The Sources of Dynamic Fracture Toughness of Steels

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(Abstract)

It is shown that the dynamic fracture toughness, or the resistance of a steel plate to rapid crack propagation, is derived from two essentially different sources. One is connected with the microscopic plastic deformation of the fracturing metal at the tip of a running crack. The other is related to the formation of macroscopic plastic enclaves at some distance from the crack line. Accordingly, the dynamic fracture toughness of steel depends on both microscopic and macroscopic material properties, which are functions of temperature. The purpose of this paper is to describe the individual material properties and resolve their respective influences in the energy balance of the propagation process, and in crack arrest.

The microscopic material properties which must be considered are derived on the basis of recent studies of the micromechanism of fracture propagation. For steels which exhibit cleavage or quasicleavage as predominant fracture modes, local material

separation is accomplished in two steps. First, the polycrystal is weakened by propagation of cleavage microcracks through grains with favorably oriented crystallographic cleavage planes ahead of the main crack tip. This easy cleavage process proceeds in the Griffith manner, follows a continuous, multiply connected nearly planar path and leaves behind disconnected links which span the opening crack. A discrete crack zone which extends over many grains thus exists at the tip of a running brittle crack. The second step in the local separation process consists of plastic straining and progressive failure of the remaining links. The stresses transmitted by the separating material in the crack zone determine the crack tip boundary conditions [1,2]. An analysis of this process shows that easy cleavage consumes only a small amount of energy, and therefore, plastic straining of the links is the primary source of fracture toughness which can be derived from microscopic material properties. It was found that the nominal plastic strain rates in the crack zone are of the order of 10^5 to 10^6 sec^{-1}. A comparison with the results of dynamic tension tests on several representative steels indicated that the flow stress at these strain rates would exceed the twinning stress. Accordingly, twinning appears to be the principal deformation mode in the crack zone so that the microscopic material properties can be assumed to be independent of crack velocity and only slightly dependent on temperature [3].

The macroscopic material properties which must be considered in crack propagation problems are the dynamic yield and flow characteristics of the fracturing metal. These can be ordinarily

measured in high rate uniaxial tests and incorporated into general yield conditions and flow rules.

The analysis of the respective influences of the two sets of material properties in fracture propagation problems is made for the case of a steady state crack which propagates under plane strain conditions in a steel plate. A numerical procedure is used for evaluation of dynamic yielding in the vicinity of the crack tip. In agreement with earlier results [4], it is shown that plastic enclaves can form at some distance from the crack line. The energy needed for their formation can represent the dominant component of the dynamic fracture toughness. The onset of enclave formation and the rate of their expansion is shown to depend on such external conditions as crack geometry and temperature, and on both the microscopic and macroscopic material properties. The enclaves are found to form only at higher temperatures which are usually connected with energy transition and crack arrest and the mechanism of these processes is explained. It is noted that the enclave formation process depends rather strongly on small changes in both the microscopic and macroscopic material properties and it follows that there is substantial room for improvement of the dynamic fracture toughness of steels by metallurgical means.

References

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