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Investigation on stress-crack opening relationship of engineered cementitious composites using inverse approach

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ABSTRACT

The stress-crack opening relationship of engineered cementitious composites was determined with an inverse method. Four cement matrixes with water to cement ratio of 0.55, 0.45, 0.35, 0.25 and fiber contents of 0.5%, 1.0% in volume were selected to form different series of composites. The results show that the σ–w relationship of the cement matrix is instant strain softening after the cracking strength. After adding polyvinyl alcohol fibers, the stress-crack opening relationship of the composites changes to a double peak mode behavior as the crack bridging first decreases from cracking strength, then increases to the second peak. After that the tensile softening is displayed again with increase of crack opening. The cracking strength is governed by the cement matrix and the second peak stress is controlled by the fibers and fiber/matrix interface. The second peak is greatly increased with increase of fiber content. The second peak stress larger than the cracking strength means strain-hardening and multiple cracking performances can be expected under tension.

1. Introduction

Concrete is a typical brittle material where first cracking in tension is accompanied by immediate localization of deformation followed by decreasing load. In normal reinforced concrete structures, as the stress reaches the tensile strength of concrete under mechanical and/or environmental loads, a small number of widely spaced discrete cracks will form and the crack width quickly opens to a macroscopically visible level. The formation of widely opened cracks allows water and other chemical agents, such as deicing salt, to go through the cover layer to come into contact with the reinforcements. The durability of the concrete structure is then significantly affected. Many methods have been proposed to improve the durability of concrete structures in the past, but most focus on the transport properties of un-cracked concrete, with little attention paid to the control of cracks. To prevent the rapid penetration of water and corrosive chemicals through cracks, a fundamental approach to reduce the crack width in concrete during its service stage has to be developed [1].

In recent years, a class of high performance fiber reinforced cementitious composite, called Engineered Cementitious Composites (ECC), with an ultimate strength higher than the first cracking strength has been developed [2]. After first cracking, tensile load-carrying capacity continues to increase, resulting in strain-hardening accompanied by multiple cracking. For each individual crack, the crack width first increases steadily up to certain level and then stabilizes at a constant value. Further increase in strain capacity is capacity is achieved by the formation of additional cracks until the cracking reaches a saturated state with crack spacing limited by the stress transfer capability of the fibers. After that, a single crack localizes and the load slowly drops with increased deformation. Typically, strain localization occurs at a tensile strain of 2–4%, with crack spacing of 3–6 mm and crack width around 60 μm [2]. Typical tensile stress–strain curve and some photos of crack pattern under tension of such material are shown in Fig. 1 [3]. Cracks of such a small width will have little effect on the water permeability of the material [4]. With little degradation in transport properties under high deformation, the durability of the structure can be maintained. Due to the super mechanical and crack control performances, the conditions of the composite to achieve above performance are of great interest from the point of material design.

The design criterion for ECC has first been proposed by Li and Leung [5] and further developed in subsequent investigations [6–8]. The requirements for steady state crack propagation necessary for cementitious composite strain-hardening behavior, and the micromechanics of the stress-crack opening relationship (σ–w) combine to provide the guidelines for the tailoring of fiber, matrix and interface in order to attain strain-hardening with the minimum amount of fibers [6]. Steady state crack propagation means that a crack extends at constant ambient tensile stress, while maintaining a constant crack opening. This phenomenon occurs when the below condition is satisfied [6].

$$\frac{K_m^2}{E_m} \le \sigma_0 w_0 - \int_0^{w_0} \sigma(w) dw \qquad (1)$$

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