Engineering Fracture Mechanics 77 (2010) 2168–2181

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

A discussion on major factors affecting crack path of concrete-to-concrete interfacial surfaces

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ARTICLE INFO

Article history:
Received 12 December 2009
Received in revised form 17 February 2010
Accepted 7 March 2010
Available online 12 March 2010

Keywords:
Concrete-to-concrete interface
Crack path
Tension softening diagram
Fracture mechanisms

ABSTRACT

This paper elaborates major factors affecting the crack path of concrete-to-concrete interfacial surfaces produced with placing joint. Eleven types of specimens were employed for the evaluation of tension softening diagram followed by surface observation of the ligament after fracture test. The surface analysis revealed that the layer of $Ca(OH)_2$ plays a primary role on the crack path. The authors discuss the relationship between fracture mechanics parameters and the ratio of fractured part which excludes detached part in the ligament. The mechanism for determining crack path near concrete-to-concrete interface is proposed using 'scattered hole model'.

1. Introduction

Every concrete structure has inevitably concrete-to-concrete interfacial surfaces such as construction joint, casting of additional concrete for reinforcement and laying of cover layer for the finishing. In these days of heading towards rational structural design and economical construction, there are lasting needs for an enhancement of structural performance deteriorated by such discontinuous interface in concrete structure. Improving the performance would be achieved through an understanding of the adhesion mechanisms aided by the identification of crack path in the interface.

There are many literatures that studied the ways of enhancing the strength of placing joint experimentally beginning at very early date [1]. But little study is conducted concerning the relationship between crack path and its leading mechanism, which the authors considered to be the most important agenda, constituting the main motivation of this study. The study of crack path should involve the observations of the interface chemically and physically.

The study is effectively conducted with employing the latest analyzing equipments such as Scanning Electron Microscope (SEM), Electron Probe Micro Analyzer (EPMA) and laser Three Dimensional (3-D) measuring equipment. The performance of the interface is adequately understood with tension softening diagram (TSD). TSD is the most fundamental feature of fracture mechanics parameters, and the study of it is inevitable for a better understanding of the basic fracture mechanisms. Kurihara et al. [2] analyzed the TSD of placing joint and led some important aspects of the mechanical properties. The authors have studied TSDs of placing joint and discussed the relationship between strength and ductility of the interface of placing joint with employing models based on TSD [3–5].

All of the previous studies focus on the individual aspects of the crack path and the mechanical performances with no integrated studies. This paper aims at integrating the features of crack path with the mechanical performance employing TSD and some micro- and meso-scale observations, finally revealing the way for identifying the weak parts and a new model for describing the mechanism of determining the crack path.

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doi:10.1016/j.engfracmech.2010.03.005

Nomenclature

a	diameter of a hole in Fig. 17d
a_0	total length of propagated crack in Eq. (2)
A	area of fractured part in Eq. (2)
Ae	effective area in Eq. (5)
Alig	total area in the ligament in Eq. (4)
$b1$, $g1$, $b2$, $g2$	distance from a hole to another hole in x direction or y direction in Fig. 17d
$b(w)$	reduced width at the height of specimen which corresponds to a specific crack width
CH	$Ca(OH)_2$ or calcium hydroxide
CMOD	crack mouth opening displacement
EPMA	electron probe micro analyzer
$E(w)$, $E(\mathrm{Wcr}_{(X)})$	entire fracture energy consumed in the ligament which corresponds to the specific crack width or $\mathrm{Wcr}_{(X)}$
fb	bending strength
FPZ	fracture process zone
ft	tensile strength or tension softening initial stress
GF, GF(w)	fracture energy or fracture energy at a specific crack width
$\mathrm{GF}_{(X)}(\mathrm{Wcr}_{(X)})$, $\mathrm{GF}_{(Z)}(\mathrm{Wcr}_{(Z)})$	GF absorbed until $\mathrm{Wcr}_{(X)}$ of specimen-X or until $\mathrm{Wcr}_{(Z)}$ of specimen-Z
$\mathrm{GF}_{(SX)}(\mathrm{Wcr}_{(X)})$, $\mathrm{GF}_{(SX)}(\mathrm{Wcr}_{(Z)})$	predicted GF absorbed until the crack width becomes $\mathrm{Wcr}_{(X)}$ or $\mathrm{Wcr}_{(Z)}$ of specimen-X
GFpx	GF absorbed until the maximum load
ITZ	interfacial transient zone
JCI	Japan concrete institute
L	total length of tension member in Fig. 17d
Pt	maximum height of surface waviness
RILEM	the international union of laboratories and experts in construction materials, systems and structures
SEM	scanning electron microscope
TSD	tension softening diagram
w	crack width
Wcr, $\mathrm{Wcr}_{(X)}$, $Wcr_{(Z)}$	critical crack width, critical crack width of specimen-X or specimen-Z
Wpx	crack width which corresponds to the maximum load
3-D	three dimensional
α	coefficient for calculating effective area in Eq. (5)
αx	height of crack tip in specimen in Fig. 13
$\sigma(w)$,$\sigma_x(w)$,$\sigma_Z(w)$	closure stress of a specimen, specimen-X or specimen-Z at a specific crack width
$\sigma_{sx}(w)$	predicted closure stress of specimen-X at a specific crack width
θ	crack opening angle
Φ	fractured ratio in the ligament

2. Experiment and results

2.1. Specimens

The authors prepared eight types of specimens with a varied type of placing joint made from different roughening or different mold on them, and three types of monolithic specimens with a varied size of maximum aggregate for references. Table 1 shows the attributes of specimens, and Table 2 the mix proportion of concrete. The compressive strength of concrete is 42.7 MPa, and the tensile strength measured by splitting test of cylinder is 3.83 MPa, which were measured at the age of 4 weeks. The joint sheet used in the specimen-J in Table 1 refers to a piece of indented plastic sheet generally used in manufacturing precast concrete members for a mold of placing concrete, whose height of cone is 8 mm and spacing between the cones is 30 mm.

The number of specimens was three for each case, which have a section of 100 mm by 100 mm and a length of 400 mm. After 24 h from the 1st cast of concrete in the half part of a mold, the joint surface was roughened in the case of specimen-R (see Table 1). Then concrete was cast in the remained half of a mold as depicted in Fig. 1. The specimens were cured in water at 20 °C for 28 days after the final cast of concrete. A 50 mm depth notch was incised at the center of the specimen before the fracture mechanics test.

2.2. Fracture mechanics test and analysis

Fracture mechanics test was conducted with observing RILEM's recommendation [6]. Load and crack mouth opening displacement (CMOD) were measured continuously during the loading. To cancel the dead weight of specimen and to obtain a