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Properties of freshly mixed carbon fibre reinforced self-consolidating concrete

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HIGHLIGHTS

- Carbon fibres greatly affected the filling ability, passing ability, and segregation resistance of SCC mixes.
- The T_{50} slump flow time was increased with the increase in carbon fibres content.
- All CFRSCC mixes clearly passed the segregation resistance requirement.
- The CFRSCC mixes with carbon fibres content up to 0.75% passed the requirements of SCC.
- The carbon fibres were well distributed in all concrete mixtures, as observed from the SEM test.

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ABSTRACT

This study examined the effects of discrete pitch-based carbon fibres on the fresh properties of self-consolidating concrete. Different carbon fibre reinforced self-consolidating concrete mixtures were produced incorporating 0%, 0.25%, 0.5%, 0.75% and 1% carbon fibres by concrete volume with two water-to-binder ratios (0.35 and 0.40). The flowing ability (filling ability and passing ability) of the concrete mixtures was determined with respect to slump flow, J-ring slump flow, and T_{50} slump flow time. The segregation resistance of the concrete mixtures was evaluated by using the sieve stability test. Visual stability index (VSI) was also used to assess the segregation resistance of concrete. Moreover, the freshly mixed concrete mixtures were tested for air content and unit weight. The hardened concretes were tested by a Scanning Electron Microscope to observe the distribution of fibres. Test results revealed that the increased amount of carbon fibres decreased the filling ability and passing ability of concrete. However, carbon fibres had no adverse effects on the segregation resistance of concrete. Also, no significant air entrapment occurred in the presence of carbon fibres. Carbon fibres were well-distributed and they slightly decreased the unit weight of concrete.

1. Introduction

Self-consolidating concrete (SCC) is a special kind of concrete, which was developed in Japan. In construction industry, Japan faced the shortage of skilled concrete workers to produce high-quality durable concrete structures; hence Japanese engineers and researchers started to develop a different kind of concrete that can be placed and finished with less skilled workers. As a result, the concept of SCC was first proposed in Japan in 1986 [1]. Ozawa and Maekawa carried out many studies to develop SCC at the University of Tokyo in Japan [2,3]. Japan was the first country that worked intensively to pragmatically use SCC in civil engineering structures [4].

SCC has many advantages over conventional concrete. SCC flows under own weight and does not require any vibrating equipment; it is an ideal material for smooth finishing and for heavily reinforced structural members. The key fresh properties of SCC are flowing ability (filling ability and passing ability) and segregation resistance. The performance requirements for filling ability, passing ability, and segregation resistance must be met to produce SCC successfully. Therefore, these properties should be determined carefully using proper test methods. The three key fresh properties of SCC can be evaluated by using various methods. These methods are either available as standard tests or proposed by some researchers. Currently American Society for Testing and Materials (ASTM) has the standard test methods to evaluate the aforementioned three key fresh properties of SCC [1,5,6].

Many studies have been carried out on the fresh and hardened properties of SCC [7]. Recently, several types of fibre such as steel, glass, and polypropylene fibres have been used to produce fibre

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reinforced SCC [8–13]. In comparison, limited studies were carried out to use carbon fibres in SCC. Adding carbon fibres to SCC significantly decreases its flowing ability (filling ability and passing ability). Carbon fibres may restrict and prevent coarse aggregates from moving uniformly, thus causing flowing ability problem [14]. However, the incorporation of carbon fibres improves many mechanical and electrical properties of SCC such as compressive and flexural strengths, toughness, and electrical conductivity [14–16].

Carbon fibres are attractive to engineers due to their low density and high thermal conductivity. Carbon fibres can be used to eliminate or reduce drying shrinkage and cracking problems. Many studies have been conducted since 1970s to investigate the effectiveness of carbon fibres on the various properties of concrete [17]. Carbon fibre reinforced concrete has been used in many projects because of its good thermal conductivity, lightweight, and high modulus of elasticity [18,19]. It has also been used significantly to produce curtain walls, partition panel, and formwork for walls [18]. However, none of the aforementioned studies used carbon fibres in SCC for applications in civil engineering structures.

Two types of carbon fibres are commercially available for use in concrete; polyacrylonitrile (PAN)-based and pitch-based carbon fibres. PAN-based carbon fibres have a very high modulus of elasticity and high tensile strength; they have been mostly used to produce aerospace and sport equipment [17,18]. Although PAN-based fibres were the first type of discrete short carbon fibres used in reinforced concrete, presently they are rarely used in civil engineering applications due to their high cost.

Pitch-based carbon fibres are usually used in civil engineering applications because of their lower cost even though pitch-based carbon fibres have lower modulus of elasticity than PAN-based fibres. Pitch-based carbon fibres are used in many industrial fields due to their lightweight, good chemical stability, and high heat and excellent abrasion resistance [18]. The use of pitch-based carbon fibres in the reinforced concrete leads to increases in flexural strength about 85%, flexural toughness about 205%, and compressive strength about 22%; on the other hand, the drying shrinkage can be decreased by up to 90% and the electrical resistivity up to 83% [20,21]. These advantages make pitch-based carbon fibres more attractive for use in SCC. Although many studies were conducted on the use of pitch-based carbon fibres in concrete, limited research has been carried out to produce SCC using this kind of fibres. In the present study, pitch-based discrete carbon fibres have been used to produce SCC. The freshly mixed carbon fibre reinforced SCC mixtures were tested for filling ability, passing ability, segregation resistance, air content, and unit weight. In addition, the distribution of carbon fibres in hardened SCC mixtures was examined using a Scanning Electron Microscope. From the test results, the effect of pitch-based carbon fibres on the tested properties was observed.

2. Research significance

Carbon fibre reinforced concrete without SCC properties has been well researched. Also, SCC incorporating steel and polymer fibres has been significantly studied. However, limited study has been conducted on the use of carbon fibres in SCC. Incorporating carbon fibres in SCC can produce a high quality special concrete known as carbon fibre reinforced self-consolidating concrete (CFRSCC). CFRSCC would offer the benefits of both carbon fibres and SCC. The main purpose of this study was to examine the effects of discrete pitch-based carbon fibres on the major fresh properties of SCC. The research outcome shall be useful to produce and commercialize CFRSCC as a new or repair material for use in concrete structures.

3. Experimental investigation

3.1. Constituent materials

Normal (Type I) Portland cement, crushed limestone (coarse aggregate, CA), manufactured sand (fine aggregate, FA), silica fume (SF), high-range water reducer (HRWR), and tap water (W) were used in this study. The manufactured sand conformed with the specification OPSS 1002 [22]. Fig. 1 shows the pitch-based carbon fibres (CFs) that was used in this study. Table 1 shows the physical properties of the concrete constituent materials.

3.2. Concrete mixture proportions

A total of ten non-air-entrained SCC mixtures incorporating different contents of pitch-based carbon fibres were produced in this study. Two water-to-binder (W/B) ratios of 0.35 and 0.40 were used in these concrete mixtures. Silica fume was kept constant at 10% by weight of binder. Two mixtures were dealt as control with no fibres and eight mixtures had different percentages of carbon fibres. Table 2 presents the details of the CFRSCC mixture proportions. The mixtures were divided into two groups based on the W/B ratio. The first group had a W/B ratio of 0.35, and the second group had a W/B ratio of 0.4. HRWR was added to the CFRSCC mixtures to enhance their filling ability and passing ability; the HRWR dosages for the first and second groups were 1.5–8.0% and 1.0–7.0%, respectively.

3.3. Preparation of concrete

The concrete mixtures were prepared using a pan-type revolving mixer of 50 l maximum capacity. The coarse and fine aggregates were first charged and mixed together with a ¼ of the total mixing water for 60 s. Then, the binder (cement

Fig. 1. Pitch-based carbon fibres.

Table 1
Physical properties of constituent materials.

Material	Properties
Normal Portland cement (C)	Relative density: 3.15
Crushed limestone coarse aggregate (CA)	Maximum aggregate size: 10 mm Saturated surface-dry based relative density: 2.74 Absorption: 1.13% Moisture content: 0.393%
Manufactured concrete sand (FA)	Relative density : 2.68 Absorption: 1.15% Moisture content: 0.144%
Pitch-based carbon fibres (CFs)	Relative density: 1.85 Tensile strength: 1770 MPa Tensile modulus: 180 GPa Length: 10 mm Diameter: 17 μm
High-range water reducer (HRWR)	Relative density: 1.064 Solid content: 33%
Silica fume (SF)	Relative density: 2.2
Normal tap water (W)	Total solids: 430 mg/L Density at 24 °C: 997.28 kg/m^3