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Effects of SiO_2 nanoparticles dispersion on concrete fracture toughness

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HIGHLIGHTS

- Effects of SiO_2 nanoparticles dispersion on concrete fracture toughness was studied.
- Acoustic Emission technique is used to evaluate the failure mechanism of specimens.
- Nanoparticles dispersion changes the fracture toughness of concrete specimens.
- Nanoparticles dispersion changes the type of induced fractures in the specimens.

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ABSTRACT

Failure of concrete structures is usually accompanied by expansion of interior cracks due to stress concentration at the cracks tip. This phenomenon shows the importance of examination of the failure behavior of concrete structures. For this purpose, 4 types of concrete samples with different amounts of nano-SiO_2 (0%, 0.2%, 0.5%, and 0.8%) were made to prepare some Central Straight-through Crack Brazilian Disk (CSCBD) specimens. The key focus of the investigation conducted was to investigate two assumptions. First, to check the pure mode I (tension) and pure mode II (shear) by compressing the standard discs with central cracks by an angle of 0° and 27° with respect to the loading axis; Second, to investigate the failure behavior of control and binary blended concrete using Acoustic Emission (AE) technique. The results show that the highest fracture toughness in both mode I and II was obtained at 0.5% of nano-SiO_2 blended concrete. Also the behavior of micro cracks which transforms from tensile mode to shear mode could be sensible.

1. Introduction

In the present century, it is well documented that the incorporation of pozzolanic nano materials such as SiO_2 and Al_2O_3 to the concrete body, can highly improve the mechanical and physical properties of control concrete [1–3]. That means, nano materials can change the concrete world due to their unique properties at ultra-fine size. Utilization of silica in micron level has been studied as the world's most widely used products in cement based concrete for more than 80 years [4].

It is worthwhile mentioning that due to the ultra-fine size of nano-SiO_2, they can accelerate the generation of nano-crystals of C–S–H gel, that can fill up most of the micro and nano pores and micro voids which were left unfilled in the traditional cement based concrete [5].

Formerly, the effects of the addition of SiO_2 nanoparticles on different mechanical properties of concrete composites have been studied. For instance, the enhancement of compressive and flexural strengths together with abrasion resistance and chloride permeability as well as flexural fatigue performance of nanomaterials binary blended concrete have been examined [6–8]. Other researchers such as Bahadori and Hosseini [9] investigated the effects of substitution of cement particles by colloidal amorphous silicon dioxide nanoparticles on the physical and mechanical properties, durability along with microstructure of concrete.

In addition, Heidari and Tavakoli [10] investigated the compressive strength as well as water absorption of binary blended concrete samples utilizing nano silica in the presence of waste ground ceramic simultaneously. They showed that the incorporation of nano-SiO_2 particles can highly improve the compressive, flexural and tensile strength plus toughness of blended concrete samples. Also, the combined effect of nano-SiO_2 particles and steel fibers on flexural properties of concrete composite containing fly ash which is showed the improved properties of binary and ternary

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blended concrete samples have been examined [11]. Moreover, the effect of silica fume on fresh properties, compressive strength at 28 days and fracture behavior of fly ash concrete composite were studied which indicates the capability of concrete composite containing fly ash to resist crack propagation [12]. It is well known that, nanoparticles can act as heterogeneous nuclei for cement pastes, then accelerating cement hydration process due to their ultra-high reactivity. Also they could act as nanofiller, and densifying the microstructure as well as reducing the porosity of concrete [13].

With respect to the significance of the above mentioned effective factors in enhancement of C-S-H gel thereby on concrete structure by utilizing the latest developments in novel technologies such as nanotechnology in association with concrete science, the fracture properties of concrete are among the emergent fields of endeavor and extremely important for the safety and durability of concrete constructions.

Despite of the previous and current efforts, only few studies are available, concerning the fracture behavior of the concrete containing nano-SiO_2 particles; especially no considerable trial information exist on the effect of SiO_2 nanoparticles on the pure mode I-II of fracture toughness.

In the present study, it is intended to investigate the effect of SiO_2 nanoparticles on fracture toughness of concrete samples. Also, Acoustic Emission (AE) sensors were used to monitor the fracturing process of specimens during the loading sequences. Such experimental investigations would help to develop a well comprehension of the cracking behavior of the concrete. Additionally, the influence of nano-SiO_2 on the different stages of cracking behavior of concrete was also discussed.

2. Fracture mechanics of concrete

Concrete is the most common building materials which has complex microstructure and performance. Due to the importance of concrete and also its fracture system, several researchers studied about this matter and fracture mechanics of control or binary and ternary blended concrete with SiO_2 nanoparticles in presence of steel fibre and fly ash which rapidly has become an active area of investigations with enormous theoretical and experimental challenges [14–16].

Additionally, studies on the fracture toughness of concrete was conducted by other researchers. Li and Zhao [17] examined the creation and localization of micro-cracks within the interior of the specimen and identified them by typical stress-axial strain curve and stress-volume strain curve of a concrete under uniaxial compression. Based on fracture behavior perceived from a uniaxial compressive test of a concrete cylinder, they have developed a model to extract fundamental fracture properties of a concrete, i.e. the equivalent fracture toughness and the size of fracture process zone.

2.1. Concrete fracture toughness

Three categories of crack propagation modes are well known in fracture mechanics which are: mode I (tension, opening), mode II (shear, in-plain shear) and mode III (off-plane shear, tearing) [18]. With respect the different kinds of loadings, crack can be propagated in each of the abovementioned modes or their combination. As mentioned before, one of the most appropriate tests for determination of the fracture toughness for mode I and also mode II is the Brazilian test with central crack [19–23].

There are several researchers such as Awaji and Sato (1978), Sanchez (1979), Atkinson et al. (1982), and Shetty et al. (1986) have determined the fracture toughness mode I and mode II with standard discs so-called Central Straight through Crack Brazilian Disk (CSCBD) with central cracks by an angle of 0° and 27° with respect to the loading axis, respectively. A number of trial testing techniques have been used for formalizing concrete fracture toughness for the abovementioned primary modes. It is worthwhile to mention that, three different methods are well documented for investigation of mode I fracture toughness which are [24]:

1. Short rod specimen method
2. Chevron bend specimen method, and
3. Cracked chevron notched Brazilian disk method

On the other hand, CSCBD method is the most famous analysis technique for determination of modes (I, II and I-II) of fracture toughness of rock samples.

The fracture toughness is achieving by compressing the standard discs with central cracks by an angle of 0° or 27° with respect to the loading axis as shown in Fig. 1 [18].

It should be mentioned that a critical idiom and following equations which have been adopted from Atkinson et al. [25] utilized for calculating the fracture toughness of concrete by CSCBD specimens:

$$K_I = \frac{P\sqrt{a}}{\sqrt{\pi}RB}N_I \tag{1}$$

$$K_{II} = \frac{P\sqrt{a}}{\sqrt{\pi}RB}N_{II} \tag{2}$$

where K_I is mode I stress intensity factor, K_{II} is mode II stress intensity factor, R is the radius of Brazilian disk, B is thickness of the disk, P is compressive load at failure, a is half crack length, N_I and N_{II} are non-dimensional coefficient which depend on ratio of half crack to radius (a/R) and crack orientation angles with respect to the diametrical load. They also proposed the following equations to determine the terms NI and NII of above questions for relatively small crack length $(a/R \leqslant 0.3)$:

$$N_I = 1 - 4\sin^2\beta + 4\sin^2\beta(1 - 4\cos^2\beta)\left(\frac{a}{R}\right)^2 \tag{3}$$

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

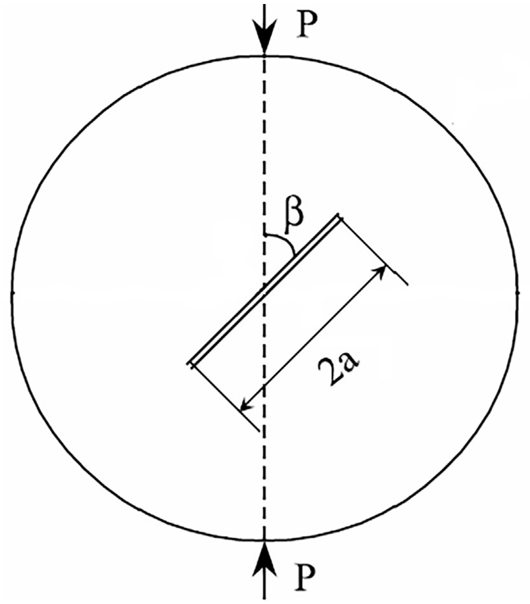

Fig. 1. Schematic of CSCBD specimen with central crack by β angle.