Experimentally analysing compressive and tensile strengths of concrete containing steel waste fibres

Poriya Kakvand*

Department of Civil Engineering,
Islamic Azad University, Zahedan Branch,
P.O. Box 98138987
3 Daneshgah Street, Zahedan, Iran
E-mail: Poriya.kakvand@yahoo.com
*Corresponding author

Reza Rahgozar

Department of Civil Engineering,
Faculty of Engineering,
Shahid Bahonar University of Kerman,
P.O. Box 76175-133,
Kerman, Iran
Fax: +98-341-3220054
E-mail: rahgozar@mail.uk.ac.ir

Mansour Ghalehnovi

Engineering Department,
Ferdowsi University of Mashhad,
P.O. Box 9177948974
Square of Azadi, Mashhad, Iran
E-mail: ghalehnovi@um.ac.ir

Mohammad Ali Irandegani

Department of Civil Engineering,
Islamic Azad University, Zahedan Branch,
P.O. Box: 9816843993
On the Bozorghmehr 8, Bozorghmeher Street,
Zahedan, Sistan and Baluchestan, Iran
E-mail: m.a.irandegani@gmail.com
E-mail: m.a.irandegani@iauzah.ac.ir

Abstract: Considering increasing growth of using other materials in concrete for increasing its quality, studies on fibres have been recently extended. Existence of fibres can compensate for some of the weaknesses of concrete in terms of its brittleness and fragility. Now, in this study, role of steel waste fibres in compressive strength of cubic samples and tensile strength of cylindrical samples at ages of 3, 7, 28 and 42 days and also tensile strength resulting from flexure of prismatic samples at age of 90 days was investigated.

The studied concrete included steel waste fibres with three different diameters of 0.8, 1.0 and 1.2 mm and two weight ratios of 35 and 70 kg/m^3, which were compared at different ages with the control sample. It was observed that the concrete containing steel waste fibres had remarkable growth in increasing tensile strength. This strength increasing trend proceeded with increase in the amount and ratio of fibres' length to width.

Keywords: concrete; waste fibres; compressive strength; tensile strength; welded wire; concrete structures.

Reference to this paper should be made as follows: Kakvand, P., Rahgozar, R., Ghalehnovi, M. and Irandegani, M.A. (2014) 'Experimentally analysing compressive and tensile strengths of concrete containing steel waste fibres', *Int. J. Structural Engineering*, Vol. 5, No. 2, pp.132–141.

Biographical notes: Poriya Kakvand has an MSc in Structural Engineering. His research interest includes retrofitting of reinforced concrete.

Reza Rahgozar received his BSc in Civil Engineering from Alababam A&M University, USA, his MSc in Civil Engineering from North Dakota State University, USA and his PhD from Bristol University, UK. He is currently the Associated Professor of Civil Engineering at Shahid Bahonar University of Kerman. His main fields of interest are behaviour of tall buildings and corrosion in steel and concrete structures.

Mansour Ghalehnovi is an Associate Professor of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran. His research interests include design steel structures, retrofitting of steel and reinforced concrete.

Mohammad Ali Irandegani has and MSc in Structural Engineering. His research interests include energy dissipation and dampers, shear panel aluminium, strengthening of structures, retrofitting, and earthquake resistance structures.

1 Introduction

Today, using fibres has caught much attention due to its positive effect on concrete. Fibres in concrete cause considerable decrease in concrete fragility and fibre concrete shows a ductile behaviour under different loads like compression, tension and strike. Fibres improve mechanical properties of concrete and provide an integral material; also, they prevent the expansion of fracture in concrete. A broad spectrum of fibres and different types of categorisation that could be done in terms of material, geometry and production method has caused fibre concretes to have extensive and versatile properties. Different types of fibres that are used in concrete include steel fibres, glass fibres, polymer fibres and natural fibres. In fact, no type of fibre improves all concrete properties and each one of them improves a specific property due to its nature. In this regard, steel fibres have high elasticity modulus, which is considered one of the most appropriate kinds of fibres due to its proper ductility and high tensile strength and could have a desirable effect on some mechanical properties of concrete like compressive strength, tensile strength and torsional strength (Ibrahim and Chebakar, 2011; Okay and Serkan, 2012). At slab-column joint, presence of steel fibres along with armature in concrete increases punching shear strength or physical deformation capacity of slab so that, in slabs containing steel fibres, there is considerable increase of punching shear strength and flexure yield of slab before occurrence of punching shear failure (Nguyen-Minh et al., 2011; Cheng et al., 2010). Existence of steel fibres in the set of slab and beam improves tensile strength and their ductility properties; this advantage causes the set of slab and beam to have an expansive layer, which decreases the heat stress imposed by fire and considerably increases strength of the set of beam and slab against fire (Fike and Kodur, 2011).

By placing the high strength concrete at beam-column joint, which contains steel fibres along with armature, the joint could bear a high degree of displacement without expanding width of fractures. As a result, load bearing capacity increases at the joint and, when exposed to frequent loadings, brittle destruction at beam-column joint would decrease so that increased dimensional stability and integration at the joint would be observed (Ganesan et al., 2007). In the beam-column joints, while being under static loading, the presence of concrete with conventional strength together with steel fibres causes softness in the form of fractures and decreases fracture depth at the joint; thus, increased continuity happens at the joint which allows for decreasing armature assembly and decreases length of inhibitory bars (Hamad et al., 2011). In concrete beams, shear and torsional strengths depend on the reinforcement of beam we band, when distance of longitudinal armatures decreases and steel fibres are placed between them, shear and torsional strengths also significantly increase (Avinash and Parekar, 2010). In the concrete reinforced with steel fibres, increased direct shear strength and ductility are observed. This desirable effect depends on distribution and orientation of fibres in the area of shear failure. When fibres are vertically placed on the shear plane, they have more desirable impact on ductility, which is observable in conventional, self-compacting and high strength concretes (Boulekbanche et al., 2012). One of the disadvantages of steel fibres' presence in concrete is decreased efficiency of concrete and conglobation of fibres in concrete, which prevents homogenous distribution and propagation of fibres in concrete mixture; but, using fibres in self-compacting concrete removes many of these defects and more advantages of fibres are exploited. Propagation of fibres among free spaces of fine-grained materials of self-compacting concrete mixture causes fitting of materials into each other and producing self-compacting concrete with good ductility and toughness; also, a definite amount of fibres joins materials together and stabilises the new flow of self-compacting concrete (Akcay and Tasdemir, 2012).

Considering the mentioned properties about role of steel fibres in concrete which has been proven by researchers, this fibre does not have a broad position in construction projects due to its high cost. However, because of the abundance and low price of steel wastes resulted from industrial workshops such as net weaving workshops, workshops of producing tire wires, workshops of producing welding wires, etc., the fibres produced from these steel wastes could be considered a substitute for imported steel fibres.

In this study, role of steel fibre wastes (welding wire) in compressive strength of cubic samples and tensile strength of cylindrical samples at ages of 3, 7, 28 and 42 days and also tensile strength resulting from flexure of prismatic samples at age of 90 days was investigated. They were compared at different ages with those of the control sample. It was observed that the concrete with steel fibre wastes had considerable growth in tensile strength. This strength increasing trend proceeded with increase in the amount and ratio of fibres' length to width.

2 Applied materials

The applied materials of this experimental work consisted of water, cement, gravel, sand and steel fibre wastes. The used water in this experiment was water of Qazvin city (Iran) with PH = 2 and the consumed cement was Portland type II, Abyek cement. The applied sand was the broken mountain mine sand with maximum size of 12.5 mm and its specifications are presented in Table 1 according to the performed tests. The gravel consumed in this research was river gravel. At first, its fineness modulus was 3.32 which changed to 2.99 after aggregation correction. Specifications of the gravel are given in Table 2. Steel fibres with length of 5 cm and three different diameters of 0.8, 1.0 and 1.2 mm were produced from the wastes resulted from the production of welding wires, the specifications of which are given in Table 3 and Figure 1.

Table 1 Specifications of the applied sand

Percent of abrasion ASTM C131	*Specific weight of material ASTM C127*			*Weight per unit volume ASTM C29*		*Specification of the sample*
	Water absorption %	*Real g/cm^3*	*Apparent g/cm^3*	*Non-compact Kg/m^3*	*Compact Kg/m^3*	
13.4	0.6	2.79	2.84	1,451	1,561	Sand

Table 2 Specifications of the consumed gravel

Percent of abrasion ASTM C2419	*Specific weight of material ASTM C128*			*Weight per unit volume ASTM C29*		*Specification of the sample*
	Water absorption %	*Real g/cm^3*	*Apparent g/cm^3*	*Non-compact Kg/m^3*	*Compact Kg/m^3*	
85	2.1	2.55	2.7	1,664	1,785	Gravel

Table 3 Specifications of steel waste fibres

Density kg/m^3	*Length to width ratio*	*Length of fibres (mm)*	*Diameter of fibres (mm)*
7,850	62.5	50	0.8
7,850	50	50	1
7,850	41.66	50	1.2

Figure 1 The applied steel waste fibres (see online version for colours)

3 Mixing plan

Mixture plan of this experiment was conducted using weight-volume method according to ACI 211.1 regulation. Considering specifications of materials mentioned above and ACI regulation, mixture plan of the samples was as shown in Table 4.

Table 4 Details of mixture plan (Kg/m^3)

Steel fibres	*Sand*	*Gravel*	*Cement*	*Water*	*Name of plan*
-	824	913	404	218	C
35	824	913	404	218	C0.8–35
70	824	913	404	218	C0.8–70
35	824	913	404	218	C1.0–35
70	824	913	404	218	C1.0–70
35	824	913	404	218	C1.2–35
70	824	913	404	218	C1.2–70

In this table, C indicates the sample without steel waste fibres. The first number after C indicates diameter of applied fibres and second number after C shows the amount of fibre existing in the mixture.

While mixing the materials, first, 75% of the required water was poured into the mixer and then the considered sand was added. Next, the considered cement was slowly added to the mixer. The gravel was slowly poured into the mixer. When 50% of the gravel was added to the mixer, the steel fibres along with sand were gradually added to the mixture. After adding the steel fibres, the remaining water was poured into the mixer. Then, the mixer continued to work for 3 min so that the mixture was completely combined. Then, the mixer was turned off for 3 min. It was turned on again to operate for 2 min. Then, it was turned off and the concrete was transferred to the moulds.

In the process of constructing samples containing fibres, steel waste fibres with three different diameters and two weight ratios of 35 and 70 Kg/m^3 were added to the control mixture plan. It should be mentioned that fibres are independent and do not replace any of concrete components. The reason could be that performance of steel fibres is not similar to any component of concrete and does not take any of their responsibility. To express it more simply, in concrete, cement and aggregate have the role of bonding and creating compressive strength, respectively; then, fibres as a member with the role of creating tensile strength are added to the mixture.

4 Test and their results

As mentioned earlier, in this experiment, compressive and tensile strengths resulting from gaps of cylindrical samples and also tensile strength resulting from flexure of prismatic samples of concrete containing steel waste fibres were investigated at different ages. Each of these concrete samples in all compressive and tensile conditions included three specimens, the mean of which was considered. Below, diagrams are drawn for each strength at different ages to easily identify effect of steel wastes on concrete.

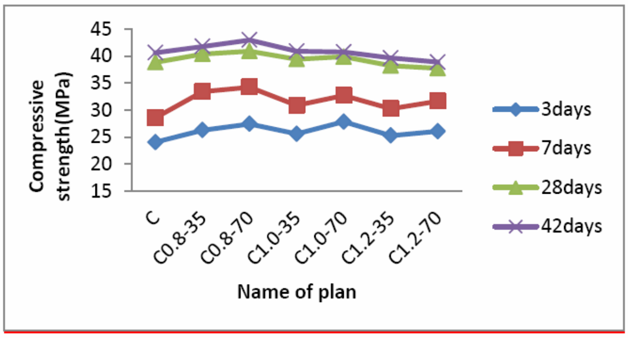
4.1 Compressive strength

Compressive strength in concrete was studied at ages of 3, 7, 28 and 42 days by a 15 × 15 × 15 cubic specimen and the results of their mean are given in Table 5 and Figure 2.

Table 5 Results of compressive strength test at different ages (MPa)

42 days compressive strength	*28 days compressive strength*	*7 days compressive strength*	*3 days compressive strength*	*Name of plan*
40.62	38.84	28.57	24.04	C
41.78	40.38	33.41	26.28	C0.8–35
42.97	40.91	34.25	27.2	C0.8–70
40.89	39.41	30.88	25.57	C1.0–35
40.73	39.87	32.7	27.83	C1.0–70
39.64	38.23	30.26	25.27	C1.2–35
38.86	37.75	31.65	26.05	C1.2–70

Figure 2 Results of compressive strength test at different ages (see online version for colours)



As could be observed from the results, steel waste fibres were effective on increasing compressive strength so that, at the age of 3 days, the presence of 70 Kg/m^3 fibres with 1.0 mm thickness in concrete increased compressive strength by 15.76% and, at the age of 7 days, presence of 70 Kg/m^3 fibres with 0.8 thickness in concrete increased compressive strength by 19.88%. However, this effect decreased with increasing age of concrete and, at ages of 28 and 42 days, no increase of compressive strength was observed in the samples. But, the presence of fibres in the studied compressive samples (as could be seen in Figure 3) changed the way the samples fractured in addition to increasing the compressive strength; also, the samples acted more integratively after fracturing. This effect was observable in all the samples containing fibres at different ages.

Figure 3 Images of compressive specimens containing steel fibres (see online version for colours)

4.2 Tensile strength

To determine tensile strength, indirect method of splitting (fission.) of cylindrical samples and tension resulting from flexure of prismatic samples were used.

4.2.1 Splitting test of cylindrical sample

This test was performed on cylindrical specimens with diameter of 15 cm and height of 30 cm. Using this method, tensile strength was studied at different ages of 3, 7, 28 and 42 days. Mean results of the studied specimens are presented in Table 6 and Figure 4.

Table 6 Results of splitting cylindrical samples (MPa)

42 days tensile strength	*28 days tensile strength*	*7 days tensile strength*	*3 days tensile strength*	*Name of plan*
3.52	3.31	2.76	2.25	C
4.35	4.23	3.37	2.83	C0.8–35
4.61	4.47	3.71	3.23	C0.8–70
4.19	4.03	3.16	2.66	C1.0–35
4.49	4.34	3.57	3.09	C1.0–70
4.07	3.87	2.93	2.68	C1.2–35
4.26	4.12	3.25	2.87	C1.2–70

According to the obtained results, it can be observed that fibres had many effects on increasing tensile strength from very early ages and this effect continued with the increased age of concrete in contrast to compressive samples so that, at the ages of 3, 7, 28 and 42 days, presence of 70 Kg/m^3 fibres with 0.8 mm thickness in concrete increased the tensile strength by 43.55%, 34.42%, 35.04% and 30.9%, respectively. As could be observed in Figure 5, presence of fibres in concrete extremely increased deformation and toughness of cylindrical samples in addition to increasing tensile strength.

Figure 4 Results of splitting cylindrical samples (see online version for colours)

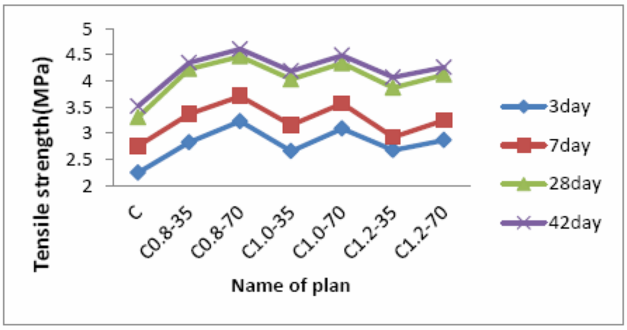


Figure 5 Images of cylindrical specimens with and without steel waste fibres (see online version for colours)

4.2.2 Flexural test

In this test, prismatic concrete specimens with dimension of 15 × 15 × 50 cm was used, which were placed under flexure at two symmetrical loading points with one-third distance from the opening.

Through this test, tensile strength resulting from flexure was studied at the age of 90 days. Mean results of the specimens under flexure are shown in Table 7 and Figure 6.

Table 7 Results of flexural test of prismatic samples (MPa)

C1.2–70	*C1.2–35*	*C1.0–70*	*C1.0–35*	*C0.8–70*	*C0.8–35*	*C*	*Samples*
8.05	7.92	8.62	8.33	8.81	8.47	7.42	90 day flexural strength

The obtained results implied that concrete specimens containing steel waste fibres had more flexural strength than specimens without steel waste fibres so that, at the age of 90 days, presence of 70 Kg/m^3 fibres with 0.8 mm thickness increased flexural strength by 18.73%. According to Figure 7, it was observed that presence of fibres in flexural specimens prevented brittle fraction and caused specimens to be able to bear the loads after fraction.

Figure 6 Results of flexural test of prismatic samples (see online version for colours)

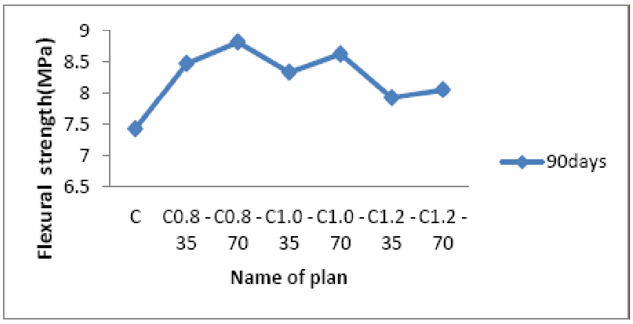


Figure 7 Images of prismatic specimens with and without steel waste fibres, (a) prismatic specimen with fibres (b) prismatic specimen without fibres (see online version for colours)

(a) (b)

5 Conclusions

In all the specimens, the concrete without fibres had more brittle and fragile behaviour while the concrete reinforced with steel waste fibres had a completely fine and ductile behaviour due to more increase of fracture and decrease in the depth of fracture. In concrete reinforced with steel waste fibres with constant length, presence of fibres with smaller diameters increased fibre's length to width ratio, which led to improvement of fracturing and increase of ductility. This effect was quite observable in cylindrical samples and presence of fibres caused cylindrical and prismatic specimens to be able to bear the load after failure due to increased toughness. Compressive strength increased with presence of fibres at early ages (3 and 7 days); but, the role of fibres in increasing compressive strength decreased with aging. Tensile strength resulting from splitting cylindrical samples significantly increased in the presence of fibres from the very beginning. Effect of fibres' presence on increasing tensile strength did not decline with aging. However, difference in effects of the amount of 35 and 70 Kg/m^3 fibres on increasing tensile strength decreased with aging.

Acknowledgements

This research was performed at Technical and Soil Mechanics Laboratory, Qazvin Province, Iran. With all due respect, the authors express their gratitude to authorities of this laboratory, especially Mr. Mohammad Keshavarz.

References

Akcay, B. and Tasdemir, M.A. (2012) 'Mechanical behaviour and fibre dispersion of hybrid steel fibre reinforced self-compacting concrete', *Construction and Building Materials*, Vol. 28, No. 1, pp.287–293.

Avinash, S.P. and Parekar, R.S. (2010) 'Steel fiber reinforced concrete beams under combined torsion-bending-shear', *Journal Civil Engineering*, Vol. 38, No. 1, pp.31–38.

Boulekbanche, B., Hamrat, M., Chemrouk, M. and Amziane, S. (2012) 'Influence of yield stress and compressive strength on direct shear behavior of steel fiber-reinforced concrete', *Construction and Building Materials*, Vol. 27, No. 1, pp.6–14.

Cheng, M.Y., Gustavo, J. and Montesinos, P. (2010) 'Evaluation of steel fiber reinforcement for punching shear resistance in slab-column connections', *ACI Structural Journal*, Vol. 107, No. 1, pp.101–109.

Fike, R. and Kodur, V. (2011) 'Enhancing the fire resistance of composite floor assemblies through the use of steel fiber reinforced concrete', *Engineering Structures*, Vol. 33, No. 10, pp.2870–2878.

Ganesan, N., Indira, P.V. and Abraham, R. (2007) 'Steel fiber reinforced high performance concrete beam-column joints subjected to cyclic loading', *ISET Journal of Earthquake Technology*, Vol. 44, Nos. 3–4, pp.445–456.

Hamad, B.S., Haidar, E.Y., Haldor, A. and Harajli, M.H. (2011) 'Effect of steel fibers on bond strength of hooked bars in normal-strength concrete', *ACI Structural Journal*, Vol. 108, No. 1, pp.42–50.

Ibrahim, I.S. and Chebakar, M.B. (2011) 'Effects on mechanical properties of industrialised steel fibers addition to normal weight concrete', *Procedia Engineering*, Vol. 14, pp.2616–2626.

Nguyen-Minh, L., Rovnak, M., Tran-Quoc, T. and Nguyen-Kim. K. (2011) 'Punching shear resistance of steel fiber reinforced concrete flat slabs', *Procedia Engineering*, Vol. 14, pp.1830–1837.

Okay, F. and Serkan, E. (2012) 'Torsional behavior of steel fiber reinforced concrete beams', *Construction and Building Materials*, Vol. 28, No. 1, pp.269–275.