POLISH ACADEMY OF SCIENCES

INSTITUTE OF FUNDAMENTAL
TECHNOLOGICAL RESEARCH
AND
COMMITTEE ON MECHANICS

40th SOLID MECHANICS CONFERENCE
29.08 - 2.09 2016, WARSAW

URL: http://solmech2016.ippt.pan.pl/table/abstracts.html

CONSTITUTIVE BEHAVIOUR OF DP500 STEEL EXPOSED TO PRIOR CYCLIC LOADINGS

W. Moćko[1], P. Grzywna[2], Z.L. Kowalewski[2], J. Radziejewska[3]
[1] Institute of Fundamental Technological Research, Warsaw, Poland
[2] Motor Transport Institute, Warsaw, Poland
[3] Warsaw University of Technology, Warsaw, Poland

1. Introduction

Recent studies in the area of hybrid analysis linking two phenomena, i.e. viscoplasticity and fatigue, clearly show that an initial cycling may influence the stress-strain curves of a material significantly [1, 2]. As a consequence, mechanical behaviour of structures designed using data for the as-received material may be different from that of the structures working under typical application conditions. Therefore, it is required to develop a reliable constitutive model capable to take into account an influence of the fatigue loading history on the stress-strain characteristics.

2. Research methodology

Paddle-shaped flat specimens cut out of a sheet made of DP500 steel in the as-received state were subjected for testing. Both fatigue and standard tensile tests were performed on the MTS 858 servohydraulic testing machine working in the closed loop feedback. Force controlled cycles were executed for the frequency of 1 Hz, stress ratio R = 0, and constant stress amplitude for the given specimen. Two series of the DP500 steel specimens were tested. The first series of fatigue specimens was tested at the cyclic stress range of 500 MPa, while the second one at 520 MPa. Both series were stopped when the total strain attained the level of: 4%, 8%, 11%, and 14%. In the next step of the experimental programme the standard tensile tests were carried out on the initially deformed specimens. The mechanical characteristics enabled evaluation of an influence of the pre-fatigue, expressed in the form of damage parameter D, on the particular coefficients of the JC constitutive equation [3].

3. Experimental results

It was assumed that the stress–strain curve of material in the as-received state is expressed by a basic relationship of the JC equation [3]:

$$\sigma(\varepsilon) = \left(A_0 + B_0 \varepsilon^{n_0}\right) \tag{1}$$

Taking into account the cumulated fatigue damage coefficient D, and the cyclic stress amplitude σ, the value of coefficients of the JC equation for the material after the prior fatigue load can be expressed as follows [4]:

$$A(\alpha_A, \beta_A, D, \chi_A, \sigma_0, \sigma, \delta_A) = A_0 + f(\alpha_A, \beta_A, D) + g(\chi_A, \sigma_0, \sigma) + h(\delta_A, D) \tag{2}$$

$$B(\alpha_B, \beta_B, D, \chi_B, \sigma_0, \sigma, \delta_B) = B_0 + f(\alpha_B, \beta_B, D) + g(\chi_B, \sigma_0, \sigma) + h(\delta_B, D) \tag{3}$$

$$n(\alpha_n, \beta_n, D, \chi_n, \sigma_0, \sigma, \delta_n) = n_0 + f(\alpha_n, \beta_n, D) + g(\chi_n, \sigma_0, \sigma) + h(\delta_n, D) \tag{4}$$

where α, β, χ - coefficients of the equation describing cyclic hardening of the material in the initial phase of cyclic loadings, δ - coefficient of the fatigue damage development rate, D - cumulated fatigue damage coefficient, σ_0 - reference value of the cyclic stress maximum, σ - cyclic stress maximum. Subsequently, the tensile characteristics of the DP 500 steel were used to calibrate

$$\dot{\varepsilon}^v = \frac{\boldsymbol{\sigma}'}{2\eta_s} + \frac{\mathrm{tr}(\boldsymbol{\sigma}) - 3\sigma_s}{9\eta_b}\mathbf{I} \tag{1}$$

where $\boldsymbol{\sigma}'$ is the deviatoric stress, $\mathrm{tr}(\boldsymbol{\sigma})$ – the trace of the stress tensor, σ_s – the sintering stress, η_s – the shear viscosity modulus η_s – the bulk viscosity modulus.

In the multiscale approach, macroscopic constitutive properties, including the elastic moduli, bulk and shear viscosity, as well as the sintering driving stress are determined from micromechanical simulations of sintering. The micromechanical model of sintering has been developed within a framework of the discrete element method [2]. The DEM considers large assemblies of particles which interact with one another through contact forces. The rheological scheme of the contact model for sintering is shown in Fig. 1b. It includes elasticity, thermal expansion, viscosity (creep) and the sintering driving force, which is consistent with the macroscopic model.

The constitutive parameters of the DEM model of sintering depend on the parameters which can be determined using atomistic models. The methods of molecular statics and dynamics will be used to determine the elastic constants, surface energy and diffusion coefficients used as input data in microscopic sintering models.

4. Case study

Sintering of NiAl powder has been analysed as a case study using the multscale approach. Figure 2 shows selected mechanisms of diffusion considered in the molecular statics analysis. Average shear viscous modulus determined from the DEM simulations is plotted in Fig. 3 as functions of sintering time and relative density.

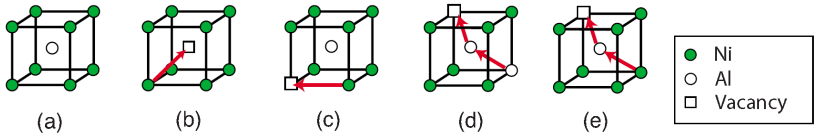

Figure 2. Schematic representation of NiAl crystal structure and selected hop mechanisms [3]

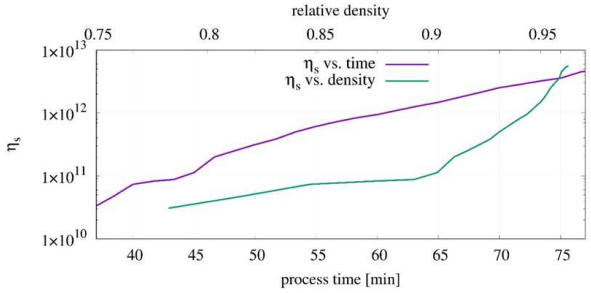

Figure 3. Average shear viscous modulus determined from the DEM simulations

Acknowledgement: This work has been financed from the funds of Polish National Science Centre (NCN) awarded by decision numbers DEC-2013/11/B/ST8/03287

5. References

[1] R. Zhang (2005). *Numerical Simulation of Solid-State Sintering of Metal Powder Compact Dominated by Grain Boundary Diffusion*, PhD Thesis, The Pennsylvania State University.

[2] S. Nosewicz, J. Rojek, K. Pietrzak, and M. Chmielewski (2013). Viscoelastic discrete element model of powder sintering, *Powder Technology*, **246**, 157–168.

[3] Q. Xu and A. Van der Ven (2010). Atomic transport in ordered compounds mediated by local disorder: Diffusion in B2-Ni_xAl_{1-x}, *Physical Review B, Condensed matter*, **81**, 064303.