Iran J Sci Technol Trans Civ Eng (2019) 43:263–271
https://doi.org/10.1007/s40996-018-0137-9

RESEARCH PAPER

Experimental Study Effect of Silica Fume and Hybrid Fiber on Mechanical Properties Lightweight Concrete

Seyed Hosein Ghasemzadeh Mousavinejad[1] **· Yaser Ghorbani Shemshad Sara**[2]

Received: 12 October 2016 / Accepted: 23 July 2018 / Published online: 7 August 2018

Abstract

This article aims to study the effect of silica fume on mechanical features of fiber lightweight concrete (steel fibers and polypropylene) including scoria lightweight aggregates. Silica fume is replaced with 10 and 15% by weight of cement. The amounts of steel and polypropylene fibers in this study were (0.4–0.8%) and (0.2%) concrete volume, respectively, and the ratio of length to diameter was 62.5 and 60, respectively. In this study, nine different mixtures of lightweight concrete with different percentages of steel and polypropylene fibers were made and compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, water absorption, and density were also tested. Results show that optimized amount of SF is 10%. Also, steel fiber compared to Polypropylene fiber has better effect on mechanical characteristics of lightweight concrete.

Keywords Silica fume · Steel and polypropylene fibers · Lightweight Scoria · Mechanical properties

1 Introduction

The use of lightweight concrete (LWC) has been a feature of construction for the past several decades. LWC has higher seismic resistance particularly for buildings located in the seismic regions. A recent study in Iran shows that destruction of most buildings is due to great inertial force and lack of structural tolerance for the load (Bargi 2001). Furthermore, LWC has some economic advantages due to concrete weight reduction suitable for multifunction construction such as high-rise construction, large span bridges, and also energy absorption in buried military structures (Shafigh et al. 2011; Babu et al. 2006).

Some techniques used for LWC production include no fine aggregate concrete, aerated concrete, and a widely used method of ways for making lightweight aggregate concrete (Demirboga et al. 2001; Topcu 1997; Al-Khaiat and Haque 1998). Structural lightweight aggregate concrete [SLWAC] criterion of ACI standard requires a 28-day cylinder compressive strength of 17 Mpa and air-dry unit weight of less than 1840 kg/m^3. However, maximum unit weight of SLWC in some European standards such as DIN-4219, PN-91, ENV92 is defined as 2000 kg/m^3 and in PREN 206 is taken to be 2100 kg/m^3 (Euro light concrete 1998). To achieve SLWAC, the use of silica fume [SF] as a pozzolanic material not only improves mechanical, chemical, and durability characteristics of cement paste but also reduces environmental impact such as emission of greenhouse gases and problems related to dimensional stability of concrete (Huntzinger and Eatmon 2009; Mehta 1986; Holland 1996; Dotto et al. 2004; Mata 2004). SLWAC like normal concretes are brittle in nature and this can be overcome by reinforcing concrete with appropriate type of fibers (Sadrodiny Mehrgerdy et al. 1990).

Shannag (2000) showed that increasing natural pozzolan and SF to 15% increased the strength. Beygi et al. (2007) found that LWC made of stone powder and 10% SF and light expanded clay aggregate (LECA) and can lead to high strength. Gesoğlu et al. (2013) concluded that the combined effect of SF and steel fibersmay increase the compressive strength. Mosavinejad et al. (2014) showed that LWC specimens containing 10% SF had higher effect on

---

✉ Seyed Hosein Ghasemzadeh Mousavinejad
h.mosavi@guilan.ac.ir

Yaser Ghorbani Shemshad Sara
yaser.ghorbani1370@yahoo.com

[1] Faculty of Engineering, University of Guilan, Rasht, Iran

[2] The Nonprofit Institute of Deylaman, Lahijan, Iran

compressive, tensile, and flexural strength than those with 15% SF. Kılıc et al. (2003) concluded that 10% SF replacement by weight of cement in comparison with the same amount of fly ash replacement had more influence on compressive and bending stresses. A similar study by Yazici et al. (2007) and Gao et al. (1997) showed that steel fiber-reinforced LWC increased mechanical properties, and Mahotian and Behradiyekta (2011) stated that PP fiber had a slight reduction on compressive strength and little impact on improving tensile and flexural strengths as compared to steel fibers.

Ranjbar et al. (2016) concluded that the inclusion of PP fiber into geopolymer paste weakened matrix strengthening in which it did not increase compressive and flexural strengths only enhanced post-peak-load-bearing capacity. In another similar study by Ranjbar et al. (2016), it was demonstrated that copper-coated microsteel fiber (MSF)did not lead to increased ultimate compressive strength though it changed failure mode, but significantly improved flexural strength and toughness of samples.

2 Laboratory Plan

2.1 Used Materials

The cement used in this study was of Portland type II made in Hegmatan cement factory, with dry density of 3150 kg/m^3 and specific surface of 2900 cm^2/gr. The SF with a 2120 kg/m^3 from Iran ferroalloy industries was used as pozzolanic material in all designs. The chemical properties of cement and SF are presented in Table 1. Properties of P10-3R as super-plasticizer that was used in concrete for gaining the proper fluidity are presented in Table 2. Two types of reinforcing fibers of polypropylene and steel (see Table 3 for more details) were used. The river sand size that ranged from 0 to 4.75 mm (Table 4) had a saturated surface dry (SSD) density of 2520 kg/m^3 and the water absorption of 3% (Table 5).

2.2 Sample Preparation and Mix Designs

In this project, the proportion of water and cement in all designs was fixed and taken as 0.3 and 10% of cement was substituted by SF by SF (see Table 6). The fibers used in this study were steel hooked fibers with the length of 50 mm and polypropylene (pp) fiber with the length of 12 mm. The incorporation of fiber in concrete is usually carried out in two ways. Some researchers have incorporated dry fiber with aggregates and then added cement and water (Sahmaran et al. 2005; Aydin 2007). However, some others made concrete without fibers first and then added fiber (GrÜnewald and Walraven 2001; DÜzgun et al. 2005). In this study, all dry lightweights were first mixed with incorporated water, which lasted for 30 min due to the LWA being wet. After that, cementitious material including cement and SF was added to the mixture and then some more water and super lubricant were added. Finally, sand was added to the mixer and the remaining water was also added. In designs containing fiber, fiber was poured on the cycling mixture for gaining dispersion and uniformity throughout the concrete. Incorporation was carried out in a way that the 30-min water absorption was actually absorbed by the materials. After preparing the concrete mix molding, the samples were kept at a temperature of 20–25 °C in laboratory environment for 24 h. After this time, the demolded samples were cured with water in laboratory temperature. Also, a summary of type, dimensions and standard of testing are presented in Table 7.

Table 1 Chemical analysis of cement and silica fume

	SiO_2	Cao	AL_2O_3	Fe_2O_3	Mg-O	SO_3
Cement	21.54	63.24	4.95	3.82	1.55	2.43
Silica fume	95.1	0.49	1.32	0.87	0.97	0.1

Table 2 Super-plasticizer characteristics

P10-3R	Name
Ether-modified poly-carboxylic	Type
Dark green	Appearance
1.1 ± 0.02	Density (kg/m^3)
Liquid	Physical state
Ionic	Nature

Table 3 Fibers characteristics

Polypropylene fiber	Steel fiber	Name
Smooth	Hooked	Shape
12	50	Length (mm)
200	800	Diameter (µm)
0.9	7.85	Density (g/cm^3)

3 Laboratory Results

3.1 Density

The chart shows that the presence of steel fiber increases density of concrete, which is due to high density of fiber (Kılıc et al. 2003). All the mixes are within the permitted weight limitation (less than 2000 kg/m^3). Therefore, it would be possible to produce SLWC with 62.8 kg/m^3 fiber.

Table 4 Aggregate grading

Sieve	Sand	ASTM C33	Scoria 9.5 mm	ASTM C330
3/4 in. (19 mm)	–	–	–	–
1/2 in. (12.5 mm)	–	–	100	100
3/8 in. (9.5 mm)	100	100	83.5	80–100
No.4 (4.75 mm)	96	95–100	16.4	5–40
No.8 (2.36 mm)	86.5	80–100	5	0–20
No.16 (1.18 mm)	68.3	50–85	1.3	0–10
No.30 (600 μm)	46.5	25–60	–	–
No.50 (300 μm)	10.6	10–30	–	–
No.100 (150 μm)	3.5	2–10	–	–

Table 5 Physical characteristics of aggregates

	Water absorption (%)		Density (kg/m^3)	
Aggregate	30 min	24 h	Dry	Saturated surface dry
Sand	3		2380	2520
Scoria (9.5 mm)	10.15	15.3	1542	1650

Table 6 Mixture designs

	Cement	MS	Water	Sand	Scoria	SP	PF	SF
Mix	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Control	500	0	150	705	676	2.5	0	0
MS 10	450	50	150	705	661	4	0	0
MS10 PP2	450	50	150	705	657	4	1.8	0
MS10 PP2 S4	450	50	150	705	649	5	1.8	31.4
MS10 PP2 S8	450	50	150	705	641	6	1.8	62.8
MS 15	425	75	150	705	653	5	0	0
MS15 PP2	425	75	150	705	650	5	1.8	0
MS15 PP2 S4	425	75	150	705	641	6	1.8	31.4
MS15 PP2 S8	425	75	150	705	633	7	1.8	62.8

SP super-plasticizer, *MS* silica fume, *SF* steel fiber, *PF* polypropylene fiber

Table 7 Summary of hardened concrete tests

Age	Dimension (cm)	Standard test	Test
7, 28 day	10 × 10 × 10	B.S1881:Part116	Compressive strength
28 day	50 × 10 × 10	ASTM C293	Flexural strength
28 day	Ø30 × 15	ASTM C496	Tensile strength
28 day	10 × 10 × 10	ASTM C567	Density
28 day	Ø30 × 15	ASTM C469	Modulus of elasticity
28 day	10 × 10 × 10	ASTM C642	Water absorption

The change in density of concrete mixes is presented in Table 8 and Fig. 1.

3.2 Compressive Strength

The results show that it is possible to make structural lightweight concrete for all nine mix designs above their minimum required structural strength. The compressive strength of all mixes is shown in Fig. 2.

According to the results, it is observed that replacing cement with 10% SF increases compressive strength to a maximum of about 32%. Increase in percentage replacement of SF from 10 to 15% reduced compressive strength, so the optimum percentage of SF is 10%. Effect of SF on increasing strength is presented in other studies as well (KÖksal et al. 2008; Valipour et al. 2013; Mazloom et al. 2004; Ahmadi and Shekarchi 2010). In the present study, PP fiber reduced the compressive strength and the

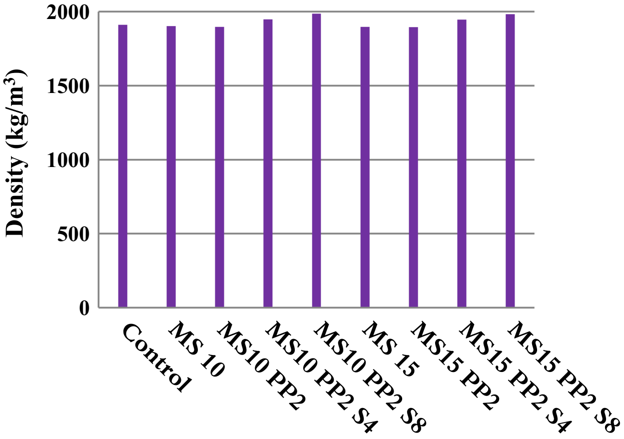

Fig. 1 Density of specimens

combined effect of steel and PP fibers increased the strength. The negligible effect of fiber on compressive strength is also reported in other studies (Shafigh et al. 2011; Ranjbar et al. 2016; DÜzgun et al. 2005; Libre et al. 2011). The increase in compressive strength under the influence of steel fiber could be justified by the existence of fiber and delay of the extension of microcracks in concrete, which, in turn, increases strength and strain under load. Furthermore, other justification for increase can be due to higher modulus of elasticity of steel fiber relative to binder as well as to its confinement effect (Ranjbar et al. 2016). However, the cause of compressive strength reduction under PP influence could be that of the difficulty in mixing fiber uniformly in concrete giving rise to an increase in pores, trapped air, and creating an empty space due to increasing the percentage of fibers. Moreover, low rigidity of PP fiber as compared to binder and aggregate as well as the existence of weak interface transition zone may lead to strength reduction (Ranjbar et al. 2016; Beygi et al. 2009). Low bond strength leads to microcracks formation through the specimens, hence decreasing the shear stress resistance (Bazant and Ozbolt 1992).

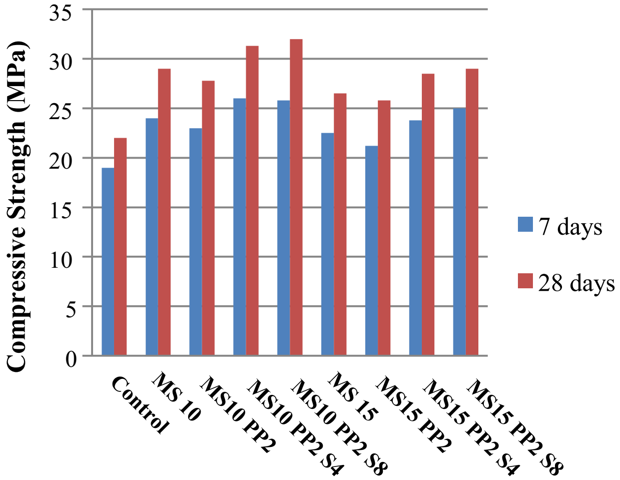

Fig. 2 Compressive strength of specimens

3.3 Splitting Tensile Strength of Cylinder

Tensile experiment for determining tensile strength of concrete was performed by splitting the cylinder, although it is reported (Denneman et al. 2011; Kim et al. 2010) that it does not yield the tensile strength properly for fiber-reinforced concrete (FRC). Difference in splitting tensile test results between plain and fibrous concretes exists in simple boundary condition and linear elastic material assumptions in the continuum mechanics model of the test with the actual ones. The samples were experimented at the age of 28 days. Average tensile and flexural strengths of all specimens are shown in Table 9. Figure 3 (*left*) represents the tensile strength of specimens and their correlation to compressive strength is shown in right.

The presence of fibers increased the tensile strength of concrete, and about 7% increase was achieved by increasing the PP fiber from 0 to 1.8 kg/m^3. The combination of steel and PP fibers increased tensile strength, and its maximum increase was 27%, which shows the effective presence of steel fibers in improving tensile strength. This increase in strength was also reported in other studies including Chen

Table 8 Results of compressive strength and dry density

Mix	7-day compressive strength (MPa)	28-day compressive strength (MPa)	Dry density (kg/m^3)
Control	19	22	1912
MS 10	24	29	1903
MS10 PP2	23	27.8	1897
MS10 PP2 S4	26	31.3	1948
MS10 PP2 S8	25.8	32	1987
MS 15	22.5	26.5	1898
MS15 PP2	21.2	25.8	1896
MS15 PP2 S4	23.8	28.5	1946
MS15 PP2 S8	25	29	1984

and Liu and Kayali et al. (1999; Chen and Liu 2005). The cause of increase in strength using steel fiber can be due to an increase in the strain resistance of the fiber during splitting of fibers through tension transmission from matrix to fibers. Tensile strength with 10% replacement of SF by cement weight reaches the highest approximate method of 25% which is attributed to SF. Also, according to the chart, it is seen that an increase from 10 to 15% SF decreased tensile strength. SF impact on increasing the tensile strength was reported in other studies as well (Valipour et al. 2013; Nili and Afroughsabet 2010; Cakır and Sofyanl 2014). Eren and Celik (1997) who studied the effect of SF and fibers on the mechanical properties of concrete stated that the addition of 5 and 10 SF with 1% steel fiber improved compressive and tensile strengths of concrete.

Figure 3 presents the compressive strength in terms of tensile strength. The relationship between compressive strength and tensile strength is one of the important properties of concrete and it is expected that these strengths be closely related to each other. Their ratio is dependent on the overall level of strength. Many factors can affect this relationship such as fine aggregate properties, aggregate grading, concrete age, curing method, and the presence of fibers.

In this study with regard to the presence of PP fiber in the concrete, it is observed that this fiber increased the tensile strength and decreased the compressive strength. So this is the reason why the correlation coefficient of compressive and tensile strengths was reduced a little bit.

3.4 Flexural Strength

The flexural test for determining the modulus of rupture in concrete was carried out in a three-point loading manner, and the results of the specimens are shown in Fig. 4 and Table 9.

As expected, the presence of fiber increased flexural strength of specimens. By increasing PP fiber from 0 to 8.1 kg/m^3 and SF from 10 to 15%, respectively, an increase of about 10 and 6.7% was obtained, respectively. The combined effect of steel and PP fibers increased the tensile strength where the highest increase of around 38.75% was measured. Replacing 10% SF with cement led to a maximum increase in flexural strength of about 27%. The percentage replacement of SF from 10 to 15% reduced the bending strength, so SF optimum percentage in this study is 10%. The increase in flexural strength due to SF was reported in other studies as well (Valipour et al. 2013; Cakır and Sofyanl 2014; Ranjber et al. 2012; Bhanjaa and Sengupta 2005). The results show that the effect of steel fiber was better than PP fiber. The performance of the fiber can be compared to a bridge that keeps the first crevices close to each other. This property continues until the fibers rupture from the matrix (Sadrmomtazi et al. 2008). Gao et al. (1997) maintained that by inclusion of 2 volumetric percent of steel fiber into concrete the modulus of rupture of high-strength lightweight concrete is increased up to 90%, which is dependent on the amount and the proportion of length to diameter of fiber. Yazici et al. (2007) reported an increase of 80% by adding 2.5% steel fiber with length-to-diameter ratio of 45. Liber et al. (2011) studied the effect of steel and PP fibers on lightweight concrete, and reported 198% increase in flexural strength with 1% steel fiber and 57% increase with 0.4% PP fiber.

Figure 4 shows the compressive strength in terms of flexural strength. Determining the compressive and flexural strengths relationship is useful because core sampling in a prismatic shape would not be as easy as coring cylindrical sample on the site. So predicting the flexural strength as criteria for design is of great importance. Regarding the figure, it could be mentioned that correlation coefficient of compressive and flexural strengths is relatively fine, because the flexural strength increases by an increase in compressive strength. However, a slight increase in compressive strength and a considerable increase in the flexural strength is the reason for a reduction in correlation coefficient.

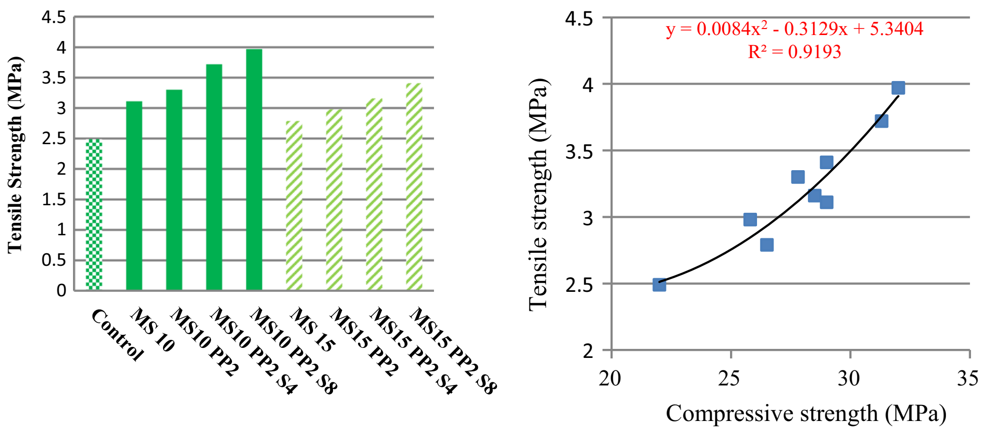

Fig. 3 Tensile strength of specimens and correlation of compressive strength and tensile strength

Table 9 Splitting tensile strength and flexural strength results

Mix	28-day tensile strength (MPa)	28-day flexural strength (MPa)
Control	2.49	3.78
MS 10	3.11	4.8
MS10 PP2	3.3	5.28
MS10 PP2 S4	3.72	6.06
MS10 PP2 S8	3.97	6.66
MS 15	2.79	4.44
MS15 PP2	2.98	4.74
MS15 PP2 S4	3.16	5.7
MS15 PP2 S8	3.41	6.06

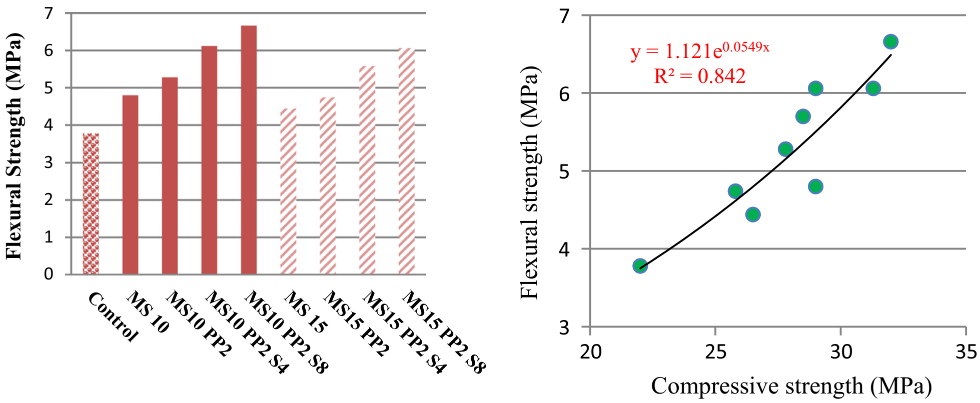

Fig. 4 Flexural strength of specimens and correlation of compressive strength and flexural strength

The relation between the flexural strength and the tensile strength is shown in Fig. 5. As stated previously, figuring out the flexural strength in terms of split tensile strength of plain and fibrous lightweight concrete would be beneficial as it presents the most important feature of fibrous concrete. Figure 5 also indicates that correlation coefficient flexural and tensile strengths are high in such a manner that flexural strength increases with increase in tensile strength. Moreover, it also shows that it increases with addition in the amount of fibers. A slight decrease in correlation coefficient could stem from loading strip size effect and post-peak-load crack. Brazilian tensile test does not provide adequate information on the post-crack behavior of the material (e.g., transversal deformation) particularly for fibrous concrete (Denneman et al. 2011; Kim et al. 2010). Mechanism of fiber performance in flexural test in comparison with split tensile test can be due to post-crack stiffening mechanism of fibers which leads to improved energy absorption of the material (Ranjbar et al. 2016).

3.5 Modulus of Elasticity

Modulus of elasticity is dependent on many factors including aggregate type, free water-to-cement ratio, and the amount of cement. The modulus of elasticity is increased by an increase in compressive strength. So the more the compressive strength, the less the strain needed for its failure and vice versa. Figure 6 and Table 10 show the amounts of modulus of elasticity of specimens.

Looking at the chart it can be observed that the greatest increase of 14.2% in modulus of elasticity is due to 10% SF. Moreover, the influence of fiber on the modulus of elasticity is very low. SF influence on the modulus of elasticity was also reported in other studies as well (Valipour et al. 2013; Sarıdemir 2013; Benaicha et al. 2015). Figure 6 presents the compressive strength in terms of modulus of elasticity. As it is shown, correlation coefficient of compressive strength and modulus of elasticity are very good, because the elasticity modulus increases by an increase in compressive strength. It should be noted that a reduction in compressive strength by PP fiber has also led to a decrease in elasticity modulus which has improved the correlation between these two.

3.6 Water Absorption

Water absorption was defined as liquid movement in the existing pores in solid masses due to surface tension. Generally, the amount of water absorption is high in lightweight aggregates concrete, which has been reported in most cases to be above 10% (Rossignolo and Agnesini 2004). However, using SF can reduce this amount. The

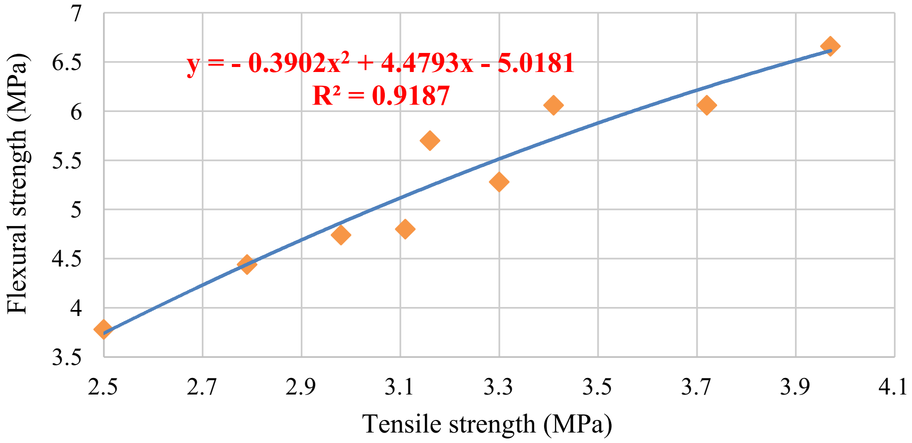

Fig. 5 Correlation of tensile strength and flexural strength

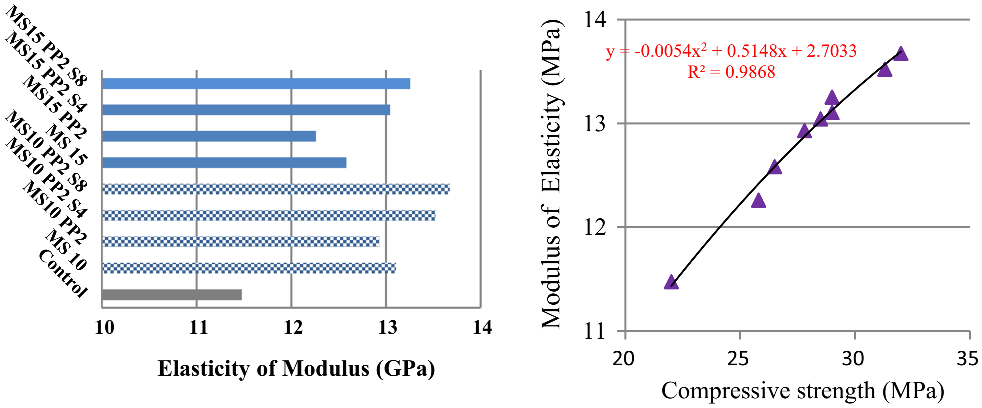

Fig. 6 Modulus of elasticity of specimens and correlation of compressive strength and modulus of elasticity

Table 10 Modulus of elasticity results

Mix	28-day modulus of elasticity (MPa)	Initial absorption	Final absorption
Control	11.475	2.21	3.89
MS 10	13.105	1.58	2.31
MS10 PP2	12.930	1.62	2.37
MS10 PP2 S4	13.522	1.77	2.51
MS10 PP2 S8	13.674	1.89	2.65
MS 15	12.583	1.79	2.66
MS15 PP2	12.261	1.84	2.74
MS15 PP2 S4	13.043	1.97	2.82
MS15 PP2 S8	13.253	2.09	2.98

quality of concrete has, respectively, been categorized by CEB-FIP (1989) in three levels of good for a water absorption of 5% and higher, medium between 3 and 5%, and weak below 3%. The presence of fiber increased water absorption and this is due to increased porosity arising from fiber. Nevertheless, based on the presented category by CEB, most samples are categorized as good. In concrete containing medium lightweight aggregates, the size of cavities is higher than the concrete without lightweight aggregates. The appropriate amounts of water absorption can be related to the use of SF. The existing silica in SF reacts with the hydration products and fills the pores in the concrete. Hence, concrete becomes denser with higher density (Mosavi 2009). Figure 7 and Table 10 present the amounts of water absorption of specimens.

4 Conclusion

- The presence of steel fiber increases the density of concrete. All the designs are within the permitted weight limit (less than 2000 kg/m^3). Therefore, it would be possible to make structural lightweight concrete with 62.8 kg/m^3 fiber.

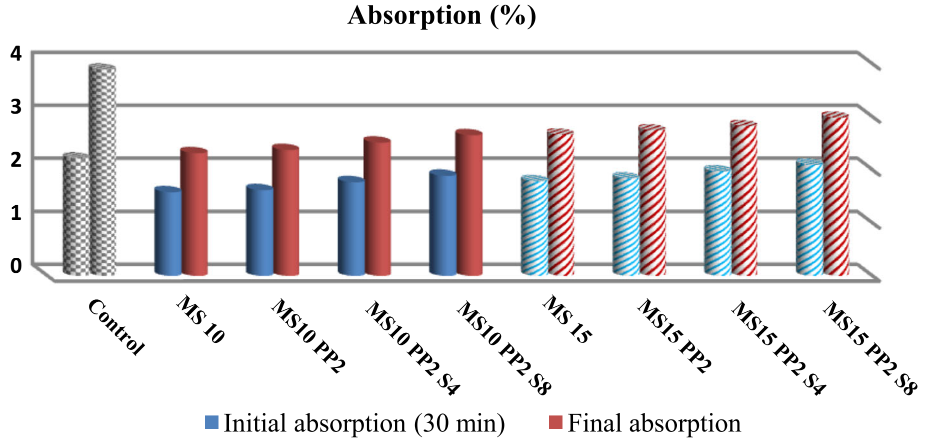

Fig. 7 Water absorption of specimens

- Compressive strength is increased to a maximum of 31.8% by replacing 10% SF with cement. An increase in SF from 10 to 15% led to a reduction in compressive strength, so the optimum percentage for SF is 10%.
- The presence of PP fiber reduced the compressive strength, and its combined effect with steel fiber has increased the strength.
- The presence of fibers increased the tensile strength of concrete, and about 7% increase is achieved by increasing the PP fiber from 0 to 1.8 kg/m^3. The combination of steel and PP fibers increased tensile strength to a maximum of 27%.
- Flexural strength of specimens is increased about 10 and 6.7%, respectively, for specimens containing SF replacement of 10 and 15% and PP fiber of 1.8 kg/m^3(0.2%). The combination of steel and PP fibers increased the flexural strength to the highest amount of about 38.75%, respectively.
- Replacing 10% SF with cement increased tensile and flexural strengths to a maximum increase in the order of about 25 and 27%, respectively.
- Modulus of elasticity is increased to the highest amount of about 14% for mixes containing 10% SF. Also, the influence of fibers on the modulus of elasticity has been very low.
- The presence of fiber increased water absorption. Nevertheless, based on the presented category by CEB, most samples are categorized as good. Also, the presence of SF has reduced water absorption.

References

Ahmadi B, Shekarchi M (2010) Use of natural zeolite as a supplementary cementitious material. Cement Concr Compos 32:134–141

Al-Khaiat H, Haque MN (1998) Effect of initial curing on early strength and physical properties of lightweight concrete. Cem Concr Res 28(6):859–866

Aydin AC (2007) Self compactability of high volume hybrid fiber reinforced Concrete. Constr Build Mater 21:1149–1154

Babu DS, Babu KG, Tiong-Huan W (2006) Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete. Cement Concr Compos 28:520–527

Bargi Kh (2001) Principles of earthquake engineering. Tehran University Press, Tehran **(in persian)**

Bazant ZP, Ozbolt J (1992) Compression failure of quasibrittle material: nonlocal microplane model. J Eng Mech 118(3):540–556

Benaicha M, Roguiez X, Jalbaud O, Burtschell Y, Alaoui AH (2015) Influence of silica fume and viscosity modifying agent on the mechanical and rheological behavior of self compacting concrete. Constr Build Mater 84:103–110

Beygi MHA, Hosseinian SB, Shafigh P (2007) Construction of light weight concrete by using light weight aggregates, stone powder and micro silica. University of Ferdowsi press, Mashhad **(in Persian)**

Beygi MH, Nikbin IMP, Babajani M (2009) Investigation different fibers effect on mechanical characteristics of self consolidating concrete containing light weight and normal weight aggregates. In: First national conference on engineering and infrastructures management, Tehran university **(in persian)**

Bhanjaa S, Sengupta B (2005) Influence of silica fume on the tensile strength of concrete. Cem Concr Res 35:743–747

Cakır Ö, Sofyanl ÖÖ (2014) Influence of silica fume on mechanical and physical properties of recycled aggregate concrete. Hous Build Natl Res Cent 11:157–166

CEB-FIP (1989) Diagnosis and assessment of concrete structures—state of the art report. CEB Bull 192:83–85

Chen B, Liu J (2005) Contribution of hybrid fibers on the properties of the high-strength lightweight concrete having good workability. Cem Concr Res 35:913–917

Demirboga R, Orung I, Gul R (2001) Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. Cem Concr Res 31:1627–1632

Denneman E, Kearsley EP, Visser AT (2011) Splitting tensile test for fiber reinforced concrete. Mater Struct 44(8):1441–1449

Dotto JMR, Abreu AGd, Dal Molin DCC, Muller IL (2004) Influence of silica fume addition on concretes physical properties and on corrosion behavior of reinforcement bars. Cem Concr Compos 26(1):31–39

DÜzgun OA, GÜl R, Aydin A (2005) Effect of steel fibers on the mechanical properties of natural lightweight aggregate concrete. Mater Lett 59:3357–3363

Eren O, Celik T (1997) Effect of silica fume and steel fibers on some properties of high-strength concrete. Constr Build Mater 11(l-8):373–382

Euro light concrete (1998) Definitions and international consensus Report, European Union BE 96-3942/R1

Gao J, Sun W, Morino K (1997) Mechanical properties of steel fiber reinforced high-strength lightweight concrete. Cem Concr Compos 19:307–313

Gesoğlu M, Guneyisi E, Alzeebaree R, Mermerdas K (2013) Effect of silica fume and steel fiber on the mechanical properties of the concretes produced with cold bonded fly ash aggregates. Constr Build Mater 40:982–990

GrÜnewald S, Walraven JC (2001) Parameter-study on the influence of Steel fibers and coarse aggregate content on the fresh properties of self-compacting concrete. Cem Concr Res 31:1793–1798

Holland TC et al (1996) Guide for the use of silica fume in concrete. ACI 234R-96

Huntzinger DN, Eatmon TD (2009) A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. J Clean Prod 17(7):668–675

Kayali O, Haque MN, Zhu B (1999) Drying shrinkage of fibre-reinforced lightweight aggregate concrete containing fly ash. Cem Concr Res 29:1835–1840

Kılıc A, Atis CD, Yasar E, Özcan F (2003) High-strength lightweight concrete made with scoria aggregate containing mineral admixtures. Cem Concr Res 33:1595–1599

Kim, D.J., Naaman, A.E., EL-Tawil, S. (2010). Correlation between tensile and bending behavior of FRC composites with scale effect. In: Fracture mechanics of concrete and concrete structures, pp 1379–1385, 23–28 May

KÖksal F, Altun F, Yiğit I, Sahin Y (2008) Combined effect of silica fume and steel fiber on the mechanical properties of high strength concretes. Constr Build Mater 22:1874–1880

Libre NA, Shekarchi M, Mahoutian M, Soroushian P (2011) Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice. Constr Build Mater 25:2458–2464

Mahotian M, Behradiyekta S (2011) Effect of steel and polypropylene fibers on mechanical characteristics of light weight concrete containing leca and pumice. In: First national conference on light weight concrete, Tehran university **(in persian)**

Mata LA (2004) Implementation of self-consolidating concrete (SCC) for Prestressed Concrete Girders. Master of Science Thesis North Carolina State University November

Mazloom M, Ramezanianpour AA, Brooks JJ (2004) Effect of silica fume on mechanical properties of high-strength concrete. Cement Concr Compos 26:347–357

Mehta PK (1986) Concrete: structure, properties and materials. Prentice-Hall, Englewood Cliffs

Mosavi SY (2009) Investigation on durability and corossion potentials of light weight concrete. Masterthesis, Engineering faculty, Guilanuniversity **(in persian)**

Mosavinejad SHG, Mohsenzadeh S, Hashami MK (2014) Study of mechanical properties of traditional Iranian cementitious material (Sarooj). In: 6th Iranian annual conference of concrete, Iran **(in Persian)**

Nili M, Afroughsabet V (2010) The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete. Constr Build Mater 24:927–933

Ranjbar N, Mehrali ME, Behnia A, Javadi Pordsari A, Mehrali MO, Johnson Alengaram U, Jumaat MZ (2016a) A compressive study of polypropylene fiber reinforced fly ash based geopolymer. PLoS ONE 11:e0147546

Ranjbar N, Mehrali M, Behnia A, Mehrali M, Alengaram UJ, Jumaat MZ (2016b) High Tensile strength fly ash based geopolymer composite using copper coated micro steel fiber. Constr Build Mater 112:629–638

Ranjber MM, Madandoust R, Ghaneh F, Isapour S, Karimi M (2012) Evaluation of mechanical properties of SCC containing pozzolan. In: 4th Iranian annual conference of concrete, Iran **(in Persian)**

Rossignolo JA, Agnesini MVC (2004) Durability of polymer-modified lightweight aggregate concrete. Cem Concr Compos 26:375–380

Sadrmomtazi A, Zerafatangiz F, Alidoust O, Haghi AK (2008) Flexural toughness and crack strength of fiber reinforced cementitious composite. Key Eng Mater 385:337–340

Sadrodiny Mehrgerdy N, Hoshdar Tehrani MH, Taeidy K (1990) Recognition, design and application of lightweight concrete construction. Building and Housing Research Center, Tehran, Iran, p 483 (**in persian**)

Sahmaran M, Yurtseven A, Yaman IO (2005) Workability of hybrid fiber reinforced self-compacting concrete. Build Environ 40:1672–1677

Sarıdemir M (2013) Effect of silica fume and ground pumice on compressive strength and modulus of elasticity of high strength concrete. Constr Build Mater 49:484–489

Shafigh P, Hilmi M, Jumaat MZ (2011) Effect of steel fiber on the mechanical properties of oil palm shell lightweight concrete. Mater Des 3(2):3926–3932

Shannag MJ (2000) High strength concrete containing natural pozzolan and silica fume. Cem Concr Compos 22:399–406

Topcu IB (1997) Semi-lightweight concretes produced by volcanic slags. Cem Concr Res 27(1):15–21

Valipour M, Pargar F, Shekarchi M, Khani S (2013) Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: a laboratory study. Constr Build Mater 41:879–888

Yazici S, Inan G, Tabak V (2007) Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. Constr Build Mater 21:1250–1253