INVESTIGATIONS OF TANTALUM AT DIRECT IMPACT COMPRESSION TESTS ON MINIATURIZED SPECIMENS

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ABSTRACT - In the paper the results of experimental and numerical investigations concerning an influence of strain rate on mechanical properties of pure tantalum are presented. Experiments were carried out using Direct Impact Compression Test (DICT) technique (Malinowski et al. [2007]). The Perzyna elasto-viscoplasticity theory (Perzyna [1966]) was applied to predict the dynamic compression yield strength of the tested material at strain rates from 1.0 x10^{-3} s^{-1} to 0.5 x10^{6} s^{-1}.

INTRODUCTION: The main details of the miniaturized DICT were presented in Malinowski et al. [2007]. In the literature, the flow stress of commercially pure tantalum has been studied at strain rates ranging from quasi-static to 1.0x10^{4} 1/s, temperatures from –200^{0}C to 700 ^{0}C (Nemat-Nasser and Isaacs [1997]), and strains up to 0.8-1.0 (Kim and Shin [2009]). There are no available data on the flow stress at higher strain rates than 1.0x10^{5} 1/s, in particular for large strains. The experimental identification of material parameters required for constitutive modelling are not sufficiently reported.

MATERIAL: Commercially pure tantalum, obtained in the form of rod from the U.K. Factory Ardec, was used in the present study. Compression tests were carried out on Ta at strain rates ranging from quasi-static to dynamic at room temperature 296 K. Quasi-static strain rates of 1.0x10^{-3} s^{-1} were achieved in a hydraulic Instron machine, whereas strain rates of 0.5 x10^{6} s^{-1} were reached using the miniaturized DICT. The mechanical properties of the material used in the simulations are as follows: Young's modulus 186 GPa, Poisson ratio – 0.34, bulk modulus - 194 GPa, shear modulus - 69.4 GPa, initial yield stress under compression – 136 MPa, melting point (K) – 3269, and density – 16600 kg/m^{3}. The material constants for striker and output bar of the maraging steel used in the calculations are as follows: Young's modulus 206 GPa, Poisson ratio – 0.32, and density – 8000 kg/m^{3}.

In Fig. 1 the Malinowski's direct impact experimental results with the experimental data adopted from Duprey and Clifton [1998], as well as from Kim and Shin [2009] are compared.

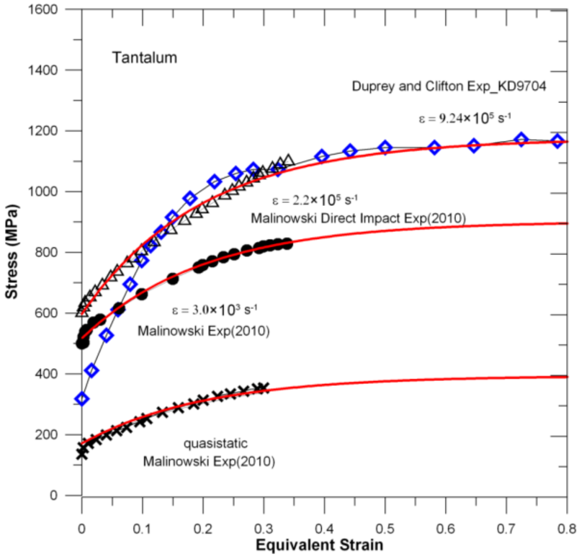

Fig. 1. True stress – equivalent strain for quasi-static and dynamic compression test. (solid lines - viscoplasticity model accounting the adiabatic softening, symbols - experimental data)

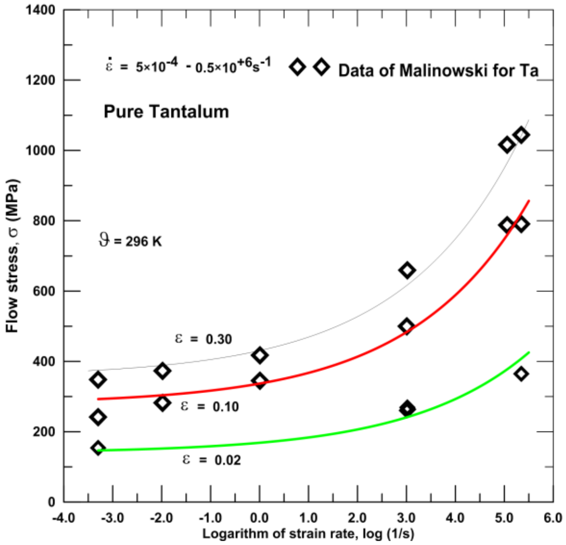

Fig. 2. The comparison of the Perzyna model predictions (solid lines) to the experimental flow stress data (symbols ◊) of tantalum with respect to logarithmic strain rate at 296 K and varying strains $\varepsilon = 0.02$, 0.1 and 0.3.

CONSTITUTIVE RELATION: The Perzyna constitutive relation, which accomplish in one formula the description of the material behaviour for the entire range of strain rates is applied, (see Perzyna [1966]):

$$\dot{\bar{\varepsilon}}^{p} = \gamma \left\langle \Phi\left[\frac{\sigma_{eq}}{\sigma_{y}(\bar{\varepsilon}^{p}, T)} \right] - 1 \right\rangle, \tag{1}$$

where γ is viscosity parameter, $\langle \bullet \rangle$ denotes the Macauley bracket and $\sigma_y\left(\bar{\varepsilon}^p, T\right)$ is the static yield stress function. The static yield stress function depends on the plastic strain $\bar{\varepsilon}^p$ and temperature *T*. The empirical overstress function $\boldsymbol{\Phi}$ is determined basing on available experimental data. The overstress function $\boldsymbol{\Phi}$ is assumed in the form of power law with the power parameter *D*. It is presumed that the inelastic strain rate is governed by the associated flow rule. The isotropic work-hardening-softening function $\sigma_y\left(\bar{\varepsilon}^p, T\right)$ is postulated:

$$\sigma_y(\bar{\varepsilon}^p,\ T) = \left[(A + B(1\text{-}\exp(\text{-}C\varepsilon))\ \right](1 - \Theta^m)\,, \qquad \Theta = \frac{T\text{-}T_0}{T_m\text{-}T_0}\,. \tag{2}$$

In Eq. (2) *A*, *B*, *C* are the material constants related to the quasi-static yield stress, *m* defines the temperature sensitivity and Θ is the modified temperature parameter given by the temperature of reference T_0 and the melting temperature T_m .

NUMERICAL MODEL: The numerical impact resistance of tantalum is analysed using ABAQUS/Explicit finite element program. In numerical simulations the specimen is supported by a output bar and is impacted by a striker bar moving with an imposed velocity. The displacements of output bar and deceleration tube in the impact direction are fixed. Both bars in contact with sample are chosen as an elastic bodies with finite friction. Penalty type of contact with friction coefficient for sample/striker (Ta/steel) and for sample/output bar (steel/Ta) equal to 0.05 is assumed. Simulation leads to plastic strain and strain rates in the range from $1.0\text{x}10^{-3}$ s^{-1} to $0.5\text{x}10^{6}$ s^{-1}. The Huber-Mises-Hencky yield criterion and Perzyna viscoplasticity model with adiabatic conditions are used. All elements in the finite elements model are of the type C3D8R (ABAQUS).

CONCLUSIONS: In comparison to the quasi-static test for the tantalum a significant increase of the yield strength was obtained at high strain rate investigations. The strength magnification factor was up to 3.0 in the range of the strain rates considered. A good correlation between the experimental data and the Perzyna overstress model predictions can by clearly observed for strain rates up to $0.5\text{x}10^{6}$ s^{-1}.

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