DIRECT IMPACT COMPRESSION TEST OF TANTALUM - EXPERIMENTAL INVESTIGATION AND MODEL IDENTIFICATION

Zbigniew Kowalewski, Zdzisław Nowak and Wojciech Moćko
Institute of Fundamental Technological Research, Warsaw, Poland

1. Introduction

The examples of high strain rate of loading, high speed impact, high speed machining, and high dissipation of energy at forming processes take place in many engineering applications. In order to predict and control behaviour of materials used under such extreme loading conditions, the mechanical parameters of materials should be precisely identified. It is well known that the mechanical behaviour of metal depends on the strain rate level. The Split Hopkinson Pressure Bar (SHPB) or Kolsky apparatus are widely used for the investigations of mechanical properties of materials at high strain rates up to $1.0\text{x}10^3$ s^{-1}. In order to reach strain rates higher than $1.0\text{x}10^3$ s^{-1}, Dharan and Hauser (1970) [1] introduced a modification of the SHPB concept by eliminating the incident bar. Thus, application of the direct impact of a striker onto a small disk or prismatic specimen supported by the transmitter bar enabled to reach strain rates up to $0.5\text{x}10^6$ s^{-1}. Such modification can be defined as the Direct Impact Compression Test (DICT), cf. Jia and Ramesh (2004) [2] or Malinowski, Klepaczko and Kowalewski (2007) [3].

2. Problem formulation

Experimental and numerical investigations of the effect of strain rate on mechanical properties of pure tantalum are presented. Experimental studies were carried out on Direct Impact Compression Testing stand. Miniaturization of the experimental setup with specimen dimensions: diameter d_S=1.5 mm and thickness l_S=0.50 mm, Hopkinson transmitter bar diameter d_H=3.0 mm and striker d_I=11.5 mm and l_I=12 mm, with application of a novel optical arrangement in measurement of striker velocity, enabled compression tests to be carried out at strain rates within the range from $1.0\text{x}10^3$ s^{-1} to $0.5\text{x}10^6$ s^{-1}. Perzyna constitutive model for the elasto-viscoplastic material, cf. Perzyna (2011) [4], was applied to predict the dynamic compression yield strength of the tantalum tested at different strain rates. The formulation of the Perzyna model with Voce hardening law can be expressed in the following way:

$$\bar{\sigma}(\bar{\varepsilon}^p, \dot{\bar{\varepsilon}}^p, T) = \left[(\mathrm{A} + \mathrm{B}(1 - \exp(-\mathrm{C}\varepsilon))\ \right]\left[1 + \left(T_{rel}\left(\bar{\varepsilon}^p\right) \cdot \dot{\varepsilon}^p\right)^D\right](1 - \Theta^m) \tag{1}$$

where T_{ref} is relaxation time, and A, B, C, D, and m are material parameters, Θ denotes the modified temperature given by:

$$\Theta = \frac{\mathrm{T} - \mathrm{T}_0}{\mathrm{T}_\mathrm{m} - \mathrm{T}_0} \tag{2}$$

where T_0 is the temperature of reference and T_m is the melting temperature.

The main objective of the paper was to investigate either experimentally or numerically a behaviour of tantalum using DICT technique. The special emphasis was taken on the description of the strain rate influence on the basic mechanical properties of pure tantalum. In order to extend the range of the analysed strain rates the experimental programme was supplemented by tests carried out on the SHPB testing stand and quasi-static hydraulic servo-controlled testing machine.

3. Experimental identification of the material model

The identification of the constitutive model parameters was obtained by an inverse method. Numerical simulation was performed with application of ABAQUS finite element program. The own VUMAT was implemented for calculations. The identification of constants was carried out using the true stress-strain diagrams. These curves were generated from the experimental tests performed at various strain rates. The elasto-viscoplastic model parameters were determined for each kind of specimen. Firstly, the computations were started assuming a broad range of the feasible parameters. Starting values of the model parameters were assumed and calculations carried out. In the next stage the final material constants were determined, and then the model was applied to execute numerical simulation in order to obtain final reaction force and displacement.

Generally, there was a good match between the experimental data and the Perzyna overstress model predictions for strain rates up to 0.5×10^6 1/s, Fig.1.

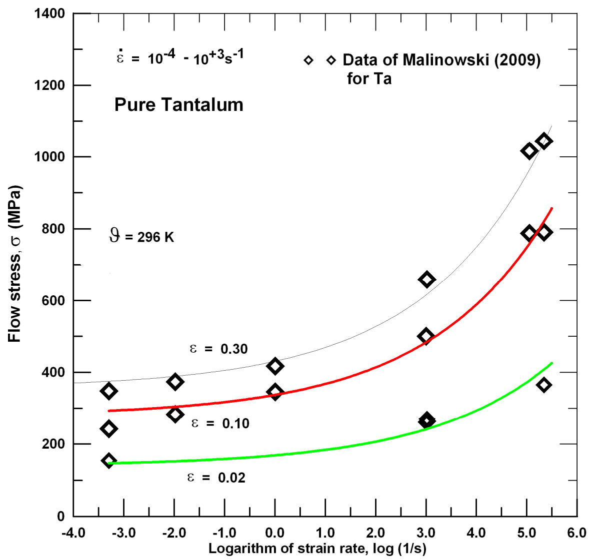

Fig. 1. Comparison of the current Perzyna model (solid lines) and the experimental flow stress data (symbols ◊) of pure tantalum with respect to logarithmic strain rate at 296 K (results for three strain levels were considered, i.e. ε=0.02, 0.1 and 0.3).

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4. References

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