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Shear Stress Distribution Analysis in Cold Formed Material

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Abstract

Determination and distribution of stresses in the deformation zone can be obtained by advanced plasticity theory, especially by experimental-analytical method such as visioplasticity. The visioplasticity method is very useful in providing a detailed analysis of the distribution of stresses, strains or strain rates in deformed material. In this paper shear stress distribution in cold formed aluminum alloy is analyzed by using visioplasticity method. The specimens were cold forward extruded trough a conical die. Further, the influence of the coefficient of friction on shear stress distribution in deformed zone of the material is investigated. The results are presented in form of diagrams.

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1. Introduction

Formability is one of the very important characteristics of aluminium and its alloys. Investigations using different methods were performed and published in the last decade to predict forming limits [1], workability of material [2], strains, stresses and other parameters in warm or cold formed materials [3, 4, 5, 6]. In this article, shear stress component distribution in forward extruded specimens of aluminium alloy is analysed using the visioplasticity method. Visioplasticity is a method of obtaining information on material flow by using experimentally determined displacement of velocity fields. The visioplasticity method gives the most realistic solution to various forming problems. This method can also be used as a means of examining the approximations of other solutions. The visioplasticity method consists of obtaining the velocity field experimentally and calculating the complete strain rate, strain, and stress fields by considering the equilibrium and plasticity equations [7].

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Many process parameters such as effective strain, tool speed, die angle or coefficient of friction of used lubricator, effects on strain and stress distributions in formed material. In the paper comparison between shear stress distribution of the specimens extruded with three different coefficients of friction are presented.

2. Obtaining of the shear stress by visioplasticity

For steady-state flow problems, it is possible to introduce a flow function θ by measuring the coordinates of the points located along grid lines (on the specimen) after steady-state conditions are reached. In the steady-state axial - symmetric extrusion, the velocity field can be expressed by the flow function $\theta\ (r,\ z)$ [7]. When the velocity components u and v are known at all points in the deformation zone, the strain rate in radial, tangential axial direction and shear strain rate can be obtained according to [8]:

$$\dot{\varepsilon}_r = \frac{\partial v_r}{\partial r} \qquad \dot{\varepsilon}_\vartheta = \frac{v_r}{r} \qquad \dot{\varepsilon}_z = \frac{\partial v_z}{\partial z} \tag{1}$$

$$\dot{\varepsilon}_{rz} = \frac{1}{2} \cdot \left(\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} \right)$$

The total effective strain (φ_e) can be evaluated by numerical integration of effective strain rate along a flow line with respect to time t [8]:

$$\varphi_e = \int_0^{t1} \dot{\varphi}_e \cdot dt \tag{2}$$

where t_1 is the time required for a point to be displaced along a flow line. Strain rate components in different directions can also be written as follows [8]:

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

where medium principal stress is: $\sigma_m = \dfrac{\sigma_r + \sigma_\vartheta + \sigma_z}{3}$ and coefficient of proportionality: $\lambda = \dfrac{3 \cdot \varphi_e}{2 \cdot \sigma_f}$

From the equations (3), equations of equilibrium, plasticity and material properties, the shear stress τ_{rz} in the deformation region for axial-symmetrical process can be calculated from [9]:

$$\tau_{rz} = \frac{\dot{\varepsilon}_{rz}}{\lambda} \tag{4}$$

3. Experimental work

In the experimental work aluminum alloy rods AW6082 were used. This alloy is a medium strength aluminum alloy with excellent corrosion resistance. The initial dimensions of specimens were Φ22 mm x 32 mm. 1 mm square grids were scribed on the meridian plane of one-half of a split specimen. The grid lines must be thin and sharp and the grid mesh should not split off, which would make the measurements difficult.

The specimens were extruded trough a conical die having a 22° half-cone angle and a 73 % reduction in area. Three different lubricants were used with different coefficient of friction (μ= 0.05, 0.09 and 0.13). Coefficient of friction for all lubricants were determined by ring test.

The cold 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. The deformed grid after cold forward extrusion is shown in Fig.1.

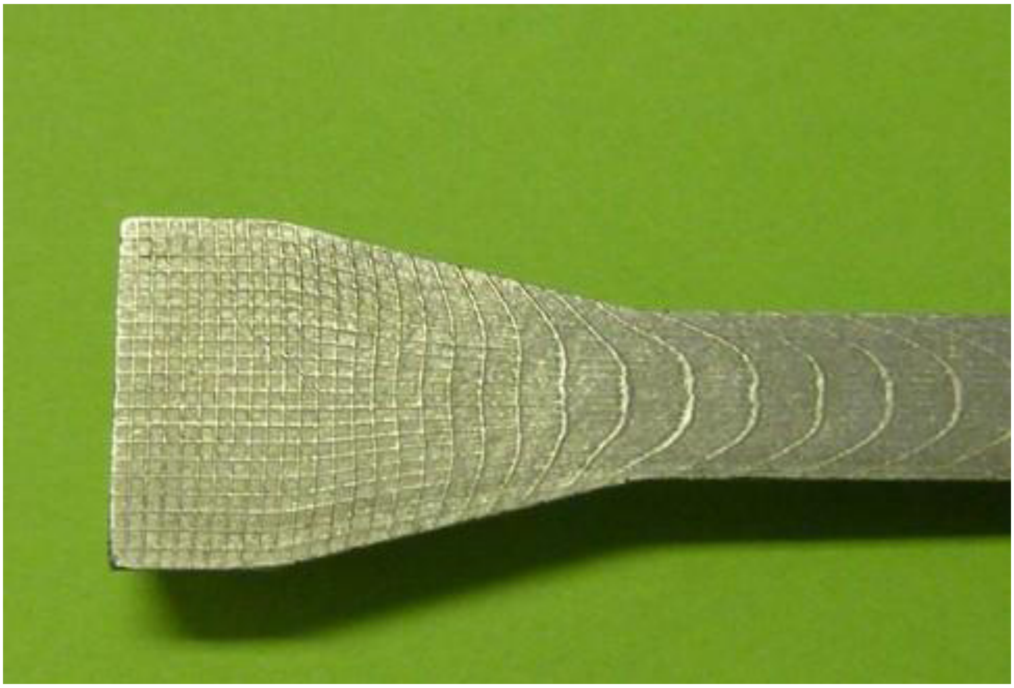

Fig.1. Deformed grid on the specimen after cold extrusion (μ=0.09, v_{punch}= 12 mm/s).

4. Results and discussion

The position of every node of the deformed grid after cold forward extrusion was obtained by measuring microscope. These values were put in the special computer program for visioplasticity, developed in our laboratory, as well as every node of 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 velocity of every point and with help of velocity values shear stress can be calculated.

Fig. 2 shows the shear stress distribution in deformed zone of the extruded alloy. Values in the Fig. 2 are presented as the ratio τ_{rz}/σ_{f0}, where τ_{rz} is shear stress and σ_{f0} is initial flow stress of the aluminium alloy. It is interesting to note that the shear stresses along the axis line z are almost zero for all cases of extrusion. The largest values for shear stress is to be found near tool profile and this value is greater in the specimen, lubricated with greater coefficient of friction (in this case μ= 0.13). This confirms that coefficient of friction of the lubricant can actually effect the surface quality of the cold extruded specimen.

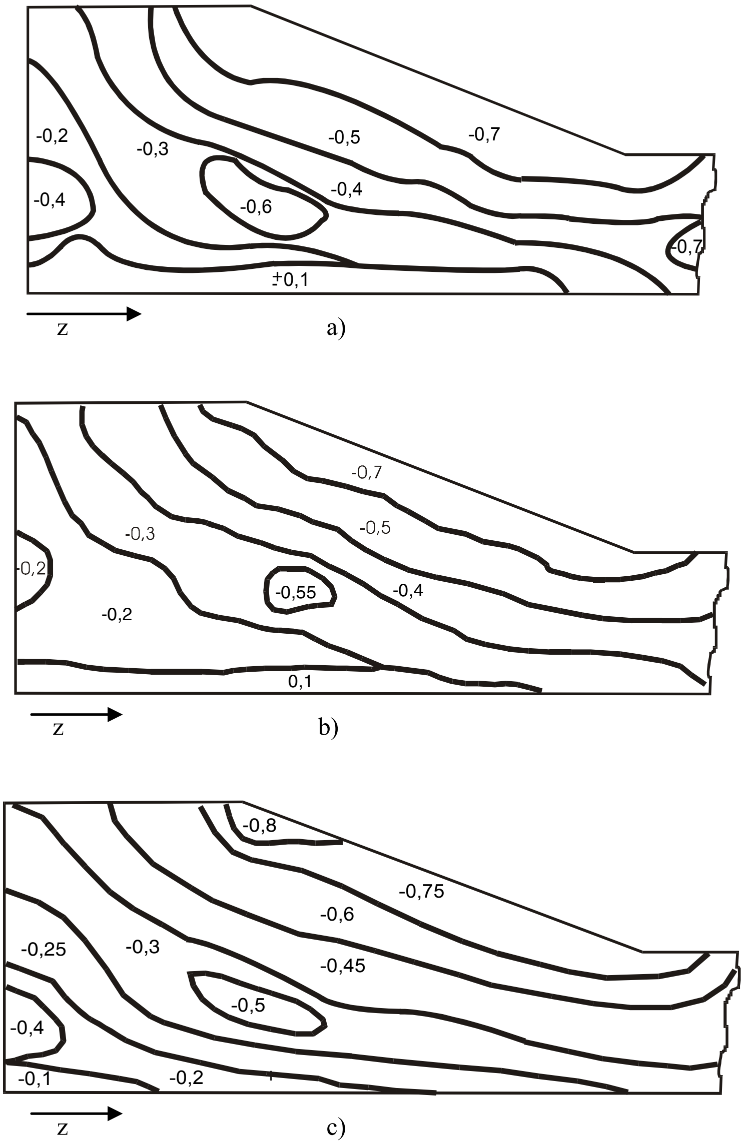

Fig. 2. The contours of shear stress $(\tau_{rz} / \sigma_{f0})$ at v_{punch} = 12 mm/s for:

a) μ = 0,05

b) μ = 0,09

c) μ = 0,13

Conclusions

The stress state in the material during the deformation process determines the achievable deformation limits. The deformation limits of the material can be predicted if the stress distribution inside the deformation zone of the formed material is known. Advanced plasticity theory can be used to determine the stresses in the deformation zone from the local strains obtained from material movement. Such method is visioplasticity, which is very effective in providing a detailed analysis of the stress and strain rate distribution in any section within the plastically deforming region.

The determination of shear stress in cold formed alloy was successfully obtained by visioplasticity method. It was possible to obtain very precise values of shear stress in the several net nodes of the deformation zone of extruded material. The experiments and calculations presented in the paper show the influence of the coefficient of friction of the used lubricant in extrusion process, on shear stress distribution in cold formed aluminum alloy.

The diagrams of shear stress distribution extruded with different lubricators were quite similar, although it could be said that greater values of the shear stress could be expected when using lubricator with higher coefficient of friction. The future plans in our experimental work will be focused on stress and strain distributions in plastic deformation zone at different cone angle of the tool die and also at different tool speed.

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