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Determination of double-K fracture parameters of concrete using peak load method

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ABSTRACT

This paper presents application of peak load for determining double-K fracture parameters of concrete. The existing conventional experimental method and analytical methods require measurement of crack opening displacement at critical condition during fracture test whereas this measurement is not required in peak load method. Further, double-K fracture parameters are computed using both conventional analytical method and peak load method for three point bending test of specimen size range 200–500 mm. The comparison of the results shows that both the fracture parameters of the double-K fracture model can be determined using peak load method without any appreciable error.
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1. Introduction

Kaplan [1] first introduced the concept of linear elastic fracture mechanics (LEFM) to pre-cracked beam for determining the fracture toughness of concrete. Since then, numerous experimental and numerical investigations have been carried out to predict fracture behavior of quasi-brittle materials like concrete. Now it is well understood that LEFM is not applicable to normal size structural concrete because of presence of a large and variable nonlinear fracture process zone at the crack-tip which can be described by two simplified nonlinear fracture principles: first using numerical approach such as cohesive crack model (CCM) or fictitious crack model (FCM) [2–14] and crack band model (CBM) [15] and the second using modified LEFM concept such as two parameter fracture model (TPFM) [16], size effect model (SEM) [17], effective crack model (ECM) [18], K_R-curve method based on cohesive force distribution [19,20], double-K fracture model (DKFM) [20–25] and double-G fracture model (DGFM) [26].

Even using LEFM principles, the double-K fracture model can describe the three important stages of crack propagation in concrete viz.: crack initiation, stable crack propagation and unstable fracture in concrete. This method is characterized by two material parameters: initial cracking toughness K_{IC}^{ini} and unstable fracture toughness K_{IC}^{un}.

Xu and Reinhardt [21,22] developed analytical methods for three point bend test (TPBT) and compact tension (CT) or wedge splitting test (WST) to determine the values of double-K fracture parameters. A simplified approach was further proposed by Xu and Reinhardt [27] for determining the fracture parameters K_{IC}^{ini} and K_{IC}^{un}. Kumar and Barai [23–25] introduced the weight function approach for determining the double-K fracture parameters with better computational efficiency as well as without loss of accuracy. Extensive experimental and numerical studies have been reported in the literature [28–37] to study the double-K fracture parameters of concrete.

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Nomenclature

a_o	initial crack length
a_c	effective crack length at peak (critical) load
B	width of beam
c_1, c_2	material constants for nonlinear softening function
D	depth of beam
Δa_c	effective crack extension at critical load
E	modulus of elasticity of concrete
F_1, F_2	geometric factors for different loading cases
$F(x/a, a/D)$	the standard Tada Green's function for edge cracks subjected to pair of forces normal to the crack face
f_t	uniaxial tensile strength of concrete
K_I	stress intensity factor in mode I fracture
K_{IC}^{ini}	the initiation toughness
K_{IC}^{un}	the unstable toughness
K_{IC}^{C}	the cohesive toughness
$m(x,a)$	weight function
M_1, M_2, M_3	parameters of weight function
S	span of beam
P_{ini}	crack initiation load
P_u	maximum applied load
σ	cohesive stress
σ_{Nu}	peak nominal stress
υ	the Poisson's ratio
w_g	the self weight per unit length of the beam

It is well known that the conventional experimental method and analytical methods for determining double-K fracture parameters of concrete are based on linear asymptotic superposition assumption. In the experimental method, the initial cracking load (P_{ini}), initial crack length (a_o), peak load (P_u) and crack mouth opening displacement at peak load ($CMOD_c$) must be recorded while P_u and $CMOD_c$ must be measured in the analytical method during the fracture test. In both the cases, $CMOD_c$ must be measured during the test which requires a sophisticated clip gauge. On the other hand P_u can be easily measured by any universal testing system. The correct measurement of $CMOD_c$ may be a difficult task in the laboratory if the clip gauges are not properly attached with the specimen. To avoid this difficulty, the double-K fracture parameters can be determined using only peak load similar to the determination of fracture parameters of two parameter fracture model [38]. This method was recently applied by Ince [39] for determining the fracture parameters of two parameter fracture model for different specimen geometries such as cubical, cylindrical and beam specimens. Further Ince [40] put forward for determining the double-K fracture parameters of concrete using weight function method with peak load obtained from experiments for various specimen geometries. In light of the above facts, the present paper attempts to determine the fracture parameters of double-K fracture model using theoretical peak load method such that the measurement of $CMOD_c$ can be avoided in the tests. The fracture parameters obtained for three point bend test using conventional method and the proposed peak load method are also compared. For this purpose, the required input data such as peak load (P_u) and $CMOD_c$ for three point bend specimen are precisely obtained using developed fictitious crack model. For completeness of the paper, brief procedures of existing experimental method as well as analytical method for determination of double-K fracture parameters are outlined in the subsequent sections.

2. Determination of double-K fracture parameters

2.1. Experimental method

It is well known that the double-K fracture parameters can be determined using experimental test results in which the primary requirement is to know the P_{ini}, a_o, P_u and $CMOD_c$ from the tests. Generally, two direct methods are employed to determine the value of P_{ini}. In the first method, the P_{ini} is directly obtained during test by means of strain gauges or with the help of acoustic emission or by laser speckle interferometry method at the tip of initial crack tip. In the second method, the starting point of non-linearity in P–CMOD curve obtained from the experiment is considered to be P_{ini}. In this method, proper care should be taken to draw a straight line along the linear part of P–CMOD curve obtained from the test and to locate the distinct bifurcation point between linear and nonlinear parts of the P–CMOD curve. This bifurcation point which is regarded as the initial cracking point yields the value of P_{ini}. Therefore experimental determination of initial cracking load requires high degree of precision and special attention during test. Once, the P_{ini}, a_o, P_u and $CMOD_c$ are recorded, the initial cracking toughness K_{IC}^{ini} and unstable fracture toughness are determined using LEFM equations.

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