IDENTIFICATION OF THE MULTISCALE MATERIAL MODEL BASED ON AN INTERNAL VARIABLE

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1. Introduction

Internal variable method (IVM) is an alternative for conventional models describing processing of materials. When the latter are used the history of the process is not accounted for. Fast change of the process conditions moves the model to a new equation of state without delay, which is observed in experiments. When external variables are replaced by internal ones, this disadvantage is eliminated. An approach, which uses dislocation density as the independent variable, was considered in the paper. This approach based on works [1,2] proved its extensive predictive capabilities. Difficulties with identification of this model limit its wide practical approach. Inverse approach to identification of the IVM was the main objective of the present work

2. Inverse approach for IVM

In the IVM differential equation describing evolution of dislocation populations (ρ) is solved:

(1) $$\frac{d\rho(t)}{dt} = A - B\rho(t) - C\rho(t - t_{cr}).$$

(2) $$A = \frac{a_1 Z^{a_3}}{b} \qquad B = a_2 \dot{\varepsilon}^{-a_9} \exp\left(\frac{a_3}{RT}\right) \qquad C = \begin{cases} 0 & \text{for } t \le t_{cr} \\ a_4 \exp\left(\frac{a_5}{RT}\right) \rho(t)^{a_8} \rho(t - t_{cr}) & \text{for } t \le t_{cr} \end{cases}.$$

where: b – length of the Burger vector, Z – Zener-Hollomon parameter, T – temperature in K, R – universal gas constant, t_{cr} – time at which critical dislocation density $\rho_{cr} = a_{11}–a_{12}Z^{a10}$ is reached, $a_1 – a_{13}$ - coefficients. External variable models can be easily identified on the basis of simple experiments, separately for the flow stress and for the static recrystallization (SRX). Since IVM uses the same equation for DRX and SRX, identification of this model is complex. Result of identification based on the flow curves only is shown in Figure 1. From one side, the model proved its capability to reproduce qualitatively the response of the material involving oscillations, which is characteristic for copper. On the other side quantitative agreement with the experiment is poor. Therefore, two-step compression was used as an experiment in this work. By changing the time between deformations it is possible to obtain data for identification of the SRX model.

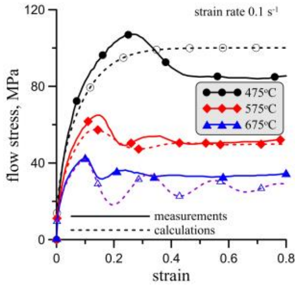

Figure 1: Measured and calculated flow stress for copper.

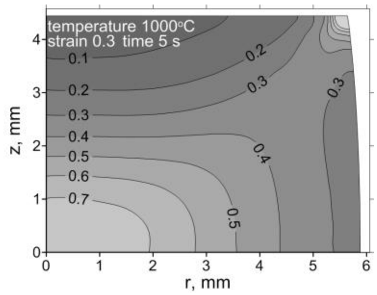

Figure 2: Distribution of the RX volume fraction at the sample cross section after 5 s interpass times.

The 2-step test involves strong inhomogeneity of strains and temperatures [3]. Inhomogeneity of deformation is well seen in Figure 1, where distribution of the RX volume fraction in 5 s after the first deformation is plotted. Therefore, inverse analysis was applied to identification of coefficients **a** in the model. Finite element (FE) code was used to simulate two-step compression test. Equation (1) was solved in each Gauss integration point of the FE model (Figure 3). The objective function was defined as a square root error between calculated and measured force in the second step.

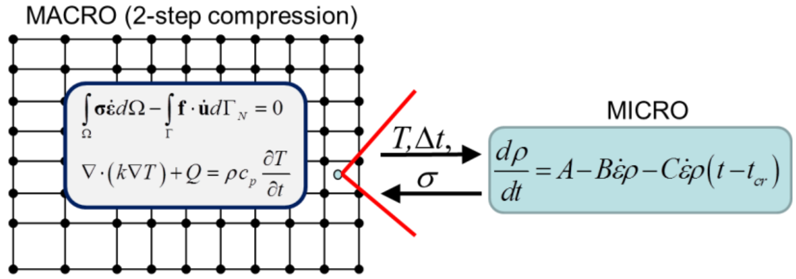

Figure 3: Schematic illustration of the multiscale model of the 2-step compression.

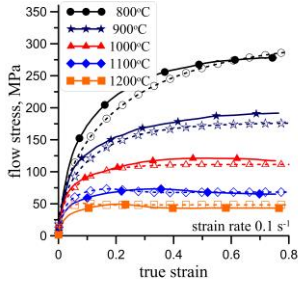

Figure 4: Measured and calculated (IVM model) flow stress.

3. Results

Identification was performed for a DP600 steel (steel A in [3]) and coefficients **a** in equations (1) and (2) were determined. Selected result of comparison of measured flow stress and calculated using optimal model is shown in Figure 4. Good agreement was obtained for all strain rates. Due to multiscale approach it is possible to follow distributions of all parameters in the test. Figure 5 shows distribution of dislocation density multiplied by 10^{-10} at the sample cross section of the sample in 4 s after the end of deformation, strain ε = 0.4, strain rate $\dot{\varepsilon}$ = 0.1 s^{-1} and temperature T = 900°C. Due to symmetry a quarter of the cross section is shown. Figure 6a shows changes of the dislocation density in the centre of the sample during 2-step test. Figure 6b shows flow stress for the 2-step tests with different interpass times.

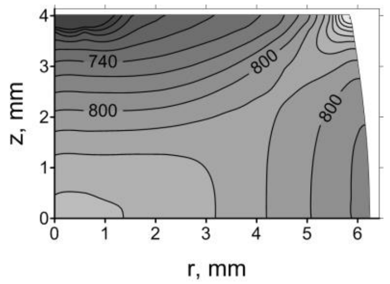

Figure 5: Distribution of the dislocation density at the cross section of the sample in 4 s after deformation.

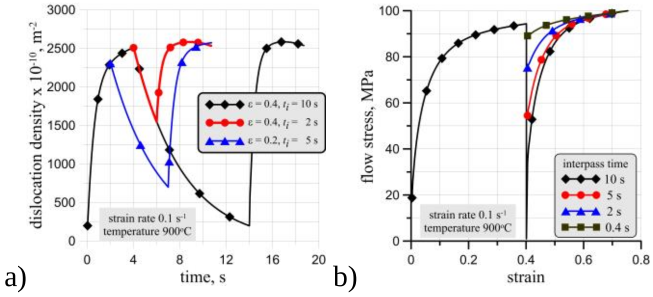

Figure 6: Changes of the dislocation density in the centre of the sample during 2-step test (a) and flow stress for different interpass times (b), first strain ε_1 = 0.4.

4. Conclusions

Multiscale model with FE in macro scale and IVM in micro scale was identified on the basis of the 2-step compression. Numerical tests confirmed extensive predictive capabilities of the model as far as far as prediction of metallurgical phenomena is considered.

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References

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