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Experimental and Numerical Study of Shear Fracture in Brittle Materials with Interference of Initial Double Cracks**

Hadi Haeri[1*] **Vahab Sarfarazi**[2] **Mohammad Fatehi Marji**[3]
Ahmadreza Hedayat[4] **Zheming Zhu**[5]

([1] *Young Researchers and Elite Club, Bafgh Branch, Islamic Azad University, Bafgh, Iran*)
([2] *Department of Mining Engineering, Hamedan University of Technology, Hamedan, Iran*)
([3] *Associate Prof., Head of Mine Exploitation Engineering Department, Faculty of Mining and Metallurgy, Institution of Engineering, Yazd University, Yazd, Iran*)
([4] *Department of Civil and Environmental Engineering, Colorado School of Mines, Golden, Colorado* 80401, *USA*)
([5] *College of Architecture and Environment, Sichuan University, Chengdu* 610065, *China*)

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ABSTRACT A simultaneous experimental and numerical study of shear fracture of concrete-like materials is carried out using Brazilian disc specimens with initial double edge cracks and fourpoint bending beam specimens with double edge-notches. The interference effects of two cracks/notches are investigated through varied ligament angles and crack lengths. It is shown that shear fracturing paths change remarkably with the initial ligament angles and crack lengths. The cracked specimens are numerically simulated by an indirect boundary element method. A comparison between the numerical results and the experimental ones shows good agreement.

KEY WORDS double edge cracks, concretelike specimens, crack propagation, indirect shear loading, overlapped cracks

I. Introduction

Concrete is one of the most widely used construction materials because of its relatively high compressive strength, high durability, long-term stability, low permeability and good fire resistance properties. A concrete structure, either plain or reinforced can be readily handled and placed into any form and cast into any desired shape, and is therefore very flexible and common in use. Cracks that occur before hardening are usually the result of settlement within the concrete mass, or shrinkage of the surface (plastic-shrinkage cracks) caused by rapid loss of water while the concrete is still plastic. In reinforced concrete the settlement cracks may develop over embedded items, such as reinforcing steel or adjacent to forms or hardened concrete as the concrete settles or subsides. In plain concrete, the settlement cracking results from insufficient consolidation (vibration) and high slumps (overly wet concrete). Plastic-shrinkage cracks are relatively short cracks that may occur before the final finishing on days with high winds, low humidity, and high temperature. Surface moisture evaporates faster than it can be replaced by rising bleed water, causing the surface to shrink more than the interior concrete.

* Corresponding author. E-mail: haerihadi@gmail.com
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As the interior concrete restrains shrinkage of the surface concrete, stresses develop and exceed the concrete's tensile strength, resulting in surface cracks. Cracks that occur after hardening are usually the result of drying shrinkage, thermal contraction, or subgrade settlement. While drying, hardened concrete will shrink. To accommodate this shrinkage and control the location of cracks, joints are placed at regular intervals within the concrete structure. However, the presence of different cracks (which are usually produced in the form of internal cracks within the concrete texture) may extremely reduce the strength of concrete structures especially in initial hours of casting and even before it is placed under loading. Concrete may break due to both shear and tension under various loading conditions. The shear fracturing of concrete may be studied by investigating the propagation mechanism of these defects (internal cracks). The shear fracture in pure Mode II (shearing mode) may occur under some peculiar conditions but the mixed mode fracture (Mode I or opening mode and Mode II) may occur in many circumstances in concrete structures[1].

The mechanical behavior of pre-notched concrete structures under shear loading condition has attracted the attention of researchers and practical engineers over the last three decades. Extensive work on the coalescence pattern and shear resistance of pre-existing cracks in solid materials have been performed in many experimental and theoretical studies[2]. The mechanical behavior of concrete may depend on the extension of pre-existing cracks (notches) which in turn depends on the geometric distribution and intensity of these flaws, their sizes, positions, orientations, and loading conditions.

Kaplan[3] investigated the fracturing behavior of notched concrete beams using the linear elastic fracture mechanics (LEFM) theory for three and fourpoint bending tests conducted on concrete and rock materials. He suggested some models for predicting the fracture behavior of concretes such as the Fictitious Crack Model (FC-model)[4], the Crack Band model[5,6] and the Two Parameter Model[7]. Ozcebe et al.[8] studied the breakage of T-type beams and Ruiz and Carmona[9] considered the effect of the shape of crack propagation paths on rectangular and T-type beams. On the other hand, Ruiz et al.[10] theoretically analyzed the initiation and propagation cracks at the head of the beam. Savilahti et al.[11] carried out direct shear tests on specimens of jointed plaster material containing non-overlapped and overlapped joints. Wong et al.[12] conducted direct shear tests on specimens of plaster material and natural rocks containing open non-persistent joints to investigate the shear strength and breakage of brittle solids. According to their findings, the breakage pattern of the specimens mainly occurred by joint separation. In addition, Gehle and Kutter[13] studied the breakage and shear behavior of intermittent rock joints under direct shear loading conditions. It has been concluded that the shear resistance of pre-cracked rock specimens may be affected by crack inclination. Many experimental studies have also been devoted to studying the initiation, propagation, interaction and coalescence of pre-existing cracks in specimens of various solids, including natural rocks or rock-like materials under compressive loading[14–18].

In the present work, the crack propagation mechanism of pre-cracked concrete specimens is studied by carrying out some indirect shear tests on the specially prepared samples (with a proper mixture of Portland Pozzolana Cement (PPC), fine sand and water) in a geotechnical laboratory. The mechanism of crack propagation in these pre-cracked specimens is also simulated numerically by a modified higher order displacement discontinuity method. A computer code is provided by using a cubic variation of displacement discontinuities along each boundary element (i.e. each boundary element contains four equal sub-elements). The Mode I and Mode II stress intensity factors are computed based on the LEFM concepts. The σ-criterion is implemented in this computer code to predict the possibility of crack propagation and estimate the crack initiation direction.

In this study, the double edge-cracked Brazilian disc and double edge-notched beam specimens are tested to study the crack propagation process of brittle concrete specimens. It is observed that the tensile cracks (wing cracks) are commonly produced in indirect shear tests (Brazilian disc and fourpoint flexure bending tests). These wing cracks are generated from the original tips of the pre-existing notches. In some cases more than one crack (single crack) may occur in concretes. As the shearing behavior of pre-cracked specimens can be studied using various cases the design of some proper specimens with different geometries and different loading conditions can further increase the knowledge and understanding of the fracturing behavior of concrete.

The specimen with double notches (cracks) represents more practical crack orientation compared to the specimen containing a single crack. Moreover, the effects of ligament angles and crack lengths on