Construction and Building Materials 112 (2016) 716–724

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete

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HIGHLIGHTS

- Compressive strength of foamed concrete significantly depends on cement and foam content.
- Increasing the volume of EPS results in lower thermal conductivity and fire resistance.
- The EPS volume substantially affects the compressive strength of EPS concrete.

ARTICLE INFO

Article history:
Received 4 April 2015
Received in revised form 17 February 2016
Accepted 26 February 2016
Available online 4 March 2016

Keywords:
Foamed concrete (FC)
Polystyrene foamed concrete (PFC)
Expanded polystyrene (EPS)

ABSTRACT

This paper deals with the contribution of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. The foamed (FC) and polystyrene foamed (PFC) concrete were designed for densities ranging from 1200 kg/m^3 to 150 kg/m^3 with an EPS volume range of 0–82.22% and water-cement ratio of 0.33. The foamed concrete (FC) with a density of 800 kg/m^3 and an EPS volume of 0% was designed as reference for polystyrene foamed concrete. The results indicated that increasing the volume of EPS causes a significant reduction of thermal conductivity, fire endurance and compressive strength of concrete.

1. Introduction

Structural lightweight concrete provides a vital improvement in terms of technical, economical and environmental aspects [1–3]. Application of lightweight concrete significantly reduced the dead load of structures and relevantly reduced the cross-section of structural elements (i.e. columns, beams, braces and plate) and foundation size. Moreover, longer spans, thinner sections and better cycling load response can be obtained by using lightweight concrete [4]. Generally, lightweight concrete is instrumental to effectively reduce the risk of earthquake damage as the earthquake acceleration and its magnitude is significantly affected by the weight of a structure. The factors such as lower density, higher strength/weight ratio, lower coefficient of thermal conductivity, better fire resistance, improved durability properties, better tensile capacity and sound insulation characteristics are considered as advantages of lightweight concrete compared with normal concrete. However, the parameters such as bulk specific gravity, unit weight, maximum size and particles shape, texture surface, strength of lightweight particles, moisture content and water absorption ratio considerably affect the properties of lightweight concrete [5,6]. Three common methods are applied: Aerated concrete, no-fines concrete [7–9] and replacement (partially or totally) of natural aggregates with lightweight aggregate [10–106]. Acetated or cellular concrete is obtained by introducing large air voids within a matrix by chemical admixture such as foaming agents or aluminum powder (increases matrix porosity and decreases the unit weight of concrete). No-fines concrete is mostly produced by using a uniform size of coarse aggregate and eliminating the fine aggregate completely from the concrete matrix. While substituting totally or practically of natural lightweight aggregate with lightweight aggregate such as pumice [10–18], perlite [19–34], vermiculite [34–39], clay [40–46], fly ash [47–49], oil palm shell [50–66], recycled plastic [67–70] and waste rubber [71–73] is another method to produce lightweight concrete. Though, conventional lightweight aggregate is associated with higher water demand and higher absorption value as a result of the porous structure of these materials [74]. In order to eliminate this problem, expanded polystyrene

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.218

aggregate (EPS) with non-absorbent, hydrophobic and close cellular properties [74–106] was introduced as a lightweight material by Cook in 1973 [104]. The EPS concrete has the potential to be used as structural elements (cladding panels, curtain walls, load bearing concrete blocks, composite flooring systems), protective layers (good energy absorption), insulated concrete [105]. However, the extremely low density and hydrophobic nature of EPS beads constrains the application of EPS concrete. In fact, beads tend to float (10–20 kg/m^3) when used as lightweight aggregate and causes serious segregation and poor mix distribution in the matrix. The bonding additives such as epoxy resin (aqueous dispersions of polyvinyl propionate), water-emulsified epoxies, and chemically treated EPS [106] particles like BST used to increase the interfacial bonding strength between beads and matrix. It was reported that mineral admixture such as fly ash [74–76], silica fume [77] and rice hush ash [77,78] were used as bonding additives to increase the interfacial bonding strength between beads and matrix and improve dispersion of EPS beads in the cement matrix [77]. A significant improvement is observed in terms of chemical attack and corrosion characteristics of concrete when EPS aggregate is replaced with normal aggregate. One researcher found [103] that the chloride permeability of polystyrene concrete is a factor of EPS volume as increasing the volume of polystyrene causes lower chloride permeability values (50–65% lower). In addition, EPS concrete has better stability against chemical attack which is due to the inert behaviour of EPS aggregate.

Foamed concrete can be produced by a pre-foaming method or mixed foaming method [107]. Mortar or cement paste foamed concrete (air-entraining concrete) is categorized as lightweight concrete due to the existence of larger amounts of homogeneous air-voids inside the matrix through a suitable foaming agent. This method causes high flowability, lower unit weight, minimal consumption of aggregate and excellent thermal conductivity [108]. The factors such as foam agent specification, foam preparation method, material characteristics, mix design method, foam concrete production and its performance in fresh and hardened state are significantly important for the design of foamed concrete [108]. Increasing the early strength of foamed concrete along with a reduction on setting time is obtained by using calcium sulfoaluminate cement [109], high alumina cement [109], and rapid hardening Portland cement [110]. Substitution of fly ash (30–70%) [110–114] with ground granulated blast furnace slag (10–50%) [115] significantly reduces the hydration heat, cost and increases the consistency of the mixture, whereas silica fume (up to 10%) substantially improves the strength of foamed concrete [116]. The density and unit weight of foamed concrete was reduced by the addition of lime [117], oil palm shell [118,119], chalk [120], crushed concrete [120], expanded polystyrene [121], Lytag fines, foundry sand [122] and quarry finer [122] as fine aggregate. Proportioning and preparation of foamed concrete needs special consideration as a lower water content causes the bubbles to break along with a stiff mixture, while segregation of bubbles occurs with a higher water content [111]. ASTM C 796-97 [123] provide a method for calculation of foamed volume with known water-cement ratio and density, while Kearsely and Mostert [114] proposed an equation based on mixture composition for estimating the foam volume and cement content. The mechanical properties of foamed concrete and its behaviour are directly influenced by the water-cement ratio, sand-cement ratio, type of foam agent, water content, cement content, foam volume, ingredients characteristics, mixing method, curing method, pore formation method and void diameter [124–129]. The compressive strength of foamed concrete enhances with an increase in density of the concrete and is decreased with increasing the diameter of voids. Thus, the strength of foamed concrete mainly depends on (a) water-cement ratio and (b) air-cement ratio.

This experimental study was conducted to provide new information about the effects of polystyrene particles (EPS) on thermal conductivity, fire resistance and compressive strength of polystyrene foamed concrete (PFC). For this purpose and to cover the objectives of this study, foamed concrete with densities of 1200, 1000 and 800 kg/m^3 and polystyrene foamed concrete with densities of 400, 250, 200 and 150 kg/m^3 were prepared. Whereas, the foamed concrete with density of 800 kg/m^3 was considered as a reference for the mixing design of polystyrene foamed concrete [112].

2. Materials and method

2.1. Materials

Ordinary Portland cement (Type GP / ASTM type II, Golden Bay Cement, New Zealand) and fly ash class C (Golden Bay Cement, New Zealand) satisfying the ASTM standard were used as mineral admixture to reduce cost, improve workability and enhance long term strength (Table 1) [112]. In addition, polystyrene beads with average diameter, bulk density and specific gravity of 6.5 mm, 16.6 kg/m^3 and 0.016, respectively were used as lightweight aggregate. Superplasticizer (Sikament HE200) with the dosage of 5 ml per kg of binder (cement + fly ash) was used to increase the workability and avoid the segregation of concrete as a result of the hydrophobic nature of EPS beads; however, the addition of fly ash causes a significant improvement in workability but differed considerably in its effectiveness as water-reducing admixture [130]. Ultra-foam and Quick Gel were used as foaming agent and viscosifier, respectively. The foamed concrete was prepared with a foam generator at a density of 56 kg/m^3.

2.2. The logic of the mix design and fabrication process

Preparation of foamed concrete needs special consideration as a lower water-binder ratio results in a too stiff mix and causes air bubbles breaking during mixing of foamed concrete, while a higher water-binder ratio makes the mixture too thin to hold the air bubbles and causes mixture segregation along with higher density. In order to achieve the target densities along with stable mixtures, Kearsley and Mostert's equation (Eq. (1)) [114] and the absolute volume method was used to calculate the mix proportions of foamed concrete.

$$\begin{cases} \delta_m = x + x(w/c) + x(a/c) + x(s/c) + x(a/c)(w/a) + x(s/c)(w/s) + RD_f V_f \\ 1000 = x/(RD_c) + x(w/c) + x(a/c)/RD_a + x(s/c)/RD_c + x(a/c)(w/a) + x(s/c)(w/s) + V_f \end{cases} \quad (1)$$

where, δ_m is the target casting density (kg/m^3), x is the cement content (kg/m^3), w/c is the water/cement ratio, a/c is the ash/cement ratio, s/c is the sand/cement ratio, w/a is the water/ash ratio, w/s is the water/sand ratio, V_f is the volume of foam (l), RD_f is the relative density of foam, RD_c is the relative density of cement, RD_a is the relative density of ash, RD_s is the relative density of sand.

The specimens were categorized in two batches; foamed concrete (FC) and polystyrene foamed concrete (PFC). The foamed concrete without EPS beads was prepared with densities ranging from 1200, 1000 to 800 kg/m^3. While the PFC specimens were cast and prepared with a variation of EPS volume and designed for 400, 250, 200 and 150 kg/m^3 densities with a 45%, 67.4%, 73.1% and 82.2% EPS volume, respectively. However, the foamed concrete with a density of 800 kg/m^3 was designed as reference for polystyrene foamed concrete. The fly ash with a ash–cement ratio (a/c) of 0.5 was used as mineral admixture to improve the distribution of EPS in the matrix along with the denser structure at the transition zone of EPS and matrix. Specific sequences are used for mixing the FC and PFC concrete. As

Table 1
Chemical composition of cementitious materials.

Composite (%)	Ordinary Portland cement (OPC)	Fly ash (FA)
Silicon dioxide (SiO_2)	22.8	40.1
Aluminum oxide (Al_2O_3)	4.2	20.4
Iron oxide (Fe_2O_3)	2.3	10.1
Calcium oxide (CaO)	64.8	19
Magnesium oxide (MgO)	1.0	3.4
Sodium oxide (Na_2O)	0.19	2.1
Potassium oxide (K_2O)	0.49	0.5
Sulfur trioxide (SO_3)	0.42	0.8
Titanium dioxide (TiO_2)	–	1.5

Table 2
Mix proportions of foam and polystyrene foamed concrete.

Specimens	Target density (kg/m^3)	Cement (kg/m^3)	Ash (kg/m^3)	Water (kg/m^3)	Foam Vol %	EPS Vol %	w/b*	Superplasticizer (ml/m^3)
FC 1	1200	589	294	294	60	0	0.33	0
FC 2	1000	486	243	243	58	0	0.33	0
FC 3	800	383	191	191	38	0	0.33	0
PFC 1	400	166	82	124	36	45	0.33	0
PFC 2	250	101	50	76	22	67	0.33	757.45
PFC 3	200	79	39	59	17	73	0.33	594.15
PFC 4	150	57	29	43	12	82	0.33	432.16

* water – binder (cement + fly ash) ratio.

for the FC, Portland cement and water were mixed for 5 min, then the foam (the foam was prepared by using the foaming agent and Quick Gel as the viscosifier and mixed with water about 2 min in a foam generator, until the uniform foam bubble obtained) was added to the mortar, followed by an additional 2 min of mixing. The mix proportion of foam and polystyrene foamed concrete are shown in Table 2.

3. Experimental procedures

3.1. Compressive strength

The unconfined compressive strength of foamed and polystyrene foamed concrete was evaluated after 28 days with 100 × 200 mm standard cylinders as per ASTM C39 [131] at the loading displacement rate of 0.1 mm/s. The specimens were demolded after 24 h and kept in water curing at 20°C for the whole curing period. The compressive tests were conducted on foamed concrete with densities of 1200, 1000 and 800 kg/m^3 along with polystyrene foamed concrete with densities of 150, 200, 250 and 400 kg/m^3.

3.2. Fire resistance

Cubes of 100 mm size were used for studying the fire resistance of polystyrene foamed concrete. Small scale sandwich panels were placed on top of a heating unit and four thermocouples (T1-T4) were inserted into the sample, which was covered with a square galvanized steel sheet with 305x305x0.55 mm on the opposite side. The ceramic heating elements were set to reach a maximum temperature of 900 °C [112]. The small scale sandwich panels were considered to fail when the cold face temperature reaches 160 °C, i.e. thermocouple T4 reached the threshold value of 160 °C. The polystyrene foamed concretes with densities of 150, 200, 250 and 400 kg/m^3 were prepared for fire resistance tests. The details of the heating unit are shown in Fig. 1.

Fig. 2. Thermal conductivity test.

3.3. Thermal conductivity

Prisms of 200 × 200 × 40 mm were cast for thermal conductivity tests and an Anacon TCA-8 thermal conductivity analyser was used for k-factor measurements (Fig. 2). The specimens were contacted by a cold and a hot plate with diameter of 10 cm, which are kept at temperatures of 37 °C and 10 °C, respectively. The TCA-8 automatically measures the thickness of the sample and combines the reading with the heat-flow measurement to yield a direct digital readout of thermal conductivity [112]. Thermal conductivity tests were conducted on five series of polystyrene foamed concrete with densities of 150, 200, 250 and 400 kg/m^3, respectively.

4. Results and discussion

4.1. Density

The differences between planned and actual densities of polystyrene foamed concrete were higher than foamed concrete specially for specimens with higher volume of EPS due to the contribution of polystyrene particles and the fact that Kearsleys equation is proposed for a mix design of foamed concrete and

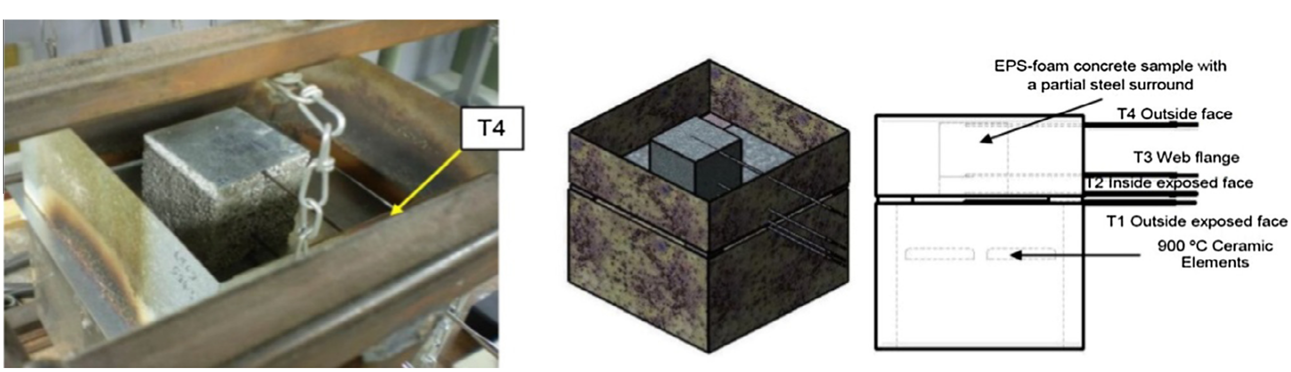

Fig. 1. The heating unit.

Table 3
The differences between target and actual densities of PFC.

Specimen	Target density (kg/m^3)	Actual density (kg/m^3)	Proposed equation density (kg/m^3)
PFC 1	400	425	432
	400	436	432
	400	437	432
PFC 2	250	257	271
	250	257	271
	250	273	271
PFC 3	200	208	222
	200	227	222
	200	231	222
PFC 4	150	127	130
	150	132	130
	150	136	130

the addition of EPS affects the actual density of fresh concrete. As a consequence the PFC specimens with densities of 400, 250, 200 and 150 kg/m^3, reveal about 4.1%, 5.02%, 11.11% and 13.76% differences, respectively. In order to increase the accuracy of the actual density, the following equation is proposed (Eq. (2)). The proposed factor (α) can be used as a modification factor for Kearsley's equation when polystyrene particles used as aggregate in foamed concrete. The differences between the target density, actual density and proposed equation density of polystyrene foamed concrete (PFC) are shown in Table 3.

$$\alpha = \frac{2B^2\sqrt{B+\frac{E}{F}}E^{\frac{F}{B}}}{EF^{2.5}}$$
$$\begin{cases} \gamma_{AD} = \gamma_{TD} + \alpha \quad 100\ \text{kg/m}^3 < \gamma \leqslant 150\ \text{kg/m}^3 \\ \gamma_{AD} = \gamma_{TD} - \alpha \quad 150\ \text{kg/m}^3 < \gamma \leqslant 400\ \text{kg/m}^3 \end{cases} \tag{2}$$

where, α is modification factor, γ_{AD} is actual density (kg/m^3), γ_{TD} is target density (kg/m^3), B is binder (cement + fly ash) content (kg/m^3), F is foam content (kg/m^3), E is polystyrene volume (%), γ is density (kg/m^3).

4.2. Compressive strength

The relationship between compressive strength and air-dry density of foamed concrete (FC) and polystyrene foamed concrete (PFC) is shown in Fig. 3. The compressive strength of foamed concrete significantly depends on density of concrete, cement content, water-cement ratio, foamed type, foam content, mineral admixture, curing method and particles specification [132]. The results showed that with identical water-binder ratio, increasing the density of concrete with higher volume of cement and lower foam content results in higher compressive strength and higher density due to lower air-void content and denser paste structure. The specimens with density, binder content and foam content of 1200 kg/m^3, 883 kg/m^3 band 21 kg/m^3 shows a higher compressive strength of about 9.18 MPa compared to specimens with densities of 800 kg/m^3 and 1000 kg/m^3. The specimens with density of 1000 kg/m^3 and 800 kg/m^3 gained 0.267% and 0.091% of compressive strength (28-day) compared to specimens with a density of 1200 kg/m^3, due to a lower cement content and a higher porosity value, respectively. However, it can be seen that the compressive strength of PFC increased with an increase of density. A comparison of compressive strength reveals that concrete with 82.22% EPS volume reached a strength of 0.08 MPa after 28 days, while the strength of 0.067, 0.24, 0.29 and 0.85 MPa was obtained for specimens containing 73.10, 67.40 and 45.0% polystyrene beads, respectively. Thus, increasing the volume of EPS directly affects the compressive strength and density of polystyrene foamed concrete due to close to zero strength of EPS particles and high compressibility behaviour which causes formation of micro cracks at the transition zone of particles and cement paste. In addition, the smooth surface of EPS and its poor bond characteristic resulting in failure which takes place at the transition zone at a much lower stress level [79]. It can be concluded that there is a direct relation between EPS volume and density as the higher volume of EPS results in higher porosity and lower density. The foamed concrete with 82.22%, 73.10%, 67.40% and 45.0% EPS particles (volume %) obtained 0.93%, 0.197%, 0.368% and 0.073% of 28-day compressive strength of foamed concrete with a density of 800 kg/m^3 due to the fact that increasing the volume of EPS causes higher porosity and lower paste content along with lower strength of EPS which accelerates the reduction rate. Thus, the compressive strength of foamed and polystyrene foamed concrete mainly depends on (a) EPS volume, (b) foam content, and (c) cement content. Equations are proposed to predict the compressive strength of foamed concrete (Eq. (3)) and polystyrene foamed concrete (Eq. (4)).

$$f'_c = 0.0034e^{0.0063\gamma}\ (R^2 = 0.9803) \tag{3}$$

$$f'_c = 0.0243e^{0.0083\gamma}\ (R^2 = 0.8075) \tag{4}$$

where, f'_c is the 28-day compressive strength, γ is the density of concrete.

4.3. Fire resistance

Foamed concrete with its porous structure results in a significant improvement in fire resistance as at a high temperature stage

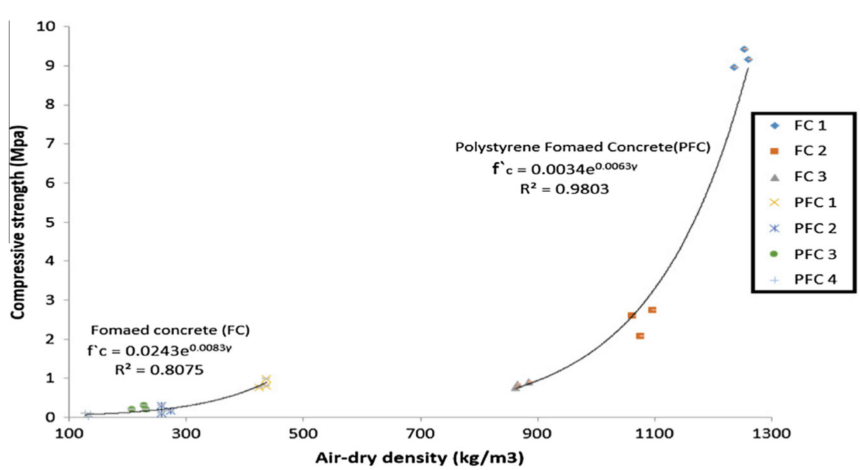

Fig. 3. The relationship between compressive strength and air dry density of foamed and polystyrene foamed concrete.

(a) (b) (c)

Fig. 4. Failure modes of polystyrene foamed concrete; (a) density of 150 (kg/m^3), (b) density of 250 (kg/m^3), (c) density of 400 (kg/m^3).

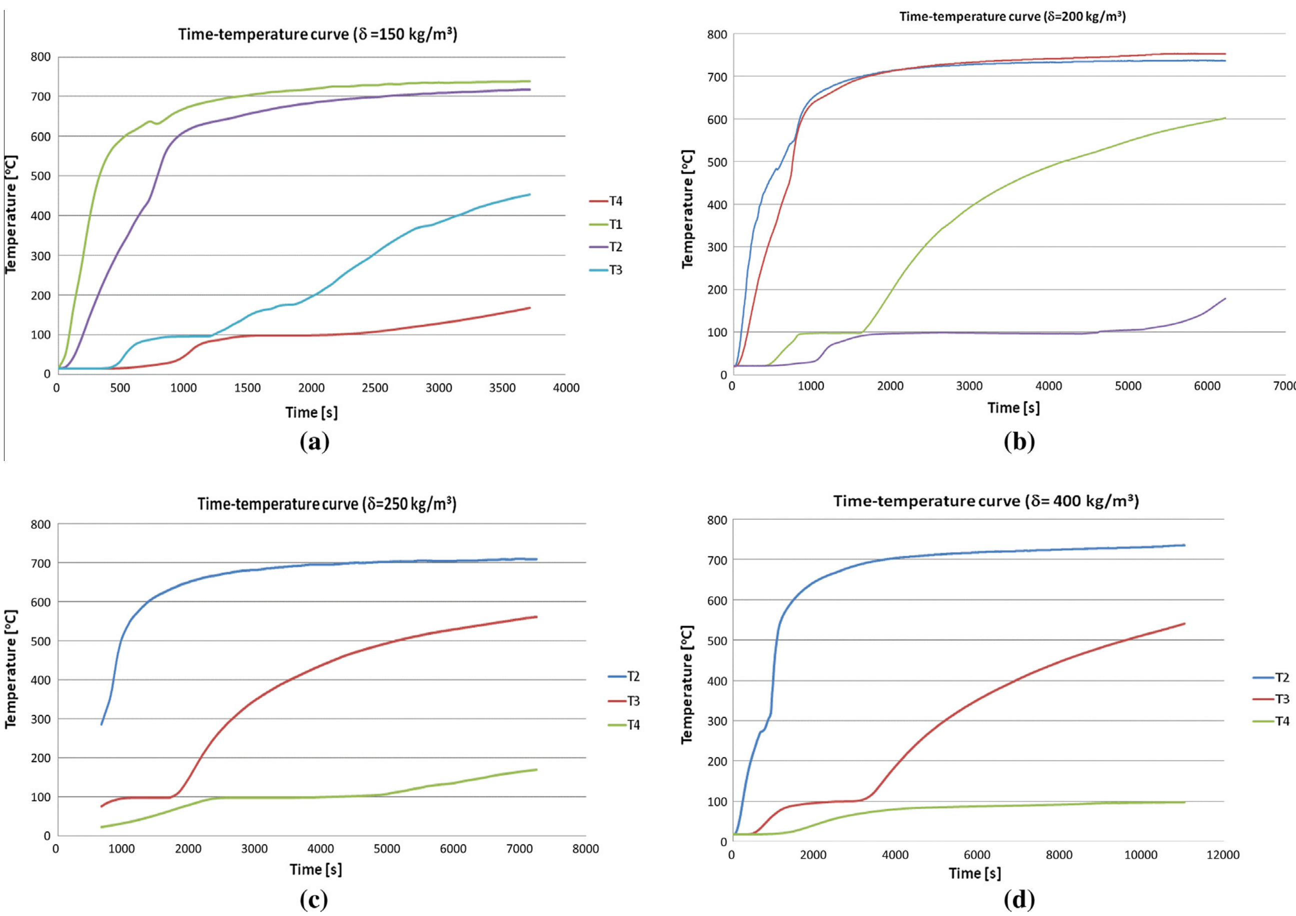

Fig. 5. Time–temperature curve; (a) density of 150 kg/m^3, (b) density of 200 (kg/m^3), (c) density of 250 (kg/m^3), (d) density of 400 (kg/m^3).

the heat transfer through porous materials is affected by radiation (radiation is an inverse function of the number of air–solid interfaces traversed). An earlier study on fire endurance of foamed concrete [133] reported that lower densities of foamed concrete showed better fire resistance compared to normal concrete while with higher densities, this trend is indicated to be inverted. Moreover, the ratio of Al_2O_3/CaO remarkably affects the fire resistance of foamed concrete as the higher Al_2O_3/CaO ratio (about 2 times) results in better fire endurance up to 1450 °C without any serious damage [108,134].

Increasing the density of concrete causes remarkable improvement in fire endurance [108]. The insulation failure of specimens with densities of 150, 200 and 400 kg/m^3 is shown in Fig. 4. The specimen with a density of 150 kg/m^3 started to burn with a small amount of smoke after 17 min and the smoke reached its highest value after 36 min. The sample started to diminish and reached the insulation failure criterion of >160 °C after 60 min because of the polystyrene beads were burned gradually as illustrated in Fig. 4a. While, the specimen with 250 kg/m^3 reached to the insulation threshold value (>160 °C) after 1 h 56 m as a results of higher density and paste content along with a lower amount of EPS beads and started to smoke after 1 h 55 m (Fig. 4b). The specimen with a density of 400 kg/m^3 (Fig 4c) did not show a significant failure and the test was stopped after 3 h as a result of the heating elements running at maximum power and continuing could damage the heating equipment. The results indicated that increasing the amount of cement paste and decreasing the volume percentage of EPS significantly improves the fire resistance of polystyrene

Table 4
Thermal conductivity of polystyrene foamed concrete.

Concrete	Thermal conductivity (W/m K)	Density (kg/m^3)	EPS (Vol %)
PFC-150	0.0848	150	82
PFC-200	0.0864	200	73
PFC-250	0.0927	250	67
PFC-400	0.1566	400	45

Table 5
Comparison between the thermal conductivity of ACI and proposed equation with experimental results.

Specimens	Experimental results (W/m K)	ACI 213R-03 [141] (W/m K)	Proposed equation (W/m K)
PFC 150	0.0848	0.1042	0.0800
PFC 200	0.0864	0.1109	0.0860
PFC 250	0.0927	0.1181	0.0932
PFC 400	0.1566	0.1424	0.1232

foamed concrete. Thus, a reduction of EPS from 82.22% to 45.0% results in an about 3 times higher fire resistance. The samples with densities of 200 kg/m^3 and 250 kg/m^3 showed a higher fire resistance of about 63% and 93% respectively than the specimen with a density of 150 kg/m^3. The time–temperature curve of polystyrene foamed concrete is shown in Fig. 5.

4.4. Thermal conductivity

Thermal conductivity of concrete significantly depends on moisture content (thermal conductivity of water is 25 times greater than air) [135,136], cement content [137], density, mineralogical characteristics of the aggregate, mineral admixture [138,139] and temperature of the concrete [140]. Moreover, thermal conductivity is a function of density as a lower density results in a lower thermal conductivity value [4]. The presence of polystyrene particles caused substantial reductions in thermal conductivity of PFC. The addition of 82.22% EPS volume is resulting in a 127% reduction in thermal conductivity relative to the specimen with 28.17% EPS volume. The specimen with 82.22% EPS exhibited the lowest thermal conductivity value of 0.0848 W/m K. The results show that the addition of 45%, 67.40%, 73.10% and 82.22% polystyrene beads results in 23.24%, 108%, 123% and 127% reduction in thermal conductivity compared to specimens with 28.17% EPS, respectively. Thus, the reduction of thermal conductivity is mainly contributed to the volume percentage of EPS and the density as a result of the fact that EPS particles have lower thermal capacity (98% air). The variations in thermal conductivity and density are summarized in Table 4.

The results show that the thermal conductivity of concrete depends on the density and the volume of EPS. ACI Committee 213R-03 (Eq.(5)) [141] recommended an equation for estimating the thermal conductivity of lightweight concrete. However the suggested equation is only relying on the density of concrete without considering the EPS volume. A specific equation with two variables (density and EPS volume) is proposed to better estimate the thermal conductivity of polystyrene foamed concrete (Eq. (6)).

$$\lambda = 0.0864e^{0.00125\gamma} \quad (5)$$

$$\lambda = \frac{7.2 \sqrt[V_{EPS}]{\frac{\gamma}{V_{EPS}.V_{Foam}}}}{V_{EPS} \sqrt[V_{EPS}]{\gamma.V_{Foam}}} \quad (6)$$

where, λ is the thermal conductivity (W/m K), γ is the density (kg/m^3), V_{EPS} is the volume of EPS (%) and V_{Foam} is the volume of foam (%)

In order to verify the proposed equation, the effective factors (density and EPS volume) were inserted into the proposed equation and consequently compared with experimental results and the ACI committee equation [141]. The results showed that the proposed equation gives a dependable estimate. Fig. 6 and Table 5 reveal the comparison between the thermal conductivity of experimental results, proposed equation and ACI equation.

5. Conclusions

The following conclusions resulted from the assessment of thermal conductivity, fire resistance and compressive strength of foamed and polystyrene foamed concrete:

(1) The factors such as cement content, foam volume and EPS volume directly affect the mechanical and thermal properties of the proposed concrete.
(2) The strength of foamed concrete was reduced with an increase in EPS volume due to the almost zero strength and lower interfacial bond strength at contact zone of matrix as results of the hydrophobic nature of EPS aggregate. In

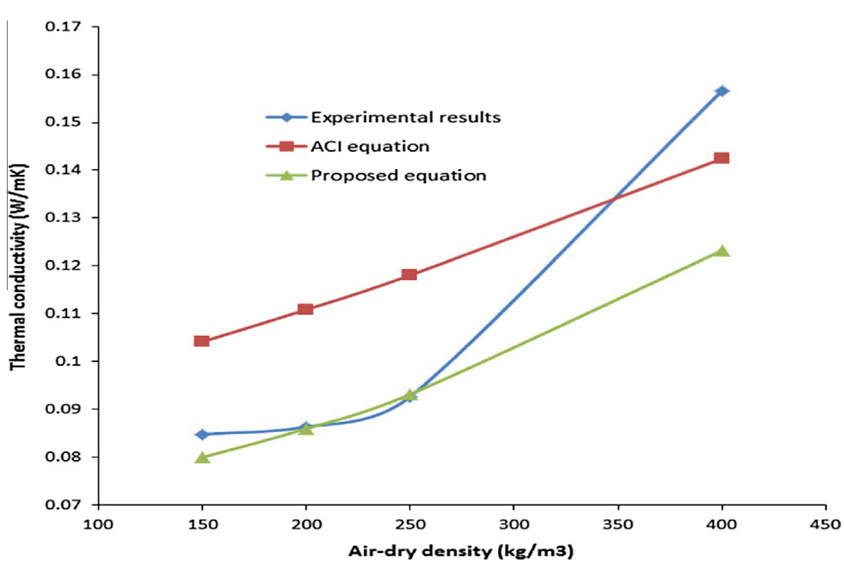

Fig. 6. Comparison the results of ACI equation, experimental results and proposed equation.

addition, the compressible behaviour of EPS aggregates accelerates the crashing of paste at the interfacial zone of matrix.

(3) An increase in volume of EPS results in lower thermal conductivity due to thermal properties of EPS aggregate (98% air and 2% polystyrene). The lower thermal conductivity of 0.0848 W/mK was observed is specimens with 82% EPS while this value was 2.5 times higher in sample with 28% EPS volume.

(4) A lower fire resistance was obtained for specimens with higher EPS volume (82%) as a result of the fact that EPS particles shrank and lost their strength when subjected to temperature. A higher fire endurance was obtained for specimens with lower EPS volume (28%) and higher cement content due to the fact that amorphous silica in the cement paste contributed to higher fire resistance.

(5) The volume of EPS significantly influenced the density of concrete, as the higher volume of polystyrene results in lower density and unit weight.

In addition, a specific equation was proposed considering the variation in EPS volume and density to predict the thermal conductivity of polystyrene concrete. A further equation was proposed to modify Kearsley‘s equation when polystyrene particles are used as aggregate in foamed concrete.

Acknowledgement

The authors would like to acknowledge the financial support of the New Zealand Ministry for Research, Science and Technology under contract number HERX0401. The support of the Auckland University of Technology (AUT), New Zealand, is also acknowledged.

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