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Effects of expanded perlite aggregate (EPA) on the mechanical behavior of lightweight concrete

V. Khonsari, E. Eslami & Ah. Anvari
Sharif University of Technology, Tehran, Iran

ABSTRACT: In this paper the results of investigation on the effects of using Expanded Perlite (EP) as an aggregate in lightweight concrete (LWC) is presented. Through a series of tests, the following properties of manufactured mixes were obtained: compressive strength after 7 and 28 days in 2 different curing conditions, splitting tensile strength after 7 and 28 days, water sorptivity (normal and cracked), and sulfate attack. The cementitious material content was kept constant at 390 kg/m^3. Super-plasticizer of 2.5% by weight of Portland cement was used. Five different multistage mixing approaches were adopted to find the best mixing approach. Expanded Perlite Aggregate (EPA) was used by various percentages (of weight), 5%, 10%, 15%, 20%, 30%, and 40%, to replace coarse aggregates. Besides, for the case of specimens with 10% perlite, effects of adding 'hooked steel,' 'wavy steel' and 'Polypropylene fibers' were investigated. Also, the strain-stress curves of perlite concrete were obtained.

1 INTRODUCTION

Lightweight aggregate concrete (LWAC) has been used successfully for structural purposes for many years; because of their improved properties such as the workability, strength, less dead load and resistance to freezing and thawing of light weight concrete (LWC) [Neville (1997), Rossignolo & Agnesini (2004)]. LWC is also known for its superior long-term durability. Hence, in many structural applications the use of LWC is increasing rapidly [Balaguru & Foden (1996)]. Different types of lightweight aggregate (LWA) suitable for construction purposes can be found on the market, varying in their composition, density, surface texture, porosity and water absorption capacity. The most frequently used LWAs are expanded clay, expanded glass, perlite, expanded vermiculite and sintered ash.

The expanded perlite aggregate (EPA) has a wide range of uses, generally due to its properties of extremely low bulk density, high brightness, high absorption, low thermal and acoustical conductivity, and non-flammability. The absence of any apparent health hazard is also increasing its usage rate. Owing to its thermal or acoustic insulation, lightweight, and fire resistance, (EPA) is generally used in construction applications, especially as concrete and mortar. EPA concrete provides sound deadening properties and is thermal insulating as well, depending on mix design [Meral (2004), Canadian Minerals Yearbook (1997)].

The use of fiber reinforced concrete (FRC) has increased during the last two decades [Eslami (2008)]. Considerable developments have been taken place in the field of steel fiber reinforced concrete (SFRC). The current fields of application of SFRC include highway and airfield pavements, hydraulic structures, tunnel linings and more [Duzgun et al. (2005), Gül et al. (2007)]. ACI Committee 544 noted that FRC has potential for many more applications, especially in the area of structural elements [ACI 544.1R-96, ACI 544.2R-89, ACI 544.3R-93, ACI 544.4R-88].

Several research works have been done to quantify the enhanced properties of FRC materials and, particularly to compare the effect of various types of fibers [Meddah & Bencheikh (2009)]. Nowadays, it is well established that the incorporation of steel fibers improves engineering performance of structural and nonstructural concrete, including better crack resistance, ductility, and toughness, as well as an enhanced tensile strength, resistance to fatigue, impact, blast loading, and abrasion as reported by Bindiganville and Banthia [Ding & Kusterle (2000), Gao et al. (1997), Chenkui & Guofan (1995), Eren & Çelik (1997), Banthia & Nandakumar (2003), Balaguru & Shah (1992), Bindiganavile & Banthia (2001)]. Flexural strength, tensile strength, strain capacity and spalling are also enhanced [Nataraja et al. (1999)]. Moreover, addition of fibers to concrete makes it more homogenous and isotropic and transforms it from a brittle to a more ductile material [Gül et al. (2007)].

The addition of non-metallic fibres such as polypropylene results in good fresh concrete properties and reduced early age cracking. The beneficial effects of non-metallic fibres could be attributed to their high aspect ratios and increased fibre availability (because of lower density as compared to steel) at a given volume fraction. Because of their lower stiffness, these fibres are particularly effective in controlling the propagation of micro cracks in the plastic stage of concrete. However, their contribution to post-cracking behaviour, unlike steel fibres, is not known to be significant [Eslami (2008), Sivakumar & Santhanam (2007), Richardson (2006)].

2 EXPERIMENTAL PROGRAM

2.1 *Materials*

2.1.1 *Cementitious materials*

The commercial type I-425 Portland cement produced by a local company in Iran complying with Iranian standard was applied. The specific weight was 3.15 and the Blaine specific surface was 310 m^2/kg. Silica fume was produced by VandChemi in Iran. The specification analysis and physical properties of silica fume are displayed in Table 1.

Table 1. Specification analysis of Portland cement, silica fume and perlite aggregate.

Component	PC (%)	SF (%)	EPA (%)
Sio2	20.06	93.9	65-73
Fe_2O_3	3.6	0.87	4-6
Al_2O_3	5.16	1.32	12-16
CaO	63.1	0.49	0.3-0.6
MgO	2.70	0.97	-
SO_3	2.32	0.10	-
K_2O	0.6	1.01	-
TiO_2	0.2	-	-
Na_2O	0.36	0.31	1-4
Sulphide (S-2)	0.17	0.1-0.3	-
Chloride (Cl-)	0.14	-	-
Undetermined	1.05	-	-
Free CaO	0.75	-	-
LOI	1.55	0.5-1.0	-

2.1.2 *Super-plasticizer*

Super-plasticizer based on poly-carboxylic acrylic produced by Chryso with specific gravity of 1.098, solid content of 40% was used. Dosage of super-plasticizer was constant at 2.5% of cement weight.

2.1.3 *Aggregates*

The crushed natural gravel with specific gravity of 2.68, nominal maximum size of 12.5mm and absorption of 1% was used as coarse aggregate. Sand with specific gravity of 2.64, absorption of 1.5%, fines module of 3.1 was used as fine aggregate. Expanded perlite aggregate with specific gravity of 0.15, absorption of 63% was used.

2.1.4 *Fibers*

Three type of steel fiber (SF1, SF2 and SF3), and one type of polypropylene fiber were used in this research. The SF1 and SF2 were hooked shape and SF3 was wavy shape. Also, the cross section of all three types of steel fibers was rectangular. Fibers were added in mixture with constant volumetric ratio of 1%. The physical properties of each fiber are presented in Table 2.

2.2 *Mix proportion*

The binder (Portland cement + silica fume) content was constant at 390 kg/m^3 with 10% replacement of silica fume (39 kg/m^3). Six main groups of mixtures were produced and specified as

EPA0 (100% Normal Aggregate),
EPA5 (95% Normal Aggregate + 5% EPA),
EPA10 (90% Normal Aggregate + 10% EPA),
EPA15 (85% Normal Aggregate + 15% EPA),
EPA20 (80% Normal Aggregate + 20% EPA),
EPA30 (70% Normal Aggregate + 30% EPA) and
EPA40 (60% Normal Aggregate + 40% EPA).

In order to study the effects of adding different fibers, four mixtures were prepared based on EPA10 control specimen. Table 3 gives the mix proportion of each mixture. For each mixture, specimens were prepared in cylindrical 100×200mm and cubical 100×100×100mm shapes, and remolded after 24±8 hours for storage in lime saturated water at 23±2 ºC. For each mixture, cubical specimens were stored in 3.0% sodium sulfate solution until the time of the tests.

In as much as it shown mechanical properties of perlite concretes are sensitive to curing environment [Kantarcı (2007)], two types of curing condition were chosen to study the effects of curing environment on the compressive strength of EPA concretes. These curing conditions consist of putting in water and under wet sack for 28 days until the test. A system was designed for keeping the sack wet all time. At 28 days, samples were tested for compressive strength of cubical concrete specimens, compressive strength of cylindrical concrete specimens, splitting tensile strength, apparent porosity, and sorptivity (normal and cracked).

2.3 *Mixing approaches*

Five different mixing methods for a specific mix proportion of EPA10 were prepared in cubical 100×100×100 mm^3 shapes to find the best slump and compressive strength. Steps of mixing approaches and preliminary results are shown in Table 4. It was found that the approach 3 had the best compressive strength slump simultaneously.

Table 2. Physical properties of fibers.

Fibers type	Tensile strength (Mpa)	Diameter (d_f) (mm)	Length (L) (mm)	Specific weight (kg/m^3)	Width (W) (mm)	Thickness (T) (mm)	Aspect Ratio (L/d_f)
SF1	650	0.597	25	78.0	0.8	0.35	42
SF2	650	0.867	50	78.0	2.0	0.30	57
SF3	650	0.668	35	78.0	1.0	0.37	47
PP	350	0.02	12	0.98	0.02	0.02	---

Table 3. Mix proportion of mixtures with and without fibers.

Mixtures	EPA (%) 0	5	10					15	20	30	40
	Without Fibers	Without Fibers	Without Fibers	1% Fibers (kg/m^3)				Without Fibers	Without Fibers	Without Fibers	Without Fibers
				SF1	SF2	SF3	PP				
w/cm	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Water	136.5	136.5	136.5	136.5	136.5	136.5	136.5	136.5	136.5	136.5	136.5
Cement	351	351	351	351	351	351	351	351	351	351	351
Silica fume	39	39	39	39	39	39	39	39	39	39	39
Gravel	1063.8	1010.6	957.4	957.4	957.4	957.4	957.4	904.2	851.0	744.7	638.3
Sand	709.2	709.2	709.2	709.2	709.2	709.2	709.2	709.2	709.2	709.2	709.2
Perlite	0	53.2	106.4	106.4	106.4	106.4	106.4	159.6	212.8	319.1	425.5
Superplasticizer	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
Fiber	0	0	0	78	78	78	95	0	0	0	0
unit weight	2309.6	2309.6	2309.6	2387.6	2387.6	2387.6	2404.6	2309.6	2309.6	2309.6	2309.6

Table 4. Steps and results for various mixing approaches.

Approach	Step 1	Step 2	Step 3	Step 4	Compressive Strength (MPa)	Standard Slump (mm)
App 1	Adding gravel, sand, cement	Mixed 5 minutes	Adding water	Mixed 5 minutes	40.3	140
App 2	Adding water, cement	Mixed 5 minutes	Adding sand, perlite, gravel	Mixed 5 minutes	30.9	170
App 3	Adding water, cement, perlite, sand	Mixed 5 minutes	Adding gravel	Mixed 5 minutes	40.4	240
App 4	Adding water, sand, cement	Mixed 5 minutes	Adding gravel, perlite	Mixed 5 minutes	39.9	45
App 5	Adding sand, cement, gravel, perlite, half of water	Mixed 5 minutes	Another half of water	Mixed 5 minutes	27.4	215

3 METHODS

3.1 *Apparent porosity*

The Apparent Porosity (AP) of tested specimens was assessed using the following expression [Kantarcı (2007)]:

$$AP\% = \frac{W_{saturated} - W_{dry}}{W_{saturated} - W_{soak}} \times 100 \qquad (1)$$

$W_{saturated}$ is the weight of the specimen at the saturated condition, W_{soak} is the weight of the specimen in water conditions and W_{dry} is the dry weight of specimen dried at 100ºC for 24h.

3.2 *Water sorptivity*

The water sorptivity including the normal sorptivity and cracked sorptivity was performed in this study. The Normal Sorptivity (NS) was calculated as following:

$$NS\,\% = \frac{W_{absorbed} - W_{dry}}{W_{dry}} \times 100 \qquad (2)$$

$W_{absorbed}$ represent the weight of specimen in water condition one hour after start of absorption, and W_{dry} is aforementioned notation.

Also, another innovative method for determining sorptivity properties named “Cracked Sorptivity (CS)” was used. This method consists of using one half of 10×20mm cylinder specimen after the splitting tensile strength test. The rest of process is similar to normal sorptivity. The cracked sorptivity would be the average number for two halves each specimen [Eslami (2009)].

3.3 *Compressive stress-strain curve*

To design and analyze structures using steel-fiber reinforced concrete for compression, the stress-strain behavior of the material in compression is needed. A number of analytical and empirical expressions for the stress-strain diagram of fibrous concrete have been proposed by researchers [Nataraja et al. (1999), Fanella & Naaman (1985), Ezeldin & Balaguru (1992), Marar et al. (2001), Hsu & Hsu (1994), Ding & Kusterle (2000), Cachim et al. (2002), Kayali et al. (2003)]. To investigate the fiber influence on the concrete behavior under compressive load of perlite concrete, 100×200mm cylindrical specimens of four mixtures were tested. Specimens were held vertically at both ends of the machine by two slot grippers and the force was then applied directly at the rate of 0.025 mm/min the data were collected by a PC-based data acquisition system.

4 RESULTS AND DISCUSSION

The detailed results are shown in Tables 5 and 6, and Figure 1. Furthermore, discussions about mechanical properties, porosity and sorptivity, and compressive stress-strain behavior are in below

4.1 *Compressive strength*

Table 5 and Table 6 summarize the results of non-fibrous and fibrous specimens respectively. Table 5 tabulates the experimental data of 7 and 28-day specimens of EPA0-EPA40. They are the averaged results from three identical specimens in the series. As expected by works of other researchers [Kantarcı (2007), Demirbog & Gul (2003), Demirboga & Gül (2003), Demirbog et al. (2001)], poor structure of EPAs results that the compressive strengths of perlite concrete decrease with increase of perlite content, since the decrease of 20% for EPA10, 24% for EPA15, 40% for EPA20, 65% for EPA30 and more than 80% for EPA40 are seen in 28-day compressive strength for cylindrical specimens. Also, It can be seen that the strength of the cylinders with compare to cubes were smaller in same batch and in range of 0.82-0.85 similar to standard size effect factor.

In addition, EPA decreases heat of hydration and needs long curing period. Curing conditions are an important factor influencing the relative performance of aggregate in concrete. The wet sack curing condition brings about the better compressive strengths for all perlite concrete, unlike the specimen without perlite (EPA0). As the results show, with increasing the perlite content, compressive strengths smoothly increase. Mannan et al. [Mannan (2003)] reported that the loss of moisture in the capillary pores due to evaporation or dissipated hydration may cause reduction in hydration resulting in lower strength. The further tests need to observe the effects of curing conditions on the properties of perlite concrete.

In Table 6, the experimental results of fibrous concrete (SF1, SF2, SF3 and PP) along with their plain concrete (EPA10) are presented. Except SF3, in all fibrous specimens, addition of fibers results the lower compressive strength; but this reduction is significant for PP concrete. Also, the compressive strengths of steel fiber reinforced perlite concrete (SF1, SF2 and SF3) changed slightly from 4 to 7% with respect to plain specimen, compatible with other steel fiber reinforced concretes [Balaguru & Foden (1996), Eslami (2008), Duzgun et al. (2005), Gül et al. (2007), Ding & Kusterle (2000), Gao et al. (1997), Chenkui & Guofan (1995), Eren & Çelik (1997), Nataraja et al. (1999), Sivakumar & Santhanam (2007)]. However, the considerable reduction in compressive strength of PP reinforced concrete containing more than 1 volumetric percent was expected [Sivakumar & Santhanam (2007), Richardson (2006), Eslami (2008)].

4.2 *Splitting tensile strength*

As shown in Tables 5 and 6, Similar to compressive strength, addition of perlite causes the dramatic decreases in splitting tensile strengths of perlite concretes. The reductions are 16%, 26%, 40%, 49%, 61%, and 68% for EPA5, EPA10, EPA15, EPA20, EPA30, and EPA40 respectively. It may due to weakness of EPA in matrix.

For fibrous specimens, fibers provided a substantial increase in splitting-tensile strength. The results approximately doubled with addition of 1% of steel fibers; although SF3 (wavy shape fiber) had the best performance, followed by SF2 (bigger hooked shape fiber) and SF1 (smaller hooked shape fiber). This strength increase may be the indication of good bonding between fibers and matrix. The wavy type of steel fibers has a better shape to improve the bonding performance than hooked types. Also, citing this fact that L/d_f for SF2 is higher than SF1, the increase in L/d_f was attributed to higher bond developed at the interface of fiber and concrete matrix [Khaloo & Sharifian (2005)]. It should be noted that lightweight concrete is typically weaker under this type of loading as compared to the normal concrete. Since the splitting tensile strength is known to provide an indication of shear strength in diagonal tension, it is an important design parameter for beams and also the increase can be utilized in structures subjected to shear [Balaguru & Foden (1996), Balaguru & Dipsia (1993)]. The test results also indicated a linear relationship between the compressive strength and splitting-tensile strength in the case of adding steel fiber, compatible with other researches [Balaguru & Dipsia (1993), Duzgun (2005)].

4.3 *Apparent porosity and water sorptivity*

According to Table 5, the apparent porosity and the water porosity indexes (normal sorptivity and cracked sorptivity) increased with increase of EPA volume. It may be due to the higher pore size of perlite concrete specimens. In concrete with EPA, the average pore size was higher than that of normal aggregate, the pores in bulk paste and interfaces were not filled completely.

Table 5. Hardened properties for variety of perlite dosages.

Mixtures	Compressive strength (MPa)					Tensile Strength (MPa)	Apparent Porosity (%)	Normal Sorptivity (%)	Cracked Sorptivity (%)
	7 days	28 days (Cubes)			28 days (Cylinders)				
	Water	Wet sack	Water	Sulfate					
EPA 0	28.6	41.9	46.7	44.5	38.2	2.19	8.58	1.25	1.44
EPA 5	29.4	46.9	44.8	42.7	37.9	1.84	9.22	2.98	3.58
EPA 10	23.3	40.4	37.5	37.0	30.4	1.62	9.95	4.07	5.96
EPA 15	18.7	38.2	37.0	34.7	31.1	1.32	10.47	6.23	9.58
EPA 20	15.1	28.3	26.9	23.9	22.9	1.12	11.83	7.17	11.88
EPA 30	8.6	17.0	15.6	13.4	13.1	0.85	13.49	9.01	15.44
EPA 40	5.1	9.8	8.5	7.1	7.1	0.71	17.61	10.56	18.58

Table 6. Hardened properties of fibrous concretes.

Mixtures	Cubical Compressive Strength (MPa)		Cylindrical Compressive Strength (MPa)	Tensile Strength (MPa)	Apparent Porosity (%)	Normal Sorptivity (%)	Cracked Sorptivity (%)
	7^{th}	28^{th}	28^{th}	28^{th}			
Plain (EPA10)	24.5	37.5	30.4	1.62	9.95	4.07	5.96
SF1	20.6	31.7	28.3	3.16	11.37	4.53	6.37
SF2	24.0	35.4	29.4	3.35	11.23	4.44	6.14
SF3	26.7	39.5	31.5	3.72	10.14	4.53	6.87
PP	19.5	30.4	23.1	2.32	12.95	6.05	9.89

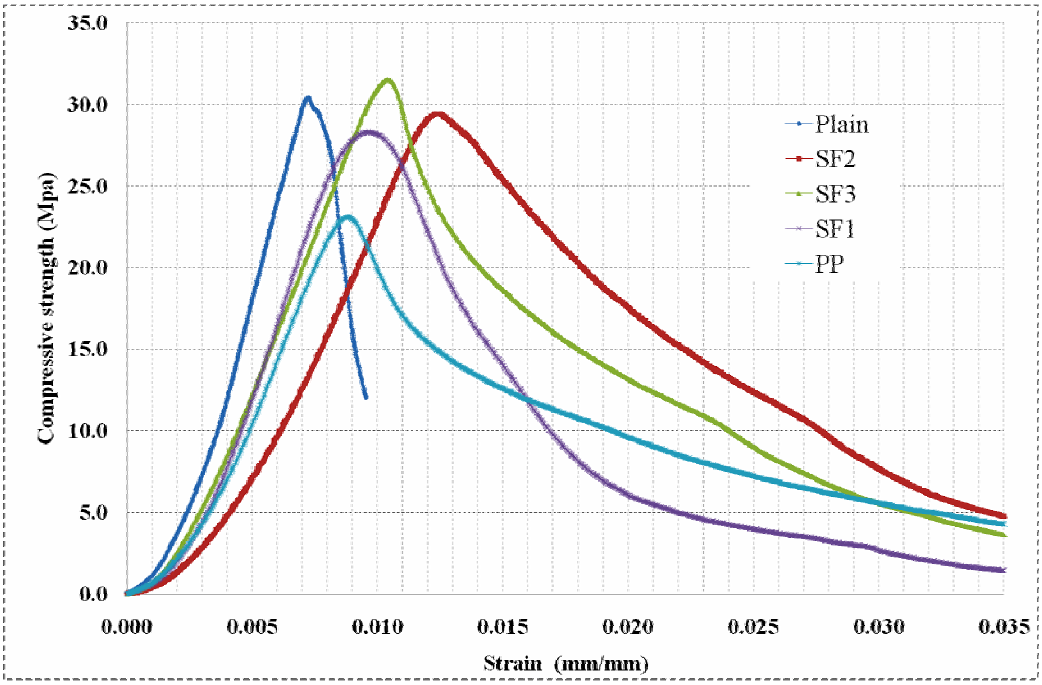

Figure 1. Compressive stress-strain curves for EPA10, SF1, SF1 and SF3.

On the other hand, AP, NS and CS indexes of concrete vary with the progress of hydration. Neville [Neville (1997)] reported that with the progress of hydration, the AP decreases rapidly because the gross volume of gel pores is approximately two times the volume of the anhydrated cement, so that the gel gradually fills some of the original water-filled space. This explanation justifies the dramatic increase of indexes with increase of perlite amount.

In fibrous specimens, addition of fibers results the increase of porosity on sorptivity indexes. The degradation of fibers creates voids inside of the concrete. The creation of these voids decrease the density and increases the porosity of the sample [Gül (2007), Miloud (2005)]. On the other side, the fiber acted as a bridge between pores so that the flow rate was increased and the water porosity indexes were subsequently also increased. It is important to mention that many studies have reported that fibers addition did not significantly increase the amount of pores above those calculated for plain concrete [Miloud (2005), Brandt (1995)]; but the combinational effect of EPA and fiber presence intensifies the extension of pore size and distribution.

4.4 *Compressive stress-strain behavior*

Figure 1 shows the typical stress–strain curves under the compressive loading. The importance of achieving a certain degree of ductility in elements of concrete structures has been widely acknowledged by engineers and researchers and codes of practice account for this capacity. The analysis and design of compression as well as flexural members are greatly influenced by the behaviour of concrete in uniaxial compression [Kayali et al. (2003)].

The addition of fibers to the mixtures increased the strain of the specimen corresponds to the peak stress. The strain capacity and deformation capability of the concrete matrix are increased considerably with the inclusion of steel fiber to the mixtures. Both ascending and descending portion of the stress–strain curves are affected by the addition of steel fiber. However, the significant effect is noticed in the descending portion of the stress-strain curve.

As it seems, the failure characteristics were completely changed as a result of the addition of fibers. After the occurrence of initial cracking, the sample did not fail suddenly. This is probably due to the randomly oriented fibers crossing the cracked section, which resists the propagation of cracks and separation of the section. This causes an increase in the load-carrying capacity [Duzgun et al. (2005)].

As expected, the fiber volume content significantly affects the energy absorption capacity of the composite. This definitions of energy absorption capacity offers a simplistic method to the relate toughness. The individual stress-strain curves for the different fiber types are significantly different. According to flexural test results, the fiber ratio increase was resulted a similar increase in the area of stress-strain curve (toughness) of variable fiber types. The polypropylene fiber addition was not resulted as great toughness as steel fibers. The relatively longer fiber length and greater stiffness of steel fibers makes a better bridging effect for crack propagation which results a better toughness. Factors such as fiber length, fiber material, fiber geometry, and bonding characteristics also influence the toughness and post-crack behavior [Gül et al. (2007)]. As can be seen in Figure 1, the hooked fibers showed better toughness than wavy type steel fibers. The shape of the wavy type steel fibers resulted in a lower pullout strength, which resulted to a lower resistance to spalling [Gopalaratnam et al. (1991)].

5 CONCLUSIONS

Based on the above experimental study, following conclusions can be drawn regarding the properties of perlite concrete:

1. The compressive and tensile strengths of perlite concrete decrease with increase of pelite content.
2. It can be seen that the strength of cylinders compared to that of cubes of the same batch was less and in the range of 0.82-0.85, similar to standard size effect factor.
3. Unlike non-perlite specimens, subjecting perlite concrete specimens to 'wet sack' curing condition increased their compressive strength.
4. The compressive strength of steel fiber reinforced perlite concrete specimens decreased slightly, from 4 to 7%, with respect to plain specimens, while this reduction of strength for PP specimens was significant.
5. Addition of perlite dramatically decreased the splitting tensile strength of perlite concrete specimens.
6. Regarding fibrous specimens, fibers substantially increased the splitting-tensile strength, approximately by 100% for steel fibers and by 40% for PP fibers.
7. Wavy shape fibers had the best performance, followed by bigger hooked shape fiber with regard to splitting tensile strength.
8. The test results indicated a linear relationship between the compressive strength and splitting-tensile strength for steel fibrous concrete.
9. The apparent porosity and the water porosity indexes (normal sorptivity and cracked sorptivity) increased with the increase of EPA volume.

10. In fibrous specimens, addition of fibers increased the porosity hence sorptivity indexes.
11. The addition of fibers to the mixtures increased the strain of the specimen corresponding to the peak stress. The significant effect is in the descending portion of the stress-strain curve. As it is seen, the failure characteristics were completely changed as a result of the addition of fibers, leading to a dramatic increase in the final strain hence in the ductility of the concrete.
12. The specimens with hooked steel fibers showed better toughness than those with wavy steel fibers.

REFERENCES

[1] ACI 544.1R-96 State-of-the-Art Report on Fiber Reinforced Concrete.

[2] ACI 544.2R-89 Measurement of Properties of Fiber Reinforced Concrete.

[3] ACI 544.3R-93 Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete.

[4] ACI 544.4R-88 Design Considerations for Steel Fiber Reinforced Concrete.

[5] Balaguru, P. Dipsia, M.G. 1993. Properties of fiber reinforced high strength semi lightweight concrete, ACI Materials Journal 90(5) 399-405.

[6] Balaguru, P. Foden, A. 1996. Properties of fiber reinforced structural lightweight concrete, ACI Structural Journal 93 (1) : 62-78.

[7] Balaguru PN, Shah SP. 1992. Fibre-reinforced cement composites. New York: Macgraw-Hill.

[8] Banthia N, Nandakumar N. 2003. Crack growth resistance of hybrid fiber reinforced cement composites, Cement and Concrete Composite 25(1) : 3-9.

[9] Bindiganavile V, Banthia N. 2001. Polymer and steel fiber-reinforced cementitious composites under impact loading – part 1: bond-slip response, ACI Materials Journal 98(1) : 10-6.

[10] Brandt, A.M. 1995. Cement-based Composites: Materials, Mechanical Properties and Performance. E & FN SPON, London.

[11] Cachim, Paulo B. Figueiras, Joaquim A. Pereira, Paulo A.A. 2002. Fatigue behavior of fiber-reinforced concrete in compression, Cement and Concrete Composites 24 : 211-217.

[12] Chenkui, H. Guofan, Z. 1995. Properties of steel fibre reinforced concrete containing larger coarse aggregate, Cement and Concrete Composites 17 : 199-206.

[13] Demirboga, Ramazan. Gül, Rüstem. 2003a. Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures, Energy and Buildings 35 : 1155-1159.

[14] Demirbog, Ramazan. Gul, Rustem. 2003b. The effects of expanded perlite aggregate, silica fume and fly ash on the thermal conductivity of lightweight concrete, Cement and Concrete Research 33 : 723-727.

[15] Demirbog, Ramazan. Orung, Ibrahim. Gul, Rustem. 2001. Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes, Cement and Concrete Research 31 1627-1632.

[16] Ding, Y. Kusterle, W. 2000. Compressive stress–strain relationship of steel fiber reinforced concrete at early age, Cement and Concrete Research 30 1573-1579.

[17] Duzgun, Oguz AkNn. Gul, Rustem. Aydin, Abdulkadir Cuneyt. 2005. Effect of steel fibers on the mechanical properties of natural lightweight aggregate concrete, Materials Letters 59 3357-3363.

[18] Eren, Ö. Çelik, T. 1997. Effect of silica fume and steel fibers on some properties of high- strength concrete, Construction and Building Materials 11: 373-382.

[19] Eslami, E. 2008a. Mechanical properties of fiber reinforced grouts, Proceeding of 7th RILEM Symposium on Fiber Reinforced Concrete Design and Applications, Chennai, India, September.

[20] Eslami, E. 2009b. Experimental investigation of using recycled asphalt pavements as aggregate in Portland cement concrete, proceedings of 8th International Conferences on Civil Engineering, Shiraz, Iran (in Persian).

[21] Ezeldin, AS. Balaguru, PN. 1992. Normal and high strength fiber reinforced concrete under compression. Journal of Materials in Civil Engineering 4(4) : 415-27.

[22] Fanella, DA. Naaman, AE. 1985. Stress-strain properties of fiber reinforced mortar in compression, ACI Journal 82(4): 475-83.

[23] Gao, J. Sun, W. Morino, K. 1997. Mechanical properties of steel fiber-reinforced, high strength, lightweight concrete, Cement and Concrete Composites 19 : 307-313.

[24] Gopalaratnam, V.S. Shah, S.P. Batson, G.B. Criswell, M.E. Ramakrishnan, V. Wecharatana, M. 1991. Fracture toughness of fiber reinforced concrete, ACI Materials Journal 88: 339-353.

[25] Gül, Rüstem. Okuyucu, Ersin. Türkmen, Ibrahim. Aydin, Abdulkadir Cüneyt. 2007. Thermo-mechanical properties of fiber reinforced raw perlite concrete, Materials Letters 61 :5145–5149.

[26] Hsu, LS. Hsu, CT. 1994. Stress–strain behavior of steel-fiber high strength concrete under compression, ACI Structural Journal 91(4): 448-57.

[27] Kantarcı, Ibrahim Abdulhamit. 2007. Effects of expanded perlite aggregate and different curing conditions on the physical and mechanical properties of self-compacting concrete, Building and Environment 42: 2378-2383.

[28] Kayali, O. Haque, M.N. Zhu, B. 2003. Some characteristics of high strength fiber reinforced lightweight aggregate concrete, Cement and Concrete Composites 25: 207-213.

[29] Khaloo, A.R. Sharifian, M. 2005. Experimental investigation of low to high strength steel fiber reinforced lightweight concrete under pure torsion, Asian Journal of Civil Engineering (Building and Housing) 6(6) : 533-547.

[30] Mannan, MA. Basri, HB. Zain, MFM. Islam, MN. 2003. Effect of curing conditions on the properties of OPS-concrete. Building and Environment 37 : 1167-71.

[31] Marar, Khaled. Eren, Ozgur. Celik, Tahir. 2001. Relationship between impact energy and compression toughness energy of high-strength fiber-reinforced concrete, Materials Letters 47 : 297-304.

[32] Meddah, Mohammed Seddik. Bencheikh, Mohamed. 2009. Properties of concrete reinforced with different kinds of industrial waste fibre materials, Construction and Building Materials 23 : 3196-3205.

[33] Meral, C. 2004. Use of Perlite as a pozzolanic addition in blended cement production, M. Sc. thesis, Department of Civil Engineering, Middle East Technical University (METU), August.

[34] Miloud, B. 2005. Permeability and porosity characteristics of steel fiber reinforced concrete, Asian Journal of Civil Engineering (Building and Housing) 6(4) : 317-330.

[35] Mineral Aggregates, 1997. Canadian Minerals Yearbook.
[36] Nataraja, M.C. Dhang, N. Gupta, A.P. 1999. Stress-strain curves for steel-fiber reinforced concrete under compression, Cement and Concrete Composites 21 : 383-390.
[37] Neville, A.M. 1997. Properties of Concrete, Fourth and final Edition, John Wiley & Sons : 271-729.
[38] Richardson, Alan E. 2006. Compressive strength of concrete with polypropylene fibre additions, Structural Survey, 24 (2) : 138-153.
[39] Rossignolo, Joao A. Agnesini, Marcos V.C. 2004. Durability of polymer-modified lightweight aggregate concrete, Cement & Concrete Composites 26 : 375-380.
[40] Sivakumar, A. Santhanam, Manu. 2007. Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres, Cement and Concrete Composites 29 : 603-608.