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Mechanical properties of slurry infiltrated fiber concrete produced with waste steel fibers

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HIGHLIGHTS

- Steel fibers recovered from scrap tires were used to produce SIFCON.
- Flexural strengths of the mixtures increased with higher amounts of waste fibers.
- Fracture energies increased substantially with waste fiber contents.
- Results confirmed that waste steel fibers can be used in SIFCON production.
- Optimization process indicated that use of waste fibers may be more desirable.

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ABSTRACT

The paper presents the results of an experimental study in which steel fibers recovered from scrap tires were used to produce slurry infiltrated fiber concrete (SIFCON). The waste steel fibers used in the study can be considered as hybrid fibers in terms of geometrical characteristics. They were balled up and their lengths were very long compared to commercially available fibers. The fibers were preplaced into molds, and then infiltrated by flowable cement slurry which has a low water/cement ratio. Mixtures with different fiber contents were cast. A plain mixture without fibers was also prepared for reference. Compressive strength, splitting tensile strength and flexural strength of the mixtures were determined. Load deflection curves including the post-peak responses were also obtained. Test results indicate that flexural strength, residual strength and toughness of the specimens increased depending on the fiber content. The mechanical properties and relative costs of the mixtures were used in a multi-objective simultaneous optimization procedure. Results from a previous study were also included in this procedure. The test results confirmed that waste steel fibers recovered from tires can be successfully used for SIFCON production.

1. Introduction

Based on the estimation that the number of vehicles around the world is 1.3 billion, it can be calculated that 5.2 billion tires are currently being used [1]. Although worn-out tires may be reused after rethreading or regrooving, they are regarded as scrap after this reuse and disposal of these end-of-life tires is a difficult problem [2–5].

Today, most of the scrap tires are being used as a source of energy for cement kilns or other energy recovery plants because of the high carbon content of the tires [5–7]. For any product, however, the reuse and material recycling should be preferred to energy recovery from waste, as these are the better ecological options [8,9]. A passenger car tire contains about 17% high strength steel fibers. Although some of the waste tires are recycled and the rubbers recovered from the tires have some uses in the industry, the high strength steel fibers recovered from these tires are considered only as scrap and since they do not have an industrial use, they are recycled by melting. However, it may possible to utilize them in various applications because of their high strengths. Reuse of the high strength steel fibers in production of new materials or in other industries may help to reduce the need for high strength fibers.

Different methods, such as pyrolysis (which is a chemical procedure), cryogenic method (which is based on processing the tires at low temperatures) or mechanical methods can be used for the recovery of steel fibers in tires [10,11]. The recovered steel fibers may not be straight as the commercial ones. Some of the waste fibers may be in bundle form consisting of individual fibers. The diameter of the steel fibers can vary depending on their location in the tire and the type of tire. Because these waste fibers are actu-

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ally continuous cords cut into smaller pieces during recovery, they may have various lengths, and their fiber aspect ratios (length/diameter) may be very high due to their long lengths.

Use of fibers in concrete is a well known application and steel fiber reinforced concretes are being widely used in construction industry. Studies indicate that the waste steel fibers can also be used in concrete [12–23]. In a recent study [24], it has been shown that with processing, fibers with various aspect ratios can be obtained from scrap tires and they can be alternative materials in producing steel fiber reinforced concrete. The waste fibers cannot be used in higher amounts because of their tendency to ball up since they are not straight and usually have high aspect ratios. The waste fibers may already be balled up and interlocked after the recovery process and they have to be processed and separated from each other before using them to produce conventional steel fiber reinforced concrete.

Slurry Infiltrated Fiber Concrete (SIFCON) is a high performance cementitious composite that can be classified as a special type of steel fiber reinforced concrete [25,26]. In SIFCON production, the fibers are preplaced into the molds, and then infiltrated by cement slurry, which usually have low water/cement ratio. This type of production is different from conventional fiber reinforced concrete production. In SIFCON, due to the pre-packing of the fibers, fiber contents can be significantly higher. As a result of the high strength cement based matrix and the high fiber content, the post-cracking strength and energy absorption capacity or toughness of SIFCON can be substantially higher compared to those of conventional steel fiber reinforced concretes. Their cost is also relatively high because of the high fiber content.

The high strength waste fibers have high potential to be used in SIFCON. Since the fibers are placed before-hand, they can be used in higher amounts, there is no need for separating the balled up waste fibers and the high strength of the fibers may be utilized more efficiently in these high performance cementitious composites. In order to use these waste fibers in conventional fiber reinforced concrete additional processing is needed, such as; separating the balled up waste fibers and also cutting or classifying them into smaller sizes if the length of the fibers are long. For the SIFCON production, however, there is no need for such preparations, which makes these waste fibers more convenient for SIFCON. In addition, price of the waste steel fibers recovered from scrap tires are substantially lower which makes them suitable for SIFCON applications.

Although there are studies available in the literature about waste fibers in concrete, the studies regarding the use of these fibers for SIFCON productions are limited [27–31]. The main objective of this experimental study was to investigate the mechanical properties of SIFCON produced with waste steel fibers obtained from scrap tires. The details and the results of the experimental study are presented in this paper.

2. Materials and methods

2.1. Materials

2.1.1. Cement and aggregate

An ordinary Portland cement (CEM I 42.5) was used in all the mixtures. The aggregate used was a siliceous sand with a maximum particle size of 0.5 mm. Percentages passing from 0.25 mm and 0.125 mm sized sieves were 53% and 6%, respectively. The aggregate grading and the maximum particle size of the aggregate were kept constant in all the mixtures. The specific gravity of the sand was 2.63 g/cm^3. A plasticizer admixture was also added in order to reduce the water requirement and to maintain the workability.

2.1.2. Fibers

Waste steel fibers from different tire recycling plants were compared as a preliminary study. The fibers recovered by mechanical processing were containing varying amounts of textiles and rubber which may be due to the recycling methods of the plants. The received fibers were compared based on their fiber and rubber content. The geometrical properties were also considered. Some of the fibers received were containing textiles and rubber and their total amount varied between 17 and 32% by weight. Removing these materials from the steel fibers was a time consuming and labor intensive process, thus such fibers were not considered in the experimental study. Since some of the fibers received had large diameters (a few millimeters) and also had rubber particles attached, they were also not used in the study. Among the fibers received, one of them was selected and used in the study. The selected fibers were recovered from scrap tires using the pyrolysis method and they were free from any rubbers or textiles, and there was also no rubber attached on the fiber surfaces. The waste fibers selected for the experimental program is shown in Fig. 1.

As seen in Fig. 1, the fibers were balled up randomly and consisted of fibers having various geometrical properties. In addition, most of the fibers were not straight as commercial fibers. To determine the geometrical properties, 4 kg of waste fibers were selected randomly and dimensions of each fiber were determined. The diameter of the fibers changed between 0.18 mm and 2.00 mm and there were some small variations in the diameters. A very small amount fibers with diameters larger than 2 mm were also present in the fibers received and since they were very easy to spot (Fig. 1), they were taken out during the placing the fibers into the molds. The length of the fibers also varied and average lengths starting from 41 mm changed up to 208 mm. It should be noted that the straight length of the fibers were measured. The length of the waste fibers were much longer than the commercially available steel fibers and therefore not possible to use them for the production of conventional steel fiber reinforced concrete, however, they were suitable for SIFCON production without additional processing such as cutting into smaller lengths. The average fiber aspect ratio (that is fiber length/fiber diameter) was between 57 and 643. Dimensions of the fibers are presented in Table 1. The amount of each fiber type by weight is also shown in the same table. Since the fibers used had different diameters and lengths, they may be classified as hybrid fibers in terms of dimensions. As shown in Fig. 1, the fibers were mostly twisted, bent and balled up which may help for a better mechanical bonding between the fiber and cement paste. The waste fibers were used in this balled up state, without separating individual fibers.

Table 1 also shows the tensile strengths of the fibers. These values were determined on the fibers that have enough length for the

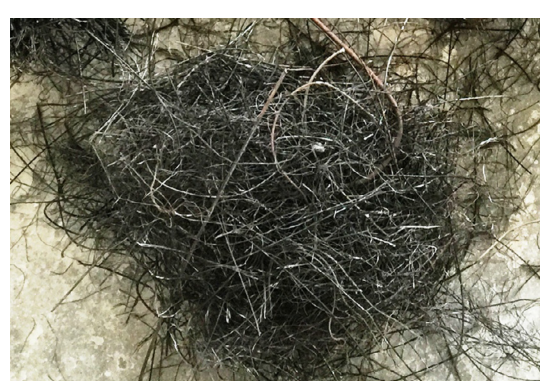

Fig. 1. Waste steel fibers used in the study.