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AN INVESTIGATION OF LOCAL STRAIN RATE VALUES DURING METAL FORMING

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ABSTRACT

In order to achieve a high quality of metal forming process, material properties, velocity, stress and strain rate distribution have to be analysed very accurate. Several different approximate methods have been developed for the analysis of cold forming processes. In this paper the visioplasticity method is used to find the strain rate distributions from the experimental data, using the finite-difference method. Specimens of copper alloy were extruded with different lubricants and different coefficients of friction and then the strain rate distributions were analysed and compared. Significant differences in strain rate distributions were obtained in some regions, especially at the exit of the plastic zone.

Keywords: material forming, visioplasticity, strain rate

1. INTRODUCTION

Although the theory of plasticity provides a sufficient number of independent equations for defining the mechanism of plastic deformation, it is impossible to obtain a complete solution for a general forming problem without simplification and approximations in the deforming mechanism. A number of approximate methods have been developed for the analysis of metal forming problems [1, 2].Different modelling [3, 4, 5] and simulation methods [6, 7] have been used for determination of main parameters in extrusion processes. Among them, the visioplasticity method gives the most realistic solution to various forming problems. Visioplasticity is a method of obtaining information on material flow by using experimentally determined displacement of velocity fields. The material flow can be determined by comparing un-deformed and deformed grids.

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 [8]:

$$\dot{\varepsilon}_r = \frac{\partial v_r}{\partial r} \quad ; \quad \dot{\varepsilon}_\vartheta = \frac{v_r}{r} \quad ; \quad \dot{\varepsilon}_z = \frac{\partial v_z}{\partial z} \qquad \dot{\varepsilon}_{rz} = \frac{1}{2}\cdot\left(\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r}\right) \tag{1}$$

The effective strain rate is then calculated from its definition:

$$\dot{\varepsilon}_e = \sqrt{\frac{2}{3}\left(\dot{\varepsilon}_r^2 + \dot{\varepsilon}_\vartheta^2 + \dot{\varepsilon}_z^2 + 2\dot{\varepsilon}_{rz}^2\right)} \tag{2}$$

Strain rate components can also be written as follows [8]:

$$\begin{aligned} \dot{\varepsilon}_r &= \lambda \cdot (\sigma_r - \sigma_m) \\ \dot{\varepsilon}_z &= \lambda \cdot (\sigma_z - \sigma_m) \\ \dot{\varepsilon}_\vartheta &= \lambda \cdot (\sigma_\vartheta - \sigma_m) \\ \dot{\varepsilon}_{rz} &= \lambda \cdot \tau_{rz} \end{aligned} \qquad (3)$$

Coefficient of proportionality λ and medium stress σ_m can be calculated from:

$$\sigma_m = \frac{\sigma_r + \sigma_\vartheta + \sigma_z}{3} \qquad (4)$$

$$\lambda = \frac{3 \cdot \varepsilon_e}{2 \cdot \sigma_f} \text{ = coefficient of proportionality,} \qquad (5)$$

The stress fields can be calculated easily from the calculated strain rate fields, using the integral equation in visioplasticity.

2. EXPERIMENTAL WORK

Rods of special copper alloy CuCrZr were used during the experimental investigation. The initial dimensions of the specimens were Φ22 mm x 32 mm. 1 mm square grids were ascribed to the meridian plane of one-half of a split specimen. This specimen was extruded through a conical die having a 22, 5 ^{0} half-cone angle and a 73 % reduction in area. Three different lubricants were used with different coefficients of friction (μ= 0, 05, μ= 0, 11 and μ= 0, 16). The major difficulty was that extremely high pressures were involved during the cold extrusion process and forming speeds were relatively low. Coefficients of friction for all lubricants were determined in the ring tests [8]. Forward extrusion was carried out at a punch speed of 12 mm/s. The deformed grid of the specimen after forward extrusion is shown in *Fig.1*.

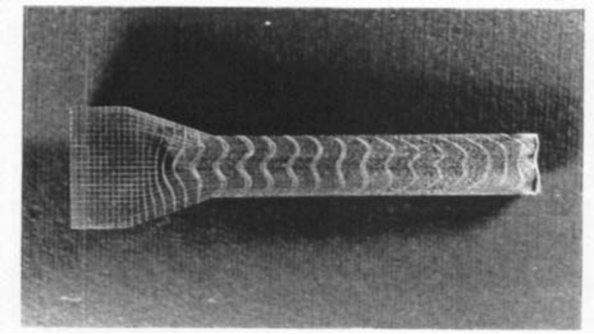

Figure 1. Deformed grid on the cold forward extruded copper alloy

3. RESULTS AND DISCUSSION

The position of every node in the deformed grid after forward extrusion was measured using a microscope. These values were put in a special computer program for visioplasticity, developed in the laboratory for material forming at the Faculty of Mechanical Engineering Maribor, as well as every node of the initial grid, distance between initial grid nodes, flow curve of the material to be formed and the punch speed. By measuring the difference between initial grid nodes and nodes on the deformed grid it was possible to calculate the velocities of every point in the r- and z-directions.

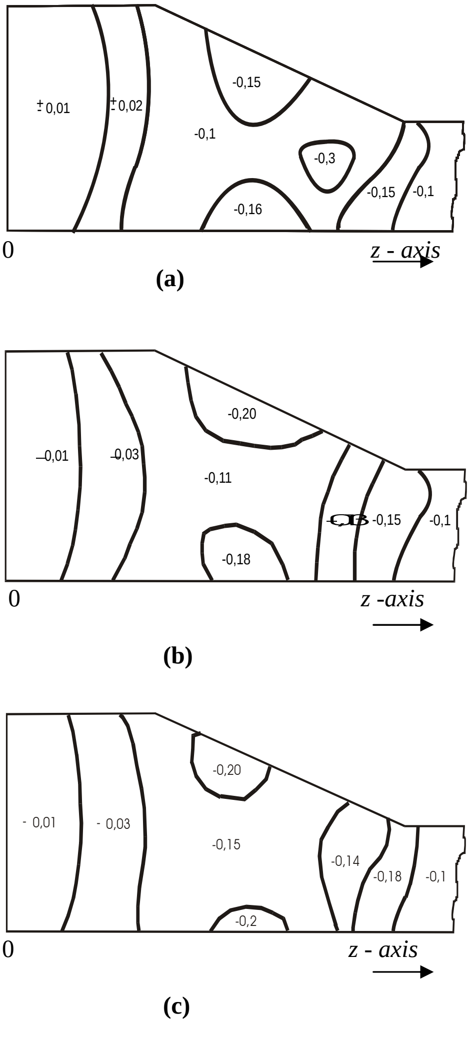

Figure 2. Contours of axial strain rate $\dot{\varepsilon}_z$
a) μ=0,05 b) μ=0,11 c) μ=0,16

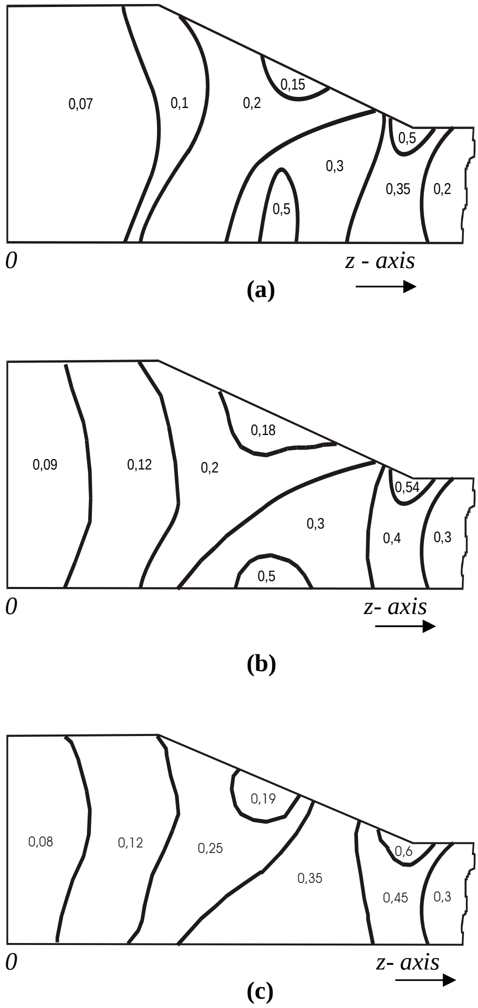

Figure3. Contours of radial strain rate $\dot{\varepsilon}_r$
a) μ=0,05 b) μ=0,11 c) μ=0,16

The radial strain rate and axial strain rate distribution in extruded alloy are presented in Fig. 2 and Fig. 3. The largest value is obtained at the end of the deforming zone, while the smallest value is observed near the entrance. There is no significant difference in the contours when the lubricant with coefficient of friction μ = 0,16 was used except on the cone line, where the strain rate for coefficient of friction μ = 0,16 is 0,18 s^{-1} compared to $\dot{\varepsilon}_r$ = 0,15s^{-1} for μ = 0,05. This represents an increase of 20% which is significant, especially because of the greater strain rate's influence on stress distribution in cold formed material**.**

The influence of different lubricants on strain rate was noticeable on the cone line and at the exit of the deformation zone where the values for axial strain rate were a little higher when lubricants with coefficients of friction μ = 0,11 and μ = 0,16 were used for the extrusion process. By using the lubricant with a lower coefficient of friction for the forward extrusion process, lower radial and axial strain rate values were reached over the whole extruded specimen, especially at the end of the deforming zone.

4. CONCLUSION

Strain rate distribution in a workpiece during the deformation process determines the stress state and achievable deformation limits. An advanced plasticity theory can be used to determine the velocity and strain rate values in the deformation zone from the local strains obtained from material movement. Visioplasticity is such a method, which is very useful in providing a detailed distribution analysis of the major field variables, such as effective strain, strain rates and stress in any section within the plastically deformed region. This article analysed the influence of different lubricants with different coefficients of friction on the strain rate values in the forward extruded copper alloy CuCrZr. The experiments have shown that the coefficient of friction's influence on the velocity components and strain rate distributions in extruded specimens is small in most measured regions of the deformed zone. Significant differences in strain rate distributions were obtained in some regions at the exit of the deformed zone. In these regions, higher values of strain rate components could be expected when using a lubricant with a higher coefficient of friction. This finding is important, especially because of the strain rate's influence on stress distributions in the cold formed material and the quality of the formed specimen.

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