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# UBET ANALYSIS, FINITE ELEMENT SIMULATION AND EXPERIMENTAL INVESTIGATION OF BACKWARD EXTRUSION

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## ABSTRACT

*In this paper analysis of backward extrusion of steel using upper bound method and finite element method has been conducted. Verification of the results are made by experiment. Process analysis includes stress-strain state determination within the volume of specimen and main process parameters – deformation load and work.*
*Keywords: FEM, upper bound method, cold extrusion, stress, strain, experiment.*

## 1. INTRODUCTION

Technology of plasticity takes significant place among other manufacturing technologies. By this technology it is possible to manufacture half-finished and finished products of wide variety of shapes, dimensions and accuracy made of steel, non-ferrous metals and their alloys.

Cold steel extrusion is one of the most important technology of metal forming. Due to its advantages when compared to other manufacturing technologies (cost, product quality, product accuracy, production time), cold extrusion has become a vital part of product manufacturing technology.

In recent time rapid development are taking place in various fields of this technology, one of which is also expansion the spectrum of the component shapes which can be manufactured by cold extrusion (fig. 1) [8], [12].

The new, very significant impact of the investigation and practical implementation of this technology has been initiated through the application of computer based softwares, which is nowadays a routine procedure.

There exist a number of different methods to analyze cold extrusion processes.

Classical slab-method requires a number of assumptions and simplifications which, inevitable, leads to less accurate results. But, for the geometrically simple deformations cases, this method can produce reliable solutions [12].

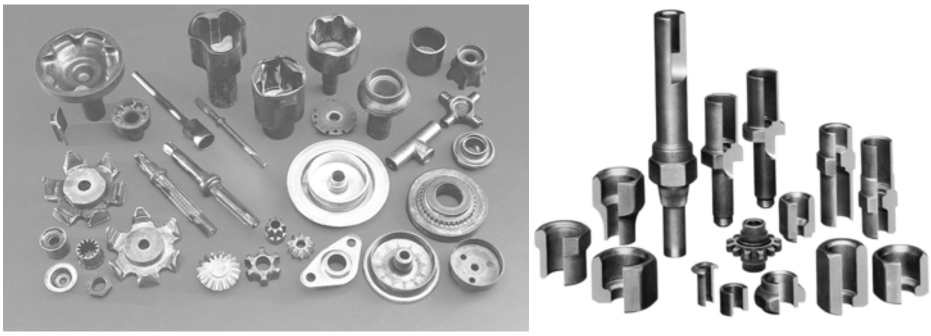

*Figure 1. Components produced by cold extrusion*

Upper Bound method offers possibility to obtain the main process parameters in the bulk metal forming processes such as load and work of deformation. One of the main preconditions for the correct Upper Bound solution is reliable assumption of kinematically admissible velocity field within the specimen volume. Initially, this method was used mainly for 2D and axisymmetric problems [1], [2], but further development of UBET made it possible to analyze 3D problems too [3], [4], [5], [6], [7].

One of the most sophisticated numerical method nowadays is finite element method, which enables comprehensive and thoroughly analysis of metal forming processes. Relevant details regarding FE application in metal forming can be found elsewhere [9], [10], [13], [14].

In this paper backward extrusion process was analyzed by UBET and finite element method. Verification of results has been done experimentally.

Load – stroke dependence, as well as the stress and strain distribution within the specimen volume has been considered.

The scheme of the process is given in the fig. 2.

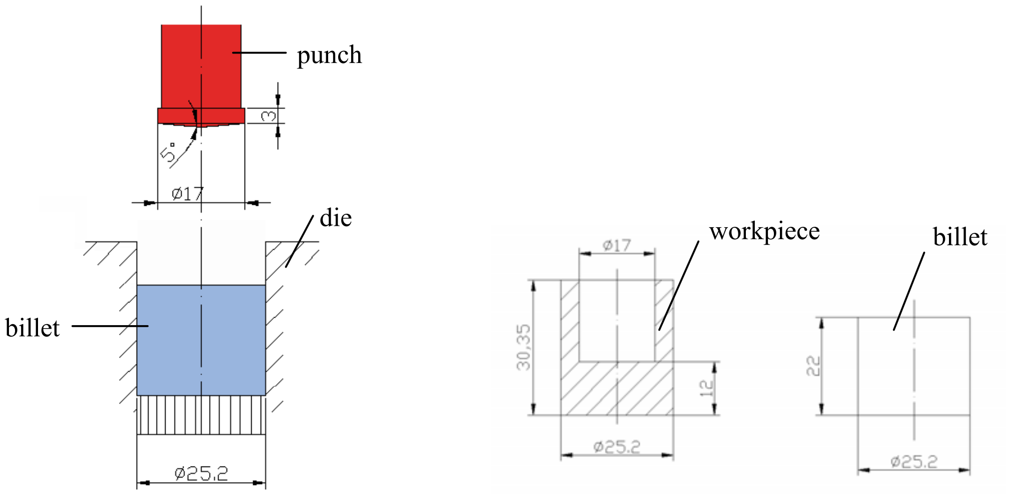


*Figure 2. Backward extrusion process, workpiece and billet dimensions*

Comparison of results determined by different methods (upper bound, finite element and experiment) is performed in the concluding part of this paper.

## 2. ANALYSIS BY UBET

UBET had been developed on the base of upper bound method principles [1], [2]. This method makes possible to obtain the basic process parameters by assuming kinematically admissible velocity field within the workpiece volume and proper boundary conditions and material properties. Performing the UBET analysis is done very comfortable in interactive way.

In fig. 3 the UBET screenshot of investigated backward extrusion process is shown.

Dependence between forming load and punch stroke for different friction coefficient, obtained by UBET simulation, is shown in fig. 4.

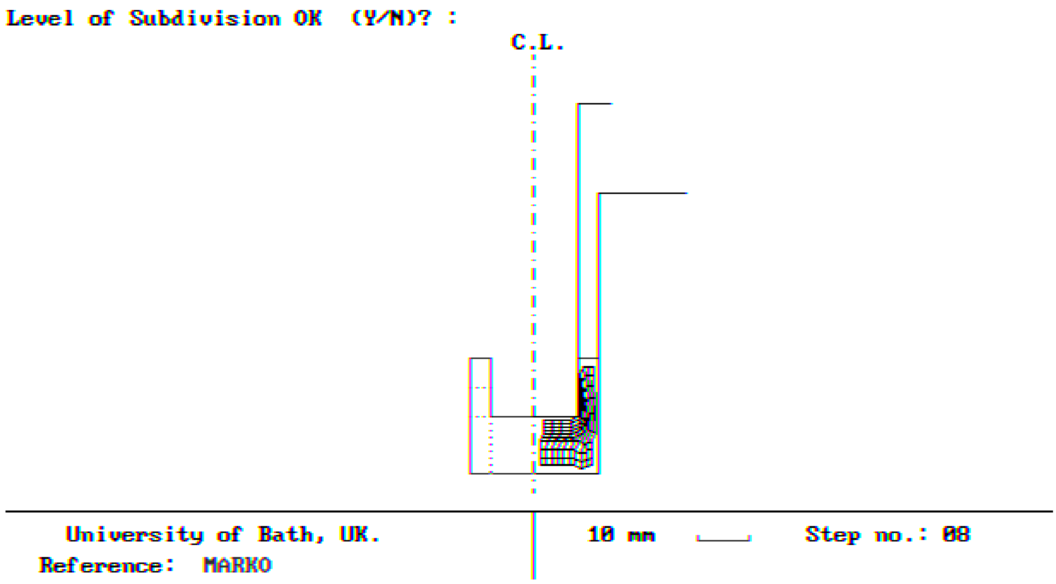


*Figure 3. Graphical visualization of UBET analysis*

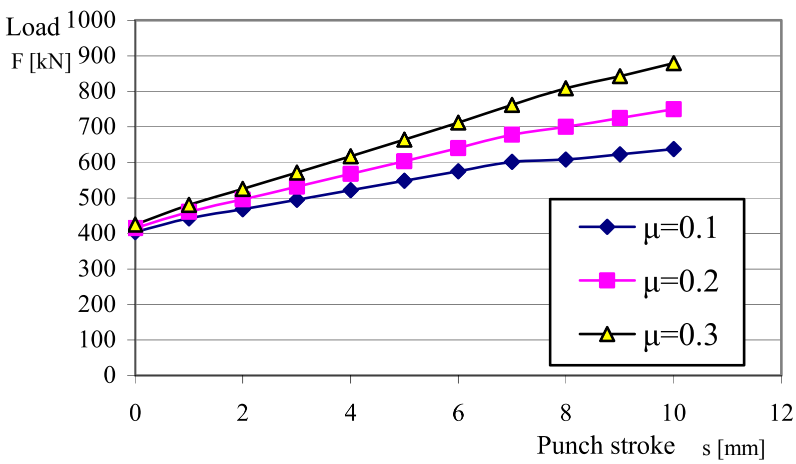


*Figure 4. Influence of friction on deformation force*

The interdependence between the number of generalized elements in which the initial billet was subdivided in UBET analysis and the deformation load is presented in fig. 5. As it can be seen, increase of element numbers causes the load increase.

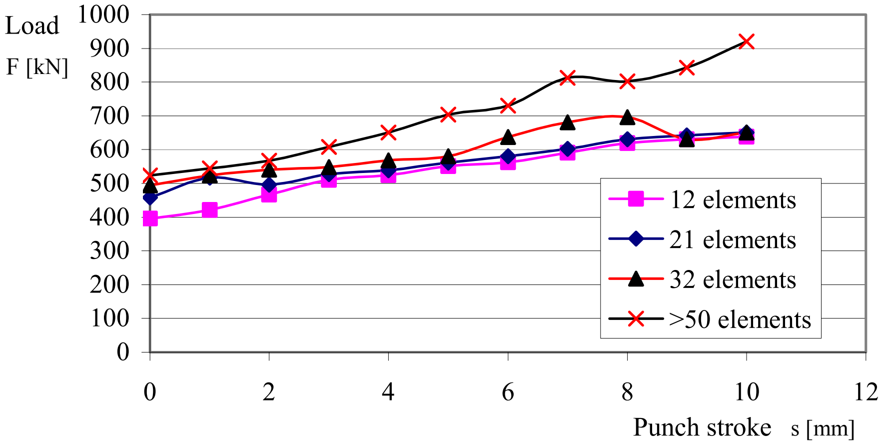


*Figure 5. Dependance between force and number of generalized elements*

Distribution of effective stress and strain within the specimen volume, obtained by UBET, is given in figure 6 and 7. As it can be seen, within the volume zones different values of stresses and strains exist. Directly beneath the punch lower stress – strain values occur whereas the highest stresses and strains appear in the zone around the punch corner.

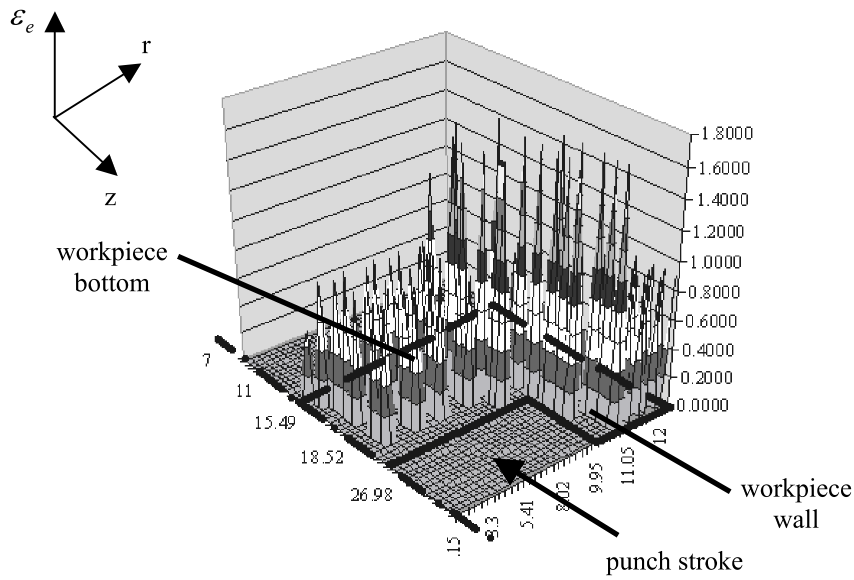


*Figure 6. Distribution of effective strain within the specimen volume*

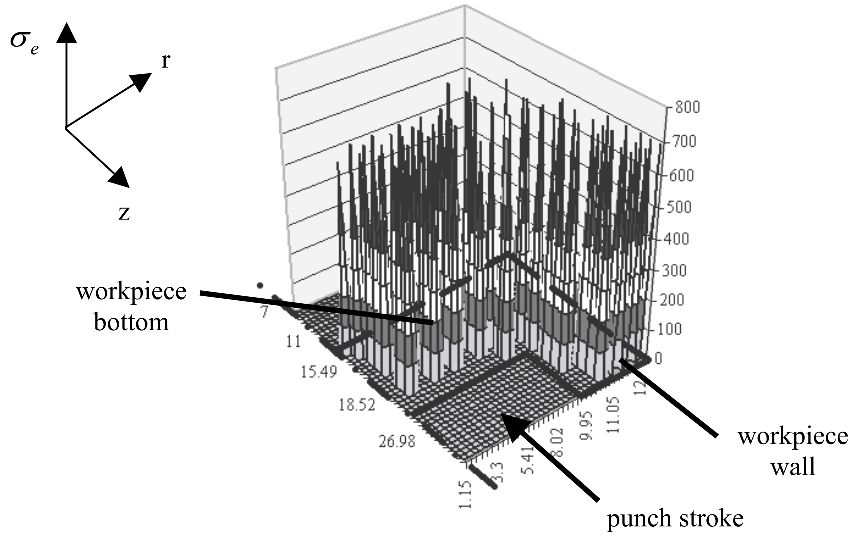


*Figure 7. Distribution of effective stress within the specimen volume*

## 3. FEM ANALYSIS

FEM is method of discrete analysis, which is based on continuum division on final dimension elements. Using suitable physically-mathemactal relations on discrete system, the system of equations are set. Solving these systems of equations, relevant values for process, likewise stress and strain components, deformation load, are obtained.

Numerical simulation of the backward extrusion processes was performed using CAMPform 2D software, which is used for FEM analysis of warm and cold bulk forming. The software was developed by professor Yong-Teak Im with associates at the KAIST Institute - Korea. Numerical module is based on FEM, with thermo-rigid-viscous-plastic elements. In essence, this approach unifies methods for solving equilibrium and energy equations using rigid-viscous-plastic constituent model with the Von Misses flow criterion. Calculation module has graphic user interface, which contains pre-processor and post-processor, for more efficient data input and graphics interpretation of simulation results.

CAMPform pre-processor allows two basic functions: input of data defining conditions of analysis and analysis control.

The post-processor generates graphical images of output functions, creating colored renderings, contour line and vector or tensor renderings. Simulation output information are: deformed shape of specimen, flow net line, strain distribution, strain rate, stress components, tool elastic deformation, tool and specimen temperatures, deformation force 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, colored rendering or meshed rendering, etc.

Maximal effective stress and strain values occur inside of workpiece wall, in the contact area with the punch, while minimum values occurs below the punch (fig. 8).

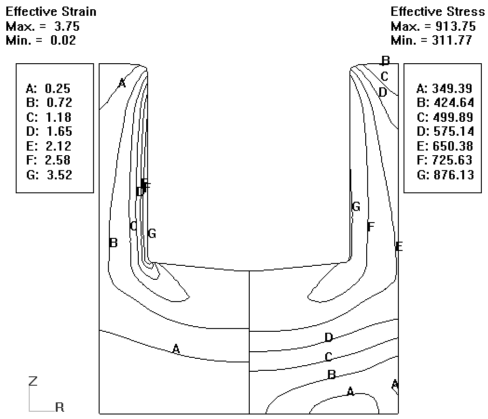


*Figure 8. Distribution of effective strain (left) and effective stress (right) (s = 10 mm)*

In fig. 9 force - stroke diagram, obtained by FE simulation is given.

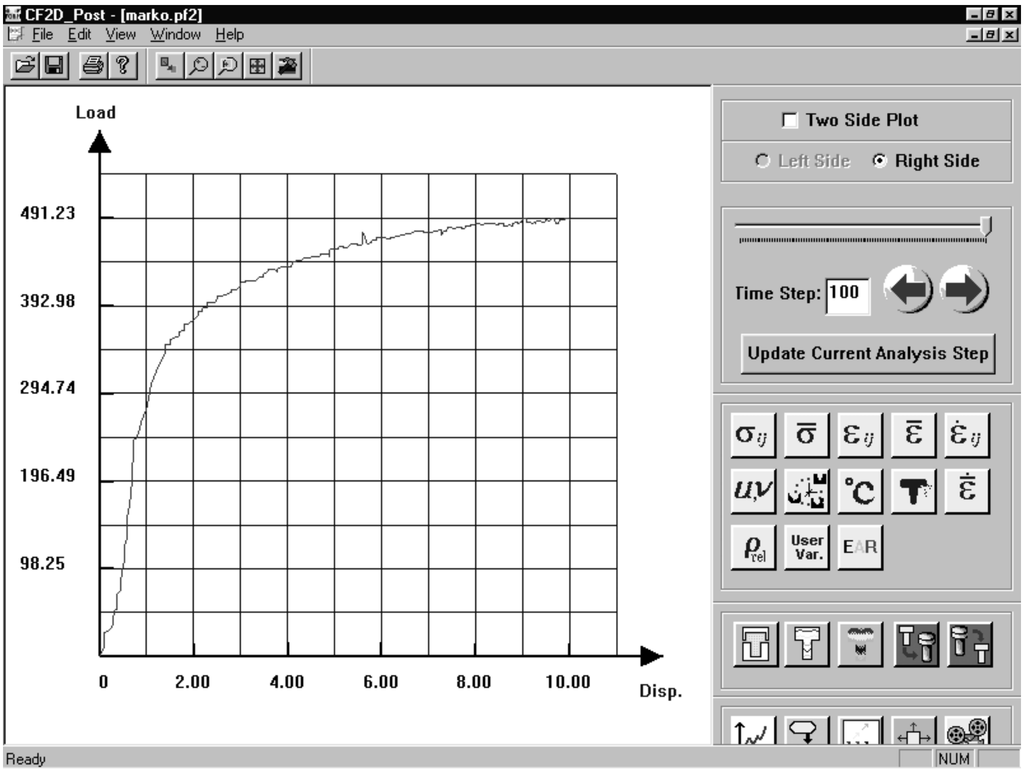


*Figure 9. Force – stroke diagram obtained by FE*

CAMPform also has ability to show alteration of finite element mesh during deformation process (fig. 10).

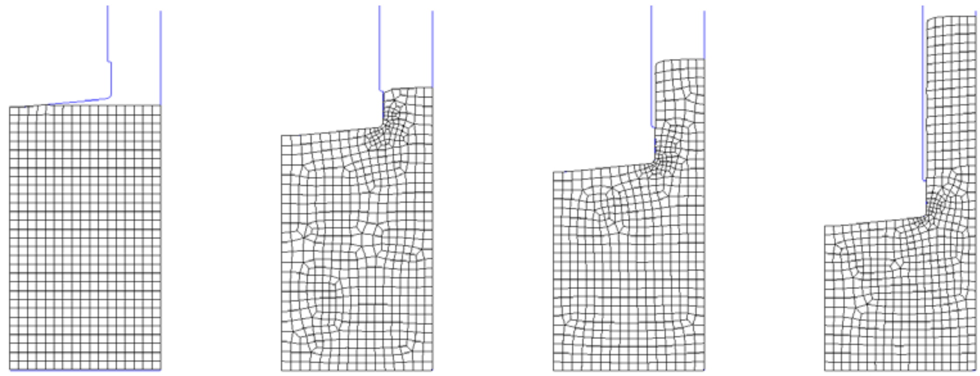

*Fig. 10. Alteration of FE mesh in one half of workpiece during deformation process (in 4 steps)*

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 [9].

## 4. EXPERIMENTAL ANALYSIS

Results obtained by UBET and FE methods were verified by experiment, which was carried out in the Laboratory for Metal Forming, FTN, University of Novi Sad. Experiment was performed on the hydraulic SACK&KIESELBACH press of 6.3 MN, by using special tooling.

Prior to backward extrusion experiment, flow curve of the billet material was determined in the Rastegaiev test.

### 4.1 Flow curve determination by Rastegaiev method

Rastegaiev method is used for flow curve determination in the region of great deformations $(\varphi > 1)$. By specific billet (cylinder) geometry (fig. 11) and lubrication, conditions with almost no friction can be achieved (i. e. nearly uniaxial compression).

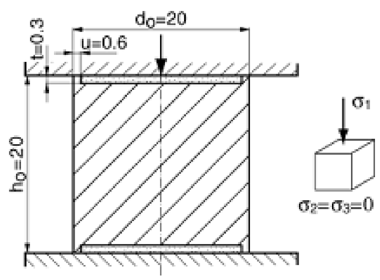


*Figure 11. Billet geometry for Rastegaiev method*

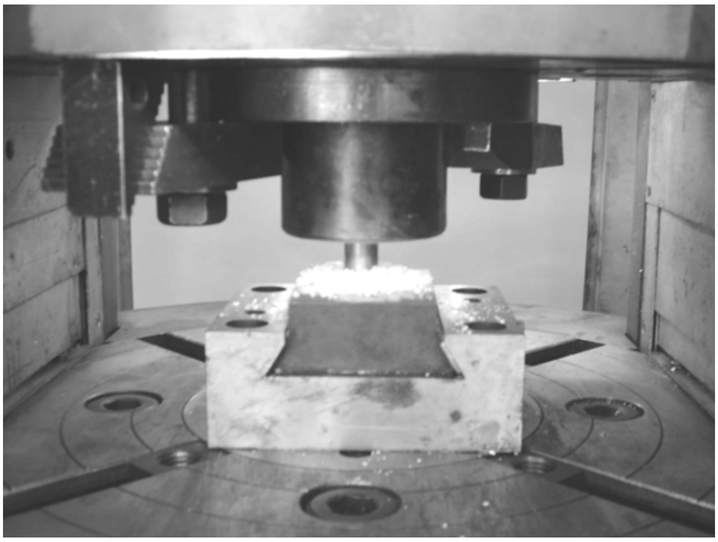

*Figure 12. Cylinder strewed with stearin ready for compression*

Flow curve was determined for the steel Č1221, which was used in numerical analysis of backward extrusion. Billet dimensions: Ø20,1×19,38 mm. Compression of cylinders was done in several increments, with direct measurement of deformation force and geometrical dimensions (diameter $D$ and height $h$) after every increment (fig. 12).

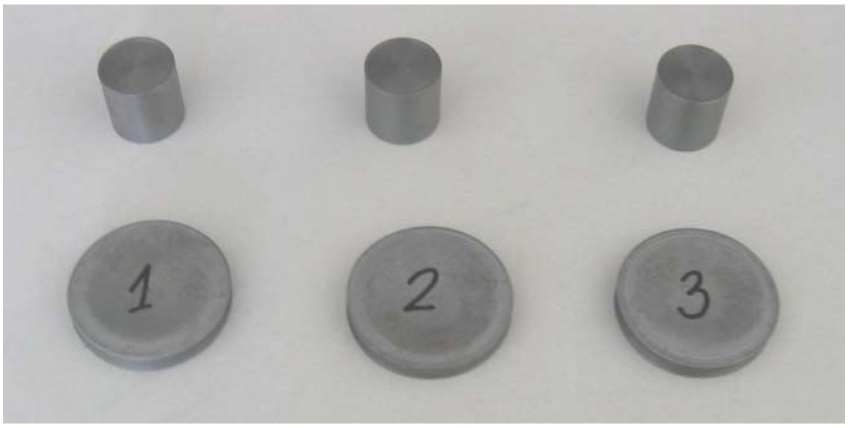


*Figure 13. Cylinders before and after compression in Rastegaiev test*

Initially, stroke per increment was 0.5 mm, and in later stage it was 1 mm. Such choice of the die stroke enables proper flow curve determination in the region of small deformations. Three identical specimens were used to increase the precision of gained results by Rastegaiev method (fig. 13).

Fig. 14 shows the flow curves in linear and exponential form. Linear form was used in UBET simulation, and exponential form in CAMPform simulation.

Linear approximation

$$K = 439.13 + 285.24 \cdot \varphi_e \ \text{[MPa]}$$

Exponential approximation

$$K = 703.63 \cdot \varphi_e^{0.1826} \ \text{[MPa]}$$

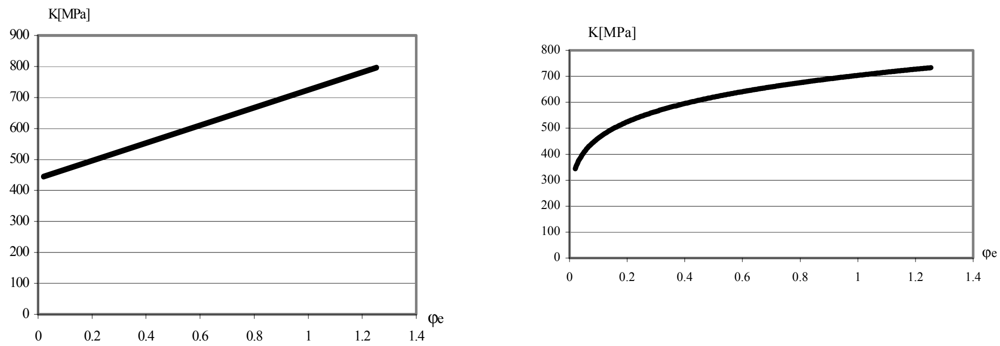


*Figure 14. Flow curves*

### 4.2 Backward extrusion

The aim of backward extrusion experiment was to determine force – stroke diagram for the specimens made of Č 1221 and to compare it with the force – stroke diagrams obtained numerically.

During extrusion process, $F - s$ diagram was continually registered. In fig. 15 force – stroke diagrams for three identical specimens (shown in fig. 2) are given.

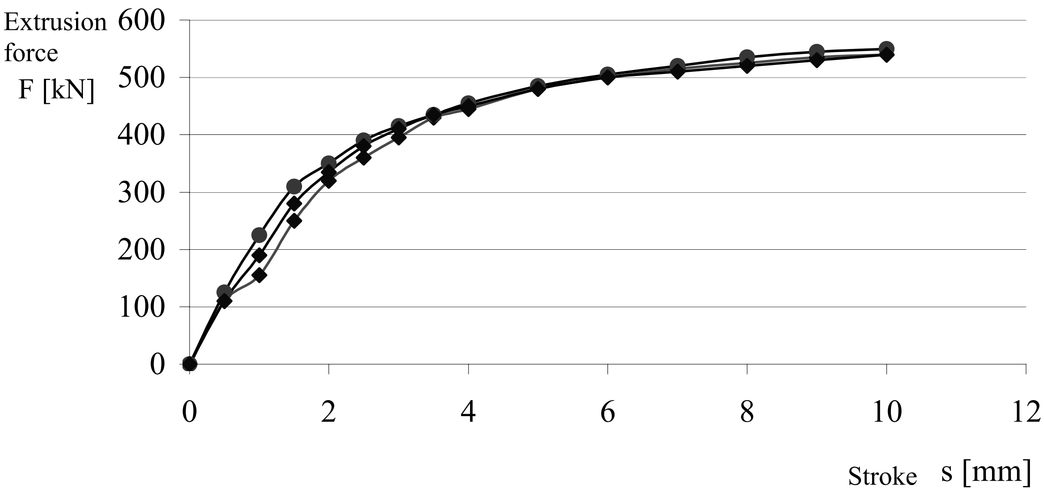


*Figure 15. Force – stroke diagram for three specimens*

The photographs of the billets and extruded workpieces are given in fig. 16.

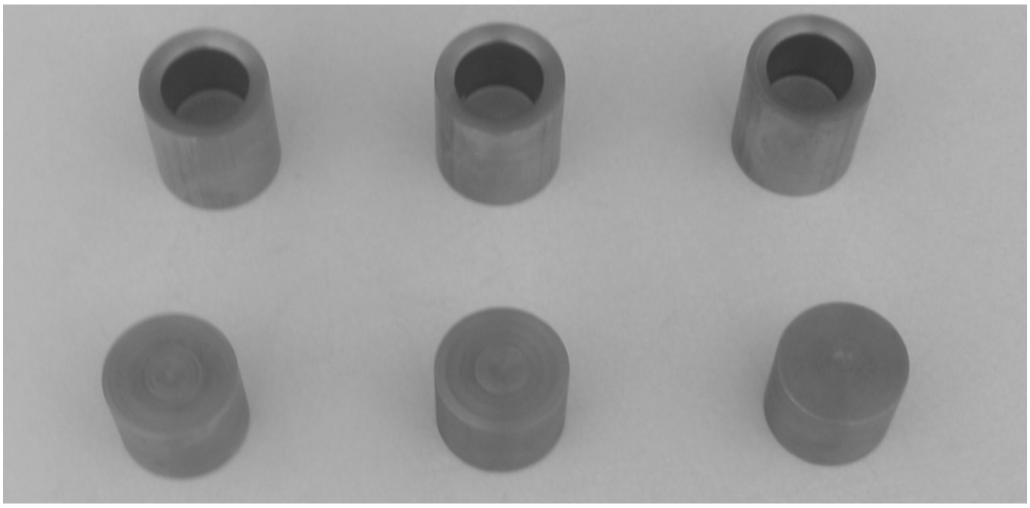

*Figure 16. Billets and workpieces*

## 5. COMPARATIVE ANALYSIS OF RESULTS WITH CLOSING REMARKS

Comparison has been performed in terms of:

a) Force – stroke diagram obtained by:
- UBET
- FEM
- Experiment

b) Distribution of effective stress and effective strain within the specimen volume, obtained by:
- UBET
- FEM

As the figure 17 shows, during process development **extrusion force** increases relatively steeply at the beginning of the process and then, at later stage, it rises gradually (it refers to FE and experimental results).

FE method gives the results which are very close to those obtained by experiment, whereas UBET results are approximately 10÷15 % higher. This difference (overestimation) can be explained with the inherent nature of the Upper Bound method.

Unlike in force-stroke comparison, by comparing the **stress and strain distribution** within the specimen volume obtained by UBET and FE, significant discrepancies occur. Although the general picture of stress and strain distribution is similar in both methods (low values beneath the punch and high values around the punch corner), the absolute values differs significantly.

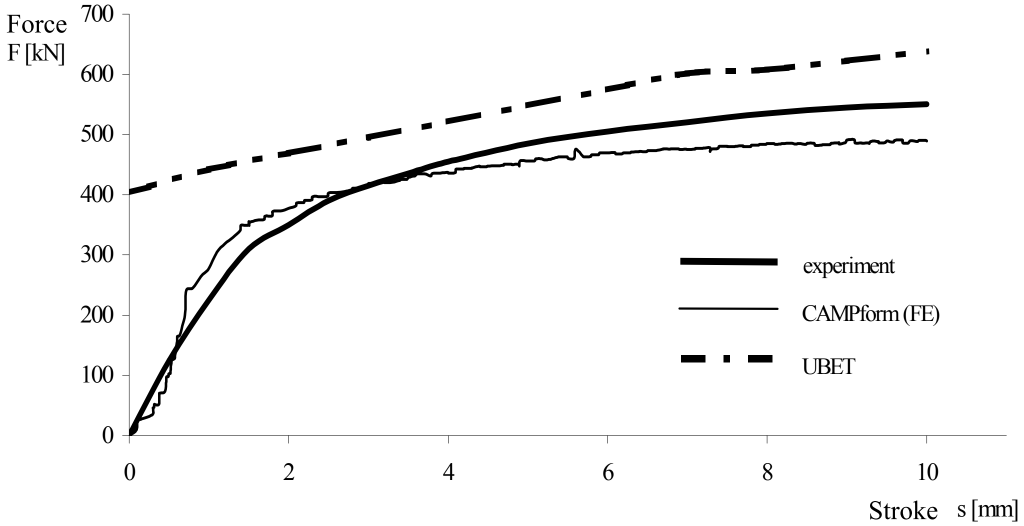


*Figure 17. Force – stroke diagram obtained by different methods*

In closing, it could be stated that UBET method is less accurate but it is very "user – friendly", i. e. very convenient and simple to use. Therefore it has been widely used for the quick load estimation in the preliminary process analysis. On the other hand, FE method gives much more sophisticated results and favorable agreement with the experiment and, nowadays, it is inevitable in every complex and deeper investigation of the process.

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# ANALIZA SUPROTNOSMERNOG ISTISKIVANJA POMOĆU UBET-A, METODE KONAČNIH ELEMENATA SA EKSPERIMENTALNOM VERIFIKACIJOM

*Marko Vilotić, Vesna Mandić, Miroslav Plančak*

## REZIME

*Analiza procesa TPD podrazumeva određivanje naponsko-deformacionog stanja po zapremini obratka, kontaktnih napona, komponenti brzina deformacije i brzine deformisanja kao i određivanje parametara procesa, tj. deformacione sile i deformacionog rada. U tu svrhu primenjuju se različite metode: teorijske, teorijsko-eksperimentalne, eksperimentalne i numeričke. U ovom radu izvršena je analiza suprotnosmernog istiskivanja primenom MKE, tj. pomoću softverskog paketa CAMPform i metode gornje granice, odnosno UBET-a. Provera rezultata izvršena je eksperimentalno, merenjem deformacione sile.*

*UBET je metoda bazirana na metodi gornje granice. U ovom radu UBET je korišćen za određivanje deformacione sile, kao i za izračunavanje efektivnog napona i efektivne deformacije u određenom broju tačaka obratka. Analiza procesa bazirana je na podeli osnosimetričnog pripremka na skup elementarnih regiona, koji se vrši automatski. Ulazni parametri su geometrija alata i pripremka, podaci o materijalu i kontaktnom trenju. Deformaciona sila dobijena UBET-om je za 10-15% viša u odnosu na eksperimentalne vrednosti, što je u skladu sa prirodom metode gornje granice.*

*CAMPform 2D je program koji se bazira na MKE čiji je proračunski modul zasnovan na termo-krutoviskoplastičnom pristupu. Ulazni podaci za simulaciju su geometrija alata, obratka i pripremka, podaci o materijalu i temperaturi obrade, podaci o kontaktnom trenju, brzini deformisanja, zatim podaci o ukupnom hodu alata i priraštaju hoda alata i dr. Simulacijom se dobijaju detaljne informacije o naponsko-deformacionom stanju po zapremini obratka, kao i podaci o deformacionoj sili. Deformaciona sila dobijena CAMPform simulacijom se dobro slaže sa eksperimentalnim podacima.*

*Poređenjem rezultata efektivnog napona i efektivne deformacije dobijenih UBET-om i CAMPform-om može se zaključiti da među njima postoji načelna saglasnost tj. maksimalne vrednosti ovih veličina prisutne su u zonama bližim unutrašnjoj površini obratka. U pogledu apsolutnog iznosa prisutne su razlike, a koji od navedenih rezultata za efektivni napon i efektivnu deformaciju realan, bilo bi moguće utvrditi eksperimentalno, merenjem tvrdoće po preseku obratka.*