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# Experimental study of the effect of micro-silica and limestone powder on the fracture toughness of concrete

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**ABSTRACT:** Fracture toughness is one of the most important properties of concrete that controls the conditions for crack propagation and ultimately concrete failure. This research uses the Brazilian disk test to prediction of crack propagation and fracture toughness in ordinary concrete samples without micro-silica and lime powder and ordinary concrete samples containing micro-silica and lime powder has been investigated. Micro-silica replaces 10% by weight of cement and limestone powder replaces 5% by weight of cement. The crack propagation process was investigated from pre-existing cracks in the specimens as well as fracture toughness in modes I, II and hybrid mode I-II. Fracture toughness tests have been performed on Brazilian disk specimens at angles of 0, 15, 28.83, 45, 60, 75 and 90 degrees relative to the pre-existing crack direction. After laboratory studies, it was found that the onset of fin cracks at angles less than 60 degrees (0 <α <60) occurs from the pre-existing crack tip and approaches the loading direction by continuing to load and propagate the crack path. However, for angles of 60 degrees or greater, the crack starts at a distance d from the tip of the crack. This distance is more in ordinary concrete samples without micro-silica and limestone powder than in ordinary concrete samples containing micro-silica and limestone powder. Samples containing micro-silica and limestone powder have higher fracture toughness of modes I, II and mixed state (I-II) than samples without micro-silica and limestone powder. .

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## 1- Introduction

Concrete is among the key building materials, increasingly consumed in all countries for multiple reasons. Studying crack development, extension, and joining plays a vital role in predicting the fracture process, as rock or concrete is eventually fractured by joining and alternative growth of cracks [1]. Fracture toughness is among the critical mechanical properties that control crack extension and rock fracture. In fracture mechanics science, the stress intensity factor estimates the critical conditions of a notched piece at the crack tip. The stress intensity factor (K) determines the local stress at the crack tip.

In this research, tests have been taked out on straight-notched Brazilian disc specimens.

This test was developed by Awaji and Sato (1978) to measure the mixed-mode fracture toughness of graphite, plaster, and marble specimens. Atkinson introduced the shear intensity factor for this method, which can be used to determine mode I, mode II, and mixed-mode fracture toughness (Figure 1) [2].

Mode I, mode II, and mixed-mode fracture toughness are calculated from Eqs. 1-5 [2].

$$K_{IC} = \frac{F_{\max}\sqrt{a}}{\sqrt{\pi}Rt} N_I \tag{1}$$

$$N_I = 1 - 4\sin^2\alpha + 4\sin^2\alpha(1 - 4\cos^2\alpha)(\frac{a}{R})^2 \tag{2}$$

$$K_{IIC} = \frac{F_{\max}\sqrt{a}}{\sqrt{\pi}Rt} N_{II} \tag{3}$$

$$N_{II} = [2 + (8\cos^2\alpha - 5)(\frac{a}{R})^2]\sin 2\alpha \tag{4}$$

$$K_{eff} = \sqrt{K_I^2 + K_{II}^2} \tag{5}$$

This research uses the Brazilian disk test to predict of crack propagation and fracture toughness in ordinary concrete samples without micro-silica and lime powder and ordinary concrete samples containing micro-silica and lime powder have been investigated.

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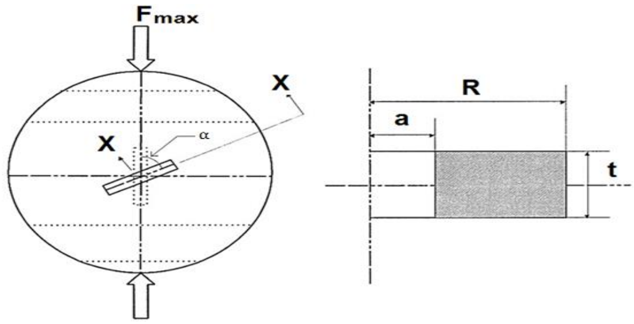


**Fig. 1. The geometry of BD specimen [3]**

**Fig. 2. Molds constructed to prepare SNBD concrete specimens**

**Table 1. The mix designs of concretes**

| Components | Conventional concrete lacking microsilica and limestone powder (content per per $m^3$ concrete) | Concrete containing microsilica and limestone powder (content per per $m^3$ concrete) |
|---|---|---|
| Type 2 Portland Cement (kg) | 350 | 297.5 |
| Sand (kg) | 1150 | 1150 |
| Gravel (kg) | 700 | 700 |
| Microsilica (wt% relative to cement) | 0 | 10 |
| Limestone powder (wt% relative to cement) | 0 | 5 |
| Water/cement ratio | 0.4 | 0.4 |
| Super-plasticizer (wt% relative to cement) | 0.8 | 0.8 |

## 2- Sample preparation

Table 1 presents the mix designs of conventional concrete lacking microsilica and limestone powder and concrete Concrete containing microsilica and limestone powder.

Special models constructed according to the straight notched Brazilian disc (SNBD) design (Figure 2) were used to prepare specimens.

According to the dimensions mentioned in Table 2, it is possible to prepare 4 discs in one mold.

## 3- Results and Discussion

Figure 3 shows diagrams for conventional concrete lacking microsilica and limestone powder and conventional concrete containing microsilica and limestone powder.

containing microsilica and limestone powder

**Table 2. Specifications of notched discs for fracture toughness test**

| The mean crack length (mm) | The mean thickness of specimens (mm) | The mean diameter of specimens (mm) |
|---|---|---|
| 15 | 25 | 75 |

As Figure 4 shows, adding microsilica and limestone powder to concrete will increase the fracture toughness in all angles compared to concrete without microsilica and limestone powder.

XRF analysis of the used microsilica showed that 99.5% of its percentage is silica. Microsilica contributes to the strength of concrete in two ways. First, active silica is able, according to (Equation 6), to convert calcium hydroxide (Ca(OH)2) in concrete cement, which is considered a concrete weakening factor, into calcium silicate (CaSiO3), which is a material It is resistant to convert [2].

$$Sio_2 + Ca(OH)_2 \rightarrow CaSio_3 + H_2O \qquad (6)$$

The second method is by filling concrete pores and reducing the effective porosity of concrete.

## 4- Conclusion

The results of this research are summarized as follows:

- Using 10% microsilica and 5% limestone powder improved the effective, mode I, and mode II fracture toughness of concrete specimens relative to concrete lacking microsilica, and limestone powder.
- The crack initiation angle of all specimens increased with increasing the crack inclination angle.
- The lowest load at failure was observed at a crack inclination angle of 45° for all specimens of concrete.
- Cracks were initiated at inclination angles equal to and less than 45° with the growth of wing cracks from the pre-existing crack tip. However, cracks were initiated at a distance of d from the pre-crack

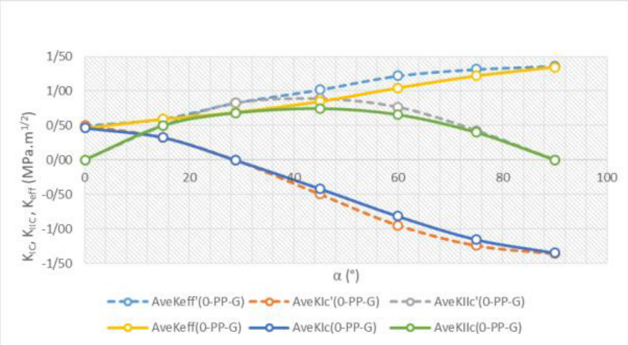


**Fig. 3. KIC-α, KIIC-α, and Keff-α diagrams for concrete lacking microsilica and limestone powder and concrete containing microsilica and limestone powder**

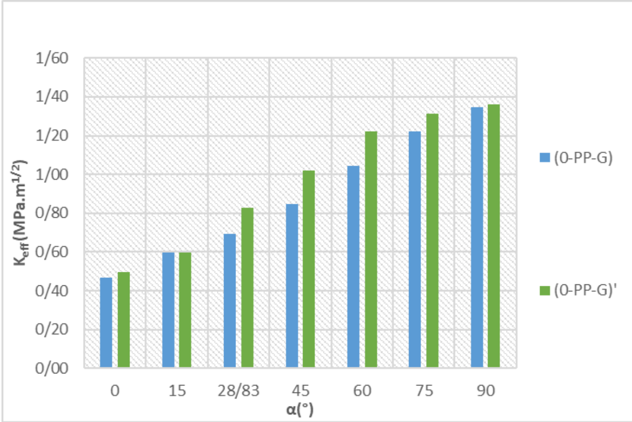


**Fig. 4. . Column chart of effective fracture toughness for concrete without microsilica and limestone powder and concrete containing microsilica and limestone powder**

tip when the inclination angle increased and reached 60, 75, and 90°.

- The failure load in concrete samples containing microsilica and limestone powder is higher than concrete samples without microsilica and limestone powder.

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