NUMERICAL MODELING OF CONTACT FRACTURE OF ELASTO-PLASTIC CRACKED BODIES

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Summary Based on the finite element method, the algorithm for numerical modelling is developed and analysis is carried out for processes of crack extension in elasto-plastic finite bodies under contact compression. It is clarified that both sliding mode and opening mode cracks can develop in an elasto-plastic body under contact compression.

PROBLEM DEFINITION

Different engineering devices are used in industrial production for fracture of elasto-plastic materials such as rock. Many of them use the mechanical principle of operation based on local indentation of the instrument into the destroyed body. Fracture occurs as a result of the crack extension in stress concentration zones near the contact area. Therefore, research of the crack extension processes in elasto-plastic finite bodies under a contact loading is important for further improvement of such devices.

Mathematical modelling of contact fracture is based on the solution of contact problems of elasto-plastic cracked finite bodies. Boundary conditions of unilateral contact with presence of the Coulomb friction are set on the surfaces of contact bodies and crack faces. Actual dimensions of contact areas of the bodies, contact areas of the crack faces and zones of engaging and slipping are unknown and are subject for definition.

Defining relation of the theory of plasticity were accepted in the generalized form

$$\dot{\sigma}_{ij} = A_{ijkl}\left(\chi_1, \chi_2, \ldots, \chi_r, \dot{\varepsilon}_{\xi\eta}\right)\dot{\varepsilon}_{kl},$$

where $\chi_1, \chi_2, \ldots, \chi_r$ are values of functionals of a deformation history. Coefficients $A_{ijkl}(\ldots)$ are homogeneous functions of a zero degree concerning components of $\dot{\varepsilon}_{\xi\eta}$ tensor. It is possible to write down the defining relation for practically all existing versions of a plasticity theory by selecting a particular kind of $A_{ijkl}(\ldots)$ coefficients.

METHODS

In the present work the variational method of contact problems solution for elasto-plastic cracked finite bodies is used. Quasivariational inequalities for definition of both velocities and displacement increments were built. Some versions of time coordinate semidiscretization are surveyed for quasivariational inequalities in velocities. Various iteration procedures were used to provide a usage of implicit integration schemes on a time for physical linearization of the problem.

In result, sequences of problems of minimization of functionals are obtained. The finite element method is used for their discretization with respect to space coordinates. Modifications of the successive overrelaxation method and the conjugate gradient method are developed for solution of the obtained finite-dimensional nonlinear programming problems.

Energy methods and path independent integrals [1, 2] were used for definition of fracture mechanics parameters. Prediction of a small crack length change and definition of its orientation was provided by a local fracture criterion. The location and orientation of the initial cracks were determined on the basis of the stress-strain analysis of a destroyed body with usage of phenomenological maximum shear stress criterion for sliding mode cracks and maximum normal criterion for opening mode cracks. The size of initial cracks was selected commensurable with the most typical defects of the material.

SOFTWARE

Developed computational algorithms are implemented as an application package for solution of elasto-plastic cracked finite bodies contact problems. The software package consists of three parts: the preprocessor of input data, the FEM processor and the graphics postprocessor. The preprocessor is intended for preparation and conversion of input data according to the interface of the FEM processor. The special attention is given to development of automatic grinding algorithms of FE grids in the area around apex of cracks. The FEM processor is intended for numerical solution of elasto-plastic cracked finite bodies contact problems by the finite element method utilizing described above computational algorithms. At the present time, the FEM processor is implemented for solution of two-dimensional problems. Triangular and quadrangular elements of the first and the second orders are used. The graphics postprocessor is intended for visualization and analysis of the calculated results.

RESULTS

The numerical modeling and analysis of crack extension in elasto-plastic finite bodies under indentation by instruments of different shapes and rigidity were obtained under conditions of a plane strain.
Dependencies of fracture mechanics parameters on sizes and positions of the cracks, which are located near to the contact area, are defined. Variations of crack extension paths with the selected local fracture criterion are investigated. Crack interaction effects are researched in case of a simultaneous extension in a body with several macrocracks.
Residual stresses in an elasto-plastic body after unloading are defined both in absence and in presence of cracks. Influence of residual stresses on behavior of cracks under a repeated local contact loading is researched.
Effect of friction force on contact surfaces of bodies and sliding mode crack faces on crack extension in elasto-plastic bodies is established.
Calculations were carried out based on various plasticity theories: the theory of small elasto-plastic deformations, the theory of plastic flow with isotropic, transmit and combined hardening. The comparative analysis of the results obtained for these plasticity theories is carried out.

CONCLUSIONS

Numerical modeling is an effective approach to research crack extension processes in elasto-plastic finite bodies under contact compression.
Based on the computational experiments, it is clarified that not only sliding mode cracks, but also opening mode cracks can develop in a body under contact compression. Regularities of residual stresses occurrence in elasto-plastic finite bodies under local compression and character of their influence on behavior of cracks under repeated contact compression are defined.
The further development of the offered approach should be directed on solution of three-dimensional elasto-plastic bodies' problems of fracture mechanics.

References

[1] Morozov Ye. M., Nikishkov G.P.: Finite Element Method in Fracture Mechanics. Nauka, Moskow, 1980. (in Russian)
[2] Computational Methods in the Mechanics of Fracture: Ed. by Atluri S.N. North-Holland, NY, 1986.