N1-O-038601

THE MECHANICAL RESPONCE OF TITANIUM ALLOYS TO DYNAMIC IMPACTS IN A WIDE TEMPERATURE RANGE*

V.A. SKRIPNYAK, V.V. SKRIPNYAK, K.V. IOHIM , E.G. SKRIPNYAK

National Research Tomsk State University, Tomsk, Russia

The titanium alloys applications in aerospace, medical, marine techniques, owing to its superior high strength-to-weight ratio, excellent corrosion resistance, and good formability. This work aimed to evaluate deformation and fracture of alpha and alpha+ beta titanium alloys under dynamic loading in temperature range from 77 K to 900 K.

The patterns of deformation and fracture of alloys during high-speed deformation at high and low initial temperatures were studied using numerical simulation of uniaxial tension of flat samples and loading of plates by plane shock waves. The response of titanium alloys to dynamic influences in a wide temperature range was described by a model of a damaged elastic viscoplastic medium. The constitutive equation takes into account the effect temperature on the flow stress, equivalent strain rate, accumulated equivalent plastic strain, pressure p, and average grain size d_g [1,2]. The macroscopic plastic flow stress was determined as the sum of the contributions of the stresses required to overcome the resistance to dislocation slip, resistance to twinning, and stresses from the inhomogeneity of the phase composition of the alloy.

The used Mie−Grüneisen equation of states takes into account the change in temperature during volumetric deformation. In this work the change in temperature due to the dissipative effect was calculated in adiabatic assumption:

$$T = T(\rho/\rho_0) + \int_0^{\varepsilon_{eq}^p} (\beta/\rho C_p)\sigma_{eq} d\varepsilon_{eq}^p, \; . \qquad (1)$$

where $T(\rho/\rho_0)$ is the temperature at volumetric strain, ρ is the mass density, and $\beta \sim 0.9$ is the parameter representing a fraction of plastic work converted into heat, σ_{eq} is the equivalent stress, ε^p_{eq} is the equivalent plastic strain.

The value of $T(\rho/\rho_0)$ calculated by the equation of states and energy conservation equation. This value is close to initial temperature of material at relatively low pressure. The accuracy of predicting the temperature rise under dynamic loadings depends on the adequacy of the description of the temperature dependence of specific heat. In this research the specific heat capacity C_p changes under dynamic loading was described by phenomenological relation. The constitutive relations have been implemented in the LS-DYNA explicit solver by writing a Fortran user-subroutine. Simulations of deformation and spall fracture of titanium plates under plane shock waves loadings were carried out using quadratic artificial viscosity, which does not introduce significant errors in determining the temperature increment during deformation in weak shock waves. The model was used for simulation of commercially pure titanium alloy, Ti-5Al-2.5 Sn, Ti-6Al-4V under uniaxial tension at strain rates from 0.1 to 1000 s^{-1}, and temperatures from 77 K to 900 K. The simulation results confirmed that strain hardening can be considered as a result of the simultaneous action of thermally activated dislocation mechanisms of plasticity and twinning, which weakly depends on temperature. The processes of spall fracture and mechanical response of titanium alloys under sub-microsecond shock pulse loading at temperatures of 103 K and 298 K at have been investigated.

The obtained results of spall fracture are consistent with the available experimental data. The calculated changes in the velocity of elastic precursors in Ti-6Al-4V plates good correlated with the experimental data at the specified initial temperatures. The calculation results showed that the damage growth rate increases in the spall zone with a decrease in the initial temperature. Spall fracture remains ductile in the considered temperature range, but a slight decrease in the effective spall strength is observed.

REFERENCES

[1] V.V. Skripnyak, A.A. Kozulyn, V.A. Skripnyak, "The influence of stress triaxiality on ductility of α titanium alloy in a wide range of strain rates", Mater. Phys. Mech. Vol. 42, 415-422, 2019.

[2] V.V. Skripnyak, V.A. Skripnyak, E.G. Skripnyak, "Ductility of titanium alloys in a wide range of strain rates". Paper presented at 6th International Conference Integrity-Reliability-Failure Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid Publ. INEGI/FEUP (2018); Paper REF: 7127 (2018)

* The work was supported by the Russian Science Foundation under grant No. 20-79-00102.