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A fracture mechanics approach to the crack formation in alkali-sensitive grains

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ABSTRACT

The cause of cracking of slow/late aggregates is supposed to be due to gel pressure in the grain. The cracking of grains is approached with the aid of fracture mechanics and the decisive parameter for crack extension is the critical stress intensity factor. Various types of rock were stored in alkaline solution. The critical stress intensity factor was determined as function of exposure time. A theoretical correlation between grain size, critical stress intensity factor, and gel pressure was established.

1. Introduction

Alkali–silica reaction (ASR) is a degradation process of concrete which has numerous aspects. One concerns the so-called slow/late aggregates which react only after several years of exposure. Another concerns the mechanism of crack formation in concrete. The literature contains and describes two fundamentally different mechanism of degradation. One mechanism claims that dissolution takes place at the surface of the aggregate grain [1] and that a gel develops at the surface of the grain which can crack the matrix around the grain due to swelling pressure. This mechanism is discussed in detail by Diamond [2]. The other theory states that internal cracks form in the grain also due to gel formation which extend into the matrix and leads finally also to cracks in concrete [3–5]. The second approach assumes that a critical expansion of the aggregate must be reached in order to start cracking. The ASR induced degradation is modeled with finite elements in [6] assuming a critical stress as failure criterion. However, here it is argued that cracks develop due to a dissolution process and that a critical crack length must exist before the grain can be split. Final splitting is caused by the swelling pressure of a gel. Whereas [3–6] assume either a limiting strain or a limiting stress as failure criterion the fracture toughness is regarded as the decisive parameter for crack extension. Fracture mechanics has been developed to describe the limit state of brittle materials under load. In fracture mechanics terms the stress field around a crack is calculated in which the stress intensity factor is the governing parameter. When the stress intensity factor reaches the critical stress intensity factor which is a characteristic parameter of the material a crack propagates. This approach will be applied to slow/late aggregates.

2. Fracture mechanics approach

According to the theory of linear-elastic fracture mechanics the stress around the tip of a sharp crack is given by a function of the stress intensity factor. The stress intensity factor depends on the loading and the geometry of the situation considered. There are several books available which list the stress intensity factors for many geometries, see for instance [7–10]. In the current study, a grain is idealized as sphere with a penny-shaped crack in the center. Fig. 1 shows the situation with R = radius of the sphere and a = radius of the crack. x, y, z are the coordinates.

In the interior of the crack, the uniform pressure p_0 is acting. If R is infinite the solution of the crack intensity factor reads for linear-elastic material [10]

$$K_I^\infty = \frac{2}{\pi} \cdot p_0 \cdot \sqrt{\pi \cdot a} \tag{1}$$

If the sphere has a finite radius Eq. (1) has to be corrected by the shape factor $Y(a/R)$. For $a/R \leq 0.60$, the closed-form solution reads [11]

$$\begin{aligned} Y(a/R) = \frac{K_I}{K_I^\infty} = {} & 1 + 1.5433 \cdot \left(\frac{a}{R}\right)^3 - 2.3870 \cdot \left(\frac{a}{R}\right)^5 + 2.3818 \cdot \left(\frac{a}{R}\right)^6 \\ & + 3.2711 \cdot \left(\frac{a}{R}\right)^7 - 6.4470 \cdot \left(\frac{a}{R}\right)^8 - 0.2107 \cdot \left(\frac{a}{R}\right)^9 \\ & + 0 \cdot \left(\frac{a}{R}\right)^{10} \end{aligned} \tag{2}$$

For $a/R > 0.60$ numerical methods have to be applied. Table 1 gives some numerical values of $Y(a/R)$.

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