The influence of recycled steel fibers on self-compacting concrete performance

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Abstract This paper presents a study on the rheological and mechanical properties of self-compacting concrete (SCC) with recycled steel fibers recovered (SFR) from waste tires. SFR were added separately to SCC mixtures at volume fraction of 0.5, 0.8, 1 and 1.5%. Water to cement ratio of 0.46, gravel to sand ratio of 1.0 and superplasticizer content of 1.0% (by weight of cement) were kept constant in all SCC mixtures. Five SCC mixtures were tested for their rheological properties by using slump flow diameter, T500 slump flow time, V-funnel flow time, L-box ratio, and the segregation resistance test. The 28-day compressive strength, flexural strength and shrinkage were also investigated. The results showed that adding recycled steel tires fibers reduced the rheological characteristics of the self-compacting concrete. It was also revealed that, increasing the content of recycled steel fibers reduced slightly the compressive strength and shrinkage but improves flexural strength.

1. Introduction
Reinforcing concrete with steel fibers for use in some applications has been widely investigated and used on site. Steel fibers improve the mechanical properties and impact resistance of concrete. However, steel has a relatively high cost and demand for steel is increasing and hence alternative sources are being investigated. Significant amount of tires are disregarded and steel fibers from waste tires could be an interesting alternative for ordinary steel fibers.

The performance of concrete with steel fibers at the fresh and hardened state have been studied by several researchers. Most researchers agree that the use of steel fibers affect negatively the fresh properties of concrete. Khaloo et al. [1] investigated the use of steel fibers at volume fraction of 0.5%, 1%, 1.5%, and 2% on the performance of self-compacting concrete (SCC). The results showed that adding steel fibers reduces the rheological properties of SCC. El-Dieb [2] reported that the addition of 0.52% steel fibers causes a decrease of 12% in the slump value of ultra-high-strength SCC. He reported that the admixture dosage should be adjusted in order to keep the slump value unaffected. However, hybrid fibers have also been studied by Tabatabaeian et al. [3] who used hooked-end steel and polypropylene fibers. The results showed that the presence of fibers prevents the flow of the cement paste. The slump flow diameter decreased by with 1.8% when 1% steel fibers are added. The reduction of the slump flow diameter is more important (42%) when a combination of 0.6% of steel fibers and 0.4% of polypropylenes fibers is used. In addition, the increase in the flow time of V-funnel test has been observed. Moreover, the capacity of passage was also affected by the fibers because of the length of the fibers which prevents the passage through the J-ring [3].

The use of waste steel fibers has also been investigated by several researchers. Aghae et al. [4] examined the mechanical properties of lightweight concrete reinforced by waste steel wires from recovered from waste steel in construction sites. However, few studies are available on the use of waste steel fibers recovered from waste tires on SCC performance. Mastali et al. [5] studied the effect of using...
silica fume as partial substitution to cement in SCC reinforced with waste steel fibers recovered from waste tires. They found that the rheological properties of the SCC are decreased by partial substitution of cement with silica fume, while the addition of waste steel fibers intensifies this decrease.

With regards to the mechanical properties, the mechanical properties such as splitting tensile and flexural strength were enhanced with the addition of steel fibers but the compressive strength decreased (Khaloo et al. [1]). In addition Irki et al. [6] mentioned that the use of steel fibers of 35 mm, 40 mm and 50 mm of length reduces the compressive strength at an average of 2%, 5%, and 10%, respectively. However, the splitting tensile strength was improved by about 30%. In addition, Aghaee et al. [4] reported that the use of 0.25% or 0.50% of waste steel wires increases the compressive strength; whereas, this latter decreases with 0.75% fibers. The fraction of 0.75% of waste wire fibers gave the highest splitting tensile and flexural strengths. In addition, Aghaee et al. [4] reported that the use of 0.25% or 0.50% of waste steel wires increases the compressive strength; whereas, this latter decreases with 0.75% fibers. The fraction of 0.75% of waste wire fibers gave the highest splitting tensile and flexural strengths.

On the other hand, Mastali et al.[5] revealed the opposite; a significant improvement of all mechanical properties was found when recycled steel fibers were added. Tabatabaeani et al. [3] reported that the compressive strength increases by 1% and 11% when the steel fibers were used by 0.5% and 1%, respectively. Furthermore, El-Dieb [2] found similar results; the mechanical properties was improved by the use of twisted steel fibers. He reported that the mode of failure of specimen becomes more ductile changing from a sudden explosive to intact failure mode because the fibers are better bonded with concrete. Moreover, according to Siddique et al. [7] the random distribution of the steel fibers in mixtures leads to control the cracks by bridging the cracks. These results were confirmed by Yehia et al. [8]. The Fibers improve the ductility of concrete due to their ability to resist tensile forces and to bridge cracks.

In order to recycle the huge amount of waste pneumatic, which is increasing every year, and preserve the environment, more and intensive detailed studies are needed. Thus the main objective of this study is to analyze the effect of recycled fibers on the performance of SCC. Therefore, the slump flow diameter test, T500 slump flow time, V-funnel flow time, L-box ratio and segregation resistance test were performed to evaluate the rheological properties. The compressive and flexural strengths and shrinkage were measured to assess the hardened properties of SCC.

2. Materials

For all self-compacting concrete mixes made in this study, a Portland cement CEM II / B 42.5N with a fineness of 4640 cm²/kg was used; two types of coarse aggregates 3/8 and 8/15 of crushed limestone origins with a density of 2.53 and 1% of water absorption were used. Dune sand was used as fine aggregates with density of 2.61; fineness modulus of 2.56 and a water absorption of 1.34%. The used recycled steel fibers are recovered (SFR) from waste tires. The geometric properties of the fibers varied due to the irregular shape of the recycled fibers. The length and the diameter of the fiber were evaluated using Vernier caliper; they are estimated from 0.8 mm to 55 mm and 0.18 mm to 1.25 mm, respectively. It should be noted that there is a quantity of residual rubber between the fibers and on their surface. The rubber content in the fibers is approximately evaluated at 10% of weight of the fibers. A polycarboxylate plasticizer with a density of 1.06 kg/m³ is used.

3. Methods

The Japanese general method [9, 10] is used for the formulation of the different mixtures of SCC studied. In order to separate only the effect of fibers on SCC; the cement content, water to cement ratio (0.46), gravel to the sand ratio (1.0) and super-plasticizer content 1.0% (by weight of cement) were kept constant in all SCC mixtures. SFR were added separately to SCC mixtures at volume fraction of 0.5%, 0.8%, 1% and 1.5%. The various proportions of the mixtures are given in table 1.
The concrete is named SCC if it fulfills at the fresh state the three conditions; filling capability, passing ability and segregation resistance as per the specifications of the European guide [11]. To satisfy these properties, essential tests such as slump flow diameter, T500 slump flow time, V-funnel flow time, L-box ratio, segregation resistance tests were conducted according to EFNARC [11]. After 24 hours of hardening, the specimens were conserved in water for 28 days. The assessment of compressive and flexural strengths was according to ASTM C39 and ASTM C78, respectively. For the compression and three-point flexion tests, it respectively used the cubic specimens of 100x100x100 mm$^3$ and prismatic specimens of 280x70x70 mm$^3$. Shrinkage tests were performed as per ASTM C878 standard utilizing specimens of 280x70x70 mm$^3$ of dimensions. Dimensional variations of specimens were recorded during the first 28 days after the unmolding.

4. Results and discussion

4.1. Properties of fresh self-compacting concrete mixtures

The results in the fresh state of all mixtures of SCC containing recycled steel fibers at volume fraction of 0.5%, 0.8%, 1% and 1.5% are shown in Figure 1. It is clearly seen that the addition of recycled fibers led to reduce the slump flow diameter (Figure 1.a) from 760 mm for the mixture of reference to 385 mm for the mixture which contains 1.5% of fibers. It should be noticed that the mixture with 1.5% fibers have a diameter (360 mm) less than 550 mm, so this mixture could not be considered as SCC according the EFNARC recommendations. Obviously, the addition of high rates of recycled steel fibers affected the fluidity of SCC, because the fibers prevents the flow of the cement paste. The obtained results are in agreement with other investigations [2, 7, 8, 12, 13]. On the other hand, the obtained results revealed that the time of T500 and V-funnel flow increase as fiber content increases from 0% to 1.5%. The increase in T500 time is estimated at 81.39% when the rate of the addition of fibers increased from 0% to 1% (Figure 1.a). In addition, the V-funnel flow time increased from 2.2 s to 9 s when fibers content increased from 0% to 1.5% (Figure 1.c); the friction between the fibers and other ingredient caused this increases in the time of flow. Mastali et al. [5] also reported an increase in the viscosity of SCC with addition of fibers leading to increase in the flow time. Figure 1.b show the blocking ratio at L-box test. It was noticed that there is a blockage once the fibers are added to the mixtures. This blockage intensifies, if not giving a complete blockage, when steel fibers rate exceeds 0.8%. Based on the European recommendations for SCC, blocking ratio must be higher 80%, therefore all the mixtures could not be considered as SCC. Siddique et al. [7] and Rambo et al. [14] have also reported similar results.

The segregation resistance test is generally used in laboratory to quantify the potential of the mixture to resist the phenomena of segregation. Figure (1.d) shows the relation between the rate of segregation and the fibers content. The laitance percentage varies from 5.87% to 3.2%, when the rate of fibers increases from 0% to 1.5% confirming other reported results in the literature [8]. However [15] reported

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**Table 1. Mix concrete proportions**

| Mix designation | Ingredients kg/m$^3$ | Cement | Gravel | Sand | Fibers | SP | Water |
|-----------------|----------------------|--------|--------|------|--------|----|-------|
| SCC0            | 3/8                  | 0      |        |      |        |    |       |
| SFRSCC0.5       | 8/15                 | 18.3   |        |      |        |    |       |
| SFRSCC0.8       |                      | 442.4  | 465.26 | 347.69 | 819.7 | 29.28 | 4.42 | 200.7 |
| SFRSCC1         |                      | 371.26 |        |      |        |    |       |
| SFRSCC1.5       |                      | 36.6   |        |      |        |    |       |
also similar results but they mentioned that there is a clear trend towards the increased segregation with increased fiber content. Although the data in Figure (1.d) might suggest that these mixtures resist the segregation (laitance <15%), it is in fact the high density of fibers which leads them to the bottom section thus closing the sieve. Hence, it can be concluded that this test is not appropriate for fiber-reinforced SCC.

![Diagrams showing slump flow diameter, T500, L-box ratio, V-funnel flow time, and segregation resistance test.](image)

**Figure 1.** Effect of recycled steel fibers on: (a) slump flow diameter and T500; (b) L-box ratio; (c) V-funnel flow time; (d) segregation resistance test.

### 4.2. Effect of rubber on hardened concrete properties

#### 4.2.1. Mechanical properties: Compressive strength and flexural strengths are evaluated at 28 days of curing for each fibers content (Figures 2 and 3). The obtained results showed that the compressive strength decreased by about 9.36% when fibers added at a rate of 1.5%. This reduction could be attributed to the remaining part of rubber particles on the fibers surface. The rubber part is a weak zone within the concrete. These weak areas could lead to the concentration of stresses in the cement paste around rubber particles [16]. It should also be mentioned that the addition of steel fibres from waste tires increases the air content in concrete. These results are in agreement with the findings of other researchers [1,6]. However, Mastali et al. [5] reported that a significant improvement of compressive strength would take a place when recycled steel fibers were added.

On the other side, the flexural strength increased with the increase of the fibers content. It varied from 5.06 MPa to 7.11 MPa (Figure 3). This increase is due to the random distribution of steel fibers in the
SCC which helps to transfer the fracture loads at one point to another and hence controls the cracks [7]. The results obtained confirm those reported by Mastali et al. [5]. They argued that this increase of flexural strength is due to the bridging action of the recycled steel fiber, preventing the cracks from further opening and forming new cracks in the vicinity.

![Figure 2. Effect of recycled steel fibers on 28 days compressive strength.](image1)

![Figure 3. Effect of recycled steel fibers on 28 days flexural strength.](image2)

4.2.2. Shrinkage: The effect of recycled steel fibers on the shrinkage of SCC is summarised on Figure (4). It can be seen that the shrinkage decreased by the increase of the content of fibres in the mixtures. This behaviour could be explained by the presence of fibers that makes it possible to slow the movement of the skeleton due to the evaporation of water or the evolution of the microstructure.

![Fig 4. The effect recycled steel fibers on the shrinkage of SCC](image3)

5. Conclusion

The effectiveness of using recycled steel fibers recovered from waste tires in SCC was experimentally investigated in the present paper. The obtained results have shown that:
The addition of waste steel fibers reduces the workability of SCC. The percentage of added fibers negatively correlates to the workability of concrete and consequently causes an increase in viscosity, a decrease in the fluidity, segregations and possible blockage.

The compressive strength of SCC with waste tires steel fibers decreases with an increase in percentage of SFR due to the presence of part of rubber particles on the fibers surface which are weak zones within the concrete.

Waste steel fibers improve the flexural strength due to the bridging action of the recycled steel fiber and the preventing of the cracks from further opening.

The use of recycled steel fibers on SCC decreases the shrinkage.

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