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Rheological, mechanical, environmental, and economic comparison of the use of industrial and recycled steel fibers in self-compacting concrete

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ABSTRACT: Industrial steel fibers (ISFs) are the most widely-used fibers for concrete reinforcement. The industrial production of these fibers is costly, and it contributes to Greenhouse gas emissions. The present study, therefore, aims to explore the ways in which these fibers can be replaced by recycled steel fibers (RSFs) made of scrap vehicle tires. To this end, the present study examined 13 mixtures containing different volume percentages (0%, 0.5%, 1%, 1.5%, and 2%) of ISFs, RSFs, and their combinations. The examinations included rheological properties of the fresh self-compacting concrete (J-ring, L-box, U-box, and V-funnel tests), mechanical properties of the hardened concrete (compressive, Brazilian tensile, and flexural strength tests), environmental characteristics (global warming potential (GWP)), and economic characteristics. Results showed that RSFs had a poorer performance than ISFs in terms of mechanical properties. The use of 2% ISFs increased the splitting tensile and flexural strengths by 114% and 82%, respectively, while the same amount of RSFs increased these parameters by 80% and 44%, respectively. On the other hand, RSFs showed better performance than ISFs in terms of rheological, environmental, and economic characteristics. Replacing ISFs with RSFs in mixtures containing 2% fibers could improve the rheological, environmental, and economic characteristics by 8%, 30%, and 65%, respectively. Finally, given the multi-criteria optimization results, RSFs were superior to ISFs in terms of rheological, mechanical, environmental, and economic characteristics.

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1- Introduction

Concrete is one of the most widely-used materials in civil engineering projects, and it shows an excellent performance in terms of compressive strength [1, 2]. In recent decades, fibers have been commonly used to reinforce the concrete, particularly when it is under tensile and flexural forces [3]. One of the most widely-used fibers for the improvement of concrete performance is steel fiber [4, 5]. During several decades, various types of steel fibers have been used within concretes, and they have had different shapes, lengths, and diameters [6, 7]. Over 300 thousand tons of steel fibers are annually used across the world, 90% of which are industrially produced [6], although the industrial production of steel fibers is costly, and it significantly contributes to emissions [8]. For this reason, researchers have been trying in recent years to find an appropriate replacement for industrial steel fibers within concretes.

On the other hand, the total number of scrap tires across the world is estimated to be around 1 billion each year [9], out of which only 33% are recycled, with the remaining being burned or left out in nature. Burning or leaving out scrap tires in nature can cause significant environmental problems, and seems that recycling is a way to resolve these problems [10]. Powdered of scrap tires can be used to produce new tires or tar, and the wires in the scrap tires can be used to produce fiber-reinforced concretes [11]. Therefore, researchers have been trying to use the fibers obtained from scrap tires as one of replacements for industrial steel fibers.

The present study comprehensively compares the influence of industrial steel fibers (ISFs) to that of recycled steel fibers (RSFs) on the behaviors of self-compacting concretes. The comparisons include rheological, mechanical, environmental, and economic aspects. To this end, 13 mixtures containing 0%, 0.5%, 1%, 1.5%, and 2% volume fractions of ISFs, RSFs, and a combination of both fibers were studied. Finally, a multi-criteria optimization was used to select the optimal mixtures.

2- Methodology

Materials: Ordinary Portland cement (Type II), recommended by ASTM C 150 [12], was used to make the specimens. The specific weight and the special surface of the cement were 3.1 and 3000 , respectively. The fine aggregates used in the present study were mountainous crystals, and the coarse aggregates were mountainous pea-shaped gravels. The water used to make the specimens was ordinary drinking water, and the polycarboxylate superplasticizer, Trademark dezobuild D4O, was used to ensure the sufficient concrete workability.

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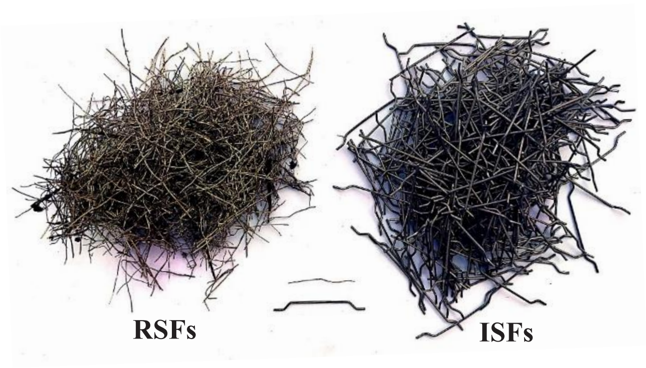

Fig. 1. Pictures of ISFs and RSFs.

The present study used two types of fibers including ISFs and RSFs for the production of fiber-reinforced concretes. The ISFs used in this study were hooked-end fibers with 50 mm and 0.8 mm length and diameter, respectively. As RSFs had different appearances, 200 RSFs were precisely measured to obtain a working specification for the present study. The measurements showed that a considerable number of fibers had a length ranging from 30 mm to 50 mm and a diameter ranging from 0.2 mm to 0.3 mm. Fig. 1 shows the pictures of ISFs and RSFs used in this study.

Mix designs and specimens preparation: The present study used 13 mixtures containing 0%, 0.5%, 1.5%, and 2% volume fractions of ISFs, RSFs, and a combination of both fibers to develop the specimens. The construction of concretes was started when the dry cement and aggregates were blended in the mixer. After 2 minutes, 90% of the water was gradually added to the mixture. The remaining 10% of the water was mixed with SP and then was added to the mixture. To prevent the fibers from clumping/collating together, ISFs and or RSFs were added to the concrete in the last stage [13]. The specimens were cured in water for 28 days and then were tasted.

3- Results and Discussion

ISFs and RSFs negatively influenced the rheological properties of self-compacting concretes, such as workability, slump flow rate, filling ability, and passing ability. The negative influence was more notable in the concretes containing ISFs.

The ISFs and RSFs effects on the compressive strength were insignificant (less than 10%). The addition of ISFs (up to 1.5% volume fraction) to concrete insignificantly increased the compressive strength, but the addition of ISFs beyond 1.5% decreased the compressive strength of concretes. The ISFs performance was more desirable when the ratios were low (i.e. 0.5% and 1% volume fractions) but the RSFs performance was better in the compressive strength tests when the ratios were high (i.e. 1.5% and 2% volume fractions).

The tensile strength of concrete was considerably increased as a result of ISFs and RSFs addition. Due to their longer lengths and their hooked ends, ISFs had more significant effects on the tensile strengths of concretes, as compared to RSFs. The specimens containing 2% ISFs volume fractions had the highest tensile strength, while the specimens containing the same amount of RSFs did not have the same increase (and actually, their tensile strengths were 80% that of those containing ISFs).

The flexural strength of concrete containing ISFs and RSFs were significantly increased. The increased strength was due to the fact that the flexural cracks were healed by ISFs, and RSFs. The ISFs showed a better behavior in terms of bridging the flexural cracks, as compared to the RSFs. The addition of 2% ISFs and RSFs volume fractions could increase the flexural strength of concrete beams as much as 82% and 44%, respectively.

In terms of flexural energy absorption as a very important parameter for the post-cracking behavior of concrete beams, the ISFs and RSFs were significantly effective at improving flexural performance of concrete beams. Due to their longer lengths and their hooked ends, however, the ISFs showed a better performance in this respect. The replacement of ISFs by RSFs decreased the flexural energy absorption from 214.9 J to 118.7 J in the concrete beams containing 2% fiber volume fractions.

Economic analysis of the mixtures showed that RSFs are more economical than ISFs, for reinforcing Concretes. Moreover, the GWP analysis of mixtures indicated that RSFs are more environmentally friendly than ISFs, and in other words, they are more sustainable than ISFs.

4- Conclusion

The multi-criteria optimization of mixtures indicated that RSFs are more valuable than ISFs when the aim is to obtain optimal rheological, mechanical, environmental, and economic characteristics.

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