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Mechanical properties of light weight concrete with hook ended Steel & Polymer Synthetic fiber

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ABSTRACT

In this study, the effect of industrial steel (ISF) and polymer synthetic fibers (PSF) on the mechanical properties of lightweight concrete with light expanded clay aggregate (LECA) is investigated. In order to determine the effect of both ISF and PSF ratio on the mechanical properties of concrete are changed. To do so, different concrete mix design are considered including fully replacement of the LECA instated of the large aggregate; adding various ratio of steel and synthetic fiber. In all scenarios, the amount of the cement content is the same. However, the slump amount is targeted to be fallen in the limited range. Based on the observations it was shown that the replacing LECA instead of the large aggregate can considerably decrease the unit weight of concrete. In addition, increase of PSF and ISF ratio does not much affect on splitting-tensile strength. However, the mixtures can compression and flexural load carrying capacity can be significantly improved.

KEYWORDS: *lightweight concrete, polymer synthetic fibers, industrial steel fiber, LECA, mechanical properties.*

INTRODUCTION

In these decades, further interest has been rewarded to the development of lightweight aggregate concrete [Short (1978), Spratt (1980), Anon (1983), Alduaij and Alshaleh K (1999), and Kayali et al. (1999)]. Because of the advantage of high strength/weight ratio, proper tensile strain capacity, low coefficient of thermal expansion resulting from the existing voids in the lightweight aggregates [Topcu (1997), and Al-Khaiat and Haque (1998)], the lightweight concrete can be wieldy used in constructions. Furthermore, the other advantage of lightweight concrete are reduction of the construction cost, eases to uses, and its reputation in the regard of the green building

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material. In general, concrete is a known as a composite material consists of cement paste, aggregate, and the interface between aggregate and cement paste [8]. However, due to the randomness of the mechanical properties of the concrete aggregate, there are always uncertainties associated with the goodness of them. Moreover, the rapid development of high-rise buildings, larger sized and larger span concrete bridges, requirements of concrete performance with higher strength and light weighted one is concerned for example the need of the light-weight concter may have a impact of the founding of Ghasemi and Nowak (2017a) regarding to the bridge design. However, due to the higher uncertainness of Light-weight concrete the dead load factor may increase (Ghasemi and Nowak 2018). In some cases, the density of the concrete is often more important than the strength. In concrete construction, self-weight contains a very large proportion of total load of the structure. Therefore, reduction of the density of concrete clearly brings an advantage to reduction of the exerting loads. The reduction of the dead loads also leads to reduction of the earthquakes loading [Ghasemi and Ashtari (2014) and Ashtari and Ghasemi (2013)]. Hence, several studies have been dealt with the investigation of properties of the high-strength, lightweight concrete [Birjandi, and Clarke, (1993), Shiiba et al. (1992), Shah et al. (1983), Saito (1984), Tachibana and Imai (1994), Tamura and Tazawa (1991), and Gjorv (1994)]. Zhang and Gjorv (1991) and Rustem Gul [(2005) stated that the tensile and compressive strength of high-strength-lightweight concrete is generally lower than the high-strength-normal weight concrete. In addition, the lightweight concrete tends to be behaved more brittle by increasing its strength level. Mehta (1986) and Topcu (1997), and Al-Khaiat H, Haque (1998) discussed about the curing conditions of the light-weight concrete. Slate et al. (1986) expressed that the stress-strain curve in uniaxial compression was steeper and more linear in a higher stress-strength ratio for the high-strength, lightweight concrete than for the low strength lightweight concrete. Shimazaki al. (1994) claimed that the compressive toughness of the high-strength-lightweight concrete was smaller than that of normal weight concrete. By increasing the strength of the high-strength-lightweight concrete, which has been used extensively as major construction materials, such as low tensile/compressive strength ratio, low flexural strength, low fracture toughness, high brittleness and larger shrinkage, banned its use in concrete structure. The addition of steel fiber to high-strength-lightweight concrete has important effects on the improvement on properties of high-strength-light-weight concrete, especially for improving tensile/compressive ratio, behavior for earthquake resistance. Also, the resistance to cracking and fracture toughness can be increased. However, the published literature contains very little information on properties of steel fiber reinforced high-strength- lightweight concrete [Jianming (1997) and SemsiYazıcı (2007)].
This matter which tempted us to focus on the effect of industrial steel (ISF) and polymer synthetic fibers (PSF) on the mechanical properties of lightweight concrete with light expanded clay aggregate (LECA).

Experimental procedures

Materials

Portland cement (PC) type II from Tehran factory, A Portland cement was used, with a Blaine surface area of 3150 kg/m3 and a density of 0.3354 gr/m^3.Silica fume in Iran was used in this study. Light expanded clay aggregate (LECA) and natural aggregate were obtained from Zarandieh-Savehand Shahriar region in Tehran. The full details of these mixtures are given in Table 1.

Table 1. Chemical composition of cement and silica fume

Complex	Sio_2	Fe_2o_3	Al_2o_3	Cao	Mgo	Na_2o	K_2o	P_2o	So_3	Lio
Cement	21.00	3.20	4.60	64.50	2.00	0.26	0.54	-	2.90	1.50
Silica fume	91.10	2.00	1.55	2.42	0.06	0.26	0.54	-	0.45	1.62

In this study, in order to enhance the workability retention, substantial water reductions, optimization of cement content, and shrinkage resistance the porosities are reduced with adding CHRYSO Fluid Optima 270.Table 2 .

Table 1. Characteristics of superplasticizer

CHRYSO Fluid Optima 270	Name
Based on modified polycarboxylate	
Liquid	Nature
Pale Yellow	Colour
1.085±0.02 gr/cm^3	Density
Less than 0.1%	Cl ion content
2 ± 6	PH

The maximum aggregate size was selected about 16 mm. The cement dosage and slump of the mixture were kept constant at 372 kg/m^3 and 3±0.5 cm throughout this study, respectively. Steel (ISF) and Synthetic fibers (PSF), which were used in this research were hooked-ends and were collated into clips of about ten individual fibers using a water-soluble adhesive. Average length and diameter of the ISF and PSF was 50, 1 mm and 50 , 0.07 mm, equivalent aspect ratio were 50 and 715, respectively which are given in Table 3. It is clear that aspect ratio is crucially important which with increasing length not only leads into multiple cracking but also less workability.

Table 3. Mechanical properties of steel and synthetic fiber

Properties	**Steel fiber**	**Synthetic fiber**
Mechanical properties		
Lengthl (mm)	50	50
Diameterd (mm)	1	0.07
Aspect Ratio =l/dRA	50	714.28
Real Density^{3}kg/m	7610	-
Tensile StrengthMPa	809	600

In this study, two different volumetric LECA instead of gravel, namely 273 and 310.25 kg/m^3 and four different volume percent fibers, namely 0.5%, 1.0%, 1.5% and 2% were used. Hence, the total of 20 different mixtures was cast for each two different water to cement ratios. The full details of these mixtures are given in Table 4.

Table 4. Concrete mixtures

Fiber	Fiber Ratio	Water m/Kg^3	Superplasticizer	Silica fume m/Kg^3	Cement m/Kg^3	LECA m/Kg^3	Sand m/Kg3	No.
-	0	168	8.4	48	372	273.00	850.00	1
Hook Ended	0.5	168	8.4	48	372	273.00	850.00	2
Hook Ended	1	168	8.4	48	372	273.00	850.00	3
Hook Ended	1.5	168	8.4	48	372	273.00	850.00	4
Hook Ended	2	168	8.4	48	372	273.00	850.00	5
-	0	168	8.4	48	372	273.00	850.00	6
Synthetic	0.5	168	8.4	48	372	273.00	850.00	7
Synthetic	1	168	8.4	48	372	273.00	850.00	8
Synthetic	1.5	168	8.4	48	372	273.00	850.00	9
Synthetic	2	168	8.4	48	372	273.00	850.00	10
-	0	147	8.4	48	372	273.00	850.00	11
Hook Ended	0.5	147	8.4	48	372	273.00	850.00	12
Hook Ended	1	147	8.4	48	372	273.00	850.00	13
Hook Ended	1.5	147	8.4	48	372	273.00	850.00	14
Hook Ended	2	147	8.4	48	372	273.00	850.00	15
-	0	147	8.4	48	372	273.00	850.00	16
Synthetic	0.5	147	8.4	48	372	273.00	850.00	17
Synthetic	1	147	8.4	48	372	273.00	850.00	18
Synthetic	1.5	147	8.4	48	372	273.00	850.00	19
Synthetic	2	147	8.4	48	372	273.00	850.00	20
-	0	168	2.1	48	372	310.25	650.18	1
Hook Ended	0.5	168	2.1	48	372	310.25	650.18	2
Hook Ended	1	168	2.1	48	372	310.25	650.18	3
Hook Ended	1.5	168	2.1	48	372	310.25	650.18	4
Hook Ended	2	168	2.1	48	372	310.25	650.18	5
-	0	168	2.1	48	372	310.25	650.18	6
Synthetic	0.5	168	2.1	48	372	310.25	650.18	7
Synthetic	1	168	2.1	48	372	310.25	650.18	8
Synthetic	1.5	168	2.1	48	372	310.25	650.18	9
Synthetic	2	168	2.1	48	372	310.25	650.18	10
-	0	147	2.1	48	372	310.25	650.18	11
Hook Ended	0.5	147	2.1	48	372	310.25	650.18	12
Hook Ended	1	147	2.1	48	372	310.25	650.18	13
Hook Ended	1.5	147	2.1	48	372	310.25	650.18	14
Hook Ended	2	147	2.1	48	372	310.25	650.18	15
-	0	147	2.1	48	372	310.25	650.18	16
Synthetic	0.5	147	2.1	48	372	310.25	650.18	17
Synthetic	1	147	2.1	48	372	310.25	650.18	18
Synthetic	1.5	147	2.1	48	372	310.25	650.18	19
Synthetic	2	147	2.1	48	372	310.25	650.18	20

The concrete mixtures were prepared in a laboratory mixer. Hand compaction was used for all samples. Precautions were taken to ensure the homogeneity and full compaction of the samples. For each mixture, six samples of 150 to 300 mm cylinders were prepared and cured for 7 and 28 days in lime-saturated water. At 20±2 °C until the testing time. At 7 and 28 days, samples were tested for compressive strength, splitting tensile strength, and flexural strength in accordance with ASTM C-192, ASTM C-496-71, and ASTM C-78-84, respectively. Compressive strength tests were conducted using cylinders capped with a sulfur compound. The strain in the middle of the cylinder was recorded using a compressometer with a reading accuracy of 0.005 mm. The certain amount of load was applied to the sample by a compression testing machine with a capacity of 3000 KN. The Brazilian splitting-tensile strength tests were conducted on 150-300 mm cylinders. In this procedure, only the failure load was recorded. In addition, flexure tests were carried out with loading the on prisms at third points over a simply supported span of 700 mm. The test results are presented in Table 5 to Table 7.

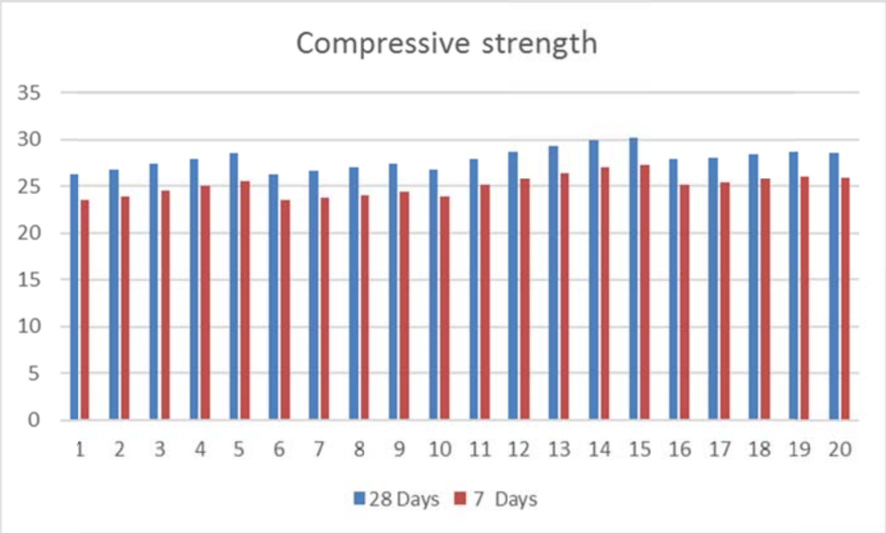

Fig. 1. Compressive strength of 7-days and 28-days concrete

Table 5. Compressive strength of 7-days and 28-days concrete with various percentage fiber

MPaCompressive strength		
28 Days	**7 Days**	Design No.
26.28	23.45	1
26.80	23.90	2
27.46	24.50	3
28.00	25.02	4
28.52	25.50	5
26.28	23.45	6
26.70	23.76	7
27.00	24.06	8
27.38	24.39	9
26.75	23.85	10
27.99	25.15	11
28.67	25.75	12
29.28	26.40	13

30.02	27.06	14
30.24	27.31	15
27.99	25.15	16
28.13	25.37	17
28.42	25.77	18
28.71	26.08	19
28.53	25.91	20

Table 6. Splitting tensile strength of 28-days concrete with various fiber

Fiber	0%	0.5%	1%	1.5%	2%
Steel	1.54	1.89	2.21	2.55	2.75
Synthetic	1.54	1.75	1.9	2.11	2.25

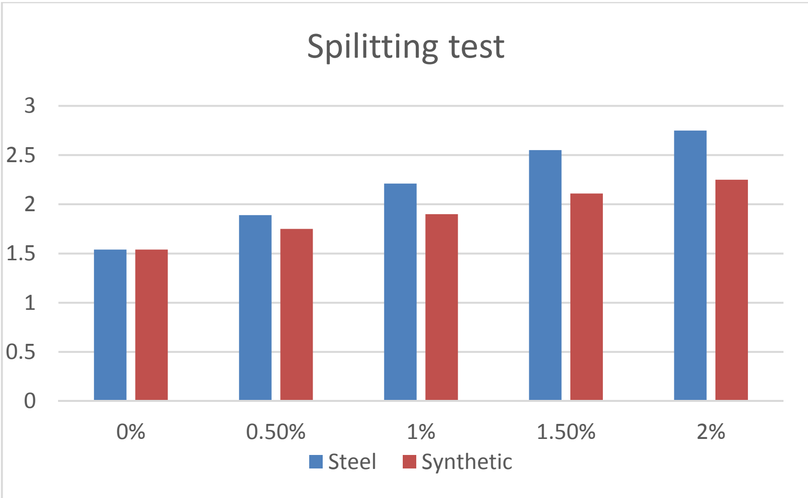

Fig. 2. Splitting tensile strength of 28-days concrete

Table 7. Flexural strength of 28-days concrete with various fiber.

Fiber	0%	0.5%	1%	1.5%	2%
Steel	1.98	2.61	3.29	3.85	4.33
Synthetic	1.98	2.33	2.75	3.01	3.16

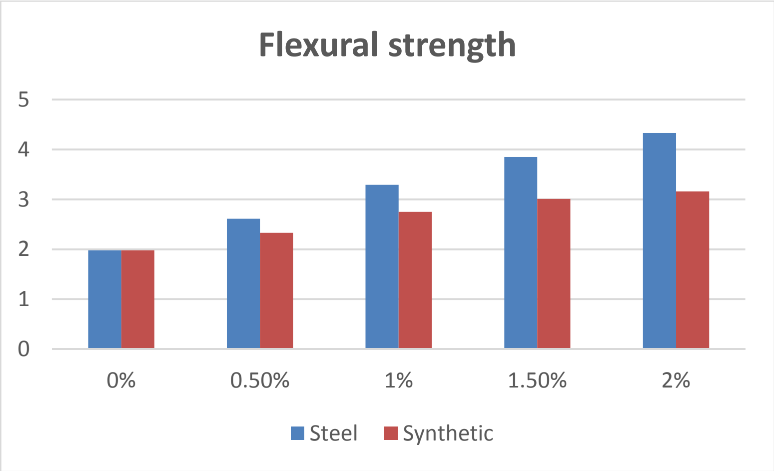

Fig. 3. Flexural strength of 28-days concrete

With increasing of water to cement ratio between 5 to 7 percent, compressive strength increase by 7.21 percent. Table 8

Table 8. Effect of various water/ cement ratio on compressive strength with various fiber

Fiber	Water /Cement Ratio	0%	0.5%	1%	1.5%	2%
Steel	0.40	26.28	26.80	27.49	28.00	28.52
Synthetic	0.35	27.99	28.67	29.28	30.02	30.24
Steel	0.40	26.28	26.70	27.00	27.38	26.75
Synthetic	0.35	27.99	28.13	28.42	28.71	28.53

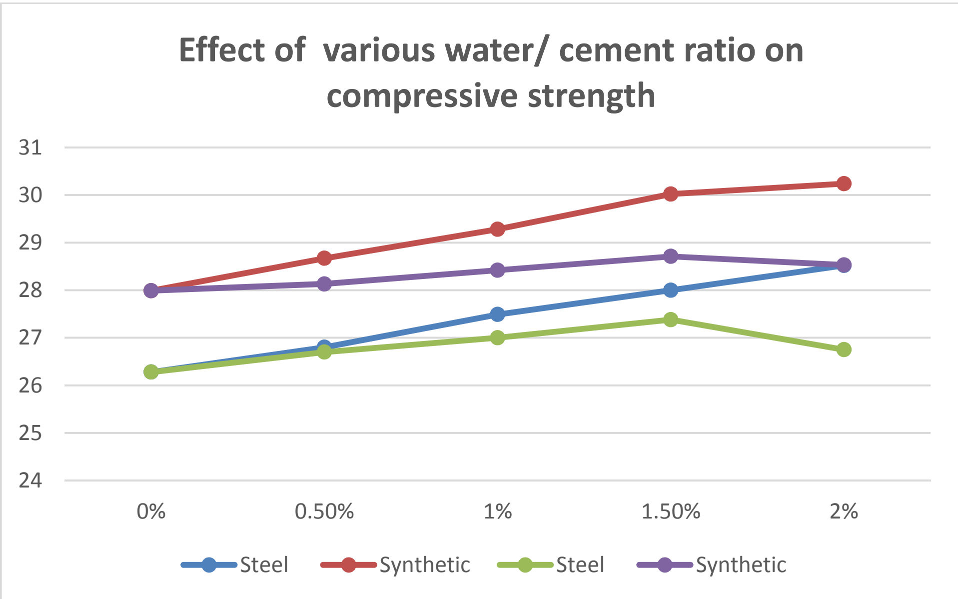

Fig. 4. Effect of various water/ cement ratio on compressive strength with various fiber

Effect of LECA, PSF and ISF on the unit weights of concretes were measured at right after mixture. The observation of Table 9 shows that the unit weight of concretes decreases significantly with replacing LECA instead of gravel in comparison with regular concrete. Although, regard to the increasing synthetic fibers in the mixtures no considerable in creation of the compressive and unit weight observed, the steel fibers the compressive strength 8.74 % and unit weight were increased besides that increasing of water to cement ratio caused that compressive strength were increased 5% – 7%.
Furthermore, water to cement ratios of 0.4 splitting tensile and flexural strength of the samples of 28 days of light weight concrete increased up to 78.57 % & 118.68 % for steel fibers and 46.10 % & 59.60 % for synthetic fibers respectively.
When comparing the control samples, increase in the unit weight due to the ISF were 2.8%, 3.2% 4.1% and 3.1% for 0.5% ISF ratio, 3.6%, 4.2%, 4.8% and 6.5% for 1.0% ISF ratio and 5.6%, 6.5%, 5.9% and 8.5% for 1.5% ISF ratio. This is probably due to ISF.

Table 9. Weight of wet concrete

Fiber	Water/cement	0%	0.50%	1%	1.50%	2%
Steel hook ended	0.4	1549	1587	1625	1664	1701
Synthetic	0.4	1549	1553	1557	1561	1565
Steel hook ended	0.35	1528	1566	1604	1663	1680
Synthetic	0.35	1528	1532	1536	1540	1543

The modulus of elasticity is a function of the compressive strength. The increase in the compressive strength of the sample also increases the modulus of elasticity. In fact, the compressive strength increases with an augment of SF ratio and decreases with an increase of PA ratio. As a result of SF and PA ratio increase, greater and lower modulus of elasticity values observed, respectively, as shown in Table 10.

Table 10. Elasticity modulus (GPa)

Fiber	0%	0.50%	1%	1.50%	2%
Steel hook ended	6.51	6.84	7.13	8.24	8.63

Lastly, the way of failure in pullout test demonstrates that the sample with ISF accompany with yielding in bar in comparison with sample without ISF which leads to crack and failure in concrete. Using fiber especially steel type can be so effective. It caused not only more cohesion but also preventing separation between concrete and bar. The cohesive strength increased almost 10%with using 1.5% ISF in comparison with control sample. Although it should be add that the aspect ratio and kind of fiber can be effective on the results. However, it is worth mentioning that the reliability of the results should be assessed using a probabilistic approaches which have been explained in [Ghasmei and Nowak (2016 and 2017b) and Yanaka et al. (2016)].

Fig. 5. Pullout test.

Conclusions

The analysis of the experimental test results leads to that no real workability problem was encountered in the mixtures when using only the ISF and PSF up to 1.5% by volume but with more than this percentage the process of mixture was encountered with problem in ISF fibers. However, steel fiber reinforced concrete mixtures required more mixing and placing time incomparison with synthetic fibers. When compared to the sample which contain no fiber, despite of the using LECA,which decreased unit weight especially in steel fiber and mechanical properties of concretes in all cases, with the increasing of ISFand ISFY ratio in the mixtures, unit weight, compressive strength, splitting-tensile strength and flexural strength of the concretes increased up almost to 10%, 8.6%, 78.58% ,118.68% and 1%, 0.5%, 46.1% , 59.60% respectively. Furthermore, the increase in ISF ratio leads to a consistent increase on both strength and ductility up to a fiber content of 2%. However, Usage of steel fiber in concrete significantly increases the split tensile and flexural strength of concrete. Finally, using the steel and synthetic fiber in lightweight aggregate concretes, the properties which are desirable in a structural member such as lightness, sound and thermal insulation, and strength can be obtained at the same time. So, more economical solutions may be possible by reducing dead loads.

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