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Investigation into the Mechanical Properties of Structural Lightweight Concrete Reinforced with Waste Steel Wires

Kamran Aghaee[a,*], Mohammad Ali Yazdi[b] and Konstantinos Daniel Tsavdaridis[c]
[a]Department of Civil Engineering, Islamic Azad University- Yazd Branch, Yazd, Iran
*Corresponding author. Tel: +98 912 572 2373; Fax: +98 351 624 7100
E-mail Address: Kamran.aghaee@gmail.com; Postal Address: No 17, Parasto Alley, Meghdad St, Maskan Sq, Yazd, Yazd, Iran
[b]School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China
[c]School of Civil Engineering, The University of Leeds, Woodhouse Lane LS2 9JT, Leeds, UK, E-mail Address: k.tsavdaridis@leeds.ac.uk

Abstract
Recently, the use of different waste fibers in concrete has started to increase rapidly due to reasons such as economic savings and positive effects on the environment. In the present study, waste steel wires taken from steel reinforcement and formworks which were previously used in buildings and infrastructures projects, were blended with structural lightweight concrete. The scope was to replace the industrial steel fibers of controlled quality with recycled ones. Compressive, tensile, flexural and impact tests were performed observing the mechanical properties of a 28-day reinforced concrete (RC) specimen to compare with the same apparatus of RC with mixed steel wires, mixed steel fibers as well as plain concrete. The percentage of fibers on all fiber reinforced concrete (FRC) specimens was 0.25%, 0.5% and 0.75% in volume fraction of the concrete. Varying the fiber content, a similar trend in all types of FRCs was observed. It was concluded that the waste wires could be used as a suitable and promising alternative to steel fibers in structural lightweight concrete.
Keywords: Structural lightweight concrete; Fiber reinforced concrete; Waste steel wire; Environment; Industrial steel fiber.

1. Introduction
For several decades, the structural lightweight aggregate concrete has used in many different applications, including, buildings, bridges, floors, partitions, etc. (Shafigh et al. 2011; Yasar et al. 2003). This kind of concrete is a popular material in construction industry due to some exclusive benefits such as good tensile capacity, low coefficient of thermal expansion and superior heat as well as sound insulation capability (Yasar et al. 2003; Hassanpour et al. 2012; Duzgun et al. 2005; Tanyildizi, 2008; Alshihri et al. 2009; Sengul et al. 2011). Furthermore, due to the use of lightweight concrete in construction the dead load is reduced and so the earthquake forces do, and hence diminish hazards for human's life. Therefore, the decrease of structural and non-structural section dimensions and cost of the construction is achieved (Duzgun et al. 2005; Libre et al. 2011; Topcu 1997; Altun and Aktas 2013). Nonetheless, there are defects in the mechanical properties of the lightweight concrete which have eliminated its use for high load bearing structural members (Hassanpour et al. 2012; Gao et al. 1997; Arisoy and Wu 2008). Conventional concrete is a brittle material with low shear capacity and bending strength (Hassanpour et al. 2012; Withers and Bhadeshia 2001; Shah and Ribakov 2011; Slater et al. 2012). These characteristics are also apparent in lightweight aggregate concrete (LWAC) for the same compressive strength (Domagala 2011; Balendran et al., 2002) due to existence of lightweight aggregates which are relatively weaker than the cement matrix while they also have low resistance against crack propagation (Naaman and Reinhardt 2003). Therefore, it is found that the addition of steel fibers in the concrete mixture is beneficial and it can decrease the aforementioned brittleness (Pawade et al. 2011; Kandasamy and Murugesan 2011). This method is commonly used for reducing the LWAC brittleness (Arisoy and Wu 2008; Pawade et al. 2011; Chanh 2004; Kayali et al. 2003).
In the past, many research studies have been examined to evaluate the properties of steel fiber reinforced concrete (SFRC) (Mohammadi et al. 2008). They have reported that adding steel fibers into lightweight concrete, the load-carrying capacity is increased while prevent the opening of macro-cracks, and reduce

the width of micro-cracks while providing great resistance against dynamic, impact and sudden loads. Moreover, steel fibers also improve the tensile strength of fiber reinforced concrete (Altun and Aktas 2013; Mohammadi et al. 2008).
Although many research studies have conducted using FRC, this composite material is not relatively economical. Therefore, the usage of waste fibers which recovered from different industrial procedures such as milling, manufacturing machinery, and textile industry can be considered as an effective alternative for origin materials (Altun and Aktas 2013). Alongside these benefits, direct reuse of raw wastes is becoming the most convenient and effective way to recycle waste materials into useful products which can be used as a viable alternative for our resources and could also save our environment. In many cases, some procedures such as mechanical, chemical and biological methods are carried out to recycle the waste materials. All of these methods are energy consuming and could be harmful for the environment by the emission of pollution into the air, water and soil, whereas when using raw material such these waste wires, similar phenomenon are not appeared and a reasonable and environmental friendly effort is considered (Wang 2010).
Wang et al. (2000) reviewed studies on the mechanical properties of FRC by using recycled fibers, including tire cords/wires, carpet fibers, feather fibers, steel shavings, wood fibers from paper waste, as well as high density polyethylene. It was reported that recovered industrial fibers in concrete could have similar mechanical properties to those common FRCs, although a higher dosage rate may be required to match the performance (Wang et al. 2000). Guoqiang et al. (2004) utilized waste tires in two forms of fibers and chips in the concrete. They have reported that the performance of fibers in the concrete is better than chips, while their strength and stiffness is higher than chips reinforced concrete (Li et al. 2004). Ghailan (2005) used waste industrial fibers replacing the aggregates in the concrete mix, and reported that the stiffness of reinforced concrete is higher than the one with plain concrete, and the comparatively high corrosion resistance against salts and acids was also achieved (Ghailan 2005). Neocleous et al. (2006) evaluated the flexural properties of concrete reinforced with tire-recycled steel fibers. It was reported that the recycled steel fibers (RSF) from waste tires have a great effect on improving the post-peak behavior of FRC (Neocleous et al. 2006). Meddah and Bencheikh (2009) investigated the mechanical properties of waste metallic and polypropylene fibers of various lengths. It was found that adding waste fibers for more than 1.5% in volume fraction of the concrete, the compressive strength of the composite concrete was decreased. Also, the incorporation of waste fibers of different lengths exhibits the best load-carrying capacity and flexural properties (Meddah and Bencheikh 2009). Aiello et al. (2009) studied the mechanical properties of concrete reinforced with recycle steel wires from waste tires. They have reported that the results obtained using waste fibers are comparable to the industrial steel fiber reinforced concrete, and hence the steel fiber from waste tires can be a promising candidate for obtaining FRC (Aiello et al., 2009). Mostafa Jala (2012) has reported that using waste fibers which was recovered from milling and machining, the compressive strength of concrete is increased (Jala 2012).
In the current research, 105 specimens were prepared and the compatibility of replacing the industrial steel fibers with waste steel wires was investigated using two types of fibers in structural lightweight concrete. The compressive, tensile, flexural and impact tests on the 28-day age of both waste steel fiber reinforced concrete and steel fiber reinforced concrete were conducted. This paper represents the results of the experimental campaign.

2. Experimental investigation

2.1. Materials

The materials utilized in the present research study are as follows:

2.1.1. Cement matrix

Ordinary Portland cement according to ASTM C150, type 2 cement with specific gravity of 3.93 was used for every concrete mixture. However, the perlite aggregate, due to its bulk density 93 kg/m^3 with a 5 mm maximum size, was used. The fine aggregate was quartzite sand with a specific gravity of 1.52 and maximum size of 5 mm. Both sand and perlite aggregates were batched in a saturated surface dry (SSD) conditions. A commercial super silica gel with a constant supply of 8% of the cement content was used in all samples.

2.1.2. Fibers

Two types of steel fibers were used; the commercial hooked-end steel fibers and pure waste steel wires. The latter type consists of the major waste material in building workshops and civil infrastructure projects made by steel reinforcement and formworks.

To make the results comparable, the size of fibers were made similar. The length and the diameter of the industrial steel fibers were 50 mm and 1.2 mm, respectively. The length and diameter of the waste steel wires were 50±10 mm and 1.2 mm, respectively. Regarding the shape of the fibers; virgin hooked-end steel fibers were used against cut waste steel wires (Figure 1). The percentage of reinforcing fibers on all specimens was 0.25%, 0.5% and 0.75% in volume fraction of the concrete.

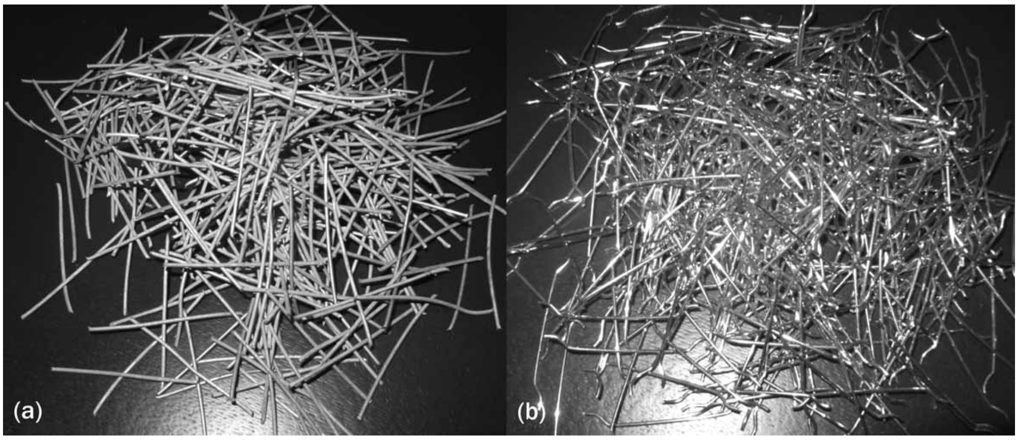

Figure 1: a) Cut waste steel wires; 1.b) Standard hooked-end steel fibers

2.2. Mixture composition

Lightweight perlite concrete is the volumetric mixing of cement, sand, perlite aggregate, steel fibers, water and super silica gel and it was used for the preparation of all the samples. For all mixtures, a water-cement ratio (w/c) of 0.4 was used and the amount of super silica gel was constant. Table 1 represents the details of the mix proportions.

For the preparation of the fiber reinforced lightweight concrete, perlite and sand were first mixed in the dry state for one minute. Then, cement was added to the mixer while running and mixing was continued for another minute. During the mixing operation, the fibers were added and all materials were mixed for further 2 minutes. Alongside the continuous addition of fibers, a spontaneous effort was made for prevention of fibers getting clumped. Finally, the required amount of a specific mixture containing water and super silica gel was slowly added to the mixer, while the mixing was continued for a period of 3 minutes. The molding process of the specimens was performed by pouring at least three layers of concrete in the molds. After filling the molds, the concrete specimens were strengthened using a vibrating table for a period of 8 to 12 seconds.

The specimens were kept in the laboratory for 24 hours under constant ambient temperature. Then all specimens were stored in the water tank at a constant 20±2 °C for 28 days, until the day of the experiments. More details about the mixture properties of the FRC specimens can be found in Table 1.

Mixture code	Perlite	Sand	Cement	Volume Fraction of Fiber (%)	W/C	Super silica Gel (%)
Plain	2	1	2	0	0.4	8
WFRC0.25	2	1	2	0.25	0.4	8
WFRC0.5	2	1	2	0.5	0.4	8
WFRC0.75	2	1	2	0.75	0.4	8
SFRC0.25	2	1	2	0.25	0.4	8
SFRC0.5	2	1	2	0.5	0.4	8
SFRC0.75	2	1	2	0.75	0.4	8

The FRC mixes were defined by the following notations: SFRC and WFRC. The first four letters (SFRC or WFRC) indicate the concrete mixture with the type of fibers used: waste steel wires (WFRC) or industrial steel fibers (SFRC) followed by a number which symbolizes the fiber content in volumetric percent.

2.3. Test Method

From each mixture, three samples were tested at the 28 days of curing. A total of 105 cubic, prismatic, cylindrical and disk specimens were prepared for compressive, flexural, splitting tensile and impact tests.

2.3.1. Compression test

A total of 21 cubic specimens with dimensions of 100×100×100 mm were prepared for compressive testing according to ASTM C39-03 Standard test (ASTM C39-03, 2003). The tests were performed using a digital automatic testing machine and a load rate of 0.15 MPa/sec.

2.3.2. Splitting tensile test

A total of 21 cylindrical specimens (150 × 300 mm) were prepared for the splitting tensile test, conforming to the ASTM C496-04 (ASTM C496-04, 2004). The test was performed by a digital automatic testing machine with the load rate of 0.7 MPa/min. A suitable jig was used to ambulate the concrete cylinder. As the loading started, the center of jig, the center of specimen and the center of thrust of the spherical bearing block were positioned along a unique axis.
The splitting tensile strength of the specimens was calculated as follows:
$T = 2P/\pi ld$
where:
T = splitting tensile strength, psi [MPa],
P = maximum applied load indicated by the testing machine, lbf [N],
l = length, in. [mm], and
d = diameter, in. [mm].

2.3.3. Flexural test

The flexural test was conducted on 21 prismatic specimens by dimensions of 500×100×100 mm, in accordance with ASTM C1018-97 Standard test (ASTM C1018-97, 1997). A universal three point loading machine of 1000 KN loading capacity was employed for the flexural testing. The loading and mid-point displacement of specimens was recorded during the experiment. The rate of increasing net mid-span deflection was adjusted to 0.1 mm/min.
The load-deflection curves were then plotted and the magnitudes of toughness indices (I_5, I_{10} and I_{20}) and residual strength factors ($R_{5,10}$ and $R_{10,20}$) were evaluated. Determining the area under the load-deflection curves up to the specific deflections (as proposed in ASTM C1018-97) and dividing it by the area up to the first crack deflection, the toughness indices were calculated (ASTM C1018-97).

2.3.4. Impact test

A total of 42 cylindrical (disc) specimens with diameter of 150 mm and thickness of 640 mm were specified for impact testing according to the recommended method proposed by ACI Committee 544 (ACI 544, 1999). Due to the use of fibers with length of 50 mm, the test specimens were cut from a full-size cylinder to minimize preferential fiber alignment (ACI 544, 1999; Nataraja et al. 2005).

According to the drop weight impact test method, disk specimens were struck by dropping a 4.5 kg hammer from the height of 45 cm, repeatedly. The load was transferred from the hammer to the specimen through a 64 mm steel ball which was placed at the center of the disc specimen (Nataraja et al. 2005). Two specifications named 'initial' and 'ultimate' failures which testify the impact resistance of the specimens were evaluated. Initial failure is the number of blows required to cause the first visible crack in specimen, and ultimate failure is the number of blows after which the disc specimen fails and comes in contact with three of the four steel lugs of the test equipment (Nataraja et al. 2005; Badr et al. 2006).

3. Results and Discussion

3.1. Compressive strength

Figure 2 presents the results for the compressive strength of WFRC in comparison to SFRC specimens as well as the plain concrete. The compressive strength of perlite lightweight concrete which used in plain and FRC specimens was 185-238 kg/cm^2 and its density was 1708.5-1800 kg/m^3. As per ASTM C330-02a, this type of concrete is known as structural lightweight concrete (ASTM C330-02a, 2002). It was observed that the increase of the steel fiber and waste wire content from 0% to 25%, also increases the compressive strength of WFRC and SFRC by approximately 5% and 18%, respectively, compared to the plain concrete. Thus, it is obvious that the effect of the industrial steel fibers on lightweight concrete is more significant than the waste steel wires. Moreover, the compressive strength of FRCs at the ratio of 0.5% is increased significantly and reached a peak of 236.2 and 243.7 kg/cm^2 in WFRC and SFRC, respectively.

However, the compressive strength of WFRC and SFRC is decreased by approximately 8% and 3%, respectively, while increasing the fiber and wire content from 0.5% to 0.75%, when compared with the plain concrete. It is worth to note that this is lower than the compressive strength of the plain concrete itself. The decrease in the compressive strength for the highest level of fiber (0.75%) may be due to the difficulty in scattering and condensing the fibers in the concrete. This phenomenon is also discussed in the literature (Hassanpour et al. 2012). In fact, Figure 2 illustrates that the effect of adding fibers (both waste steel wires and industrial steel fibers) of different contents, is the similar for the decrease or increase process of the compressive strength of FRCs.

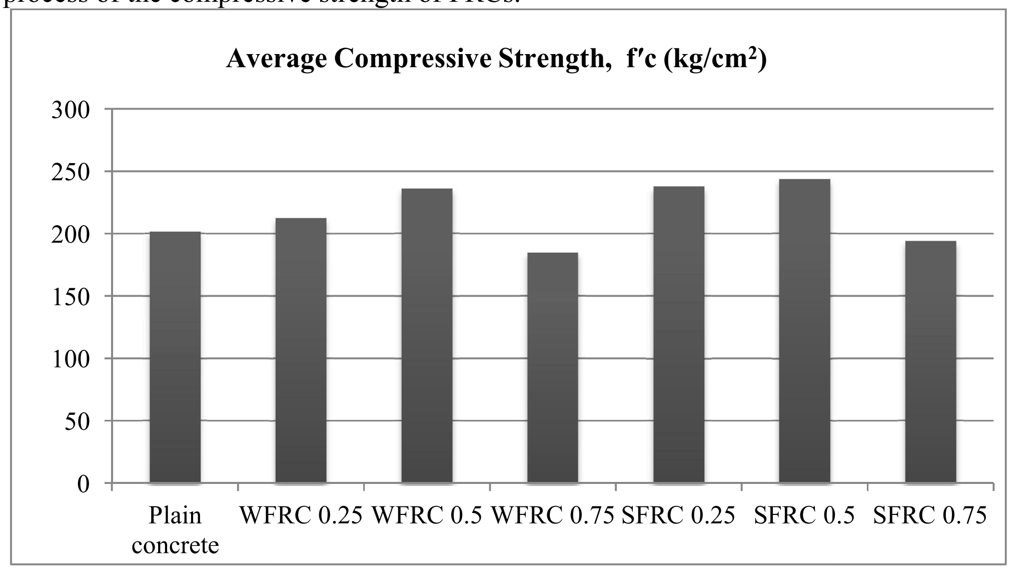

Figure 2: Average compressive strength of WFRC, SFRC and plain specimens in kg/cm^2

3.2. Splitting tensile strength

Figure 3 depicts the results for the splitting tensile strength of plain concrete and FRCs specimens. The test results represent that the use of fibers greatly increases the splitting tensile strength of concrete, for using either waste or industrial ones. Compare to the plain concrete, the splitting tensile strength of WFRC and SFRC is increased by approximately 28% and 26.33% on average, respectively, through the addition of fibers at ratio of 0.25%, 0.5% and 0.75% in volume fraction of the concrete. This indicates that the use of waste steel wires has significant effect compared to the industrial steel fibers on the splitting tensile strength of FRC, especially when high fiber contents. Jianming Gao (1997) reported that the enhancement of the fiber volume fraction from 0% to 2%, increased the splitting tensile strength from 4.95 to 8.8 MPa (Gao et al. 1997). This phenomenon is well represented in Figure 3. Ultimately, the increase in splitting tensile strength is based on the connection between the fibers and the cement matrix. In fact, by adding only 0.25% of fibers into the concrete, the splitting tensile strength increases, significantly. This exemplifies that by any addition of fibers, the splitting tensile strength of FRCs improves remarkably. This observation conforms with the results of Payam Shafigh (2011) and Balendran (2002) (Shafigh et al. 2011; Balendran et al. 2002).

Figure 4 illustrates the plain concrete rupture with a brittle failure following the tensile strength peak. On the other hand, when FRCs used, only small surface cracks in the direction of the load transfer, across the length of the specimens were observed. Therefore, both fibers played a significant role to make the concrete capable of resisting crack propagation.

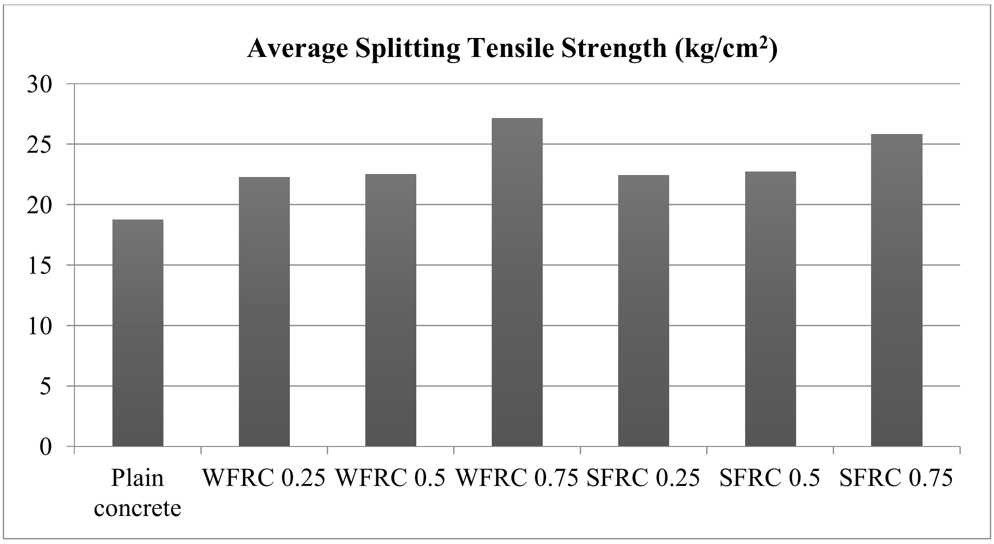

Figure 3: Average splitting tensile strength of WFRC, SFRC and plain specimens in kg/cm^2

Figure 4: Comparison of failure pattern of FRC specimens after splitting tensile strength: (a) WFRC; (b) SFRC

3.3. Flexural strength

The flexural test results of different mixes are synopsized in Table 2. Each result is the mean value recorded from three tests. The results indicate that all values of the first crack strength (FCS) of FRC specimens are higher than that of the plain concrete specimens. Also, the first crack deflections of flexural specimens are increased by increasing the fiber percentage compared to the plain specimens. The maximum amount of FCS of FRCs is 749.09 kg.f, which is 40% higher than the first crack strength of the plain samples. This value is related to the waste steel wire reinforced concrete with 0.75% fibers in volume fraction of fibers. The maximum amount of FCS of steel fiber reinforced concrete is approximately 29% higher than the plain concrete.

In order to determinate the energy absorption capability and toughness of flexural specimens, the toughness indices and the residual strength factors are assessed as suggested by ASTM C1018-97 standard test.

The toughness indices indicate the ability of FRCs to transfer the stresses across a cracked section and this can be considered as their energy absorption capacity. From Table 2, it is observed that increasing the volume fraction of fibers, the toughness indices are ameliorated. This case conforms for both WFRC and SFRC specimens. The results of Table 2 indicate that the toughness indices of WFRCs is higher than SFRCs at 0.25% and 0.75% of the fiber content, while relatively these values are numerically equal for both WFRC and SFRC specimens in 0.5% of fiber content.

The results show that the toughness indices of WFRC0.5 and WFRC0.75 are approximately equal. This reveals that the post-peak area in the load-deflection curves has been increased compared to pre-peak area, in a proportional manner. In contrast, the toughness indices of SFRC0.5 are markedly higher than SFRC0.25 and SFRC0.75. Therefore, in case of 0.5% of steel fiber content, the post-peak area increases significantly compared to the pre-peak area, whereas in other SFRCs the post-peak area has been increased proportionally to the pre-peak area (Figure 5 and Figure 6).

The residual strength factors (RSF) represent the average level of strength retained after the first crack occurred as a percentage of the FCS over a specific deflection interval (ASTM C1018-97, 1997). It is observed that by increasing the fiber content the higher amount of RSF is achieved, while the concrete reinforced with the waste steel wires receives higher RSF compared to those with industrial steel fibers.

Table 2: The values of first-crack strength, first-crack deflection, toughness indices and residual strength factors of bending specimens

Specimen code	V_f (%)	First-crack strength (kg.f)	First-crack deflection (mm)	Toughness indices			Residual strength factors	
				I_5	I_{10}	I_{20}	$R_{5,10}$	$R_{10,20}$
Plain	0	535.266	0.642	-	-	-	-	-
WFRC0.25	0.25	605.508	0.853	2.58	4.14	6.56	31.2	24.2
WFRC0.5	0.5	662.478	1.087	4.26	7.31	11.47	61	41.6
WFRC0.75	0.75	749.090	0.946	4.13	7.28	11.91	63	46.3
SFRC0.25	0.25	703.033	0.855	2.29	3.61	5.85	26.4	22.4
SFRC0.5	0.5	658.945	1.005	4.65	8.09	12	68.8	39.1
SFRC0.75	0.75	688.081	1.480	3.42	4.95	6.67	30.6	17.2

In Figure 5 and Figure 6 the average load-deflection curves are plotted for different percentages of fiber content. According to the load-deflection curves and the flexural experiments, the behavior of the specimens under bending actions can be classified in two types. The first one is related to the specimens without fiber. These samples failed in a brittle manner once the peak load was reached; they separated in two pieces suddenly, while the area under the load-deflection curves of these specimens illustrates the low amount of the energy absorbed. The second behavior was mainly found in FRC specimens. These specimens exhibited a ductile behavior due to the characteristic bond between the fibers and the cement across the cracks. In these samples, the fibers are randomly spread across the cracked section, which is a preparation method of resisting crack propagation and sudden failures. Observing the load-deflection curves, it is revealed that the first crack is followed by a sharp drop in the load carrying-capacity and then a deep curve follows leading to the ultimate failure. The results show that the ultimate deflection of WFRC and SFRC specimens, made by 0.75% fibers content, is about 32 and 26.5 times greater than that of plain concrete, respectively.

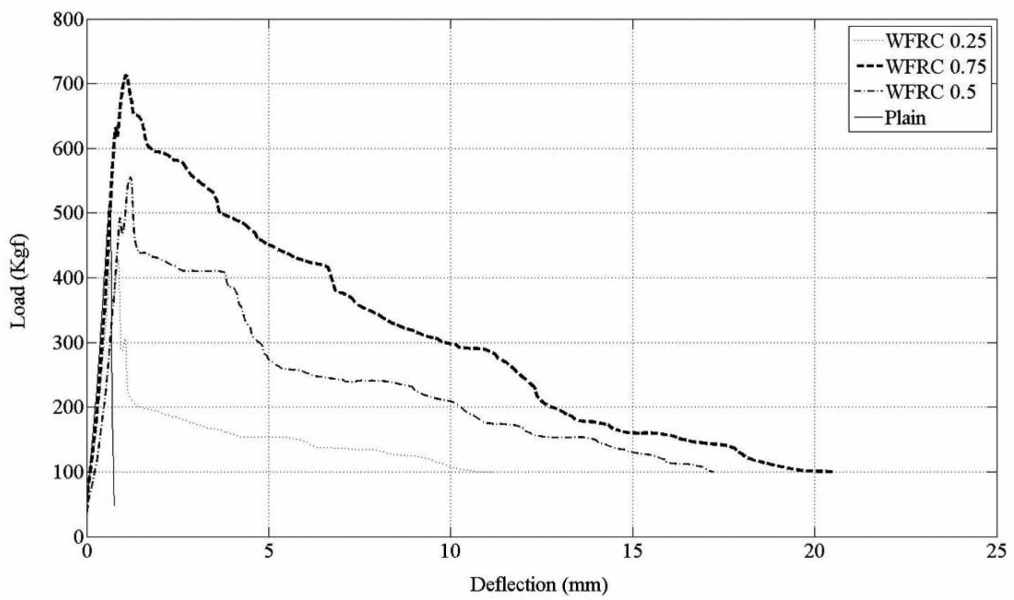

Figure 5: Flexural load-deflection curves of WFRC and plain specimens

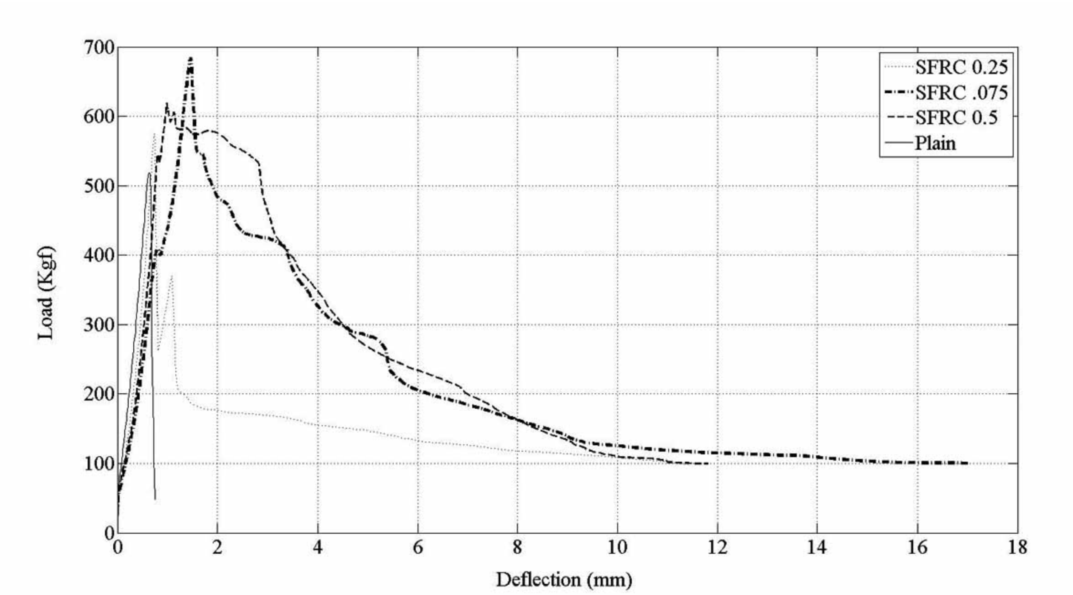

Figure 6: Flexural load-deflection curves of SFRC and plain specimens

The absolute toughness is assessed by estimating the total area under the load-deflection curves up to the ultimate failure. Figure 7 presents the absolute toughness (or absorbed energy) achieved by FRCs in comparison to the specimens with plain concrete, which is significantly higher in the former case. The highest amount of energy absorption is achieved by WFRC0.75 specimens. On average, this value is equal to 6276.63 kg.mm and it is about 28.5 times higher than the one with plain concrete. In contrast, the absorbed energy by SFRC0.75 is 3585.994 kg.mm, which is considerably lower than the one achieved by WFRC0.75.

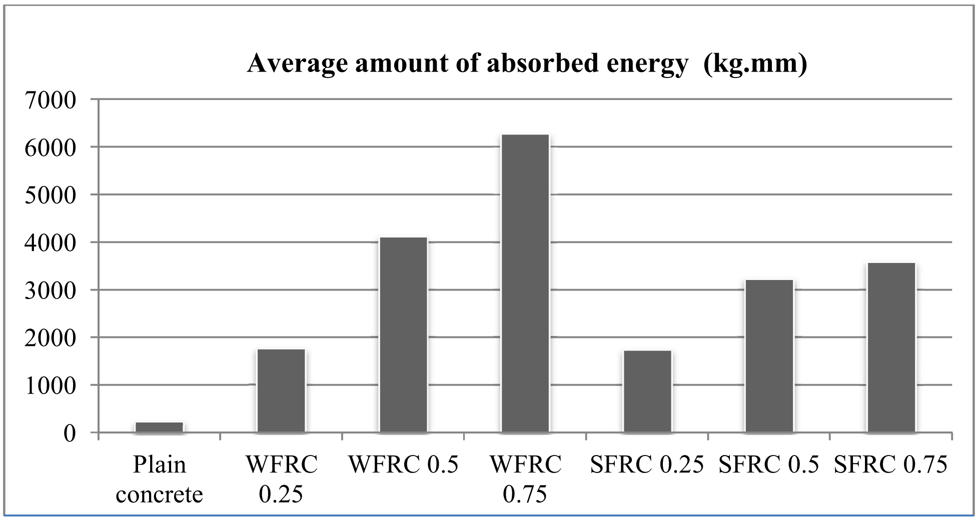

Figure 7: Average amount of absorbed energy by bending samples in kg.mm

3.4. Impact strength

The results of the impact tests are represented in Table 3. The evaluations of the first crack resistance (FCR) and the ultimate resistance (UR) are averaged having considered six specimens for each mixture. As it is shown, the number of blows required to cause the first visible crack and the number of blows to cause the ultimate failure increases by increasing the fibers in the mixtures. Specimens with plain concrete presented a brittle behavior and very low resistance after the initial crack. The specimens with fewer blows reached the ultimate failure earlier. However, the fiber reinforced concrete specimens were able to bear more blows up to the ultimate failure. This increase, in the post-crack resistance is depending on the fiber content (eg. 833% to 1667% for WFRC specimens and 933% to 1575% for SFRC specimens). According to that, by increasing the volume fraction of two types of fibers (waste steel wires and commercial steel fibers) in structural lightweight concrete, a significant improvement of the impact resistance is essentially achieved.

When fibers are spanning across the cracks, the impact energy of hammer blows can be absorbed as well as prevent from crack propagation within the concrete, while the splitting of the concrete into small pieces is also avoided. When SFRC specimens are used, a better performance is perceived while the specimens resisted higher blows compared to WFRC specimens, due to the hooked-end steel fibers and the good adhesion between the fibers and the concrete (Figure 8). The impact resistance of SFRC0.75 and WFRC0.75 is about 17 and 13 times greater compared to the specimens with plain concrete, respectively.

Table 3: Impact test results

Specimen code	First crack resistance (FCR) blows	Ultimate resistance (UR) blows	Increase in resistance from FCR to UR (%)	FCR of SFRC & WFRC / FCR of PC	UR of SFRC & WFRC / UR of PC
PC	2	3	50.00	-	-
WFRC0.25	3	28	833.33	1.5	9.33
WFRC0.5	3	36	1100.00	1.5	12.00
WFRC0.75	3	53	1666.67	1.5	17.67
SFRC0.25	3	31	933.33	1.5	10.33
SFRC0.5	4	48	1100.00	2	16.00
SFRC0.75	4	67	1575.00	2	22.33

The specimens after the ultimate failure from the impact tests are shown in Figure 8. It is noted that the plain concrete specimens are separated in three pieces and that implies to the brittle failure mode that has been encountered. On the other hand, the FRC specimens have failed by at least four polar cracks due to the uniform stress distribution in the concrete. The width of SFRC cracks is smaller than the width of WFRC cracks. This phenomenon indicates that the SFRC specimens possess higher impact resistance, gained from the effective bridging of the fibers across the cracks. Hooked-end steel fibers in concrete are more tangled up and avoided expanding the cracks.

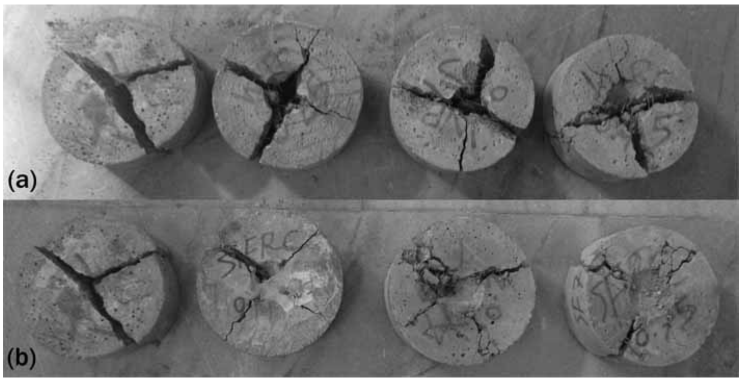

Figure 8: Comparison of failure pattern of FRC specimens after the impact test: (a) WFRC; (b) SFRC

4. Conclusions

In this study, the mechanical properties of structural lightweight concrete reinforced with waste steel wires were investigated. The experimental results were then compared to the mechanical properties of steel fiber reinforced lightweight concrete.

The incorporation of waste wires and industrial steel fibers up to 0.5% in volume fraction of the fiber content in the structural lightweight concrete increases the compressive strength of FRCs. However, the addition of more than 0.5% of the waste wires and steel fibers decrease the compressive strength of FRC specimens. Moreover, it is observed that the trend of increase and decrease of the strength with respect to the fibers in volume fraction in both types of fiber concrete is the same. However, the fiber reinforced concrete has considerably higher splitting tensile strength compared to the plain concrete, even when a low volume of fibers (either waste wires or steel fiber) is used. The positive effect on the splitting tensile strength of LWAC, while adding fibers is predominant in WFRC compared to SFRC specimens. It is further remarkable that even very small volume fractions of steel fibers can assist in preventing the brittle failure of LWAC.

Examining the flexural results, the maximum flexural strength and energy absorption was obtained by WFRC0.75 specimens. This value was 28.5 times greater than the one with the plain concrete and 75% higher than SFRC0.75.

Further, an addition of waste steel wires at 0.75% in volume fraction of the lightweight concrete led to an eighteen-fold increase in the ultimate impact resistance of WFRC specimens compared to the specimens with the plain concrete. While this practice improved the impact resistance, still it was slightly lower than that of SFRC0.75 due to the actual shapes of fibers.

References

1. Shafigh P, Mahmud H and Jumaat MZ (2011) Effect of steel fiber on the mechanical properties of oil palm shell lightweight concrete. J Mater Design 32:3926-32.

2. Yasar E, Atis CD, Kilic A and Gulsen H (2003) Strength properties of lightweight concrete made with basaltic pumice and fly ash. J Mater Lett 57:2267-70.

3. Hassanpour M, Shafigh P and Bin Mahmud H (2012) Review of lightweight aggregate concrete fiber Reinforcemen. J Constr Build Mater 37:452-61.

4. Duzgun OA, Gul R and Aydin AC (2005) Effect of steel fibers on the mechanical properties of natural lightweight aggregate concrete. J Mater Lett 59:3357-63.

5. Tanyildizi H (2008) Effect of temperature, carbon fibers and silica fume on the mechanical properties of lightweight concretes. J New Carbon Mater 23:339-44.

6. Alshihri MM, Azmy AM and El-Bisy MS (2009) Neural networks for predicting compressive strength of structural light weight concrete. J Constr Build Mater 23:2214-9.

7. Sengul O, Azizi S, Karaosmanoglu F and Tasdemir MA (2011) Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. J Energ Buildings 43:671-6.

8. Libre NA, Shekarchi M, Mahoutian M and soroushian P (2011) Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice. J Constr Build Mater 25:2458-64.

9. Topcu IB (1997) Semi-lightweight concretes produced by volcanic slags. J Cem Concr Compos 27:15-21.

10. Altun F and Aktas B (2013) Investigation of reinforced concrete beams behavior of steel fiber added lightweight concrete. J Constr Build Mater 38:575-81.

11. Gao J, Suqa W and Morino K (1997) Mechanical properties of steel fiber-reinforced, high377 strength, lightweight concrete. J Cem Concr Compos 19:307-13.

12. Arisoy B and Wu HC (2008) Material characteristics of high performance lightweight concrete reinforced with PVA. J Constr Build Mater 22:635-45.

13. Withers PJ and Bhadeshia HKDH (2001) Residual stress, Part 1: measurement techniques. J Mater Sci Tech 17:355-65.

14. Shah AA and Ribakov Y (2011) Recent trends in steel fibered high-strength concrete. J Mater Design 32:4122-51.
15. Slater E, Moni M and Alam MS (2012) Predicting the shear strength of steel fiber reinforced concrete beams. J Constr Build Mater 26:423-36.
16. Domagala L (2011) Modification of properties of structural lightweight concrete with steel fibers. J Civ Eng Manag 17:36-44.
17. Balendran RV, Zhou FP, Nadeem A and Leung AYT (2002) Influence of steel fibers on strength and ductility of normal and lightweight high strength concrete. J Build Environ 37:1361-7.
18. Naaman AE and Reinhardt HW (2003) High performance fiber reinforced cement composites (HPFRCC4), fourth International RILEM Workshop on High Performance Fiber Reinforced Cement Composites (HPFRCC 4). Ann Arbor, USA
19. Pawade PY, Nagarnaik PB and Pande AM (2011) Influence of Silica fume in enhancement of compressive strength, flexural strength of steel fibers concrete and their relationship. Int J Civ Strut Eng 2:43-55.
20. Kandasamy R and Murugesan R (2011) Fiber reinforced concrete using domestic waste plastics as fibers. J Eng Appl Sci 6:75-82.
21. Chanh NV (2004) Steel fiber reinforced concrete. Faculty of Civil Engineering Ho Chi Minh City University of Technology, pp 108–16
22. Kayali O, Haque MN and Zhu B (2003) Some characteristics of high strength fiber reinforced lightweight aggregate concrete. J Cem Concr Compos 25:207-13.
23. Mohammadi Y, Singh SP and Kaushik SK (2008) Properties of steel fibrous concrete containing mixed fibers in fresh and hardened states. J Constr Build Mater 22:956-65.
24. Wang Y (2010) Fiber and Textile Waste Utilization. J Waste Biomass Valorization 1:35-143.
25. Wang Y, Wu HC and Li VC (2000) Concrete reinforcement with recycled fibers. J Mater Civ Eng 12:314-319.
26. Li G, Stubblefield MA, Garrick G, Eggers J, Abadie C and Huang B (2004) Development of waste tire modified concrete. J Cem Concr Res 34:2283-2289.
27. Ghailan AH (2005) Modified Concrete by Using a Waste Material as a Coarse Aggregate Construction Research Congress: Broadening perspective-Proceedings of the Congress, pp 217-226
28. Neocleous K, Pilakoutas H and Waldron P (2006) From used tires to concrete fiber Reinforcement, Proc., 2nd Int. FIB Congress. Italy
29. Meddah MS and Bencheikh M (2009) Properties of concrete reinforced with different kinds of industrial waste fiber materials. J Constr Build Mater 23:3196-3205.
30. Aiello MA, Leuzzi F, Centonze G and Maffezzoli A (2009) Use of steel fibers recovered from waste tires as reinforcement in concrete: Pull-out behavior, compressive and flexural strength. J Waste Manage 29:1960-1970.
31. Jala M (2012) Compressive Strength Enhancement of Concrete Reinforced by Waste Steel Fibers Utilizing Nano SiO2. Middle East J Sci Res12:382-391.
32. American Society for Testing and Materials, ASTM C39-03 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, 2003.
33. American Society for Testing and Materials, ASTM C496-04 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, 2004.
34. American Society for Testing and Materials, ASTM C1018-97 Standard test method for flexural toughness and first-crack strength of fiber-reinforced concrete (using beam with third-point loading), West Conshohocken (PA): ASTM International, 1997.
35. ACI Committee 544. ACI 544.2R-89: Measurement of properties of fibre reinforced concrete, Reapproved 1999.
36. Nataraja MC, Nagaraj TS and Basavaraja SB (2005) Reproportioning of steel fiber reinforced concrete mixes and their impact resistance. J Cem Concr Res 35:2350-2359.
37. Badr A, Ashour AF and Platten AK (2006) Statistical variations in impact resistance of polypropylene fibre-reinforced concrete. Inter J Impact Eng 32:1907–1920.

38. American Society for Testing and Materials, ASTM C330-02a. Standard Specification for Lightweight Aggregates for Concrete Masonry Units, 2002.