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PARAMETER SENSITIVITY OF THE SICO TEST

Lechoslaw Trebacz, Wojciech Mitkowski, Maciej Pietrzyk
Akademia Górniczo-Hutnicza,Krakow, Poland
e-mail: pietrzyk@metal.agh.edu.pl, web page: http://www.kmpm.metal.agh.edu.pl

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Summary. *The objective of the present work is determination of sensitivity of Latham&Cockroft criterion with respect to parameters of SICO test, which are temperature, die velocity and such material parameters as: strain rate sensitivity and consistency. The first part of the work provides information about temperature evolution model during heating in SICO tests. Results of simulations and sensitivity analysis are presented in the second part.*

1 INTRODUCTION

Development of quantitatively accurate fracture criterion is crucial for efficiency and accuracy of the finite element models, which predict properties of products of forming processes. Commonly used criteria, based on calculations of the local stress/strain history, see for example [1], give reasonably good qualitative predictions for a selected material, but quantitative results are usually far from observations. It is due to difficulties with determination of the material parameters in the fracture criteria. Problem of development of more general criterion, in which the composition and structure of the material is an independent variable, is still open. The Strain Induced Crack Opening (SICO) test is used to determine materials tendency to fracture during hot forming [2]. Due to strong inhomogeneity of temperatures, strains and stresses in the SICO test, interpretation of results of this test presents difficulties. Thus, a suggestion is made in this work that application of the inverse analysis should enable to obtain values of the parameters independently of the inhomogeneity of strains, stresses and temperatures. The particular objective of the present work is modelling of resistance heating of samples and determination of the sensitivity of the fracture criterion function with respect to the test parameters and properties of deformed material.

2 SICO TEST

SICO test is hot workability technique with good reproducibility and possibility of high strains. The test is divided into two stages: the resistance heating of the sample to get required temperature, and upsetting until fracture appearance (Fig. 1). The tests conditions were:

- ✓ dimensions of sample: ϕ10.0x86.36 mm, steel containing 0.21%C, 1.32%Mn
- ✓ heat transfer coefficient for the tool-workpiece interface was assumed at 20 kW/m^{2}K for high pressure contact and 10 kW/m^{2}K for sides of the sample,
- ✓ sample heating rate was 5ºC/s for about 230 s,
- ✓ stroke during upsetting was ~16 mm.

Simulations of SICO test are described in detail in the authors earlier publications [3,4].

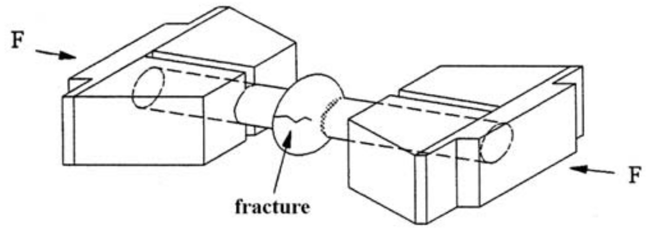

Fig. 1. SICO test

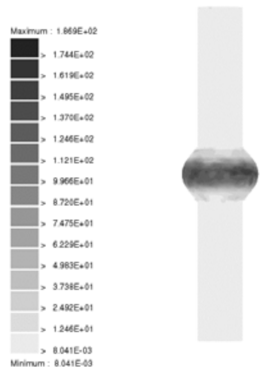

Fig. 2. Temperature distribution after heating and compression

SICO test, characterized by strong inhomogeneities of temperatures, strains and stresses, is used to determine materials tendency to fracture during hot forming [2,3]. A suggestion is made that application of the inverse analysis should enable to obtain values of the parameters independently of the observed inhomogeneities. Inverse method allows to determine the coefficients in the fraction criteria for the investigated steel and to find correlation between these coefficients and the chemical composition of the material. This criterion, with the optimized coefficients, is implemented into the finite element code, which simulates hot metal forming processes, and analysis of tendency to fracture is performed for selected forging operations. Determination of the sensitivity of the fracture criterion with respect to the test and material parameters is crucial.

3 HEATING

Heat generated as result of electric current flow along the length L, which is a function of resistance and time, is described by equation:

$$Q = I^2 R t \tag{1}$$

where: I – current, R – resistance, t – time of heating.

Resistance changes with temperature T according to the formula:

$$R(T) = R_0 \left(1 + \alpha T\right) \tag{2}$$

where: α – temperature resistance coefficient, R_0 – resistance in temperature 0ºC.

Distribution of temperature is described by the following equations:

$$A \frac{\partial T(x,t)}{\partial t} = \frac{\partial^2 T(x,t)}{\partial x^2} + Q(x,t), \quad T(x,0) = a, \quad t \geq 0 \tag{3}$$
$$T(0,t) = a, \quad T(L,t) = a, \quad 0 \leq x \leq L$$

Density of heat source is nonlinear function:

$$Q(x,t) = b(x) R_0 \left[1 + \alpha T(x,t)\right] I^2(t) \tag{4}$$

where: $b(x)$ - appropriate bell shape function obtained from experimental data, which represents intensify of heating at the centre ($x = L/2$). In such approach, nonlinearity effect, which comes from nonlinearity of the thermal conduction coefficient, is accounted for.

Spatial and time discretization was made for numerical calculation and temperature distribution at final time step was obtained (Fig. 3). Control theory was applied to determine electric current changes [5] and the results are presented in Figure 4. Calculated temperature field was used as an initial condition for the further simulation of the SICO tests.

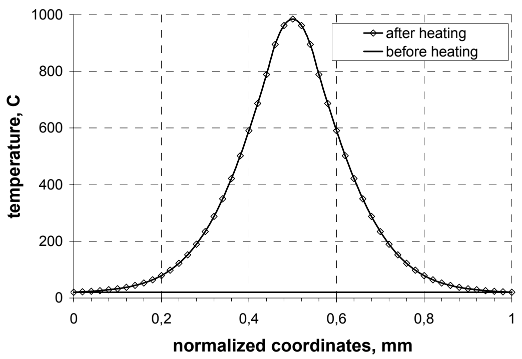

Fig. 3. Temperature distribution along the sample.

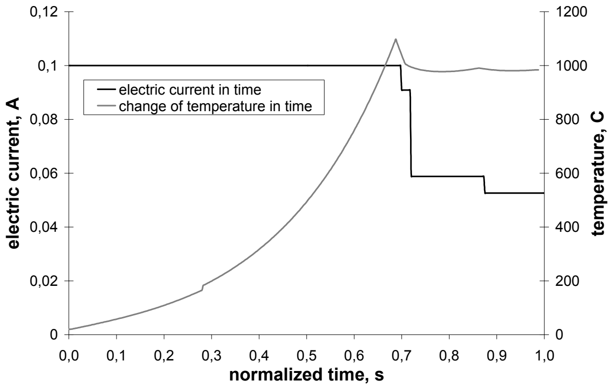

Fig. 4. Change in time of the electric current and the temperature at the sample centre.

4 SENSITIVITY ANALYSIS

Goal of this work was investigation of sensitivity of Latham&Cockroft criterion (fracture criterion) with respect to SICO test and to material parameters. Evaluation of the sensitivity will supply the information, which will make, in the further investigation, the inverse analysis of SICO test more efficient. Values of parameters and Latham&Cockroft criterion were estimated for circumferential strain equal 0.65. The independent variables of the process in the analysis were temperature at fracture moment (T) and die velocity (v). Variables describing material properties were strain rate sensitivity (m) and consistency (K), which are parameters describing flow stress in the following equation:

$$\sigma_0 = \sqrt{3}^{(1+m)} K \varepsilon^n e^{(-\beta T)} \dot{\varepsilon}^m \quad (5)$$

where: n – hardening exponent, β – temperature sensitivity coefficient.

Forge 3 code was used in the solution. In this analysis Latham&Cockroft criterion was calculated as maximum LC value in the sample. Sensitivity coefficient were defined as:

$$\varphi_{LC,T} = \frac{T}{LC}\frac{\partial LC}{\partial T}, \varphi_{LC,v} = \frac{v}{LC}\frac{\partial LC}{\partial v}, \varphi_{LC,m} = \frac{m}{LC}\frac{\partial LC}{\partial m}, \varphi_{LC,K} = \frac{K}{LC}\frac{\partial LC}{\partial K} \quad (6)$$

Derivatives in equations (6) were calculated using finite difference approximation.

Reference values of parameters were $T = 1160^{o}C$, $v = 90$ mm/s, $m = 0.139$ and $K = 2512$. Values of sensitivity coefficients were calculated as a function of temperature for the range from 910°C to 1170°C and the results of calculations are presented in Figure 5.

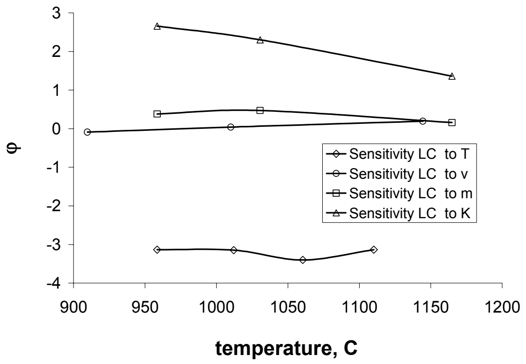

Fig. 5. Sensitivity of Latham&Cockroft criterion to temperature *T*, die velocity *v*, strain rate sensitivity *m* and consistency *K*.

5 CONCLUSION

Analysis of the result of the sensitivity calculations supplies information regarding importance of various parameters in the SICO tests. It is seen in Figure 4 that Latham-Cockroft criterion is sensitive to both process conditions and material properties. Maximal sensitivity is observed with respect to temperature and consistency parameter *K* in equation (6). Increase of temperature results in decrease of sensitivity to change of consistency parameter. It is also seen that fracture criterion value is less sensitive to change of die velocity, slight increase of this parameter with increasing increasing temperature is observed, and to strain rate sensitivity *m*, slight decrease of this parameter with increasing temperature is observed.

The general conclusion from the work is that, in the inverse analysis of the SICO test, the critical value of the criterion should be a function of the temperature and consistency. Coefficients of this function should be determined by inverse calculations, accounting for the history of deformation. The effect of the die velocity *v* and the strain rate sensitivity coefficient *m* can be neglected.

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