IDENTIFICATION OF STRESS STATE IN THE CRITICAL ZONE IN UPSETTING OF PRISMATIC SPECIMEN BY CYLINDRICAL DIES

DRAGISA VILOTIC, MIROSLAV PLANCAK and VLADO VUJOVIC
University of Novi Sad, Yugoslavia

ABSTRACT

The analysis of material formability is based upon precise evaluated stress - strain components in the zone of cracks occurrence. For the solution of this problem various theoretical and theoretical-experimental methods have been used. In this paper three different methods for the estimation of stress-strain state in the critical point of deformation zone have been applied. The investigated process was the upsetting of prismatic specimen by cylindrical dies.

KEY WORDS

Stress state, strain state, material formability

1. INTRODUCTION

The occurrence of cracks in metal forming processes indicates the exhaustion of the formability potential of material for given conditions. The amount of plastic deformation up to the first crack occurrence (limit deformation φ_{el}) depends on material properties (M), material structure (S), deformation velocity ($\dot{\varphi}$), temperature of process deformation (T) and, to the great extent, on the stress state (T_σ):

$$\varphi_e^l = f(M, S, T, \dot{\varphi}, T_\sigma) \tag{1}$$

The equation (1) represents the function of the material formability and if the considerations is limited to one variety of material (M=const.), as well as structure (S=const.), under the conditions of cold deformation (T=const.), at $\dot{\varphi}$=const., then above equation is transformed in dependence on the limit deformation of the stress state:

$$\varphi_e^l = f(T_\sigma) = f(\beta) \tag{2}$$

in which β (indicator of the stress state) is defined by the relation of invariant values of the tensor and the deviator of the tensor stress [1]:

$$\beta = \frac{\sigma_1 + \sigma_2 + \sigma_3}{K} \tag{3}$$

where:

σ_1, σ_2, σ_3 - components of the principal normal stress;
K - effective normal stress.

The graphics interpretation of the function (2), according to a number of investigation, is presented in Fig. 1. As the Fig. 1 shows, in the working systems where the pressure components are predominant, higher values of deformation could be achieved than in the system where tensile stresses prevails.

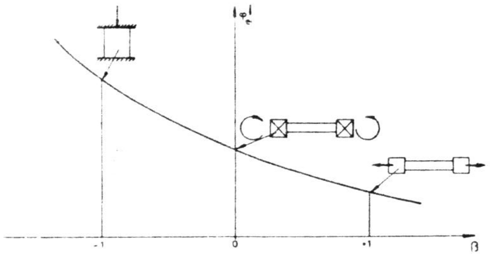

Fig. 1 Formability limit diagram [1]

The methodology of determination of formability limit curve consists of defining certain points by means of corresponding deformation process or models [1], as for example:

a) Single - axis compression of cylinder ($\beta=-1$);

b) Torsion test ($\beta=0$);

c) Single - axis tension ($\beta=+1$).

A more detailed definition of formability limit curve requires experimental investigation in additional deformation processes. The basic problem that appears then is the determination of stress and strain states in the zone of fracture appearance. In this paper the stress and strain state within the volume of prismatic specimen during upsetting by cylindrical dies has been analyzed..

The upsetting of prismatic billet by cylindrical dies [3] is one of the method of bulk deformation by combined dies (Fig. 3). The curved geometry of the dies creates complex stress state in the deformation zone, and in the case of longer workpiece the process performs in plane strain conditions ($\varepsilon_z=0$). For the stress state determination in this process, different methods have been applied: slab method, visioplasticity and pin load cell method. In this paper comparison of results is given.

2. LOCATION OF CRACK ZONE

In the analysis of material formability, besides the identification of stress and strain state, it is necessary to determine the location of crack, and the moment of appearance of damages in material structure.

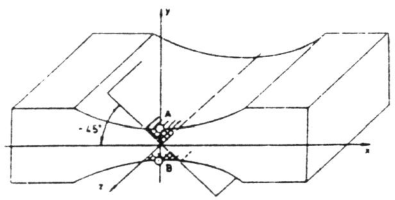

Fig. 2 Location of crack on the specimen

By the metalographic analysis of steel specimen with C=0.35% , it was established that first cracks in compression by cylindrical dies appeared in the central part of workpiece, starting from the top and bottom edges (Fig. 2, points A and B).

3. THE ANALYSIS OF STRESS - STRAIN STATE

3.1 Slab method

In the paper [3] determination of the stress state in compression of prismatic billet by cylindrical dies (Fig. 3) using cross section method was presented.

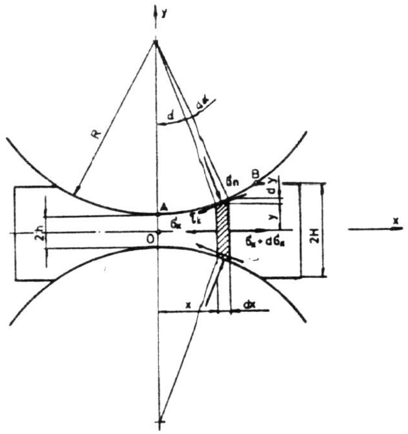

Fig. 3 Stress components

The basic differential equation is obtained from the stress scheme Fig. 3, and after some mathematical transformation the final form is given:

$$\frac{d\sigma_x}{d\alpha}+\sigma_x\frac{\mu\cos\alpha}{a-\cos\alpha}+(1,15)K\frac{\sin\alpha-\mu\cos\alpha}{a-\cos\alpha}=0 \qquad (4)$$

where:

a =1+h/R - geometrical parameter (Fig. 3),

K - the effective stress,

μ - friction coefficient.

By solving the equation (4) numerically, σ_x component is obtained, and by using the equation of plasticity, σ_n component is defined:

$$\sigma_n = 1,15K-\sigma_x \qquad (5)$$

The effective stress K is determined according to the dependence:

$$K = K_0 + a\varphi_e^b \qquad (6)$$

where

$$\varphi_e = (1,15)\ln\left(\frac{H}{y}\right) \qquad (7)$$

On the basis of the established values of stress components by using the expression (3) the stress indicator (β) is obtained.

3.2 Visioplasticity method

The determination of stress components on the free surface of the specimen was carried out by deformation theory, with the assumption of the monotonous deformation.

The components of small deformation have been determined on the base of displacement function of the mesh knot points (Fig. 4).

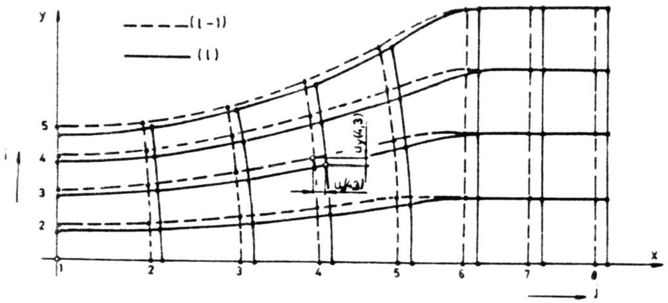

Fig. 4 Displacement of the mesh knot points

$$\varepsilon_x = \frac{\partial U_{xn}}{\partial x} = \frac{dF_1(x)}{\partial x}$$
$$\varepsilon_y = \frac{\partial U_{yn}}{\partial y} = \frac{dF_3(x)}{\partial y} \qquad (8)$$
$$\gamma_{xy} = \frac{\partial U_{xn}}{\partial y} + \frac{\partial U_{yn}}{\partial x} = \frac{dF_2(y)}{\partial y} + \frac{dF_4(x)}{\partial x}$$

where:

$$U_{xn}(x) = F_1(x) \quad for \quad y = const.$$
$$U_{xn}(y) = F_2(y) \quad for \quad x = const.$$
$$U_{yn}(y) = F_3(y) \quad for \quad x = const. \qquad (9)$$
$$U_{yn}(x) = F_4(x) \quad for \quad y = const.$$

represent the displacement functions evaluated by experiment.

The stress state has been determined by solving the equilibrium equations (with the assumption of monotonous deformation) and by using the relationship between deviatoric stress tensor and deviatoric deformation tensor:

$$\sigma_x - \sigma = \frac{2}{3}\frac{\sigma_e}{e_e} e_x$$
$$\sigma_y - \sigma = \frac{2}{3}\frac{\sigma_e}{e_e} e_y \qquad (10)$$
$$\tau_{xy} = \frac{1}{3}\frac{\sigma_e}{e_e} e_{xy}$$

where:

e_x , e_y, e_{xy}, e_e - the values of final deformation.

Based on the shown equations the stress components have been determined as:

$$\sigma_{x\ y=const.} = \frac{1}{3}\int_x^{x_c} \frac{d}{dy}\left(\frac{\sigma_e}{e_e} e_{xy}\right) dx$$
$$\sigma_y = \sigma_x - \frac{2}{3}\frac{\sigma_e}{e_e}(e_x - e_y) \qquad (11)$$
$$\tau_{xy} = \frac{1}{3}\frac{\sigma_e}{e_e} e_{xy}$$

where x_c - coordinate which defines boundary condition: for $x = x_c$, $\sigma_x = 0$. The stress state indicator in the critical point was determined by equation (3).

3.3 Pin load cell method

In the paper [3] the methodology of experimental determination of contact stress in compression process by cylindrical dies is presented.

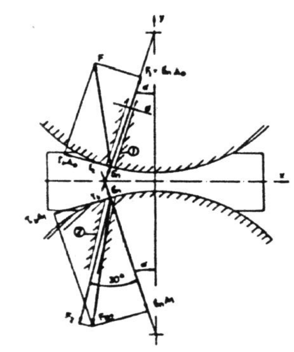

Fig. 5 Loading scheme

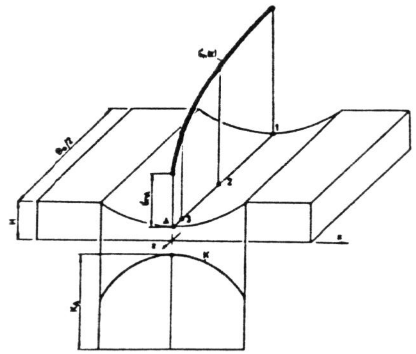

Fig. 6 Stress state in critical zone

Analyzing the loading on the measuring elements (Fig. 5), the contact stress components are determined:

$$\sigma_n = \frac{F_1}{A_0} \qquad \tau_k = \sqrt{3}\,(\frac{F_2}{A_0} - \sigma_n) \qquad (12)$$

where:

F_1, F_2 - loading on the measuring elements 1 and 2;

A_0 - surface of the cross section of pin load cell.

For the analysis of the material formability at the observed process it is sufficient to determine the stress components in the points 1, 2, and 3 (Fig. 6), and then by means of the regression analysis σ_n component is defined. Component σ_x is defined from equation of plasticity (5).

4. EXPERIMENTAL INVESTIGATION

In the experimental investigation of stress - strain state and material formability at compression of prismatic specimen by cylindrical dies a lot of tests with the variations of different parameters has been made. A part of the results obtained on the specimen of steel (C=0.35%), with initial dimensions 2H=18 mm and B=40 mm, in this paper are presented. The surfaces of the specimens were ground and phosphated and lubrication with mineral oil was applied.

The deformation of specimens were carried out by cylindrical dies (Fig. 7) with built-in measuring elements, and hydraulic press "Sack-Kieselbach" - 6.3 MN. In the Fig. 8 the upsetting phases (1-7) one of specimen (with the mark B) is given. This specimen was used for the estimation of stress-strain state by visioplasticity method. Fig. 9 shows the contact stress distribution along surface on which the measurement was made.

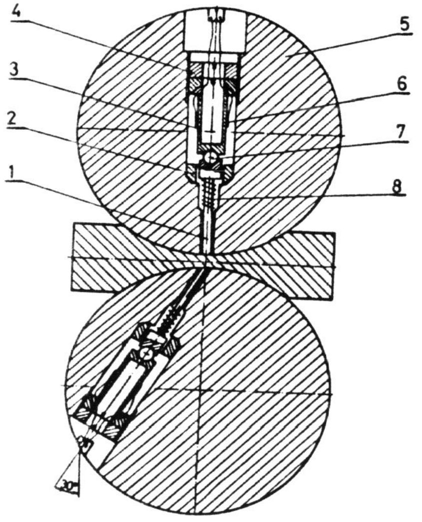

Fig. 7 The die for the experiment

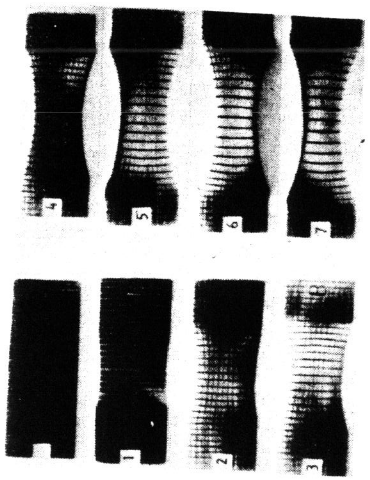

Fig. 8 Phases of deformation

On summary, the result of the stress-strain investigation is shown in Fig. 10. The "history" of deformation, e.g. the change of β–indicator during the process of deformation is given as well as the point which indicates the end of deformation due to the first crack occurrence.

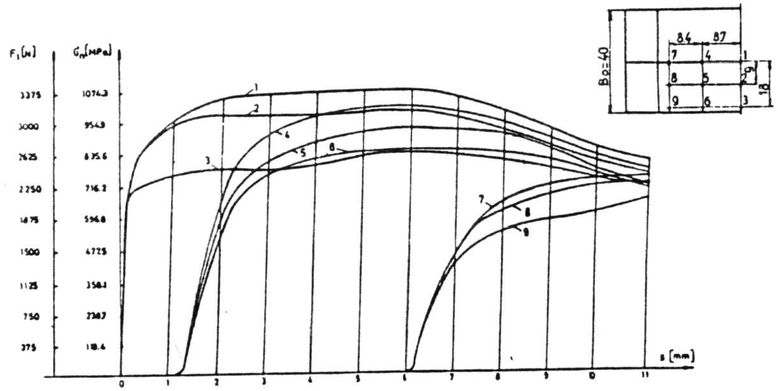

Fig. 9 Normal contact stress distribution

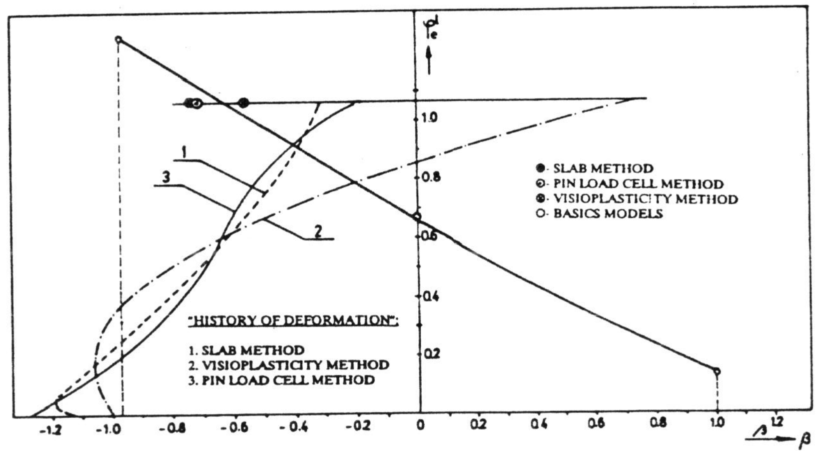

Fig. 10 Formability limit diagram

5. DISCUSSION OF RESULTS

Determination of stress-strain state in the technology of plasticity is essential as the knowledge of this state enables the determination of basic process parameters such as: deformation force, mean pressure and work of deformation. Furthermore, it makes possible to analyze the potential of material formability.

The work presented in this paper is a part of a broader investigation in which most suitable method for the estimation of stress-strain state in the deforming zone by upsetting of prismatic specimen by cylindrical dies has been determined.

The results showed that all applied methods give similar results. The visioplasticity is quite complicated for application. For the further investigation we suggest the pin load cell method as it makes possible to measure the stress state in the critical point of specimen in rather simple way.

The slab method is suitable for preliminary investigation of material formability and for determination of forming load and other process parameters in upsetting by cylindrical dies.

LITERATURE

1. Vujovic V., Shabaik A.: *"Workability Criteria for Ductile Fracture"*, Transaction of the ASME - Journal of Engineering Materials and Technology, Vol. 108 pp. 245-249, 1986.

2. Plancak M., Vilotic D.: *"Application of Pin Load Cell for Measuring of Contact Pressure in Extrusion and Compression Processes"*, Proceedings of the 9th International Conference on Experimental Mechanics, Vol. 1, pp. 31-38, Copenhagen, 1990.

3. Vilotic D., Shabaik A.: *"Analysis of Upsetting with Profiling Dies"*, Transaction of the ASME - Journal of Engineering Materials and Technology, No. 4., Vol. 107, pp. 261-263, 1985.

4. Kolmogorov V. L. : *"Naprjaženija, deformacii, razrušenie"*, izd."Metallurgija", Moskva, 1971.