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DYNAMIC FRACTURE OF HEXAGONAL CLOSE PACKED ALLOYS*

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Predictions of the mechanical behavior of metals and alloys with a hexagonal close-packed (HCP) lattice, under dynamic loadings are in demand in solving a wide range of applied problems.

This work aimed to study the processes of deformation, damage and ductile fracture of HCP alloys under dynamic influences. Based on the generalization of the obtained experimental data, a version of the model is proposed that allows to adequately describe the regularities of plastic deformation during tension, the formation of zones of localization of plastic shears and the development of damage and fracture in the range of strain rates from 10^{-3} to 10^{3} s^{-1} at the values of the triaxiality parameter of the stress state from 0.33 to 0.6 [1,2]. The model was used for 3D numerical modeling of uniaxial tension of specimens and spall fracture in Ti, Zr, Be, Hf plates under plane shock waves impacts. The influence of the damage parameter, the stress state triaxiality parameter on the flow stress is taken into constitutive equation.

The proposed constitutive equation takes into account the change in flow stress in wide range of a cumulative plastic strain, a homologous temperature, and the logarithm of the normalized equivalent strain rate. The modification damage equation makes it possible to describe the kinetics of the damage parameter D increasing at spall fracture as a result of nucleation, growth and coalescence of voids:

$$dD/dt = dD_1/dt + dD_2/dt, \quad (1)$$

where D is the damage parameter, D_1 is the constituent of D associated with damages caused by negative pressure, D_2 is the constituent of damages caused by voids evolution under repeated loading.

$$dD_1/dt = \alpha_1 \min[0, dp/dt]\, H(-p + p_c), \quad (2)$$

where H(·) is the Heaviside function, p is the pressure, α_1, and $p_c < 0$ are constants of the material.

$$dD_2/dt = [1/(\gamma_1 \cdot A \cdot \sqrt{2\pi})] \cdot \exp[-(\ln(A)/\gamma_1 \cdot \sqrt{2})\ 2], \quad (3)$$

where $A = \int_0^t \frac{W^e}{\beta_1 \exp\left(-\beta_2 W^p\right)\cdot(1-D)} \frac{dW^p}{dt}\, dt]$, β_1, β_2, γ_1, are constants of the material, W^e, and W^p are the specific internal energy, and the specific dissipated energy, respectively.

The processes of spall fracture and mechanical response of Ti, Zr, Be, Hf alloys under sub-microsecond shock pulse loading have been investigated by numerical simulations. The computer simulations were performed with the use of LS DYNA (ANSYS WB 15.2, ANSYS, Inc., Canonsburg, PA, USA) software.

The calculations were carried out using the second order accuracy finite-difference scheme. Computational domains were meshed with eight-node linear bricks and reduced integration together with hourglass control. The constitutive relations have been implemented in the LS-DYNA explicit solver by writing a Fortran user-subroutine. We adopted Becker's implicit return mapping algorithm for the Gurson-type yield potential. Employed algorithm provides accurate integration of the damage in shock impact problems where the loading direction can change significantly at a time step.

It was shown that parallel cracks oriented normal to the direction of impact are formed by damaged mesoscopic volumes.

Thus, the proposed constitutive equations and damage model make it possible to describe the main regularities of the mechanical behavior of a subgroup of HCP alloys with a lattice parameter ratio $c/a < 1.633$ in a wide range of strain rates and weak shock wave amplitudes.

REFERENCES

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