An important role of elastic vortices in unsteady propagation of longitudinal shear cracks in brittle materials

Evgeny V. Shilko*[1], Sergey G. Psakhie[1] and Valentin L. Popov[2]

[1] Institute of Strength Physics and Materials Science SB RAS (ISPMS SB RAS)
2/4, pr. Akademicheskii, 634021 Tomsk, Russia
e-mail: shilko@ispms.tsc.ru, web page: http://www.ispms.ru

[2] Berlin University of Technology (TU Berlin)
Sekr. C 8-4, Str. Des 17. Juni 135, D-10623 Berlin, Germany
e-mail: v.popov@tu-berlin.de, web page: http:// http://www.tu-berlin.de/reibungsphysik

ABSTRACT

Dynamic propagation of longitudinal shear (mode II) cracks has been widely studied experimentally and theoretically in the contexts of earthquakes, fracture of materials (including nanostructured materials) and friction. The main feature of the dynamics of unstable shear rupture is formation of the shear stress concentration ahead of the crack tip. The shear stress peak was an object of intensive study by different authors due to its governing role in shear rupture transition from conventional sub-Rayleigh to supershear (intersonic) regime. Despite this basic understanding of the mechanisms of longitudinal shear crack propagation, some fundamental questions concerning the material deformation in the vicinity of the crack tip are still not fully understood. In particular, the physical mechanisms of the formation of a stress concentration region ahead of the crack tip and its stability as well as necessary conditions for the intersonic crack propagation have not yet been completely understood. Presented study is devoted to the numerical analysis of this problem.

The study was carried out by means of numerical modeling using distinct element method. A two-dimensional slab containing low-strength interface with initial crack was considered. Both parts of the slab were assumed to be made from the same high-strength brittle material. Shearing deformation of the slab in the direction parallel to the interface line was modelled.

Simulation results have shown that a vortex-shaped motion pattern (hereafter referred to as elastic vortex) is formed in the vicinity of the shear crack from the very beginning of crack propagation. With progressing growth of the crack the elastic vortex involves more and more of the medium ahead of the crack tip. The propagation velocity of the elastic vortex quickly approaches the shear wave speed, while the crack advances at a velocity lower than the Raleigh wave speed. Therefore, during the course of propagation the vortex gradually moves away from the crack tip and finally detaches from it. After separation of the elastic vortex from the crack the new vortex starts to form at the tip. Finally, mode II crack propagating in conventional sub-Rayleigh regime generates a chain of elastic vortices moving ahead of the tip at a shear wave speed. The most important feature of these elastic vortices is shear stress concentration in their frontal parts. The position of the maximum of shear stress distribution in the vortex corresponds to the position of the stress peak ahead of the crack as described by different authors. Analysis of the simulation results gives grounds to state that unsteady character of shear crack propagation in conventional sub-Rayleigh regime (including crack velocity oscillation) is explained by generation and emanation of elastic vortices. Note that the concept of vortex-related dynamics of unstable rupture is useful for general understanding of instabilities in brittle fracture.

Finally, the conditions under which the acceleration of a longitudinal shear crack to an intersonic speed takes place are discussed. It is shown that geometrical parameter governing such acceleration is the ratio (P) of the initial crack length to a parameter which may be called the “crack thickness”. If the initial crack is characterized by the magnitude of the geometrical parameter $P<P_{crit}$ (where P_{crit} is the value, at which the peak stress at the interface ahead of the crack reaches the interface strength), the crack can overcome the Rayleigh wave velocity barrier and propagate in intersonic regime. The value of the critical parameter P_{crit} depends on material elastic and viscous properties. Specific forms of these dependencies are discussed.