NUMERICAL MODELLING OF THE MINIATURIZED DIRECT IMPACT COMPRESSION TEST METHOD

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1. Introduction

Miniaturized DICT [1] method allows testing mechanical properties of materials in the strain rate range of 10^4 s^{-1} to $1.5x10^5$ s^{-1}, i.e. much higher than the strain rate achievable in the Split Hopkinson Pressure Bars (SHPB). This enables a fuller description of material behaviour in the area of deformation under dynamic conditions. The results are then used during designing and testing of elements and impact protection structures, such as armours, projectile-proof vests, helmets etc. Specimen deformation during tests at very high strain rates is accompanied by a number of unfavourable phenomena which influence the results, such as friction, inertia, adiabatic heating, excitation of elastic waves. The compression test of a tantalum specimen was performed to check the agreement of the developed model predictions with experimental data. The results were compared with data calculated in the ABAQUS environment. This study aimed at developing a numerical model of a miniaturized DICT testing stand, to trace the phenomena occurring during the testing of specimens and to validate the results.

2. Experimental Results

Experiments on tantalum under compressive loads at very high strain rates were conducted using specimens of diameter d_{S0} = 1.5 mm and length l_{S0} = 0.55 mm. The stress vs. time, strain vs. time and strain rate vs. time curves obtained with a miniaturized DICT method are presented in Fig. 1. The recording time for the data used in subsequent analyses is equal to 6μs. The remaining part of recorded data not useful to determine the material characteristics reflects the projectile breaking process in a thrust sleeve and projectile elastic rebound off the sleeve. The specimen strain rate is reduced from $8x10^4 s^{-1}$ to $7x10^4$ s^{-1}. It is caused by plastic deformation of material leading to increase of contact areas between specimen and supporting bar. The assumed average strain rate was $7.5x10^4$ s^{-1}. The specimen deformation process, in form of the true strain vs. time curve is almost linear. The curve inclination increases over time, and as a consequence the strain rate also increases. It has to be notices that the strain rate is determined as a derivative of the nominal strain. The true stress curve in the specimen shown in Fig. 1 and calculated on the basis of electrical signal from strain gauge bonded to the transmission bar has very strong oscillations caused by reflecting elastic wave inside the specimen.

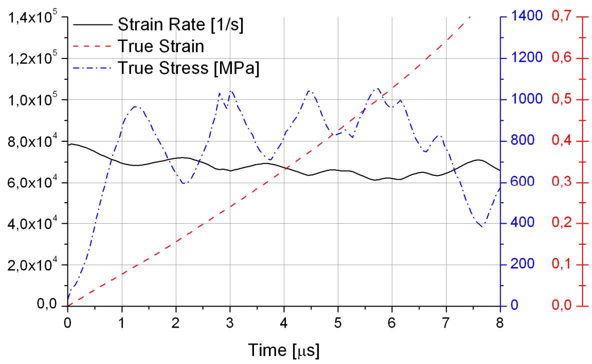

Fig. 1: Stress, strain and strain rate curves for tantalum obtained by DICT experimental method.

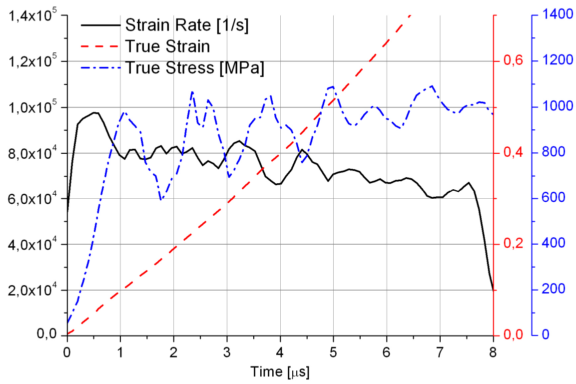

Fig. 2: Stress, strain and strain rate curves for tantalum obtained with FEM method at reference conditions.

The oscillation magnitude is reduced for subsequent waves from 400MPa to about 200 MPa for the last, fourth wave. As a result of change of sample geometry during deformation the distance between summits of successive oscillations is reduced from 1.68 μs to 1.25 μs.

In our study, the numerical analysis was performed to make a simulation, using the dimensions of specimen, testing stand, and parameters of test identical as those in the experiment applied. The goal was to check whether it is possible to carry out computer simulation reflecting phenomena occurring during very fast deformation of miniature specimens. A model of a miniaturized DICT test stand was prepared for numerical analyses. The basic elements of the model were: projectile, supporting bar, thrust sleeve and the specimen. The dimensions and relative position of individual model elements were the same as those on the testing stand. Boundary conditions were specified for the model: constrain of the displacement of bar and thrust sleeve fixing plane in both axes, initial specimen temperature of 298K, no exchange of heat through contact between the projectile and bar, and the initial projectile velocity. In the ABAQUS environment the axis symmetric model was applied. It reflected the effects of adiabatic heating and friction between the projectile – specimen and projectile – bar interfaces, for the friction coefficient μ=0.1. The following physical and mechanical properties of maraging steel were assumed: Young's module E_S=200 GPa, specific gravity: ρ_S=7860 kg/m^3. Moreover it was assumed that the elements of the testing stand will be subjected to elastic strain. Hence, the elastic model of material was used in the simulation. The data calculated according to the Z-A (Zerilli – Armstrong) constitutive model were used for tantalum. The model can be represented by the following equation [2]:

$$\sigma = c_0 + B_0 e^{-(\beta_0 - \beta_1 \ln \dot{\varepsilon})T} + K\varepsilon^n \quad (1)$$

The following values of the equation parameters were used in calculations: c_0=30MPa, B_0=1125 MPa, β_0=0,00535 1/K, β_1=0.000327 1/K, n=0,44.

3. Summary

The paper presents the result of compression test of polycrystalline tantalum using a miniaturize DICT stand. The experimental results (Fig. 1) were compared with those of computer simulation (Fig. 2) conducted in the ABAQUS environment, on the basis of numerical model of the testing stand elaborated. Comparison of FEM predictions with experimental data exhibits relatively good agreement, ie.

- the strain rate is slightly reduced from 8x10^4 s^{-1} to 7.5x10^4 s^{-1} over 6 μs of the test,

- the strain vs. time curve has a very similar shape (at 6th μs of the test ε=0.65),

- in both cases, the stress vs. time curves have characteristic oscillations, amplitude and average level are comparable.

Finally may be concluded that the numerical results obtained using proposed model of miniaturized DICT exhibits reasonable good agreement with experimental data. Therefore, the model seems to be applicable for investigation and analysis of the phenomena occurring during the specimen deformation, under dynamic loading.

4. Acknowledgements

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5. References

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