THE EXPRESS METHOD OF DETERMINING THE FRACTURE TOUGHNESS OF BRITTLE MATERIALS

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Abstract. This paper presents a novel method of fracture toughness determination, - a method that does not require introduction of an initial crack or notch-type defect in a sample. The corresponding formula for calculating fracture toughness, which does not depend on crack length is derived. This “express” test is useful for industrial applications because it economical and may be used for a wide range of brittle materials from ceramics to concrete and rocks. Test results are shown to be in good accord with the results obtained by ASTM methods.

1. Introduction. Much work has been done on elaboration of laboratory test methods of fracture toughness determination for such materials as ceramics, concrete, rocks, etc. (for review, see Murakami (1987)). However, easily accessible and reliable test methods that industry needs for the material evaluation at wide range of temperature and environmental conditions seem to be missing.

The existing methods of measurement of fracture toughness (see, for example, Jaeger and Cook (1983), Nisitani and Mori (1985), Hertzberg R. (1983), and Staroselsky et al. (1990)) involve laborious process of introduction of a crack which initiates fracture. Furthermore, fatigue crack growth cannot be recommended for brittle materials, since it increases lengths of existing microcracks and other defects that change the properties of the sample.

Here, we suggest a method that eliminates these deficiencies. Fracture toughness determination is performed using samples without initial cracks. A sample has the shape of a disk with a circular hole in the center. It is monotonically loaded by a pair of compressive forces as shown in Fig.1. The central hole, playing the role of the defect, initiates fracture.

All existing methods for \( K_{IC} \) determination are based on elasticity solutions for bodies with cracks. Therefore, the corresponding expressions for \( K_I \) involve the initial crack length as a parameter. For the “crackless” sample and the loading scheme suggested here we obtain a formula for \( K_{IC} \) that depends only on the sample dimensions and on the critical value of the load.
The proposed method does not require any essential preliminaries to tests. It is particularly useful in industrial tests if the supply of material is limited.

2. Test Configuration and Mechanical Model. The basic idea behind the method is to eliminate the process of introduction of the initial crack. The sample (Fig. 1) is a ring with outer radius \( R_{out} \), inner radius \( R_{in} \), and thickness \( h \) that is sufficient to realize plane strain conditions. It is loaded by a pair of point forces \( P \) acting along diameter (AB). The distribution of the load across the thickness of the disk is uniform.

![Test sample and loading scheme.](image)

Figure 1. Test sample and loading scheme. \( R_h \) is the hole radius; \( R_{dd} \) is the disk radius; \( h \) is the disk thickness, and \( P \) is the magnitude of applied load.

Friedman et al. (1972) show that drilling a hole creates a process zone (zone of microcracking) with a thickness of roughly one to two diameters of the average grain size appears around the hole. When the force is applied, the microcracks situated in close proximity to the line of the force (AB) at the edge of the inner hole start to grow and, at some value of the force, give rise to a macrocrack. Other pre-existing cracks within the specimen do not grow. A radial crack nucleates and propagates from the inner hole along the line of force (AB).

In the ring sample subjected to the compression along the diameter (AB) the normal stress component in the circumferential direction \( \sigma_\theta \) is predominately tensile for the cross section (AB) and mostly compressive for the orthogonal cross section (CD). The corresponding elastic two-dimensional solutions for stress distribution in a solid ring have been obtained by Timoshenko and Goodier (1970) and Ripperger and Davids (1947) as an infinite series, and in different form by Muskhelishvili (1963). Because brittle materials are typically strong in compression and relatively weak in tension, failure starts at the point of the inner boundary along the diameter (AB).

To obtain the formula of fracture toughness for this load scheme, we take as a basis the approximate solution obtained by Murakami et al. (1986). Using the