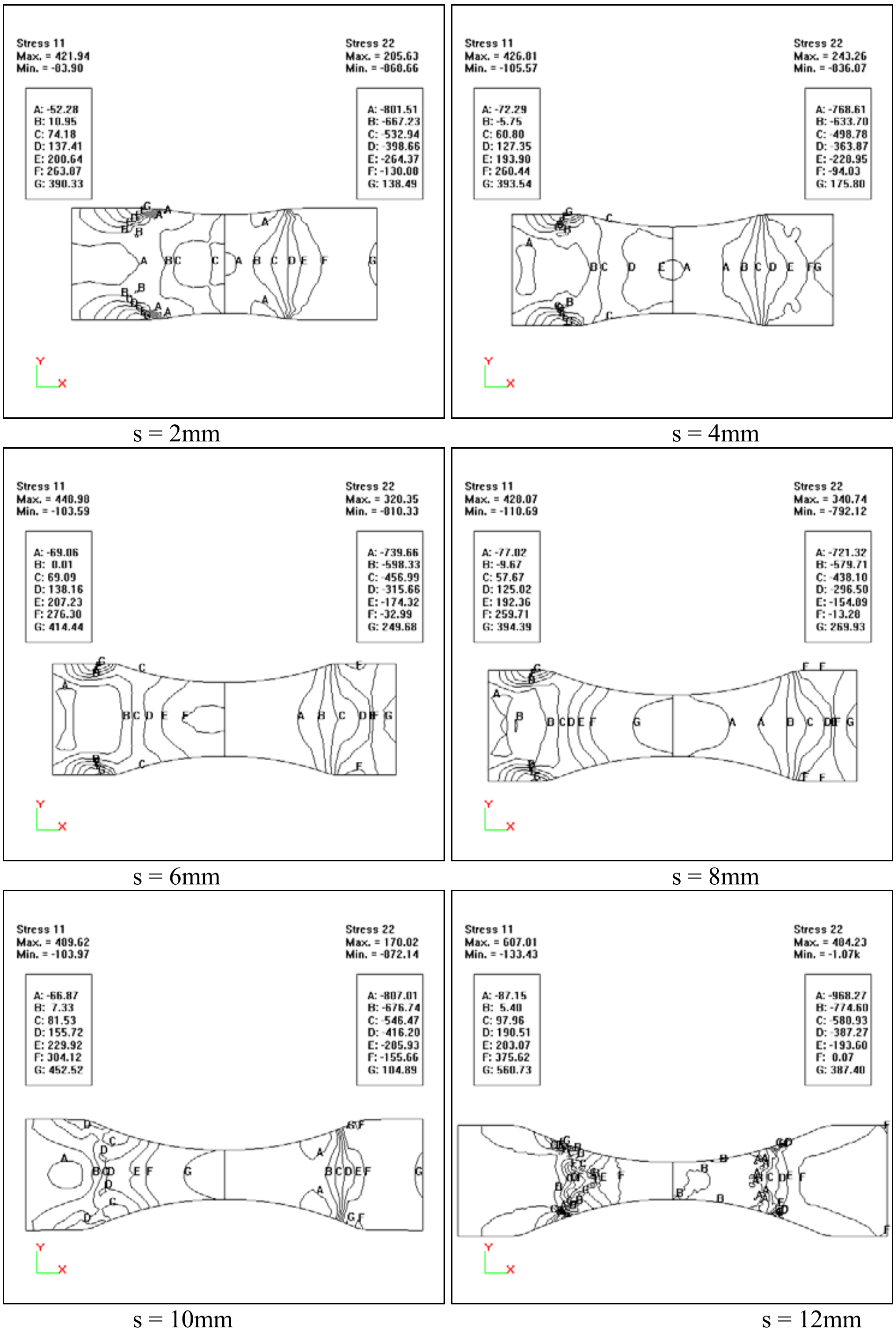


Fig. 9 Distribution of stress components σ_x (left) and σ_y (right) through phases of process SP300

FEM simulation of radial upsetting of cylinder (ϕ18x18mm) was also performed based on the conditions of plane strain state. The initial FE mesh of specimen and tool geometry are shown in Figure 10. Stress field distributions for this model of process, for material type Č1220, are shown in Figure 11, for several process phases.

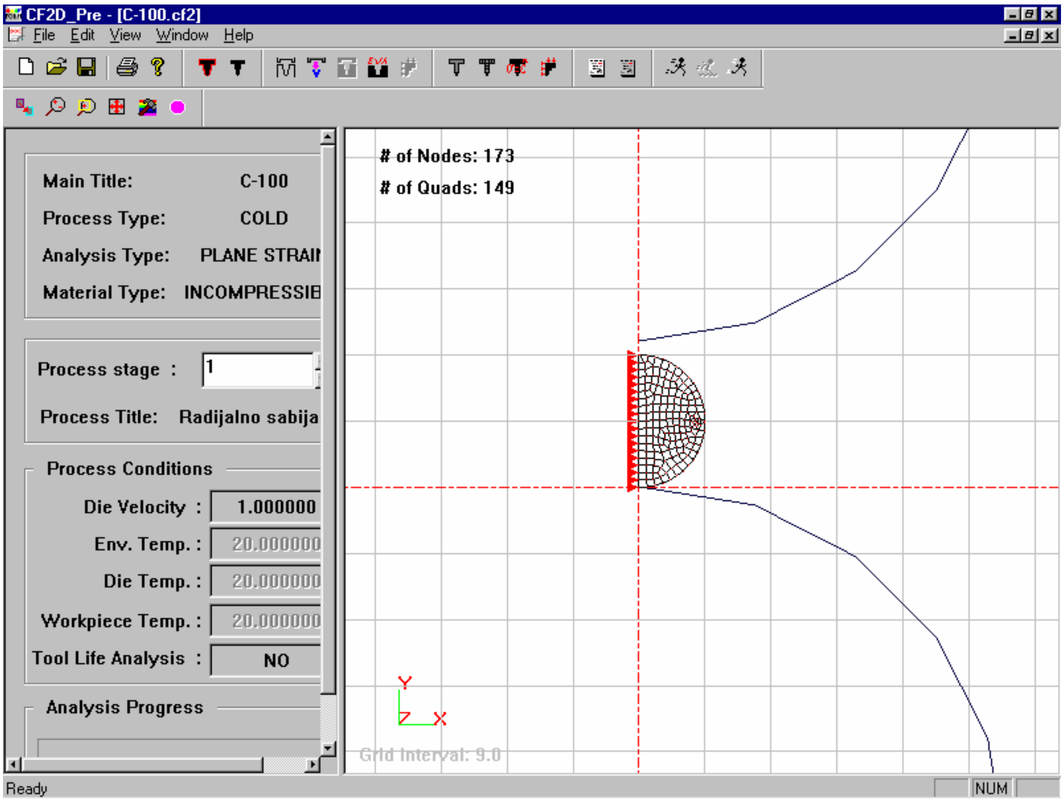
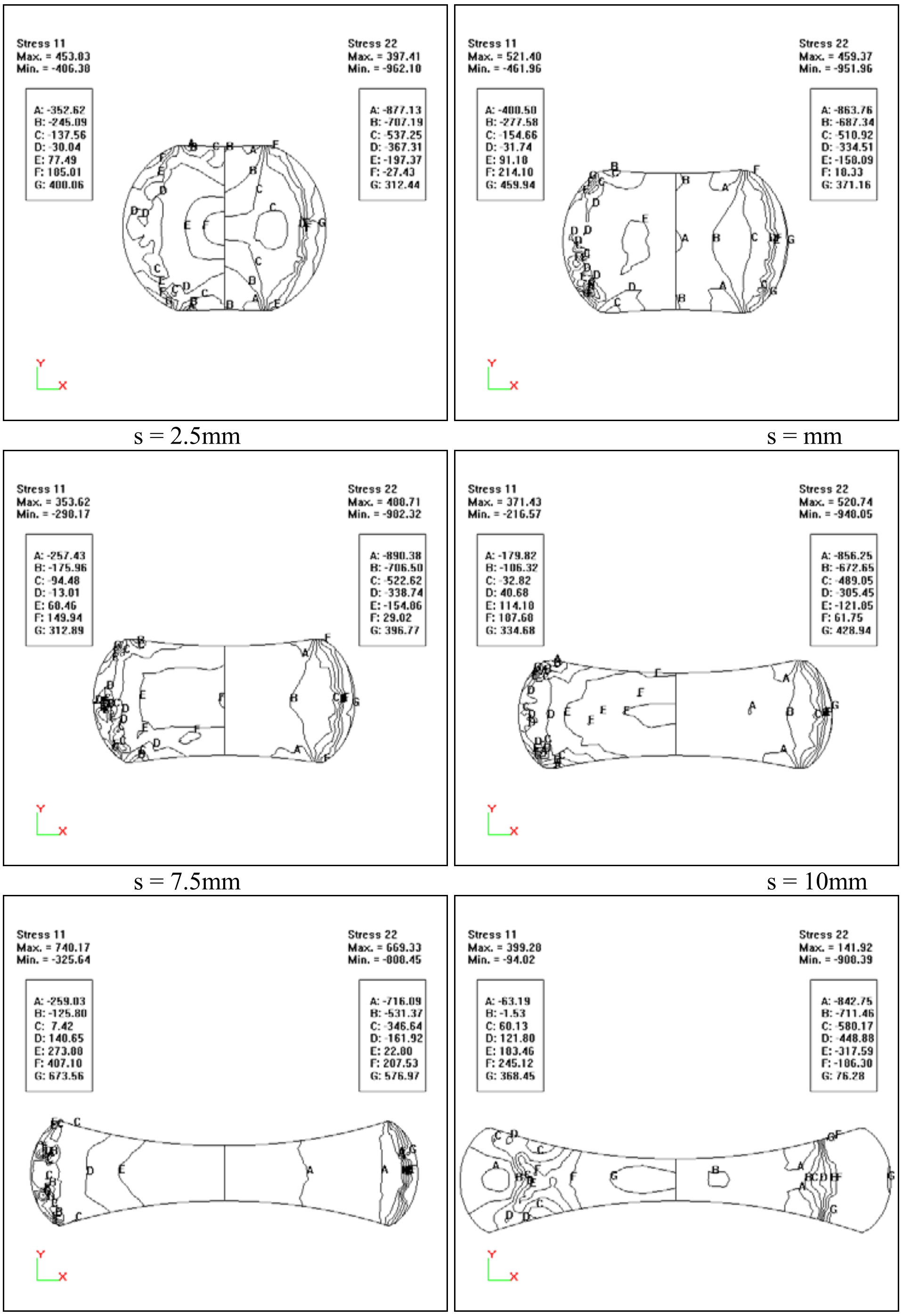


Fig. 10 Initial FE mesh of specimen and tool geometry in CAMPform 2D editor, for process C100

Stress fields in the specimen vary with the change of material type, and so does the forming load diagram. Stress field distribution, for radial upsetting of the specimen Č1431, are shown in Figure 12.



s = 2.5mm s = mm

s = 7.5mm s = 10mm

s = 12.5mm s = 14mm

Fig. 11 Stress field distribution σ_x (left) and σ_y (right) through process phases, for process C100

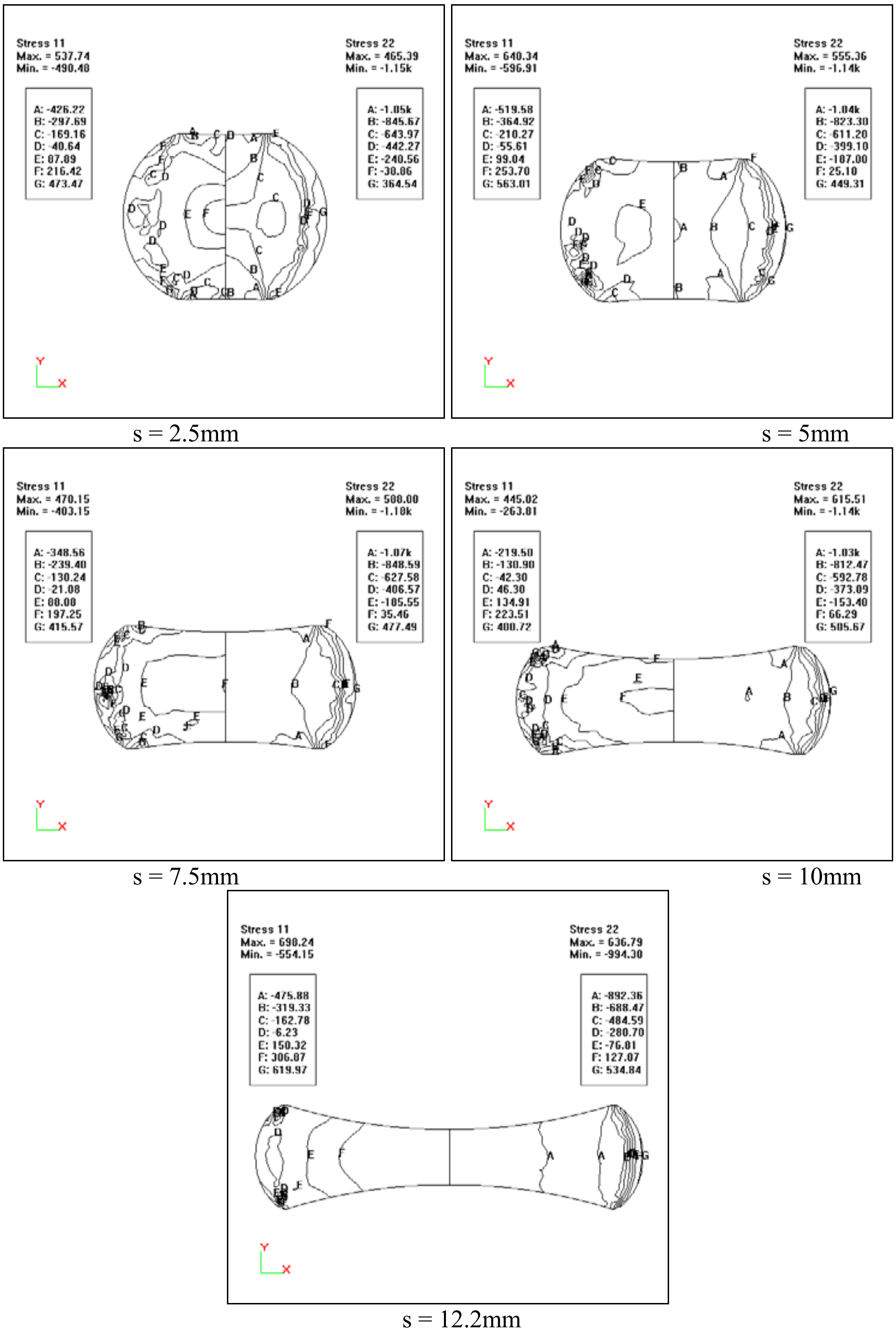


Fig. 12 Stress field distribution σ_x (left) and σ_y (right) through process phases, for process C100

Diagrams for forming load for specimens SP–100 and SP–300, are shown together with the experimentally derived data (Fig. 14).

3. UPSETTING OF CYLLINDER BY CYLLINDRICAL TOOLS

Analysis of thois strain model (Fig. 1b) was conducted by CAMPform simulation for two sets of specimens, C100 (Č.1221) and C300 (Č.1431) with the following dimensions: ϕ18x18mm. The forming load obtained by FEM analysis, was also confirmed experimentally.

4. THE EXPERIMENT

Verification of theoretical and FEM results for upsetting prismatic and cyllindrical specimens by cyllindrical tools, was performed experimentally, where the forming load was measured. For that purpose, special tool was used, with the radius of R=50mm, and Sack and Kiesselbach hydraulic press with the nominal force of 6,3MN (Fig. 13). Prior to upsetting, the specimens were phosphated and their contact stress coefficient was measured by method of ring upsetting. The friction coefficient derived was μ=0,09.

Fig. 13 Equipment used in the experiment

Shown in Fig.14 are diagrams of forming load, determined experimentally and theoretically, using FEM analysis, for prismatic (SP–100 and SP–200) and cyllindrical specimens (C 100 and C 200) which were made of steel Č.1221 and Č.1431.

For the purpose of numerical analysis, flow curve was obtained experimentally for Č.1221 and Č.1431, using the Restegaev specimen method.

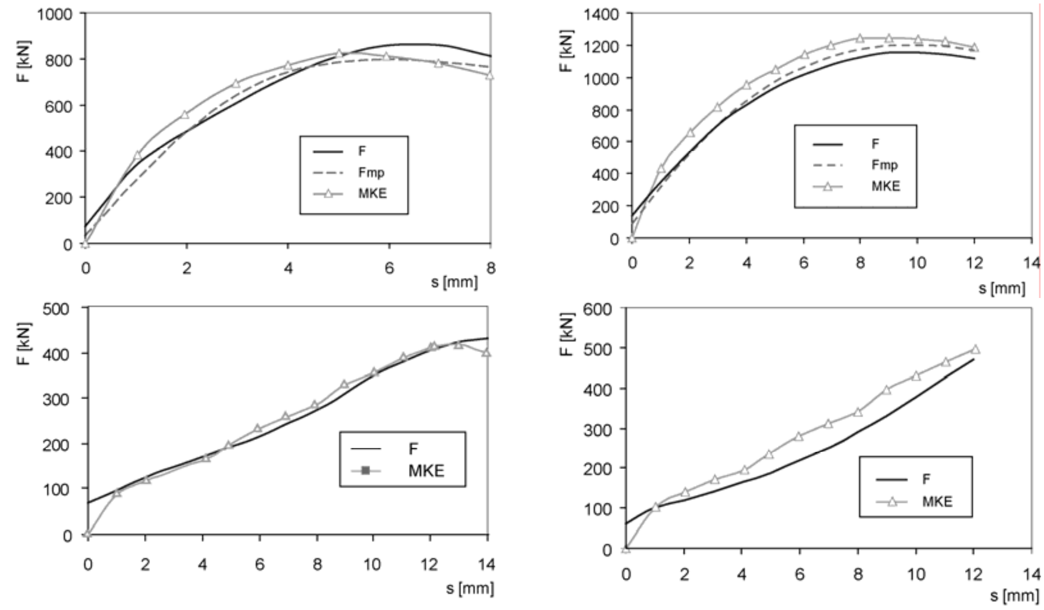


Fig. 14 Forming load diagram
a) for specimens SP–100, b) for specimens SP–300, c) for specimens C–100,
d) for specimens C–200

The multiphase forming of the specimen from series 300, with the previously applied coordinate mesh, yielded the flow image which was compared against the CAMPform simulation (Fig. 8).

5. CONCLUSION

Upsetting processes exist as production phases in most technologies for cold and warm volumetric forming. They are performed with tools whose geometry often differs from the standard plane slab, while the specimens vary in shape. Analysis of processes in plastic forming technology requires the stress-strain state to be determined as well as the basic process parameters (forming load and forming work). For this purpose, various methods are used, e.g. theoretical, theoretical and experimental, experimental, numerical methods, etc. Recent developments have lead to broader application of methods for numerical simulation, with FEM being the most wideky used method in analysis of various processes in plastic forming technology.
This paper presented a comparative review of results obtained using Slab method, FEM and experiment for the process of upsetting of prismatic and cyllindrical specimens by cyllindrical tools. Based on the forming load diagram for all specimens, one can conclude that FEM analysis of upsetting by cyllindrical tools, performed with CAMPform software, resulted in a very high agreement with the forming load obtained by experiment. Also, the flow image obtained by this method with specimens from series 300, matches the experimental results to a high degree.
Slab method also yields satisfactory results regarding the forming load in prismatic specimens. Contact stresses obtained by this method, agree well with the FEM analysis results. CAMPform

allows complete volumetric process analysis, outputs stress and strain components, strain velocity, and also determines basic parameters of the process. As such, CAMPform has obvious advantage over all the other methods discussed in this paper.

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ANALIZA PROCESA SABIJANJA CILINDRIČNIM ALATIMA METODOM KONAČNIH ELEMENATA SA EKSPERIMENTALNOM VERIFIKACIJOM

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REZIME

U radu su prikazani rezultati analize procesa sabijanja prizmatičnih i cilindričnih obradaka pomoću cilindričnih alata primenom različitih metoda. Sabijanje prizmatičnih pripremaka analizirano je pomoću metode rešavanja približne jednačine ravnoteže i metodom konačnih elemenata, a sabijanje cilčindričnih pripremaka analizirano je metodom konačnih elemenata. MKE analiza izvedena je pomoću CAMPform simulacije a rezultati analize su provereni eksperimentalno na osnovu dijagrama deformacione sile.

Rezultati prikazani u ovom radu deo su istraživackih aktivnosti na projektu "Istraživanje i razvoj savremene tehnologije u proizvodnji kotrljajnih ležaja radi povećanja konkurentnosti na ino-tržištu" - MIS.3.02.3206.B finansiranog od strane Ministarstva za Nauku i Tehnologiju Srbije.