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Concrete with triphasic conductive materials for self-monitoring of cracking development subjected to flexure

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ABSTRACT

In this study, the macro steel fiber (SF), carbon fiber (CF) and nano carbon black (NCB) as triphasic conductive materials were added into concrete, in order to improve the conductivity and ductility of concrete. The influence of NCB, SF and CF on the post crack behavior and conductivity of concrete was explored. The effect of the triphasic conductive materials on the self-diagnosing ability to the load–deflection property and crack widening of conductive concrete member subjected to bending were investigated. The relationship between the fractional change in surface impedance (FCR) and the crack opening displacement (COD) of concrete beams with conductive materials has been established. The results illustrated that there is a linear relationship between COD and FCR.

1. Introduction

The crack diagnosing is relevant for crack control in serviceability limit state and for durability requirements of concrete member. The monitoring of load-bearing capacity regarding the whole load–deflection curve can be evaluated as one of the significant points of the safety of structure member. The real-time structural health monitoring systems may able to assist engineers using non-destructive testing and early damage detection, so that proper maintenance can be applied. Electric conductive concrete could be capable of sensing its own strain and damage by the electrical resistance measurement [1–11]. The self-sensing ability of strain and damage of electrically conductive concrete can be one of the useful methods for the non-destructive evaluation of concrete members in practice. Furthermore, electrically conductive concrete also provide wide prospect in specialist applications, such as vibration control, electromagnetic shielding, traffic monitoring and de-icing [12–14].

In order to obtain electrical conductive concrete, conductive substance like NCB, CF or SF, can be incorporated into a cementitious matrix [1–11]. Electric conductive fibers, such as carbon fibers and steel fibers, are effective as admixtures for improving electric conductivity due to the formation of a continuous conducting path [13]. The NCB, with its electric conductivity, low cost and fine filler effect can also be used as ideal admixture for conductive concrete [6–10]. Prior work in the combined use of NCB and CF in cement-based materials has been reported [6–16]. The advantage of combined use of NCB and CF is the synergistic effect, which refers to the filling (i.e. conductive filler) of the microscopic space between adjacent fibers by NCB, thereby resulting in enhancing the electric conductivity of composites [14–17]. Some previous studies on the self-sensing concrete are focused on the using of monophase or diphasic conductive materials, the relationship between the fractional change in resistance and the tension strain before concrete cracking has been suggested. The investigations on the strain and damage of micro carbon fiber and micro steel fiber reinforced cement specimens under compression and tension have been carried out [1–9]; but, there is a shortage of using micro fibers or NCB as self-sensing materials because they cannot keep the conductive path after concrete cracking. Until now, the investigations are mainly concentrated on the self-sensing of concrete damage before cracking [1–17], no literatures regarding self-monitoring of crack development in the post crack region of concrete under bending was found. In fact, it is important to realize that the concrete bending member works usually with cracks under service load. The concrete member may lose its serviceability by excessive cracking. The crack control is one of the key points of the serviceability, and any cracking should be limited to hairline cracks for reasons of both serviceability and durability. After all, how to self-monitor the crack open displacement and the whole load–deflection process of concrete beam is still an open problem. This work can be considered as a pioneering tentative and paved a

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new path for the self-diagnosing of the crack opening displacement.

One of the innovation ideas of this work is to use macro SF in the triphasic conductive materials. There are two reasons to provide macro-SF, NCB and CF as triphasic conductive materials:

(1) Macro SF can enhance the mechanical properties before cracking, avoid the brittle failure of concrete member during the concrete cracking and bridging the cracks.
(2) In the whole process after cracking of the concrete beam, only the macro SF is capable to restrict the crack widening (Fig. 1(b) and (c)), to improve the cracking resistance and toughness, to demonstrate a stable load–deflection curve and to maintain the conductive path of the cracked concrete matrix (Fig. 1(b) and (c)) while the NCB and micro CF are incapable to cross the crack surfaces [7,18].

Based on the previous investigations on the self-diagnosing of damage before cracking by means of the relationship between FCR and strain [8], this study is mainly aimed at investigating of the self-diagnosing ability to cracking property and to load–deflection behavior of concrete beam. The relationship between FCR and COD of triphasic electric conductive concrete beams under bending has been established using a tentative data return's method. The results show that the relationship between the FCR and crack opening displacement of concrete beams can be well linearly fitted.

2. Experimental Investigations

2.1. Materials and mixture design

In this test program, the base mix design of concrete beams without conductive admixture (NCB, CF and SF) was as follows: cement CEM I 42.5R 390 kg/m^3, fly ash 155 kg/m^3; fine aggregate 848 kg/m^3 (0–5 mm), coarse aggregate 822 kg/m^3 (5–10 mm); water 272.5 kg/m^3; water binder ratio 0.5, Superplasticizer (SP) 7.63 kg/m^3 (1.4% of the binder).

The NCB content with particle size ca. 30–90 nm (Fig. 2(a)) was between 0.1% and 0.3% by mass of binder (0.55–1.64 kg/m^3), the density of NCB was about 0.5 g/cm^3 and the volume resistivity was 2.3 Ω cm. The carbon fiber content with diameter of 12–15 μm and length of 6 mm (Fig. 2(b)) was between 0.4% and 1.2% by mass of binder (2.18–6.54 kg/m^3), the density of CF was about 1.6 g/cm^3 and the volume resistivity of CF was between 3 and 7 mΩ m. The macro steel fiber content with diameter of 0.55 mm and length of 35 mm (Fig. 2(c)) was between 4% and 8% by mass of binder (22–44 kg/m^3), the density of SF was about 7.85 g/cm^3 and the volume resistivity of SF was 10^{-6} mΩ m. A methylcellulose was used in the amount of 0.4% by mass of cement and a defoamer was used in the amount of 0.19% of sample volume. The different dosages of the conductive admixtures SF and triphasic conductive materials (BCS: NCB + CF + SF) by mass of binder in various concrete samples are compared and listed in Table 1.

2.2. Samples and set-up description

The specimens prepared for testing were beams with the size of 100 × 100 × 400 mm, demolded after 1 day and cured at room temperature in air (relative humidity = 100%) for 28 days. Then, four electrical contacts were prepared in the form of conductive adhesive tape, which was adhered on the tension side of the specimen. Based on the four probe method of electric resistance measurement, contacts A and D were for passing current while contacts B and C were for measuring of voltage [1–2,8–9]. The relationship between FCR and flexural load-bearing capacity has been studied. We also analyzed the relationship between FCR and COD. The FCR measured is the fractional change in surface resistance on

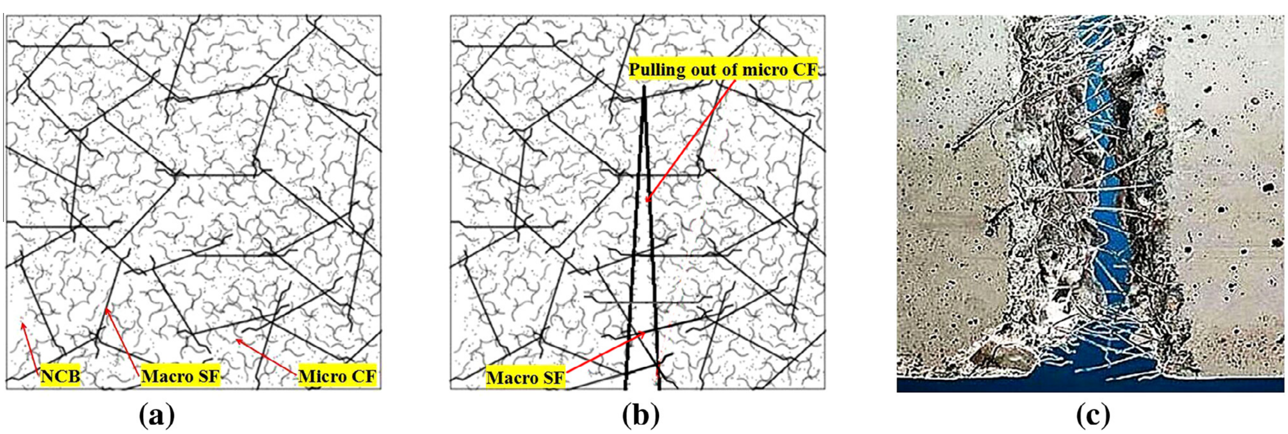

Fig. 1. Conductive network of triphasic materials in the concrete matrix (a) before cracking, (b) after cracking, (c) Macro SF cross concrete crack.

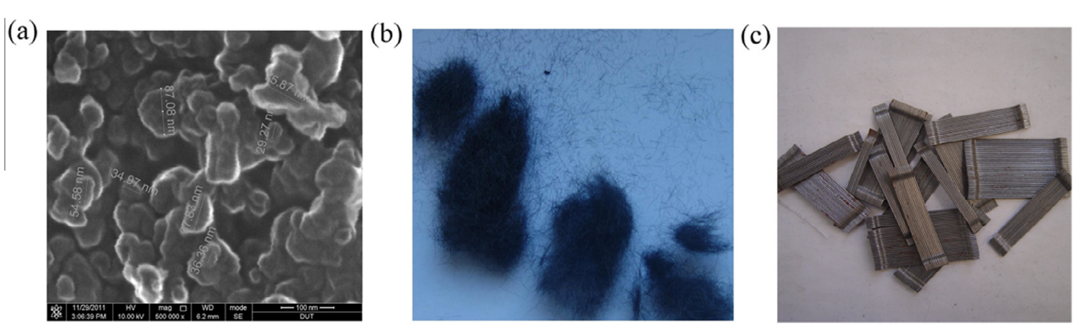

Fig. 2. (a) Particle size of nano carbon black using high resolution field emission SEM and (b) carbon fiber and (c) macro steel fiber.