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Experimental Investigating the Effect of Glass Fibre on Mode I, Mode II, and Mixed Mode (I-II) Fracture Toughness and Crack Propagation in Fibre-Reinforced Concrete

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Abstract

Pre-existing joints, cracks and fractures are inevitable in stones and the other material used in engineering and are an inherent feature of all materials, which cause rock structures or masses to fail more quickly under mechanical loads or other environmental factors. Concrete is the most widely-used material in civil engineering and often contains the cheapest and most common matter. It can therefore cause irreparable damages due to cracks and fractures. The creation of fibre-reinforced concrete in recent years has largely rectified the aforementioned shortcomings. This study uses the direct crack Brazilian disk test to evaluate fracture toughness and crack propagation in fibre-free and glass fibre concrete samples in 0.2, 0.35 and 0.5 volume percentages. Moreover, fracture toughness and crack propagation from pre-existing cracks were calculated for samples in mode I, mode II, and mixed mode (I-II). The samples were subjected to the Brazilian disk test at 0, 15, 28.83, 45, 60, 75 and 90-degree angles relative to the pre-existing crack's trajectory. Laboratory investigations showed that the wing crack at sub 75-degree ($0<\alpha<75$) angles was initiated from the pre-existing fracture's tip and approached loading trajectory as the load on the crack growth and propagation trajectory continued. At the same time, crack initiation at 75-degree angles and above begins at a distance of d from the tip, which is greater in fibre-free samples. The results also showed that using 0.2% glass fibre in mode I, II and mixed mode (I-II) resulted in a higher fracture toughness than fibre-free samples.

Keywords: *crack propagation, fiber-reinforced concrete, mode I fracture toughness, mode II fracture toughness, mixed mode (I-II) fracture toughness*

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Extended Abstract:

1. Introduction

Concrete is considered the most widely used material in civil engineering, and its mix design should be determined in accordance with application, material type, and environmental conditions.

Despite a good compressive strength, concrete suffers from a low tensile and bending strength and ductility. By adding glass fibers to concrete and fabrication of fiber-reinforced concretes in the recent years, efforts have been made to eliminate these drawbacks to a large extent. Fibers play a key role in improving the above-mentioned drawbacks during concrete cracking. Random distribution of fibers and their directions in the fiber-reinforced concrete prevents crack formation and growth in various regions and directions by bridging the two crack edges.

Few studies are available on the mixed-mode fracture toughness and crack propagation in concretes. Luo et al. (Lou et al., 2017) studied crack initiation and propagation in BD specimens of marble rock at inclination angles of 0, 18, 36, 54, and 72°. When the crack was parallel to the loading direction, new cracks were formed at the crack tip and began to propagate along the loading direction. Wing cracks were formed at the tip of cracks at low inclination angles (β=18°). With increasing the inclination angle, the initiation of wing cracks deviated from the crack tip towards the center of the disc. In the case where the crack angle was perpendicular to the loading direction, the wing cracks did not initiate from the pre-existing crack tip.

The centrally straight-notched Brazilian disc (CSNBD) concrete specimens without glass fibers and those containing 0.2, 0.35, and 0.5 vol% of glass fibers were tested to predict crack propagation and fracture toughness. Furthermore, crack propagation from the pre-existing cracks in the specimens as well as the mode I, mode II, and mixed-mode (I-II) fracture toughness were calculated.

2. Materials and methods

To study the effect of glass fibers on the mode I, mode II, and mixed-mode (I-II) fracture toughness and crack propagation in the fiber-reinforced concrete, a total of 21 Brazilian discs specimens containing 0.2 vol% glass fibers, 21 specimens containing 0.35 vol% glass fibers, 21 specimens containing 0.5 vol% glass fibers, and 21 specimens without glass fibers were prepared with the same mix design with an average thickness and diameter of 25 and 75 mm, respectively. A crack with an average length of 15 mm was created in the center of the Brazilian disc.

The fracture toughness of the specimens was calculated at inclination angles of 0, 15, 28.8, 45, 60, 75, and 90° with respect to the central crack and relative to the loading direction.

A pressure loading test machine capable of recording stress and strain with jaws for the Brazilian test was used to determine the uniaxial compressive strength and the Brazilian tensile strength. An ultrasonic device was used to determine the velocity of longitudinal waves. A total of 5 specimens were used to determine each of the properties. The CSNBD specimens were tested to determine the fracture toughness. This test was developed by Awaji and Sato for the mixed-mode fracture of graphite, plaster, and marble specimens. Introduced by Atkinson, the stress intensity factor for this method can be used to determine the mode I, mode II, and mixed-mode (I-II) fracture toughness (Krishnan et al., 1998). Figure 1 schematically shows the geometry of the BD specimen.

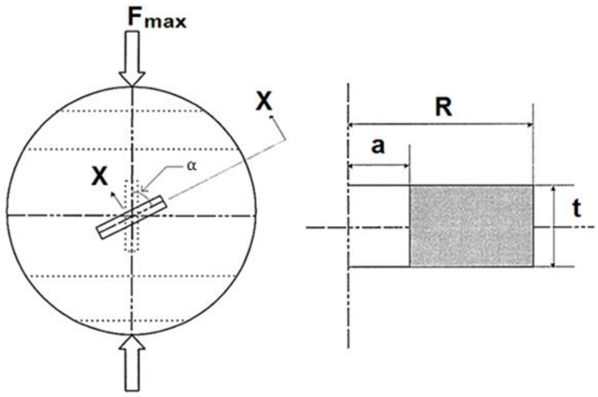

Figure 1. The geomerty of the BD specimen (Krishnan et al., 1998)

3. Tests results

The mode I fracture toughness of the concrete reinforced with 0.2 vol% of glass fibers increases by 19.6 and 7.2% relative to the fiber-free concrete at crack inclination angles of 0 and 90°, respectively. The pure shear mode fracture occurring at an inclination angle of 28.83° increases by 20.6% in the reinforced concrete relative to the fiber-free concrete. The specimen containing 0.2 vol% of glass fibers shows the highest increase in the fracture toughness among the concrete specimens. The effective fracture toughness (Keff) of the concrete reinforced with 0.2 vol% of glass fibers at crack inclination angles of 0, 15, 28.83, 45, 60, 75, and 90° is, respectively, 19.6, 6.6, 20.6, 18.6, 22.8, 5.4 and 7.2% higher than that of the fiber-free concrete specimen.

4. Conclusion

The results are as follows:

- Comparison of the diagrams obtained for the specimens containing different glass levels showed that the specimen reinforced with 0.2 vol% of glass fiber content had the highest fracture toughness.
- In all tested specimens, the crack initiation angle increased with increasing the crack inclination angle. The wing cracks then propagated towards the disc edge in a curvilinear path parallel to the loading direction. Interestingly, the crack initiated with a larger angle in the fiber-reinforced specimens and then propagated towards the loading point at the disc edge.
- At crack inclination angles equal to or less than 60°, the crack initiated with the growth of wing cracks of the crack tip. With increasing the crack inclination angles to 75 and 90°, the crack initiated with a distance of d from the crack tip. By adding the glass fibers, the specimens were fractured at inclination angles of 75 and 90° such that the distance d was lower than that in the fiber-free concrete specimens. In other words, unlike the fiber-free specimens, the fiber-reinforced concrete specimens began to fail from the center of the disc.
- The force required for the failure of the specimens decreased as the crack inclination angle increased from 0 to 45°, and then increased as the inclination angle increased from 45 to 90°.

References:

Krishnan, G.R., Zhao, X.L., Zaman, M. & Roegiers, J.C., (1998). Fracture Toughness of a Soft Sandstone. Int. J. Rock Mech. Min. Sci. (35)6, 695-710.

Lou, L., Li, X., Qiu, J. & Zhu, Q., (2017). Study on Fracture Initiation and Propagation in a Brazilian Disc with a Preexisting Crack by Digital Image Correlation Method. Materials Science and Engineering, Article id 2493921, 13 pages.