

## DETERMINATION OF THE EFFECTIVE STRAIN FLOW IN COLD FORMED MATERIAL

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### ABSTRACT

*In the article the effective strain distributions of cold forward extruded copper alloy were analysed by using the visioplasticity method and micro-hardness technique. Two different lubricants with different coefficient of friction were used to analyse the influence of different coefficients of friction on the effective strain distribution in forward extruded material. Comparisons were made between effective strain distributions calculated with both techniques.*

*The effective strain distributions in cold formed alloy were presented in a form of diagrams. Visioplasticity and micro-hardness techniques were extremely useful in providing a detailed analysis of the distributions of the effective strain in any section within the plastically deforming region.*

**Key words:** *effective strain, visioplasticity, micro-hardness, cold forming, copper alloy*

### 1. INTRODUCTION

To reach high quality of the metal forming process and full functionality of a product, the material properties, material flow, stress, strain, strain rate distribution, etc., have to be determined as precisely as possible. Stress and strain distributions in the deforming body play an important role for design of machine tools.

Many modeling techniques have been applied for the analysis of metal forming processes such as the slip-line theory, the slab method, the upper-bound theorem etc [1, 2]. One of the most important method is visioplasticity method which has been widely used for strain, stress and strain rate analysis of axi-symmetric deformation processes.

The effective strain is one of the most important parameters of the forming processes. Because of the relation between micro-hardness and effective strain in cold formed material it is possible to

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determine the values and distribution of the effective strain in any section within the plastically deforming region also by measuring the Vickers micro-hardness. With known values of the effective strain a new flow stress of cold formed material can be predicted.

## 2. VISIOPLASTICITY METHOD FOR CALCULATION OF THE EFFECTIVE STRAIN

In the visioelasticity method, the flow field must be determined experimentally. This can be accomplished in a number of ways, for example by placing a grid pattern on the meridian plane of a cylinder. The grid lines must be thin and sharp and the grid mesh should not split off, which would make the measurements difficult [3].

For steady-state flow problems in which the flow field does not vary with respect to time, it is possible to introduce a flow function  $\theta$  by measuring the coordinates of the points located along grid lines after steady-state conditions are reached [4].

In the steady-state axisymmetric extrusion, the velocity field can be expressed by the flow function  $\theta(r,z)$  as follows [1]:

$$\begin{aligned} v_z &= \frac{1}{r} \cdot \frac{\partial \theta}{\partial r} \\ v_r &= -\frac{1}{r} \cdot \frac{\partial \theta}{\partial z} \end{aligned} \quad (2.1)$$

where  $v_z$  and  $v_r$  are the velocity components in the z- and r- directions.

When the velocity components  $v_z$  and  $v_r$  are known at all points in the deformation zone, the strain rate components can be obtained according to [1]:

$$\begin{aligned} \dot{\varepsilon}_r &= \frac{\partial v_r}{\partial r} \\ \dot{\varepsilon}_\theta &= \frac{v_r}{r} \\ \dot{\varepsilon}_z &= \frac{\partial v_z}{\partial z} \\ \dot{\varepsilon}_{rz} &= \frac{1}{2} \cdot \left( \frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} \right) \end{aligned} \quad (2.2)$$

The effective strain rate is then calculated from its definition:

$$\dot{\varphi}_e = \sqrt{\frac{2}{3} \left( \dot{\varepsilon}_r^2 + \dot{\varepsilon}_\theta^2 + \dot{\varepsilon}_z^2 + 2\dot{\varepsilon}_{rz} \right)} \quad (2.3)$$

The total effective strain can be evaluated by numerical integration of effective strain rate along a flow line with respect to time:

$$\varphi_e = \int_0^{t_1} \dot{\varphi}_e \cdot dt \quad (2.4)$$

where  $t_1$  is the time required for a point to be displaced along a flow line.

### 3. EXPERIMENTAL WORK

#### 3.1. Preparation and extrusion of the specimens

In the experimental investigation rods of special copper alloy CuCrZr were used. The initial dimensions of specimens were  $\Phi 22$  mm x 32 mm. 1 mm square grids were scribed on the meridian plane of one-half of a split specimen. The specimens were extruded through a conical die having a  $22,5^\circ$  half-cone angle and a 73 % reduction in area. Two different lubricants were used: special grease with coefficient of friction  $\mu = 0,05$  and oil with coefficient of friction  $\mu = 0,11$ . Coefficients of friction for both lubricants were determined by the ring test [1]. The forward extrusion was carried out at a punch speed of 12 mm/s and the extrusion process was stopped when a sufficient length of specimen was extruded to ensure the establishment of a steady-state motion.

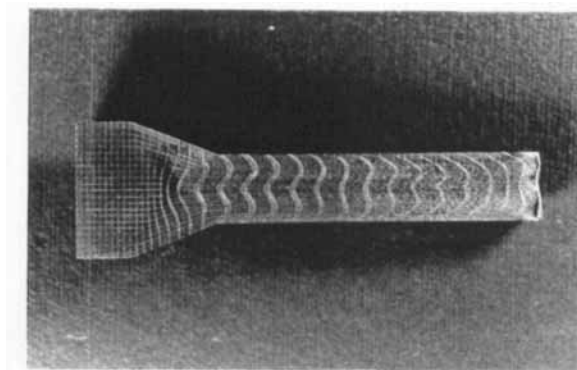


Fig. 1. Deformed grid on specimen after forward extrusion ( $\mu = 0,05$ , ,  $R_{area} = 73$  %)

### 3. 2. Micro-hardness measurements and analysis

Vickers micro-hardness measurements were carried out in the radial and axial directions of the plastic deformation region at grid position with 1 mm distance between each measuring point, as shown in Fig. 2. Measurements were carried out on the microscope Zwick 3212 with a force of 4, 9 N.

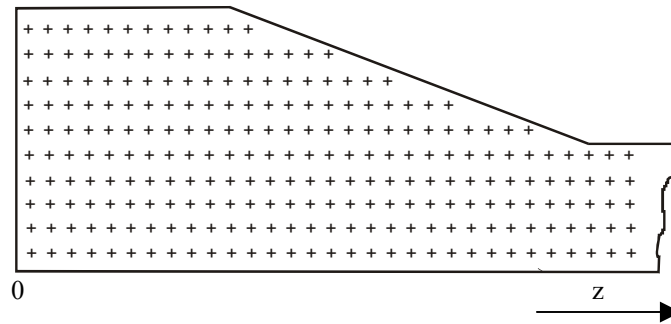


Fig. 2. Micro-hardness measurement points of the extruded specimens ( $R_{area} = 73\%$ )

The relation between effective strain and micro-hardness for the testing material was based on the micro-hardness measurements of several specimens with known values of effective strain. Therefore it was necessary to carry out a compression tests, using  $\Phi 10\text{mm} \times 14\text{mm}$  specimens of copper alloy CuCrZr lubricated with teflon foil (to ensure close-to-frictionless conditions)[5].

The micro-hardness was measured around the center of each specimen in order to avoid problems of inhomogeneity. An approximation for the relation between micro-hardness and effective strain was determined by using polynomial regression analysis. An universal mathematical model for regression method was chosen according to [6]:

$$y(x) = b_0 + \sum_{i=1}^n b_i x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^n b_{ij} x_{ij} + \sum_{i=1}^n \sum_{j=i}^n b_{ij} x_{ij}^2 \quad (3.2.1)$$

Where  $y$  is dependent variable,  $x_i$ ,  $x_{ij}$  are independent variables, while  $b_0$ ,  $b_i$ ,  $b_{ij}$  are coefficients to be determined by using regression analysis. In our case dependent variable was the effective strain  $\varphi_e$  while micro-hardness ( $HV$ ) was the independent variable. Equation (3.2.1) can be written as:

$$\varphi_e = b_0 + b_1 HV + b_2 HV^2 \quad (3.2.2)$$

Coefficients  $b_0$ ,  $b_1$  and  $b_2$  were determined by using regression analysis program SPSS. By inserting the values of the three coefficients into the equation (3.2.2), we got the mathematical model which describes the relation between micro-hardness  $HV$  and effective strain  $\varphi_e$ :

$$\varphi_e = 13,31 - 0,1997 \cdot HV + 0,000748 \cdot HV^2 \quad (3.2.3)$$

#### 4. RESULTS AND DISCUSION

By inserting the measured micro-hardness values for every measuring point on the extruded specimen in the equation (3.2.3) it was possible to calculate the values of the effective strain rate in those points. The results are presented in a form of diagrams which show the distribution of the effective strain determined by micro-hardness measurements and by visioelasticity method for two different coefficients of friction (Figures 3a, 3b and Figures 4a, 4b).

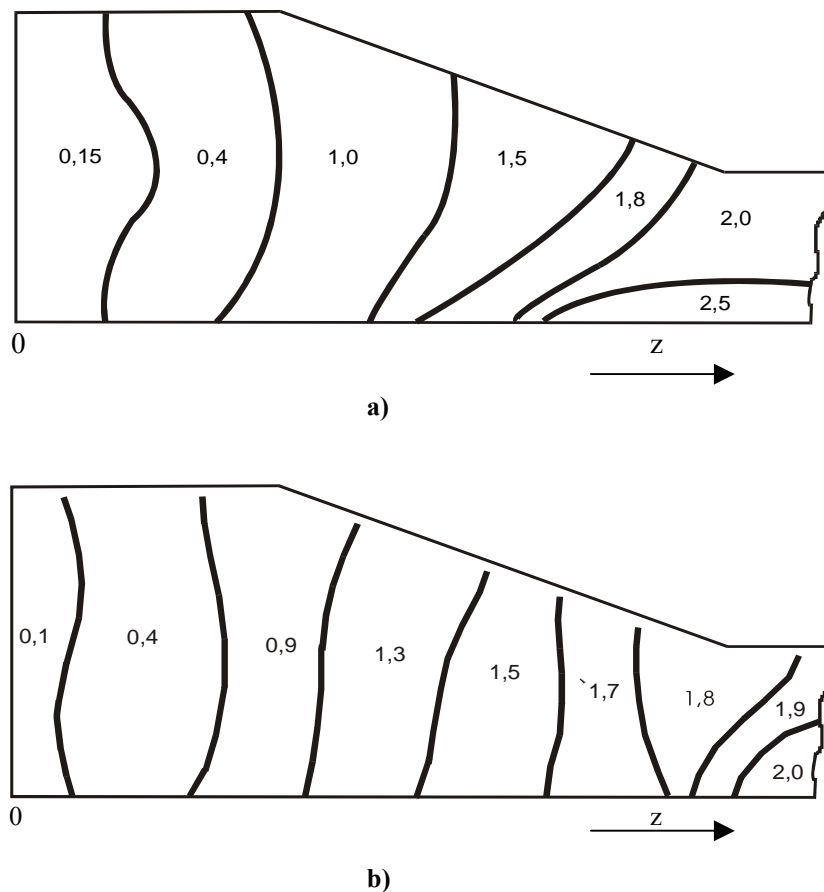


Fig. 3. Effective strain distribution in cold extruded alloy ( $\mu = 0,05$ ,  $R_{area} = 73$  %):  
 a) obtained by visioelasticity method  
 b) obtained by micro-hardness measurement

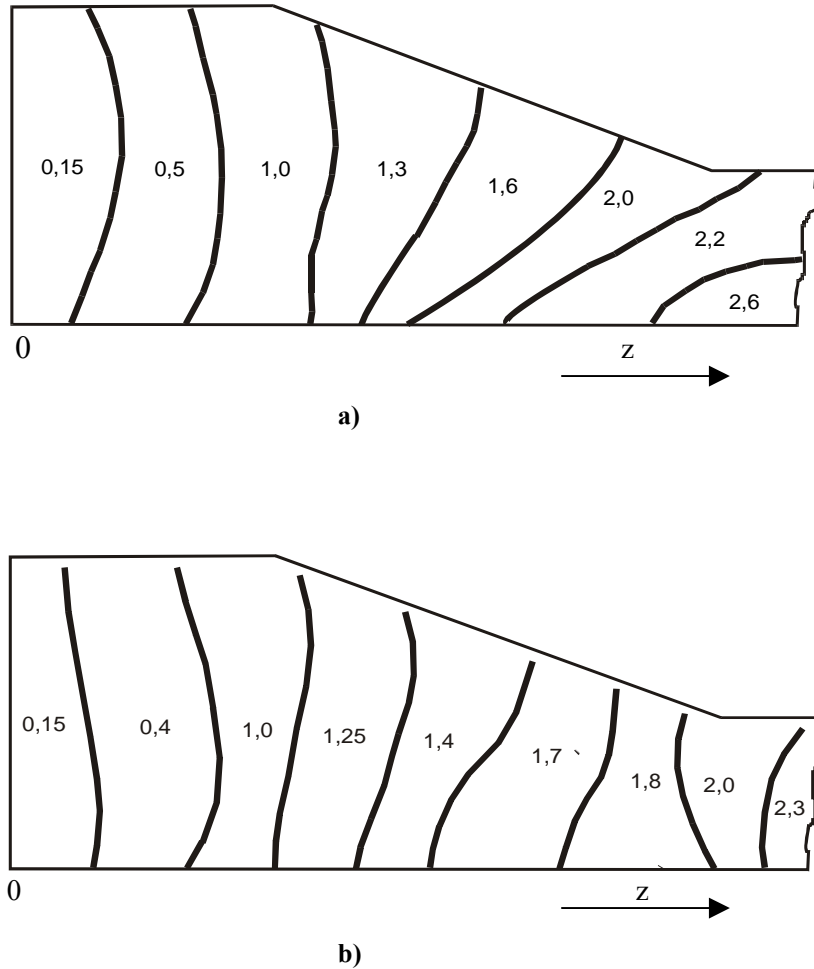


Fig. 4. Effective strain distribution in cold extruded alloy ( $\mu = 0,11$ ,  $R_{area} = 73\%$ ):  
 a) obtained by viscoplasticity method  
 b) obtained by micro-hardness measurement

The comparison between the two distributions in both cases (extruded with  $\mu = 0,05$  and  $\mu = 0,11$ ) shows very good accuracy of values up to effective strain  $\varphi_e = 1,1$ . At the exit of the plastic region some differences in the distribution can be observed. This is probably because the mathematical model (3.2.3) for the relation between micro-hardness and the effective strain is not reliable for  $\varphi_e \geq 1,2$  because the experimental area of the compression tests for regression analysis

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was in the range  $\varphi_e = 0$  to 1,1 and micro-hardness curve becomes very flat by higher values of effective strain. So, at higher values for effective strain ( $\varphi_e \geq 1,2$ ) it is much more relevant to use values calculated by viscoplasticity method than those obtained by micro-hardness technique.

The effective strain distribution in the plastic region of the specimen extruded with lubricant coefficient of friction  $\mu = 0,05$  is quite similar to effective strain distribution of the specimen, extruded with coefficient of friction  $\mu = 0,11$ . Some differences can be found only at the exit of the plastic region (exit of the cone). When extruded with  $\mu = 0,11$  values for effective strain are 5%-8% higher as when extruded with lower coefficient of friction ( $\mu = 0,05$ ).

#### 4. CONCLUSION

Viscoplasticity and micro-hardness techniques are useful in providing a detailed analysis of the distribution of the mayor field variables in any section within the plastically deforming region. The experimental and analytical analysis of the effective strain distributions in steady-state conditions determined from both techniques have showed that it is possible to get accurate results of the effective strain by measuring micro-hardness when effective strain  $\varphi_e < 1,1$ . At higher values of effective strain some discrepancies can be observed. Possible explanation for these discrepancies can be found by examination the limitations of the two techniques, especially micro-hardness measurement technique.

#### REFERNECES

- [1] K. Lange: Handbook of Metal Forming, McGraw-Hill Book Company, New York 1991
- [2] B.P.P.A. Gouveia, J.M.C.: Rodrigues, P.A.F. Martins: Steady-state finite element analysis of cold forward extrusion, Journal of Materials Processing Technology 73 (1998), pages 281 – 288, Elsevier 1998
- [3] Gusel L., Anžel I., Brezočnik M.: Effect of lubrication on the stress distribution in an extruded material, International Journal of Advanced Manufacturing Technology, Vol 25 (2005), pp. 288 – 291
- [4] J.P.Wang: A new approach to viscoplasticity in plane-strain extrusion, Journal of Materials Processing Technology 79 (1998), pages 145 – 154, Elsevier 1998
- [5] P.Leš: Hladno iztiskovanje kovin, Univerza v Mariboru, Fakulteta za strojništvo, Maribor 1994
- [6] Barnes J. W.: Statistical Analysis for Engineers and Scientists – A Computer based Approach, University of Texas, Austin, McGraw – Hill, 1994

## **ODREĐIVANJE TOKA EFEKTIVNE DEFORMACIJE U HLADNO DEFORMISANOM MATERIJALU**

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### **REZIME**

*U radu se analizira raspored efektivne deformacije hladno deformisanom obratku uz pomoć metode vizioplastičnosti i merenja mikro tvrdoće. Korišćena su dva različita sredstva podmazivanja sa dve vrednosti koeficijenta trenja. Na taj način se analizirao uticaj različitih koeficijenata trenja na raspored efektivne deformacije u procesu istosmernog istiskivanja. Komparativna analiza je sprovedena na bazi rezultata dobijenih sa obe metode. Raspored efektivne deformacije dat je u obliku dijagrama. Pokazalo se da su obe metode – vizioplasticnost i mikro tvrdoća- veoma upotrebljive u cilju dobijanja veličine efektivne deformacije u različitim delovima zapremine koja se nalazi u stanju plastičnog deformisanja.*