
FRESH AND HARDENED PROPERTIES OF CONCRETE CONTAINING STEEL FIBRE FROM RECYCLED TIRE

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Abstract: This paper presents some results and discusses the feasibility of adding recycled steel fibre from scrap tires as reinforcement in concrete. A number of tests were conducted to investigate fresh and hardened state properties like slump, Vebe time, ultrasonic pulse velocity, compressive, tensile and flexural strength of recycled steel fibre reinforced concrete (RSFRC). The effect of incorporation of recycled steel fibre on various aspect ratios (l/d) of 45, 67 and 89, and volume fraction (V_f) of 0.5, 1, 1.5 and 2% were experimentally investigated. Test specimens comprising of cube, cylinder and prism were prepared and tested after 1, 7 and 28 days of water curing. It has been found that the workability of RSFRC, in general, was reduced as the volume fraction of the fibre increased. The compressive strength and splitting tensile strength of RSFRC reached a maximum at l/d ratio of 67. In terms of volume, the compressive strength of RSFRC was not significantly increased by incorporation of recycled steel fibre. However, the tensile and flexural strength of RSFRC was remarkably improved with the increase of fibre content. The results obtained and the observation made in this study suggests that recycled steel from waste tires can successfully be used as fibre reinforcing material in concrete.

Keywords: fibre reinforced concrete, recycled tire, steel fibre, workability and strength.

1.0 Introduction

The technology of concrete reinforcement is not new, and fibres have been used for reinforcement since ancient times. Fibre reinforced concrete is a type of concrete that includes fibrous substances homogeneously dispersed and oriented in the concrete matrix. Fibres commonly used in concrete are steel fibers, synthetic fibres, glass fibres, and natural fibres. Since the advent of fibre reinforcing of concrete, a great deal of testing has been conducted on various fibrous materials to determine the actual characteristics and advantages for each product. Over the decades different types of steel fibres have been successfully used to reinforce concrete.

Steel fibres may be produced either cutting wire, by shearing sheets or from a hot-melt extract. The first generation of steel fibres was smooth so they did not develop sufficient

bond with the cementitious matrix. Major efforts have been made in recent years to optimize the shape and size of the steel fibres to achieve improved fibre-matrix bond characteristics (Mindes *et al.*, 1996; Colin, 1982, Ibrahim *et al.*, 2011) It was found that steel fibre reinforced concrete (SFRC) containing hook-ended stainless steel wires has better physical properties than those containing straight fibres. This is attributed to the better anchorage provide and higher effective aspect ratio than that for the equivalent length of straight fibre (Swamy and Mangat, 1976). The addition of steel fibres to concrete necessitate an alteration to the mix design to compensate for the loss of workability due to the extra paste required for coating the surface of the added steel fibres.

The utilization of SFRC over the past years has been varied and widespread. The most common applications are pavements, tunnel linings, bridge deck slab repairs, and so on. Unfortunately the fibres themselves are relatively expensive. A 1% steel fibre addition, for instance, will approximately double the material cost of the concrete, and this has tended to limit the use of SFRC to special applications. In recent years, there has been an increased interest in using the recycled steel waste especially from tire products. In all parts of the world large quantities of scrap tires are generated each year resulting in environmental hazards. It has been estimated that over 8 million units of scrap tire have been generated in Malaysia, and 60% of the scrap tires are disposed via unknown route (Jalil, 2010). These scrap tires are dangerous not only due to potential environmental threat, but also from fire hazards and provide breeding grounds for rats, mice, and mosquitoes. Today, scrap tire disposal has become a serious issue and research works have been devoted to the use of steel fibres recovered from waste tires in concrete. Concrete obtained by adding recycled steel fibres has evidenced a satisfactory improvement of the fragile matrix, mostly in terms of toughness and post-cracking behavior (Tlemat *et al.*, 2006 and Naik and Singh, 1991). This paper highlights the use of recycled steel fibre from scrap tires as reinforcement of normal concrete and discusses various fresh and hardened state properties of concrete containing the fibre

2.0 Materials and Test Methods

The aim of this study as mentioned above is to investigate the properties of concrete reinforced with recycled steel fibre recovered from waste tires. The fresh properties of recycled steel fibre reinforced concrete (RSFRC) were slump and Vebe times while the hardened properties of were compressive strength, splitting tensile strength, flexural strength and ultrasonic pulse velocity. The materials used and the methods followed for conducting the tests are given in the following sections.

2.1 Materials

Cement corresponding to ASTM Type I from a single source was used throughout the experimental work. The coarse aggregate was crushed granite with a maximum size of 20mm. Natural river sand with fineness modules of 2.5 was used as a fine aggregate. Both coarse and fine aggregates were batched in a saturated surface dry condition. Supplied tap water was used throughout the study in mixing, curing and other purposes. A commercial polynaphthalene sulfonate type superplasticizer conforming to ASTM C494-92 was utilized as high range water reducing agent in the concrete. The dosage of superplasticizer was kept constant for all concrete mixes in order to eliminate any probable effect of this parameter on the properties of hardened concrete.

2.2 Preparation of Steel Fibre from Recycled Tire

Steel fibres used in this research were recovered by a shredding process of waste tires. The steel was successively separated from rubber by a pyrolysis process. The steel fibres, shown in Figure 1, are characterized by different diameters and length. The average fibre length was 30mm with an average tensile strength of 1033 MPa.



Figure 1: Recycled steel fibre before and after shredding

A preliminary characterization was carried out by a statistical analysis in order to evaluate the variability of the geometric properties after the shredding process without any further treatment. The characterization is fundamental to eventually defining the opportune treatments for improving the final properties of the concrete. A sample of about 200 steel fibres, extracted randomly after the shredding process, was analysed. The diameter of each fibre was recorded by a micrometer and determined averaging three measures, namely at the two extremities of the fibre and at the midpoint.

2.3 Concrete Mix and Preparation of Test Specimens

The recycled steel fibres were added at different aspect ratio (l/d) and volume fraction (V_f) to determine the applicability of the fibre as reinforcement in concrete. The steel fibre recovered from waste tyre was employed to concrete mixtures with aspect ratios (l/d) of 45, 67 and 89 followed by volume fractions of 0.5%, 1.0%, 1.5% and 2.0%. A total of 63 cubic specimens, 21 cylindrical specimens and 21 prismatic specimens was fabricated and cured in water until testing. Water to cement ratio was settled to 0.4 according to ACI Committee such as to provide good mechanical strength and adequate workability of the mixtures. The mix proportion of recycled steel fibre reinforced concrete is shown in Table 1.

Table 1: Mix design of recycled steel fibre reinforced concrete.

Mixture code	l/d ratio	V_r (%)	Cement (kg/m^3)	Water (L/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Fibre (kg/m^3)	SP (kg/m^3)
PC	-	-	562	225	925	670	-	5.63
RSFRC -1	45	0.5	562	225	925	670	12.5	5.63
RSFRC -2	67	0.5	562	225	925	670	12.5	5.63
RSFRC -3	89	0.5	562	225	925	670	12.5	5.63
RSFRC -4	67	1	562	225	925	670	25	5.63
RSFRC -5	67	1.5	562	225	925	670	50	5.63
RSFRC -6	67	2	562	225	925	670	70	5.63

The mixing procedure was divided into three stages. In the first stage cement, fine and coarse aggregates were weighed and mixed by hand until all the constituents are mixed uniformly. In the second stage, the recycled steel fibres were added slowly and uniformly to eliminate the recycled steel fibres clumped together. In the final stage, measured water and superplasticizer were added and mixed thoroughly until a homogeneous mix is obtained.

2.4 Tests on Fresh and Hardened Concrete

Slump test, following ASTM C143 standard was carried out to measure the consistency of a concrete which has a close indication to workability. Along with slump test, the Vebe test was conducted conforming to ASTM C 1170. In order to investigate the

compressive strength of concrete, uniaxial compression test was carried out on 100 mm cube specimen following BS 1881-127:1990. The splitting tensile test was, however, performed on the standard test cylinders measuring 100x200mm conforming ASTM C496/C496M-04. The flexural strength test was conducted using 100x100x500mm beams under third point loading following the ATSM C1609/C1609M -10.

In addition to compressive, tensile and flexural strength tests, an ultrasonic pulse velocity test (conforming ASTM C597) was also conducted (Figure 2) to measure the uniformity of concrete, and to investigate the relationship between compressive strength and ultrasonic pulse velocity of concrete cubes with different fibre volume fractions.



Figure 2: Testing of ultrasonic pulse velocity.

3.0 Result and Discussion

3.1 Properties of Fresh Concrete

In this study both the slump and Vebe time tests were conducted to investigate workability of concrete. The slump value and the Vebe time of all the concrete mixes for different aspect ratio (l/d) and fibre volume fraction (V_f) are tabulated in Table 2. As shown in the Table 2, slump values of concrete decreased as the l/d ratio and V_f increased. Meanwhile, Vebe time of concrete increased as the l/d ratio and V_f increased. For fibre volume of 1% and above the workability of concrete is dramatically decreased. It is to note that the interlocking of fibres resists the flow of fresh concrete affecting the workability of concrete. The result on unit weight of concrete, presented in the same table reveals that the unit weight of concrete increased uniformly with the increase in fibre volume fraction. This is obvious as the specific gravity of recycled steel fibres is higher than those of other components of concrete. Regardless of fibre volume, it was further observed that the unit weight of RSFRC decreased by the increase of fibre aspect ratio because of air content in the concrete by orientation and distribution of long fibres.

Table 2: Slump, Vebe time and unit weight of concrete mixtures.

Mixture code	l/d ratio	V_f (%)	Slump (mm)	Vebe time (s)	Unit weight (kg/m ³)
PC	-	-	50	3.05	2420
RSFRC-1	45	0.5	45	3.88	2440
RSFRC-2	67	0.5	40	4.06	2435
RSFRC-3	89	0.5	30	5.62	2430
RSFRC-4	67	1	25	6.35	2445
RSFRC-5	67	1.5	20	7.85	2465
RSFRC-6	67	2	10	12.32	2470

The aspect ratio (l/d) of recycled steel fiber has a predominant effect on the workability of concrete mixtures. The slump value has been found to decrease in concrete mixture realized with fiber aspect ratio of 45 and 67. A significant drop from 50mm to 30mm for concrete mixture was realized with fiber aspect ratio of 89. Table 2 reveals that higher the aspect ratio higher was the Vebe time for the same fibre content. This is due to the fact that long fibres tend to mat together while short fibres does not interlock and can be dispersed easily by vibration.

The experimental results obtained in this study are in close agreement with the research findings from Yazici *et al.* (2007). It has been shown that slump of concrete decreased as the l/d ratio of steel fibre increased. Like that of slump value, the Vebe time also found to be influenced by the aspect ratio of recycled steel fibers.

Like aspect ratio, the amount of fibre i.e. the volume fraction (V_f) significantly influenced the workability of fibre reinforced concrete. Higher the amount of fibre lower was the slump value. With an increase in the amount of fibre for 1 to 2 percent, the Vebe time of the SFRC has been found to be almost double. This is to be expected because lower amount of fibre can easily disperse in the concrete matrix.

With further addition the fibres start to clump together showing a balling effect (Figure 3). Furthermore, the interlocking and entangled around aggregate particles and considerably reduce the workability. A similar observation has been made by Uygunoglu (2010) who found that the unit weight of SFRC increased with the increase in fibre content for both 30mm and 60mm steel fibre.

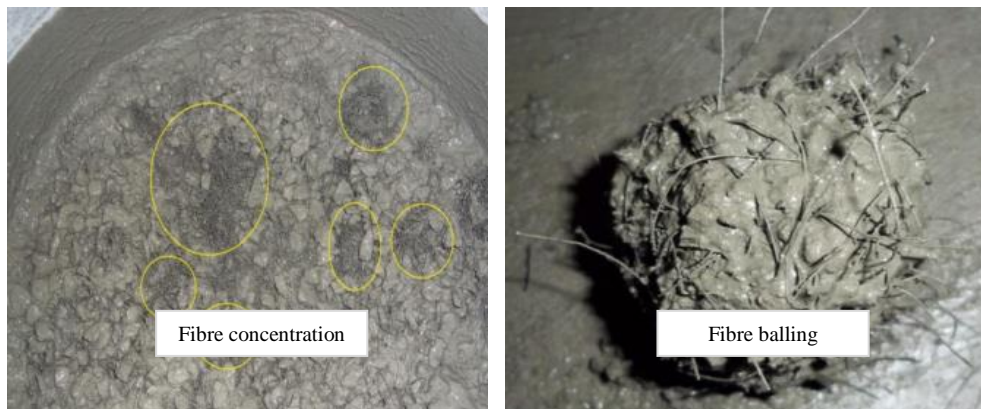


Figure 3: Fresh concrete mix showing fibre concentration and balling effect.

3.2 Hardened Properties of Concrete

The mechanical properties of recycled steel fibre reinforced concrete investigated in this study are compressive strength, splitting tensile strength and flexural strength. The results obtained for all categories of strength investigation are presented in Table 3. Along with strength, ultrasonic pulse velocity of the concrete specimen was also studied to examine the relationship.

Table 3: Mechanical properties of different concrete mixes.

Mix code	l/d ratio	V_f (%)	Compressive strength, f_c (MPa)	Relative f_c (%)	Splitting tensile strength, f_{st} (MPa)	Relative f_{st} (%)	Flexural strength, f_f (MPa)	Relative f_f (%)
PC	-	-	55.85	100	3.80	100	4.60	100
RSFRC-1	45	0.5	57.15	102	6.50	172	5.20	113
RSFRC-2	67	0.5	58.50	105	6.90	181	5.45	118
RSFRC-3	89	0.5	57.85	104	6.65	175	5.65	123
RSFRC-4	67	1.0	58.20	104	7.10	187	5.75	125
RSFRC-5	67	1.5	59.00	106	8.15	215	6.15	134
RSFRC-6	67	2.0	58.70	105	9.45	249	6.95	151

3.2.1 Compressive Strength

The 28-day compressive strength values of concrete specimen are presented in Table 3. Among the three aspect ratios, the l/d ratio of 67 (RSFRC-2) exhibited the maximum compressive strength value. It can be seen that on average, compressive strength of RSFRC are about 2-6% higher than that of control mixture. RSFRC with fibre volume of 1.5% showed the highest compressive strength for aspect ratio of 67. A close observation has been made by Modtrifi *et al.* (2011) who reported that an addition of 0.7% recycled steel fibres in concrete resulted in an increase of approximately 12% in compressive strength.

Although the compressive strength of SFRC was much affected by the presence of fibre, the failure mode, however, exhibited a considerable change from fragile to ductile state. Due to bridging effect of the fibre, the cubic specimens did not crush but held their integrity up to the end of the test. Figure 4 illustrates the typical failure mode of plain concrete and recycled steel fibre reinforced concrete.

There appears to be a good correlation between compressive strength and ultrasonic pulse velocity containing recycled steel fibre. The relationship shown in Figure 5 suggests that higher the compressive strength higher was the ultrasonic pulse velocity. This is in agreement with the research findings in concrete containing recycled aluminium can fibre (Awal *et al.*, 2011) and the relationship demonstrated by Neville and Brooks (1994).

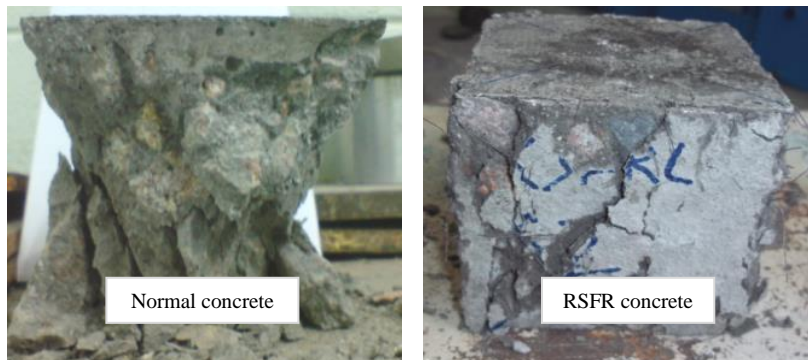


Figure 4: Typical failure pattern of normal and recycled steel fibre reinforced concrete cube.

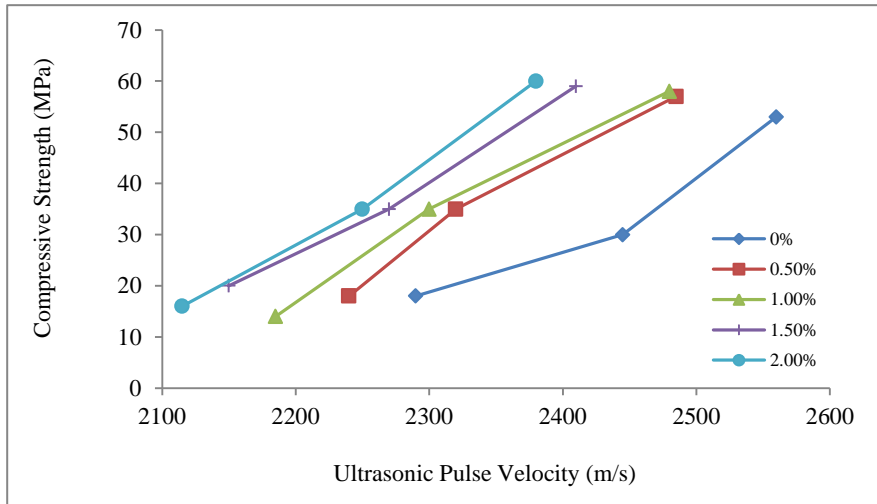


Figure 5: Relationship between compressive strength and ultrasonic pulse velocity of concrete with different amount of fibre.

3.2.2 Splitting Tensile Strength

In general, the tensile strength of RSFRS was found to increase with increasing amount of fibre. But in all mixes, concrete with fibres volume fraction of 0.5%, l/d ratio of 67 (RSFRC-2) showed the maximum strength gain. The relative splitting tensile strength values of RSFRC according to V_f and l/d ratio are also given in Table 3. The test results indicated that splitting tensile strength of RSFRCs is about 70-149% higher than the control mixture. Indeed, recycled steel fibres significantly improved the splitting tensile strength of concrete as compared to compressive strength. The results obtained in this study are consistent with previous studies (Modtrifi *et al.*, 2011; Awal *et al.*, 2011; Papakonstantinou and Tobolski, 2006).

During the splitting tensile test, the effect of the recycled steel fibres was apparent. The recycled steel fibres appear to control the cracking of RSFRC and alter the post cracking behaviour. The recycled steel fibres seem to provide a load redistribution mechanism after initial cracking. Unlike in normal concrete, it was difficult to separate the fractured specimens because the recycled steel fibres were bridging the gap that kept the two concrete parts together, as shown in Figure 6. Figure 7 illustrates the distribution of fibres at the cracked section of a broken cylinder. It can be seen that the distribution of fibres in RSFRC specimens is quite homogeneous. Some recycled steel fibres were broken and a lot of effective fibres can be observed on the surface of the split specimens.



Figure 6: Concrete cylinder after splitting tensile test.



Figure 7: Distribution of steel fibre in broken cylinder.

3.2.3 Flexural Strength

Experimental data given in Table 3 reveals that flexural strength of RSFRC is about 14-52% higher than the control sample. The flexural strength of control specimen, for example, is 4.60MPa. For l/d ratio of 45 (RSFRC-1), 67 (RSFRC-2) and 89 (RSFRC-3) the flexural strength values are 5.20, 5.65 and 5.45MPa respectively. The relative flexural strength values of RSFRC according to V_f and l/d ratio are also depicted in Table 3. Evidently the flexural strength of concrete has significantly been improved by incorporating recycled steel fibres. Higher the aspect ratio and volume fraction higher was the strength gain.

An important aspect that can be outlined from experimental results is the ductility and tenacity of RSFRC increase when fibre content volume is increased, and for the same fibre content, when fibre length is increased. This phenomenon could be due to the higher deformability and energy absorption of RSFRC during the cracking phase.

Interestingly the RSFRC shows a higher bending stiffness and a different cracking pattern than the normal concrete. Most cracks showed a reduced width and they appeared from casting surface due to the presence of recycled steel fibres, which tend to move to the lower portion of the specimen. The differences in the failure mode of plain and RSFRC are illustrated in Figure 8 and 9.



Figure 8: Failure mode of plain concrete beam in flexure.



Figure 9: Failure mode of fibre reinforced concrete beam in flexure.

4.0 Conclusions

The results obtained and the observation made in this study draw some conclusions. These are:

- 1) The inclusion of steel fibre from recycled tire significantly affected the workability of concrete. It has been found that the workability of concrete mixes decreased with the increase in the aspect ratio (l/d) and the volume fraction (V_f) of fibre.

- 2) Recycled steel fibre has been found to improve the overall strength of concrete. This improvement has been shown to be prominent in case of splitting tensile and flexural strength as compared to that of compressive strength. Generally, higher the l/d and V_f , higher was the strength development.
- 3) There has been a good co-relation between compressive strength and ultrasonic pulse velocity of concrete. Like that in other reinforced concrete, the ultrasonic pulse velocity of this concrete was found to increase with the increase of compressive strength.
- 4) The overall findings in this study suggest that the recycled steel fibre from waste tire has a good potential as reinforcing material. Long-term investigation including deformation behavior and durability aspects of concrete, however, has been put forward for future study to obtain better understanding of this material in concrete.

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