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Communication

Properties of lightweight expanded polystyrene concrete reinforced with steel fiber

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Abstract

Expanded polystyrene (EPS) concrete is a lightweight, low strength material with good energy-absorbing characteristics. However, due to the light weight of EPS beads and their hydrophobic surface, EPS concrete is prone to segregation during casting, which results in poor workability and lower strength. In this study, a premix method similar to the 'sand-wrapping' technique was utilized to make EPS concrete. Its mechanical properties were investigated as well. The research showed that EPS concrete with a density of 800–1800 kg/m^3 and a compressive strength of 10–25 MPa can be made by partially replacing coarse and fine aggregate by EPS beads. Fine silica fume greatly improved the bond between the EPS beads and cement paste and increased the compressive strength of EPS concrete. In addition, adding steel fiber significantly improved the drying shrinkage.

Keywords: Concrete; Fiber reinforcement; Silica fume; Compressive strength; EPS

1. Introduction

Expanded polystyrene (EPS) is a kind of stable foam with low density, consisting of discrete air voids in a polymer matrix. The polystyrene beads can easily be incorporated in mortar or concrete to produce lightweight concrete, with a wide range of densities [1]. The research on EPS concrete can be traced back to 1973, when Cook [2] investigated EPS as an aggregate for concrete. Now, EPS lightweight concrete can be used in varied structural elements such as cladding panels, curtain walls, composite flooring systems, load-bearing concrete blocks, the subbase material for a pavement, floating marine structures, etc. [3–7]. Especially, it can be used within the protective layer of a structure for impact resistance due to its good energy-absorbing characteristics [8].

However, polystyrene beads have two disadvantages that constrains the application and popularization of EPS concrete: (1) they are extremely light, with a density of only 12 to 20 kg/m^3, which can cause segregation in mixing, and (2) they are hydrophobic. Hence, chemical treatment of its surface is needed. In previous reports, some bonding additives were suggested, such as epoxy resin or aqueous dispersions of polyvinyl propionate [3–6]. However, these are costly. In addition, EPS concrete in these reports was within very low strength range.

Therefore, in this study, a type of fiber-reinforced concrete with EPS light aggregates was developed, with up to 20 MPa design strength. Fine silica fume, instead of bonding additives, was used to improve the dispersion of EPS in the cement paste and the interfacial bonding strength. The effects of different volume contents of EPS on the strength and shrinkage were investigated as well.

2. Experimental details

2.1. Materials and mix proportions

The materials used in this study were ordinary Portland cement conforming to BS12: 1991, river sand with a fineness modulus of 2.85, crushed granite with a maximum size of 20 mm, silica fume, and steel fibers with length of 25 mm and aspect ratio of 60. Two types of commercially available spherical EPS beads that are essentially single-

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Table 1
Details of EPS concrete mixes containing steel fiber

Series	Mix number	Cement (kg/m^3)	Silica fume (%)	Water (kg/m^3)	Gravel (kg/m^3)	Sand (kg/m^3)	EPS (kg/m^3)		% Volume of EPS	Steel fiber (kg/m^3)	Superplasticizer (ml/kg of cement)
							Type A	Type B			
Series I	1	472	–	175	1133	620	–	–	–	–	4.0
	2	472	–	175	710	392	1.75	0.74	25	–	4.2
	3	472	–	175	710	392	1.75	0.74	25	70	4.2
	4	472	–	175	455	255	2.8	2.21	40	–	4.5
	5	472	–	175	455	255	2.8	2.21	40	70	4.5
	6	472	–	175	201	118	3.85	3.03	55	–	5.1
	7	472	–	175	201	118	3.85	3.03	55	70	5.1
Series II	8	425	10	175	1133	620	–	–	–	–	4.0
	9	425	10	175	710	392	1.75	0.74	25	0	4.2
	10	425	10	175	710	392	1.75	0.74	25	70	4.2
	11	425	10	175	455	255	2.8	2.21	40	0	4.5
	12	425	10	175	455	255	2.8	2.21	40	70	4.5
	13	425	10	175	201	118	3.85	3.03	55	0	5.1
	14	425	10	175	201	118	3.85	3.03	55	70	5.1

sized (Types A and B) were used. The grading shows that Type A has mostly 3.0-mm-size beads and Type B has mostly 8.0-mm-size beads. The bulk density was 20 kg/m^3 for Type A and 8.5 kg/m^3 for Type B. A naphthalene-based superplasticizer was used to produce the mixes a flowable or highly workable nature, to suit the hand compaction adopted. The complete details of the concrete mixes are presented in Table 1.

2.2. Mixing of EPS concrete

Concrete was mixed in a planetary mixer of 30-l capacity. A technique similar to 'sand-wrapping' was applied on the EPS beads. EPS beads were wetted initially with 30% of the mixing water and superplasticizer before adding the remaining materials. Mixing was continued until a uniform and flowing mixture was obtained. The fresh concrete was then poured into molds and compacted by hand.

2.3. Casting, curing and testing of concrete specimens

A number of standard test specimens of different sizes were chosen for investigating the various parameters. Cubes of 150-mm size were used for studying the compressive strength at 3, 7, 14, 28, and 60 days. Split tensile strength tests were conducted on cubes of 100 mm. Prisms of $100 \times 100 \times 515$ mm were used for shrinkage testing at 3, 7, 14, 28, and 60 days.

From each batch, 15 cubes of 150-mm size, three cubes of 100 mm and three $100 \times 100 \times 515$ mm prisms were cast. The specimens were stripped approximately 24 h after casting and were placed in a fog room (95 ± 3% RH, 22 ± 2 °C). For shrinkage testing, after the specimens were cured in the fog room for 23.5 ± 0.5 h, the specimens were demolded, placed in a controlled testing condition (RH >60%, 20 ± 3 °C), and immediately measured to get initial values. After that, the specimens were returned to the curing room, and then taken

Table 2
Strength and density of EPS concrete mixes

Series	Mix number	Fresh concrete density (kg/m^3)	Compressive strength (MPa)					Split tensile density (kg/m^3)
			3 days	7 days	14 days	28 days	60 days	
Series I	1	2435	25.4	44.2	54.6	59.2	60.0	8.70
	2	1820	9.0	16.5	20.3	22.1	22.2	2.31
	3	1883	8.6	15.9	19.3	21.4	21.3	2.62
	4	1356	7.4	12.6	16.5	17.6	17.4	2.14
	5	1403	6.9	11.7	15.6	16.7	16.8	2.53
	6	876	4.3	7.6	9.8	10.6	10.6	1.32
	7	910	4.0	7.3	8.9	9.9	10.0	2.08
Series II	8	2440	33.5	54.0	63.6	68.3	68.2	9.70
	9	1850	12.3	20.0	24.4	25.7	25.6	2.4
	10	1929	12.6	21.1	25.0	25.9	26.0	2.73
	11	1370	8.1	13.2	18.4	20.1	20.2	2.22
	12	1415	8.6	13.7	18.7	20.8	20.7	2.68
	13	882	4.9	8.1	10.1	11.3	11.5	1.73
	14	892	4.9	8.0	9.8	10.9	11.0	2.31

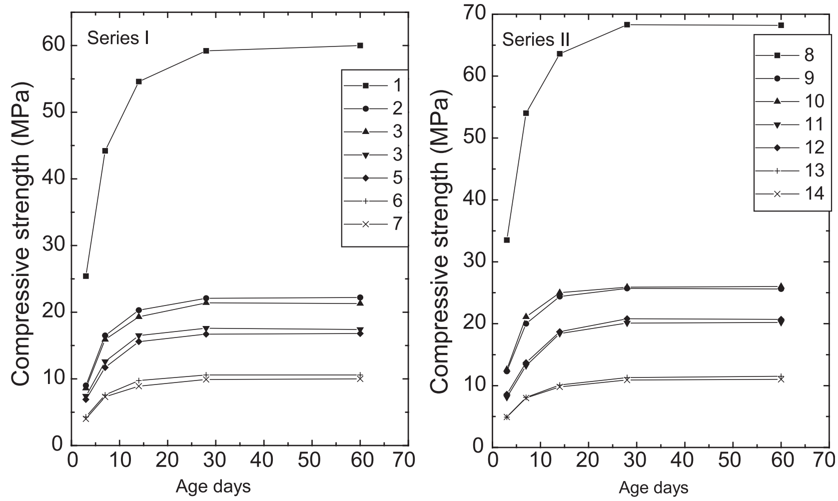

Fig. 1. Compressive strength versus time for Series I and Series II mixes.

out and tested at the appropriate testing ages. After the water on the surface of each specimen was wiped off with a damp cloth, the length change was measured and the shrinkage strain was calculated according to ASTM C490–93a. Compressive strength tests were carried out in a testing machine of 2000 kN capacity, at a loading rate of 2.5 KN/s. The split tensile strength test was conducted on cubes at 28 days, according to ASTM C 496–89.

3. Results and discussion

A comprehensive summary of EPS concrete with different strengths and plastic densities of all the concretes is presented in Table 2.

3.1. Compressive strength

3.1.1. Effect of age

Fig. 1 shows the development of compressive strength with the age for EPS concrete. The compressive strength of EPS concrete in almost all mixes displayed a continuous increase with age. The rate of strength development was greater initially and decreased as the age increased. However, a comparison of strengths at 7 days revealed that concretes with no silica fume developed almost 70–75% of its 28-day strength, while those containing silica fume developed almost 85–90% of the corresponding 28-day strength. Comparison of the strength at 28 and 60 days indicated that at those ages, all mixes, except Mix 1, showed no appreciable improvement in compressive strength with age.

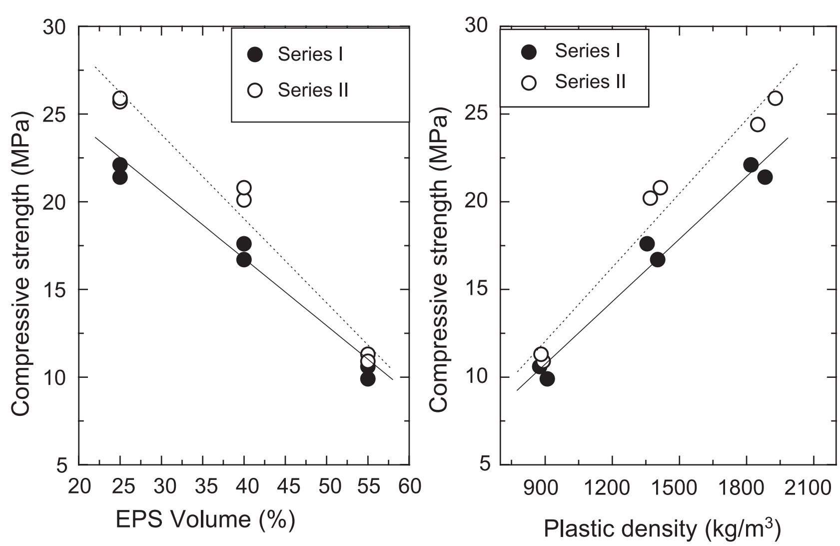

Fig. 2. Variation of strength with EPS volume and density.

3.1.2. Effect of density and EPS volume

The compressive strengths of EPS concretes with different plastic densities of concrete and the volume content of EPS are presented in Fig. 2. The strength of EPS concrete appeared to increase linearly with an increase in concrete density, or with a decrease in the EPS volume, which is consistent with the results from Ref. [6]. The plastic density of normal concrete with a compressive strength of 59.2 MPa was 2435 kg/m^3. As for EPS concrete, when its plastic density was 75%, 55%, and 35% of that of normal concrete, its strength was 35%, 30%, and 20% of that of normal concrete, respectively. Therefore, a lightweight material that can provide up to 30 MPa of strength and only 70% of the density of normal concrete is available by using EPS with different sizes to partially replace coarse and fine aggregate.

In addition, the failure mode of EPS concrete under compression is different from that of normal concrete. The failure was observed to be more gradual (more compressible), and the specimens were capable of retaining the load after failure, without full disintegration. This clearly indicated the high energy absorption capacity of EPS concrete that was reported earlier [6]. Therefore, EPS concrete may be considered for mitigating vibration.

3.1.3. Effect of silica fume and steel fiber

Fig. 3 illustrates the effects of fine silica fume and steel fiber on the compressive strength of EPS concrete. It can be seen that with the same volume content of EPS, fine silica fume can significantly increase compressive strength (at most, up to around 15%), which indicated that fine silica fume can improve the dispersion of EPS in the cement paste and interfacial bonding between EPS and cement paste. However, with an increasing content of EPS, the increase was reduced. When the volume content of EPS was 55%, the compressive strength increased only around 8%. Therefore, at an appropriate content, silica fume can replace some special bonding agents to improve the strength of EPS concrete.

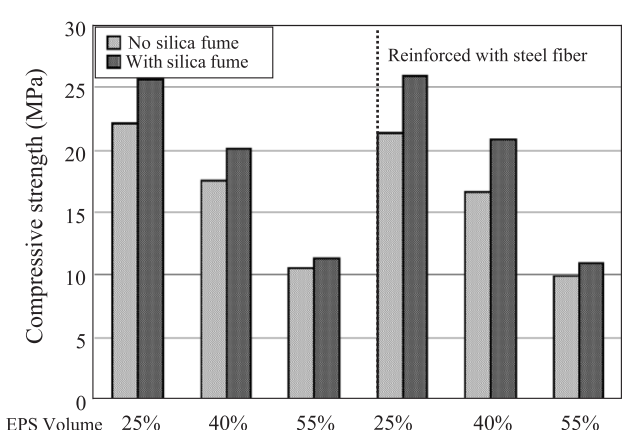

Fig. 3. Effect of silica fume on the compressive strength of EPS concrete.

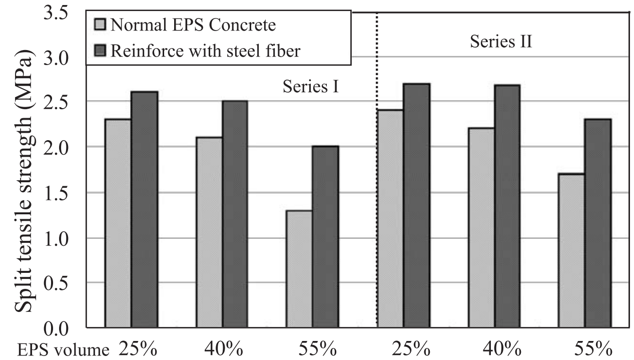

Fig. 4. Variation of split tensile strength with EPS volume.

3.2. Split tensile strength

Fig. 4 displays the effect of steel fibers on the split tensile strength of EPS concrete with different EPS contents. Steel fibers greatly increased the split tensile strength of EPS concrete. The EPS concrete with fine silica fume showed the highest increase of split tensile strength (up to 25%). In addition, the failure mode of EPS concrete during the splitting was different from that of normal concrete. EPS concrete, especially that with steel fiber failed gradually instead of abruptly.

3.3. Shrinkage

Two of the most significant factors affecting the shrinkage of concrete are the degree of restraint by the aggregate, that is, its elastic properties and the volumetric proportion of the paste in the mix. The EPS beads offer little hindrance to the shrinkage of the paste [8]. Hence, as the volumetric proportion of the EPS is increased, the shrinkage would increase as well, which is shown in Fig. 5. At 90 days, the drying shrinkage of normal concrete was 630 microstrain. For EPS concrete, when the volume content of EPS was 55%, the drying shrinkage at 90 days

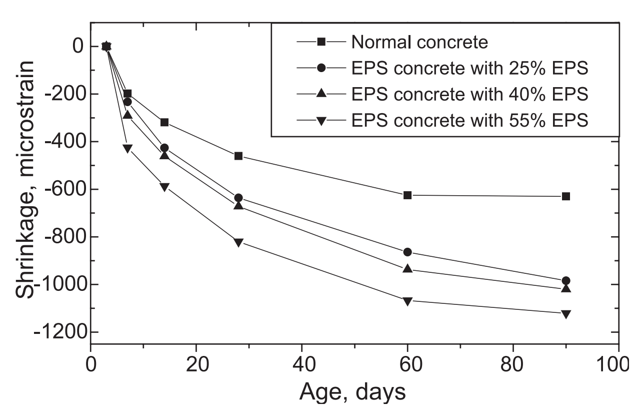

Fig. 5. Relationship between drying shrinkage strain of EPS concrete and reference concrete with age.

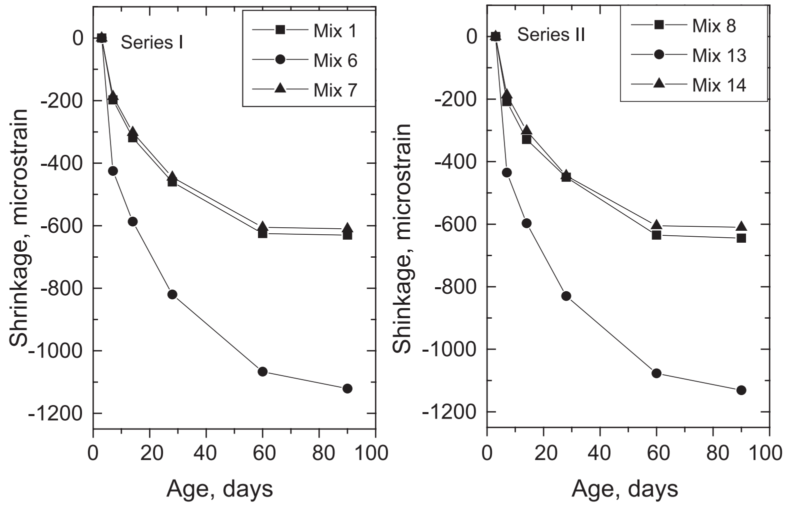

Fig. 6. Effect of steel fiber on the drying shrinkage strain of EPS concrete and reference concrete with age.

was up to 1121 microstrain, which indicated the disadvantage in the application of EPS.

The effect of steel fiber on the drying shrinkage of EPS concrete is shown in Fig. 6. It can be seen that steel fiber improved the drying shrinkage of EPS concrete greatly. Even for EPS concrete with 55% of volume content of EPS, the drying shrinkage at 90 days was 610 microstrain, which was less than that of normal concrete.

4. Conclusion

1. A technique similar with sand-wrapping to make EPS concrete enables good workability and easy compaction and finishability, without adding special bonding agents. The compressive strength of EPS concrete can be up to 10–25 MPa, at densities from about 800–1800 kg/m^3 of density.
2. Fine silica fume can increase the strength of EPS concrete (at most 15%) by improving the dispersion of EPS beads in the cement matrix and then the bonding between EPS beads and cement paste.
3. Steel fibers can significantly increase the split tensile strength of EPS concrete and improve its shrinkage resistance properties.
4. The mechanical and shrinkage properties can be optimized by adding fine silica fume and steel fibers at appropriate contents.

References

[1] D.J. Cook, Expanded polystyrene concrete, concrete technology and design: (1), in: R.N. Swamy (Ed.), New Concrete Materials, Surrey Univ. Press, London, 1983, pp. 41–69.
[2] D.J. Cook, Expanded polystyrene beads as lightweight aggregate for concrete, Precast Concr. 4 (1973) 691–693.
[3] S.H. Perry, P.H. Bischoff, K. Yamura, Mix details and material behaviour of polystyrene aggregate concrete, Mag. Concr. Res. 43 (1991) 71–76.
[4] C. Bagon, S. Frondistou-Yannas, Marine floating concrete made with polystyrene beads, Mag. Concr. Res. 28 (1976) 225–229.
[5] R.S. Ravindrarajah, A.J. Tuck, Properties of hardened concrete containing treated expanded polystyrene beads, Cem. Concr. Compos. 16 (1994) 273–277.
[6] K.G. Babu, D.S. Babu, Behaviour of lightweight expanded polystyrene concrete containing silica fume, Cem. Concr. Res. 33 (2003) 755–762.
[7] V. Sussman, Lightweight plastic-aggregate concrete, J. Am. Concr. Inst. 72 (1975) 321–323.
[8] P.H. Bischoff, Polystyrene aggregate concrete subjected to hard impact, Proc. Inst. Civ. Eng., Part 2 6 (1990) 225–239.