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DETERMINATION OF FORMABILITY OF EXTRUDED STEEL BY USING VISIOPLASTICITY METHOD

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ABSTRACT
In the paper formability of forward extruded steel specimen as a function of the stress field was analyzed. By means of the indicator of the stress state and the effective strain, which are calculated in several points of the extruded specimen, those places are determined where the possibility of cracks is the greatest. On the basis of known values of the stress components it is possible to calculate the indicator of the state of stresses β in the individual points of the extruded specimen by means of equation. The results of calculations are shown in the diagram of formability.
Key words: forward extrusion, formability, visioplasticity, stress state.

1. INTRODUCTION
By determination of formability of the cold forward extruded steel with the indicator of the state of stresses β and the effective strain, it is possible an accurate determination of the areas of extruded specimen in which the reserve of formability has already been rather exhausted. Formability of material can be expressed by the effective strain $\varphi_{e,max}$ on occurrence of the first cracks in the material as a function of the indicator of the state of stresses β giving the ratio of the invariant variables of the tensor and for the deviatory stresses in the following form [1]:

$$\beta = \frac{I_2}{\sqrt{3J_2}} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_e} \qquad (1)$$

where: σ_1, σ_2, σ_3 are the main stresses, I_2 is the first invariant of the stress tensor, J_2 is the second invariant of the deviatory stress and σ_e is the effective stress.
If for some material the value of the indicator of the state of stresses β is applied to the axis of abscissas and the effective strain, with which for a given state of stresses the first crack occurs, is applied to the axis of the ordinate, the diagram of formability of the material for massive forming is obtained as shown in Fig. 1.The limit line in the diagram of the formability represents the points in which the first crack occurs [2]. The points located below the limit line represent the area of safe work (cracks do not occur) while the points above the limit line represent the area of unsafe work (cracks occur).The position of the point A in the formability diagram is defined if in that point of the deformation area the state of stresses characterized by β and φ_e (Fig.1) prevails. The limit effective strain φ_{eAIII} corresponds to that state of stresses. Comparison between φ_{eA} and φ_{eAIII} shows that in point A a certain reserve (R) of formability exists that can be defined as [3]:

$$R = \frac{L_0 - L_1}{L_0} = \frac{\varphi_{eAIII} - \varphi_{eA}}{\varphi_{eAIII}} \cdot 100\% \qquad (2)$$

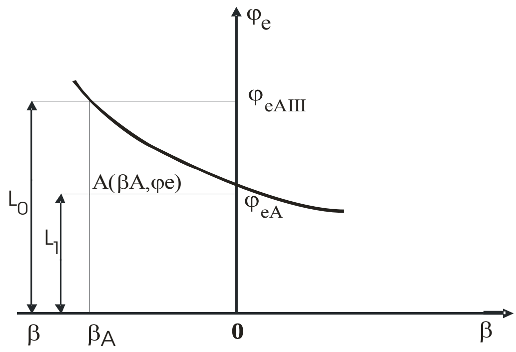

Figure 1. Diagram of formability [3]

The problem described in the paper is determination of formability of cold forward extruded steel 1.4057 by means of indicator of the stress β and the effective strain. The critical place of crack occurrence was determined. It was necessary to use a computer program for visioplasticity method which was written in our laboratory.

2. EXPERIMENTAL WORK AND RESULTS

In the frame of the experimental work the process of cold forward extrusion of a cylinder of the steel 1.4057 (X22CrNi17) was analyzed. The cylinders of dimension Φ 22mm x 32 mm were extruded in a special tool for cold forward extrusion at T = 20°C (temperature), v_t = 12 mm/s (tool speed), μ = 0.05 (lubricant friction coefficient), φ_e = 1.29 (effective strain) and F = 510 kN (required force). For the analysis of formability it is necessary to calculate the stress field in the extruded piece. We obtained it by the visioplasticity method. In the visioplasticity method, the flow field must be determined experimentally [7, 8, 10].This can be accomplished in a number of ways - for example by placing a grid pattern on the meridian plane of a cylinder. From the two consecutive grid patterns, the instantaneous velocity components can be determined assuming that a previous grid point moves to its new position with average velocity during an incremental deformation step. The relative displacements of grid points between each consecutive step are calculated from the measurements of the coordinates of the grid points. The instantaneous strain rate components can be calculated from the known velocity components. The instantaneous stress components at any point in the deformation zone can be determined from the strain rates. In the steady state axisymmetrical extrusion, the velocity field can be expressed by the flow function θ (r, z) as follows [4, 5]:

$$v_z = \frac{1}{r}\cdot\frac{\partial\theta}{\partial r}\ , \qquad v_r = -\frac{1}{r}\cdot\frac{\partial\theta}{\partial z} \tag{3}$$

where v_z and v_r are the velocity components in the axial and radial directions.

When the velocity components v_z and v_r are known at all points in the deformation zone, the strain rate can be obtained from:

$$\dot{\varepsilon}_r = \frac{\partial v_r}{\partial r} \qquad \dot{\varepsilon}_\vartheta = \frac{v_r}{r} \qquad \dot{\varepsilon}_z = \frac{\partial v_z}{\partial z} \qquad \dot{\varepsilon}_{rz} = \frac{1}{2}\cdot\left(\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r}\right) \tag{4}$$

From the equations (4) and equations of equilibrium, the stress field in the deformation region for axisymmetrical process can be calculated. To this end it was necessary to make special samples by milling two cylindrical samples up to the half. On the one half the rectangular coordinate net was engraved on the precision coordinate engraver. Both halves of milled cylinders were then adapted and extruded in the tool. Because of accuracy of results several tests were made at the same conditions. The deformed net occurring on the half of the cylinder after cold forward extrusion is shown in Fig. 2. By measuring the coordinates of the deformed net and their comparing with non-deformed net it is possible with the equations of plasto-mechanics to calculate first strain rate field and then stress field in certain point of the extruded piece [6, 11]. By means of the computer program for the visioplasticity method the axial, radial and tangential stresses and effective strain for each nodal point on the net were calculated. On the basis of known values of stress components in every three directions it is possible to calculate the indicator of the state of stresses β in the individual points of the extruded piece by means of equation (1).

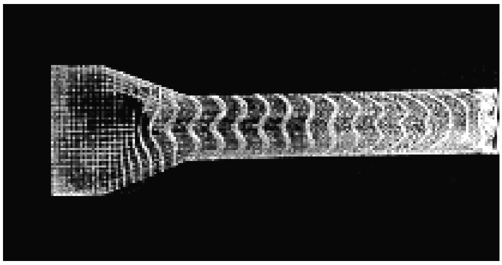

Figure 2. Deformed net after cold extrusion
(φ_e=1.29, μ = 0.05)

The results of calculation are shown in the diagram of formability in Fig. 3. The limit line in the diagram was determined experimentally by tensile, pressure and torsion tests. In the diagram it can be seen that in many points of the deformation zone there is no likelihood of occurrence of cracks or other damages in given conditions of extrusion. The points A and B located at the exit from the forming zone (along the axis) are very near the limit line of the formability diagram.

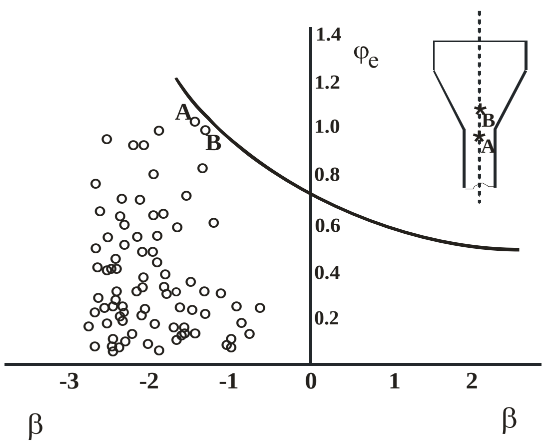

Figure 3. Formability diagram with calculated stresses in individual points of the cold extruded steel 1.4057

The reserve of formability in those two points according to equation (2) is from 10% to 15%, which means that the first cracks in the extruded piece will occur just at that place. Thus, this is the critical place of occurrence of cracks for given conditions of cold forward extrusion of steel 1.4057 (X22CrNi17). For most of the other points in the forming area the hazard of occurrence of cracks is much smaller.

3. CONCLUSION

In this paper formability of cold formed steel as a function of stress field was analyzed. By means of the indicator of the stress state and the effective strain, which are calculated in several points of the cold formed specimen, those places are determined where the possibility of cracks is the greatest.The limit or critical effective strain φ_{emax}, at which damages to the structure of material occur, depends on the combination of stress components acting in the critical zone of the formed piece. With the increase of the hydrostatic pressure the limit effective strain increases ($\beta < 0$) and with the increase of the positive value of the hydrostatic stress it decreases ($\beta > 0$).

By determining the formability of the cold forward extruded steel 1.4057 with the indicator of the state of stresses β and the effective strain φ_e it is possible well enough to determine the areas in which the reserve of formability has already been rather exhausted.

Although in our researches no cracks were noticeable on the samples it is possible on the basis of the calculated values to conclude that in case of forward extrusion of the steel in given conditions the hazard of occurrence of internal cracks in the extruded piece exists particularly in the area along the extruded piece axis.

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