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Effect of Expanded Polystyrene Foam Aggregate on Strength and Shrinkage Characteristics of Foamed Concrete

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Abstract A study has been undertaken to assess some characteristics of foamed concrete, with a given density of 1200 kg/m^3, made with expanded polystyrene foam aggregate (EPS). In addition, EPS particles were thermally treated to produce modified expanded polystyrene foam aggregate (MEPS). Thermally treating approach was applied as an effective method to enhance strength of expanded polystyrene foam particles leading to enhance the properties of produced concrete. To investigate the effect of foam presence, normal concrete mix was designed and compared with foamed concrete mix produced with the same mortar content. Properties such as compressive strength, tensile strength and drying shrinkage were assessed. It was found that adding recycled expanded polystyrene foam (EPS) as aggregates helped in slightly enhancing both the strength and shrinkage of foamed concrete. However, thermally treated of EPS to produce MEPS particles resulted in increasing the compressive and tensile strengths by about 68% and 79%, respectively; and reducing the shrinkage by about 52% of that of conventional foamed concrete mix, without EPS. In addition, adding polystyrene aggregates in both states (EPS and MEPS) slightly reduced the spread diameter.

Keywords Foamed Concrete, Expanded Polystyrene Foam, Strength, Shrinkage

1. Introduction

Foamed concrete is one type of lightweight concrete consisting of either Portland cement paste or mortar with pore structure created by entraining foam bubbles into the matrix during mixing [1]. Due to its void structure, foamed concrete has excellent properties such as low self-weight, good workability and high insulation. However, for the same reason; it has lower strength compared to normal concrete [2]. It is well known that foamed concrete is used for semi-structural applications. However, recently, its structural features have gained interests. Therefore, besides its strength and durability, shrinkage (volumetric change) is an important property which has not yet studied well. It has been reported that the drying shrinkage of foamed concrete is up to 10 times greater than that of normal concrete [3].

Regan and Arasteh [4] indicated that mixing of foamed cement matrix with lightweight aggregate appears to offer the possibility of a material to reducing the weight of structure and having sufficient strength with excellent thermal insulation for many applications. Watts and Jones [5] pointed out that one of the methods used to reduce shrinkage in concrete is the addition of lightweight aggregate. Also, the same finding was found by Nambiar and Ramamurthy [6].

Babu and Babu [7] stated that expanded polystyrene foam (EPS), as virgin or waste, can be used with various volume percentages as ultra-lightweight aggregate for developing concrete in both structural and non-structural applications.

According to Kan *et al*. [8], once it comes to its end; waste EPS foams can be recycled in different ways. Identifying a recycling method is based on technical, economic and environmental considerations. Babu *et al*. [9] pointed out that the EPS aggregate is consisting of a closed cell structure with basically air of 98%. A wide range of concrete densities can be achieved by incorporating the EPS aggregate at different volumes in the cement paste, mortar or concrete, Kan and Demirboga [10] stated that a new technique had been developed to improve the properties of waste EPS foam particles by thermally treated them leading to create modified waste expanded polystyrene foams (MEPS) as lightweight aggregate. The MEPS aggregates showed higher strength values than the normal EPS aggregate. Heat treatment modified the behavior of the EPS in a beneficial manner to maximize service life, such as density, strength properties, water absorption and thermal conductivity. Thermal treatments are used in many industries to improve the mechanical properties of wastes. It was reported that most clean waste EPS have been recycled effectively, while dirty waste EPS with their low recycling rate have been dumped into landfill sites [8]. Therefore, the aim of this paper was to use waste material, expanded polystyrene foam, as its own and after modifying it to enhance some properties, strength and shrinkage, of foamed concrete.

2. Methodology

The aim of this study is not only to improve the strength of foamed concrete, by adding expanded polystyrene foam aggregate, but also to reduce its high shrinkage. To achieve this aim, the experimental program was divided into two stages in order to examine the possibility of enhancing the strength and shrinkage characteristics of foamed concrete. Firstly, to examine the effect of foam presence; two mixes were designed. The first mix was foamed concrete (FC12) with a design density of 1200 kg/m^3 while the second mix was normal concrete (NC) which was designed by replacing the foam volume in FC12 mix with coarse aggregate of maximum size of 10mm. Secondly, to examine the effect of expanded polystyrene foam; recycled expanded polystyrene foam was used as lightweight aggregate instead of (15%, 20% and 25%) of added foam volume in FC12 mix as FCE15, FCE20 and FCE25, respectively. It should be noted here that the void volume comes from two sources which are the added foam and the air pores within the expanded polystyrene foam aggregate. Polystyrene foam was used in two states: expanded polystyrene foam (EPS) in FCE15, FCE20 and FCE25 mixes as well as modified expanded polystyrene foam (MEPS) in FCM15, FCM20 and FCM25 mixes.

3. Materials and Mix Design

Ordinary Portland cement (Type I) with the specific gravity of (3.15) was used in production of investigated foamed concrete mixes. River sand with specific gravity of (2.65) and maximum sizes of 2.36 mm was used. Drinkable water was used as mixing water. In addition, a protein foaming agent was dissolved in water by a ratio of (1: 40 gr, foaming agent: water) and put in a tank of foam generator and mixed under applying compressed air of 80 bars to produce foam of about 30 kg/m^3 density.

For normal concrete mix, natural aggregate (NA) with maximum size of 10 mm and specific gravity of (2.68) was used.

To investigate the effect of expanded polystyrene foam aggregate (EPS), waste of expanded polystyrene, with density of 18 kg/m^3, was cut into cubic shapes particles as much as possible with maximum size of 10 mm, see Figure 1. In addition, modified expanded polystyrene foam aggregate (MEPS) particles were cut from EPS pieces with double sizes of EPS particles then put in the oven for 15 minutes under a temperature of 130°C to obtain sizes close to those of EPS particles but with rougher surface [11], see Figure 2. Increasing of MEPS aggregates density may be related to the melting of EPS foam material. The above observation indicated that the best exposed temperature and duration were 130°C and 15 minuets [8]. Table 1 shows the properties of EPS and MEPS) used.

Table 2 shows the constituent proportions of conventional foamed concrete (FC mix), normal concrete (NC mix), foamed concrete with EPS (FCE mixes) and foamed concrete with MEPS (FCM mixes). All casting specimens were maintained in a laboratory at the temperature of 21±1°C and after 24 h all the specimens were removed from mold and then cured by wrapping them in cling film and being kept at temperature of 21±1°C until the test age.

Table 1. Properties of EPS and MEPS

Properties	Density (kg/m^3)	Compressive strength (MPa)	Thermal conductivity (W/mK)	Absorption by weight (*S*a) (%)	Absorption by volume (Sh) (%)
EPS	18	0.45	0.033	3.2	0.834
MEPS	210	10.2	0.0555	4.1	0.58

Table 2. Constituent proportions of all investigated mixes

Materials/ Mixes	FC12	NC	FCE15	FCE20	FCE25	FCM15	FCM20	FCM25
Cement (kg/m^3)	450	450	450	450	450	450	450	450
Sand (kg/m^3)	516	516	516	516	516	516	516	516
W\C	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Foam (m^3)	0.428	-	0.323	0.323	0.323	0.323	0.323	0.323
NA (kg/m^3)	-	1147	-	-	-	-	-	-
EPS (kg/m^3)	-	-	1.927	1.927	1.927	-	-	-
MEPS (kg/m^3)	-	-	-	-	-	25.7	25.7	25.7

Figure 1. (Left) Expanded polystyrene foam aggregate (EPS) and (Right) Modified recycled expanded polystyrene foam aggregate (MEPS).

Figure 2. Surface texture of (Left) EPS and (Right) MEPS particles (with thermal treatment) [5mm×5mm]

4. Tests

4.1. Consistency

Consistency and stability of foamed concrete are affected by its water content added to the dry raw materials to produce a base mixture (unfoamed) and the volume of foam added to the base mixture to produce foamed concrete mix [12].

The consistency of unfoamed mixture affects the stability of foamed mix which can be achieved by making a density ratio (fresh density divided by design density) close to unity. For foamed concrete, its consistency is defined by its spreadability which reduces with adding foam to the base mixture (unfoamed), while for a given density; it depends on filler type [13]. Flowability of investigated mixes was measured before and after adding foam to the mixture by measuring the spread diameter of a 75 × 150 mm cylinder filled with concrete [14].

4.2. Compressive Strength

In accordance with ASTM C513-11[15], three cubes with dimensions of 100×100×100 mm were tested for compressive strength for each mix at ages of 7 and 28 days and the average of their readings was taken.

4.3. Tensile Strength

In accordance with ASTM C496-11[16], three cylinders with dimensions of 100×200 mm were tested for tensile strength at ages of 7 and 28 days and their average was taken.

4.3. Drying Shrinkage

Prismatic specimens were used for drying shrinkage test with sizes of 40×40×160 mm in accordance with the recommended practice of RILEM-ACC 5.2 and IS 6441-part II - 1972 for foamed concrete [6].

Dial gauge with accuracy of 0.001mm was used and linked vertically by a holder to measure a length change of each sample. This holder was placed in a humidity chamber with a temperature of 23 ± 2 °C and relative humidity of 50 ± 4 %, (ASTM C 157-08) [17] for 28 days and measurements were taken every two days. For all investigated mixes, three specimens were used for drying shrinkage test and the average of their readings was taken.

5. Results

5.1. Consistency

Foamed concrete is characterized by its high flowability compared to normal concrete. For the same cement, water and sand contents, when replacing the required foam volume in mix FC12 with coarse aggregate to produce NC mix, no flow was noticed, due to the high restriction of the normal aggregates, see Figure 3.

Figure 3. Flowability of (left) normal concrete (NC) (middle) foamed concrete (FC12) and (right) with polystyrene aggregate (FCE15)

Table 3 presents the spread diameter values of all investigated foamed concrete mixes before and after adding foam. In terms of foamed concrete mixes (after adding foam), for all investigated mixes; a reduction in spread diameter (between 20mm and 35mm) was noticed after adding foam compared to that of unfoamed mixtures. For unfoamed mixtures (before adding foam) and foamed mixes (after adding foam), it was noticed that adding polystyrene aggregates in both states (FCE and FCM) slightly reduced the spread diameter (10 -15 mm) compared to FC12 mix, see Figure 3.

Table 3. Spread diameter of foamed concrete mixes

	FC12	FCE15	FCM15
Fresh density (kg/m^3)	1220	1215	1210
Before adding foam (mm)	240	230	225
After adding foam (mm)	220	210	205

5.2. Compressive Strength

Foamed concrete is known to have a very little compressive strength compared to normal concrete; therefore using it in structural applications is quite limited [18]. Conventional foamed concrete is typically produced to achieve low compressive strength (between 1 and 10 N/mm^2) [19]. This is due to several reasons, one of which is the absence of coarse aggregate and presence of air voids instead of it. From the results, the following findings can be observed and discussed as follows.

In terms of the effect of foam presence, to determine the influence of foam presence on strength, the volume of the foam (FC12 mix) was replaced with coarse aggregate to produce normal concrete (NC mix). Figure 4a shows the effect of foam presence on compressive strength with the same mortar components i.e. cement, sand and water contents are constant in both FC12 and NC mixes.

With regards to the effect of expanded polystyrene foam, for a given density; using EPS increased the compressive strength slightly, while with using MEPS the strength improved significantly compared to FC12 mix. This implies that applying thermal treatment on polystyrene foam particles helped in enhancing their strength. The results showed that MEPS aggregate in (FCM25) helped in increasing the compressive strength by about 68% of that of conventional foamed concrete (FC12 mix), see Figure 4b, noted that a similar behaviour was noticed by Hernández *et al.* [20].

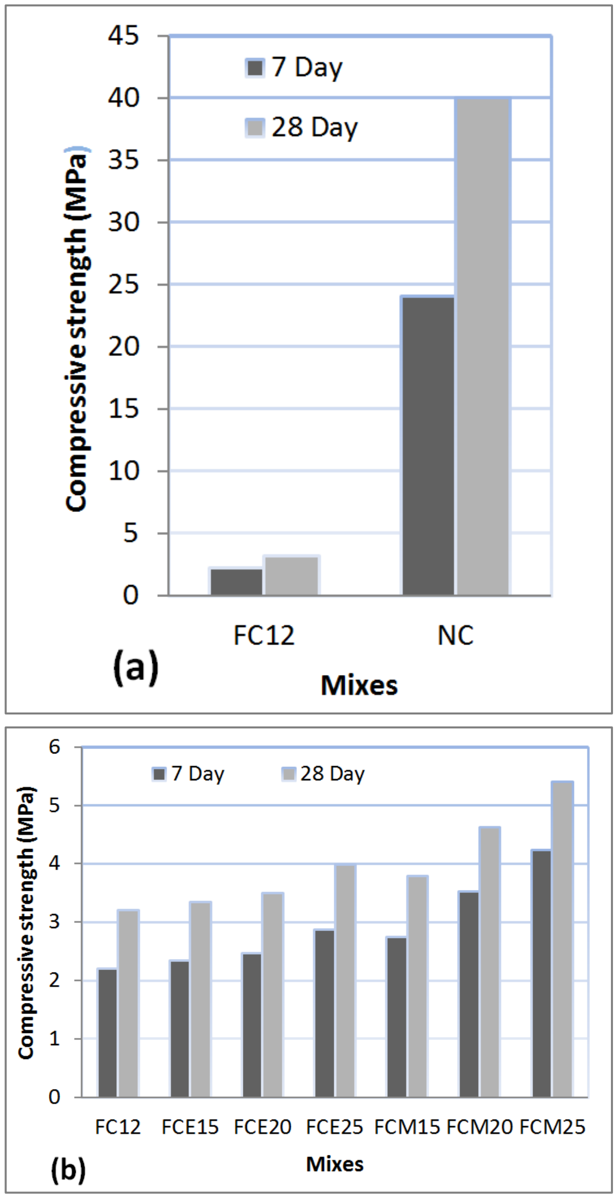


Figure 4. Compressive strength for (a) foamed concrete and normal concrete (b) different foamed concrete mixes

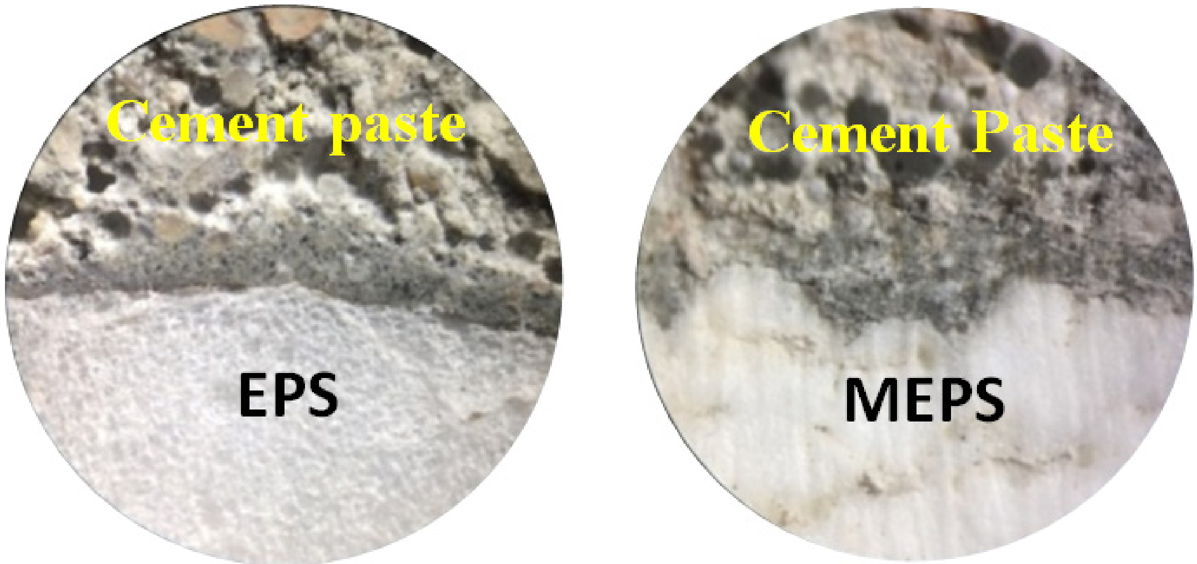


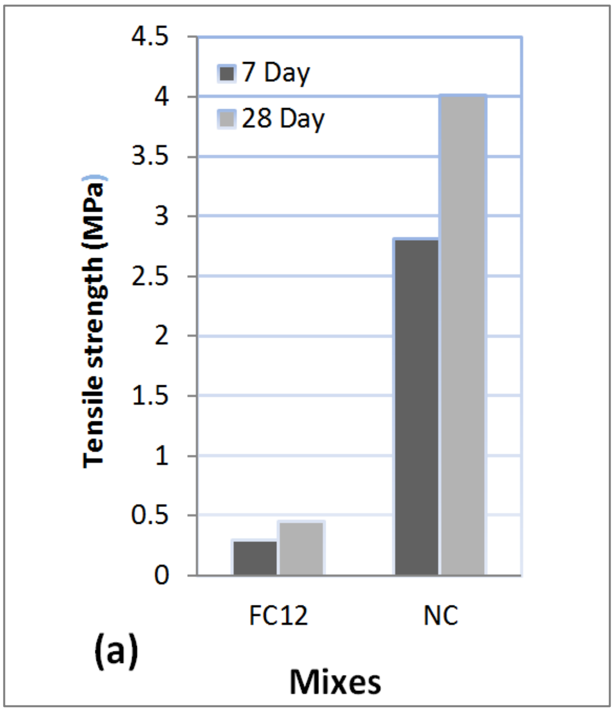
Figure 5. Contact area between different lightweight aggregate used (EPS and MEPS) and cement paste, [5mm×5mm].

It was found that the crashing load of MEPS aggregate particle was higher than that of expanded aggregate particle (EPS) by about 20 times, which results in gaining compressive strength for mixes containing MEPS higher than that of EPS mixes. In addition, it was noticed, from the microstructural investigation, that the tortuosity of the contact line between the aggregate particle and the cement paste was more obvious for the MEPS particle rather than EPS particles leading to enhance the bond between it and cement paste and finally increasing the strength [21], see Figure 5. According to Sayadi *et al.* [22], when EPS is used as grains; the compressive strength is less due to a smooth surface of EPS particles and its weak bond characteristic resulting easy propagate of cracks in the interfacial transition zone (ITZ) at lower stress level. Under compressive loading, concretes containing EPS aggregate showed more gradual and ductile failure, because of the weak bond between the EPS aggregate and the matrix [9]. Mehta [23] concluded that the nature and microstructure of the ITZ vary depending on the aggregate type, the surface structure of aggregate, pore structure of the aggregate, the porosity of the cement paste, and the bleeding of water beneath the aggregate.

5.3. Tensile Strength

In terms of foam presence effect, Figure 6a shows the tensile strengths of foamed and normal concrete mixes for 7 and 28 days. It can be seen that the tensile strength increases over time and there is a very significant difference between tensile strength of foamed concrete and normal concrete. Noted that in these two mixes, cement, water and sand content were kept constant and the only variable was using coarse aggregate in normal concrete mix (NC) instead of the added foam volume in foamed concrete mix (FC12). Usually coarse aggregate improves the tensile strength due to the bonding between it and the cement paste.

With regard to effect of expanded polystyrene foam, Figure 6b, compared to FC12 mix, using of EPS particles in foamed concrete led to a slightly increase in compressive strength. The higher the EPS content the higher the strength increment.



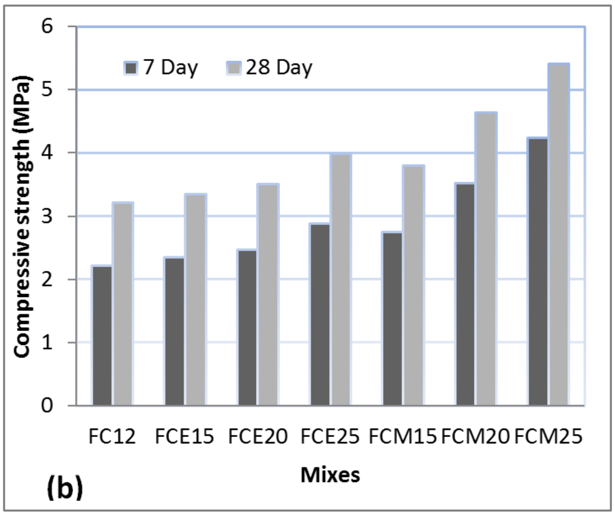


Figure 6. Tensile strengths of (a) conventional foamed concrete and normal concrete (b) different foamed concrete mixes with the same density (1200 kg/m^3)

In tensile test, the failure mode of concrete specimen containing EPS aggregate did not exhibit the typical brittle failure which was observed in normal concrete. The failure observed of concrete containing EPS volumes of 20% and 25% was more gradual and the specimens were not separated into two pieces. Similar behavior was observed by Babu *et al.* in their study on lightweight concrete [9]. On the other hand, the results showed that the MPES aggregate, FCM25 mix, helped in improving the tensile strength by about 79% of that of FC12 mix.

In their review about foamed concrete, Amran *et al.* [3] pointed out that an empirical model was proposed to predict the splitting tensile strength of lightweight foamed concrete from its compressive strength as in following equation:

$$f_t = 0.23(f_c')^{0.67} \quad (1)$$

Where f_t: splitting tensile strength of lightweight foamed concrete in MPa;

f_c': compressive strength of lightweight foamed concrete at 28 days in MPa.

It can be seen from Table 4 that the predicted splitting tensile strength values are closed to those of the experimental results and the tensile splitting strength of lightweight foamed concrete mixes increases with the increasing of its compressive strength [24]. Hilal *et al.* [25] concluded that adding lightweight aggregate (LWA) as partial substitution of foam volume helped in improving of tensile strength of lightweight foamed concrete compared to a conventional foamed concrete, without LWA.

Table 4. Measured and predicted tensile splitting strength.

Mix	Compressive strength fc' (MPa)	Tensile splitting strength ft (MPa)		Measured/ Predicted	ft/fc' %
		Measured results	Predicted results		
FC12	3.21	0.453	0.50	0.90	14.1
FCE15	3.34	0.48	0.51	0.93	14.3
FCE20	3.49	0.495	0.53	0.92	14.1
FCE25	3.98	0.536	0.58	0.92	13.4
FCM15	3.79	0.617	0.56	1.09	16.2
FCM20	4.63	0.715	0.64	1.11	15.4
FCM25	5.41	0.812	0.71	1.13	15.0

5.4. Drying Shrinkage

Drying shrinkage, a volumetric change due to drying of hardened concrete, is caused by the diffusion of water from hardened concrete to the surrounding environment [26].

Foamed concrete has very high shrinkage compared to normal concrete. For structural and semi- structural purposes, cast-in-place, shrinkage can pose some problems [27]. Shrinkage of foamed concrete depends on type and amount of cement used, water-to-cement ratio, size of element, type of curing method and density [28]. In this study, all the above variables were kept constant.

However, two types of expanded polystyrene foam aggregate (EPS and MEPS) were added to examine their effect on shrinkage of foamed concrete. Figure 7 shows the variation of drying shrinkage over time for all investigated mixes, while Figure 8 illustrates the total shrinkage strains at age of 28 days. From these two figures, the following findings can be observed in terms of the specific aspects:

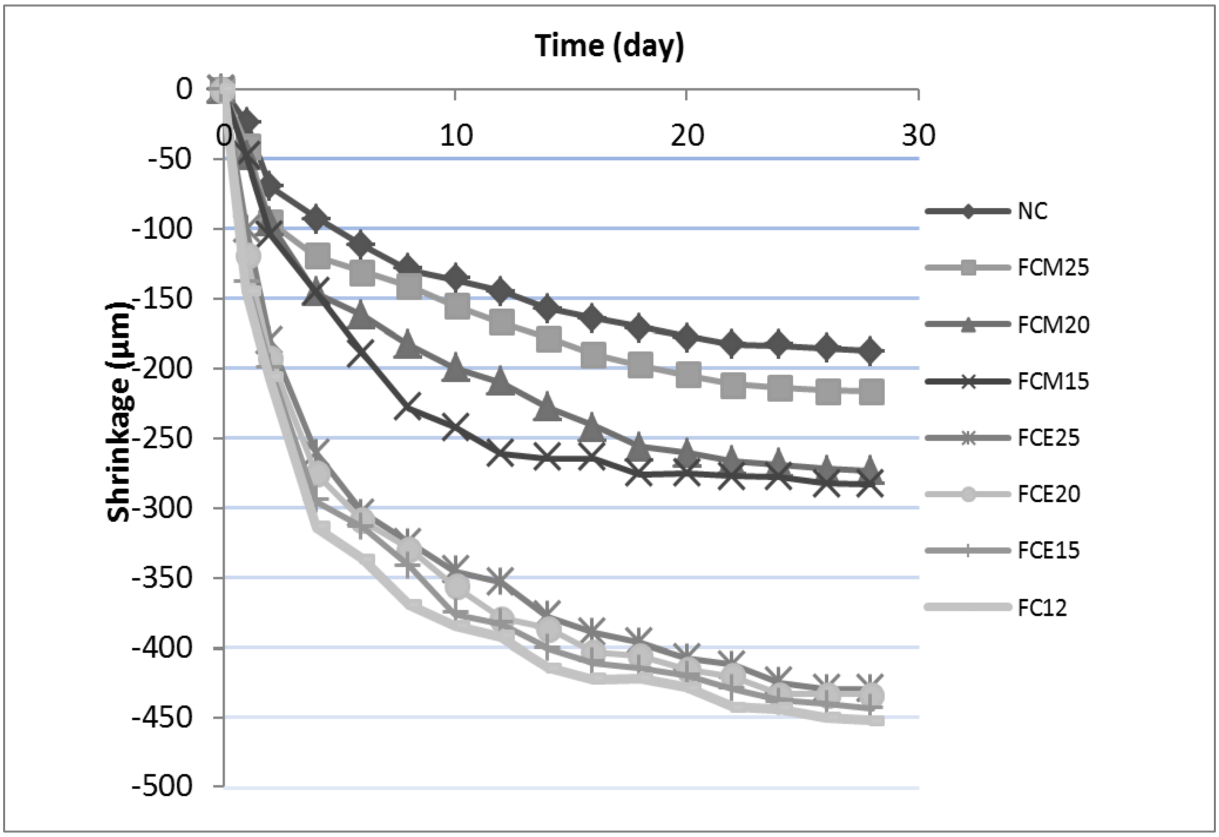


Figure 7. Drying shrinkage for all investigated mixes with time

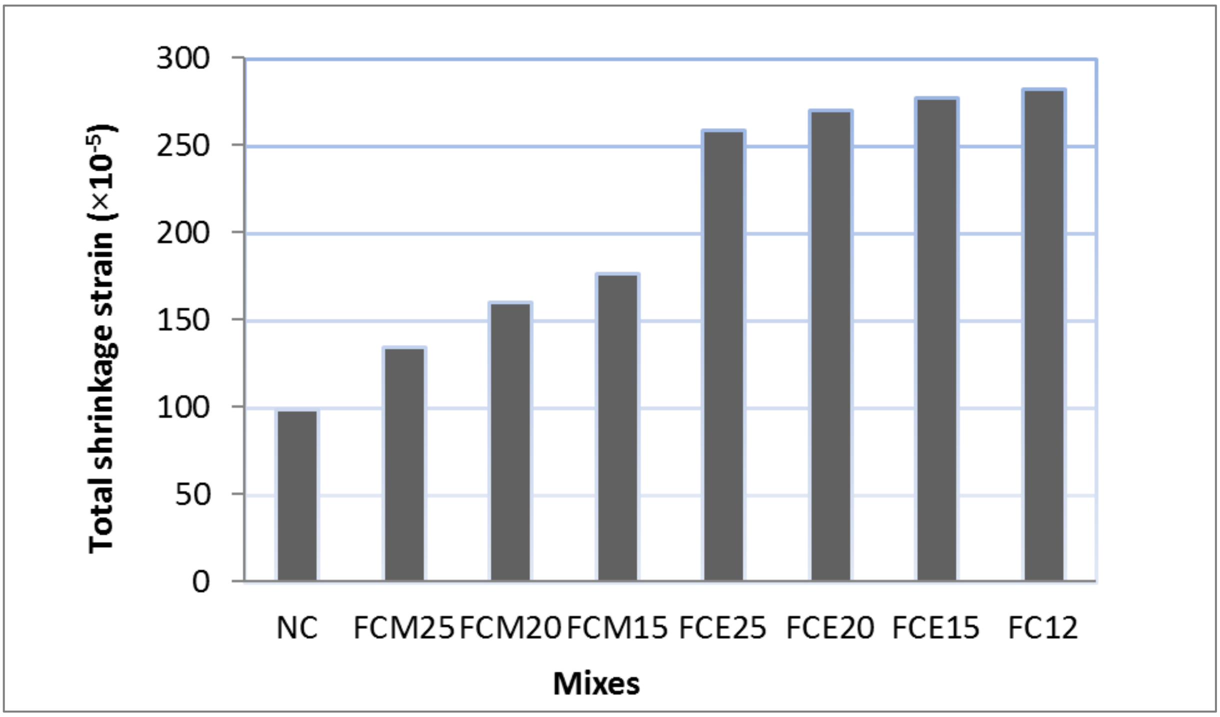


Figure 8. Total shrinkage strains ($\times 10^{-5}$) for all investigated mixes at age of 28 days.

In terms of the effect of foam presence, in spite of having the same contents of cement, water and fine sand, the shrinkage of conventional foamed concrete mix (FC12) was higher than that of normal concrete (NC) by more than five times. This is dues to the absence of coarse aggregate and presence of foam instead of it in FC12 mix.

With regards to the effect of recycled expanded polystyrene foam, EPS helped in gaining a little reduction in shrinkage by about 5% of that of FC12 mix. However, a big reduction, 52% of shrinkage of FC12 mix, was noticed with using MEPS aggregate. This indicated that the thermal treatment helped in enhancing the structure of MEPS particle making it tougher (load test results) and rougher (see Figure 9) than that of EPS particle. Also, this reduction can be attributed to the closed air structure in EPS particles which is different from that of added foam in terms of void size distribution and connectivity.

In general, compared to normal aggregate, lightweight aggregate usually results in higher shrinkage because of its lower modulus of elasticity and greater voids content [29]. In comparing normal concrete with polystyrene aggregate concrete (PAC), the magnitude of drying shrinkage of PAC increases with the proportion of polystyrene aggregate in concrete. This magnitude is comparatively greater than that of control concrete by a range of 10–85%. The main reason is the high compressibility and low stiffness of polystyrene aggregates which offer negligible restraint to the shrinkage process when they added to normal concrete [30]. However, in this study, it was noticed that adding modified polystyrene foam to the foamed concrete helped in enhancing volumetric change of the later by reducing shrinkage by about 52% of that of convectional mix.

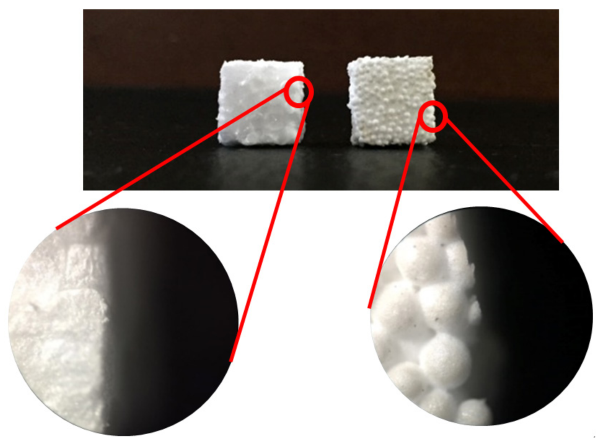


Figure 9. Roughness of Expanded polystyrene foam used (left) natural EPS (right) thermally treating MEPS, [5mm×5mm].

6. Conclusions

The results of this research highlight that although adding the recycled expanded polystyrene foam (EPS) as aggregates helped in enhancing both the strength and shrinkage of foamed concrete, thermally treated it, to produce MEPS particles; resulted in increasing the compressive and tensile strengths by about 68% and 79%, respectively, and reducing the shrinkage by about 52% of that of conventional foamed concrete mix, without EPS. In general, compared to conventional mix; lighter foamed concrete with good strength and very low shrinkage was made by using local waste materials. In addition, adding polystyrene aggregates in both states (EPS and MEPS) slightly reduced the spread diameter.

This study has suggested a number of avenues for future research including:

- Investigating the effect of adding EPS on pore structure of foamed concrete in terms of pore size shape, distribution and connectivity.
- Investigating the thermal conductivity and freeze and thaw behavior and permeation properties of foamed concrete containing EPS particles as aggregate.

REFERENCES

[1] A. A. Hilal, N. H. Thom, and A. R. Dawson, "On entrained pore size distribution of foamed concrete," *Constr. Build. Mater.*, 2015.

[2] M. A. O. Mydin, N. Mdnoordin, A. S. M. Said, and N. Mohamad, "Preliminary Study of Low Densities Lightweight Foamed Concrete Brick for Non-Load-Bearing Wall System," vol. 2508, no. 5, pp. 1405–1410, 2018.

[3] Y. H. M. Amran, N. Farzadnia, and A. A. Abang Ali, "Properties and applications of foamed concrete; a review," *Constr. Build. Mater.*, vol. 101, pp. 990–1005, 2015.

[4] P. E. Regan and A. R. Arasteh, "Lightweight aggregate foamed concrete," *Struct. Eng.*, vol. 68, no. 9, pp. 167–173, 1990.

[5] G. R. A. Watts and M. R. Jones, "Specification for foamed concrete," 2001.

[6] E. K. K. Nambiar and K. Ramamurthy, "SHRINKAGE BEHAVIOR OF FOAM CONCRETE," *J. Mater. Civ. Eng.*, vol. 26, no. 1, pp. 58–61, 2002.

[7] K. G. Babu and D. S. Babu, "Behaviour of lightweight expanded polystyrene concrete containing silica fume," *Cem. Concr. Res.*, vol. 33, no. 5, pp. 755–762, 2003.

[8] A. Kan and R. Demirboga, "A new technique of processing for waste-expanded polystyrene foams as aggregates," *J. Mater. Process. Technol.*, vol. 9, pp. 2994–3000, 2008.

[9] D. S. Babu, K. G. Babu, and W. Tiong-Huan, "Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete," *Cem. Concr. Compos.*, vol. 28, pp. 520–527, 2006.

[10] A. Kan and R. Demirboga, "A novel material for lightweight concrete production," *Cem. Concr. Compos.*, vol. 31, pp. 489–495, 2009.

[11] S. Slabaugh, C. Swan, and R. Malloy, "Development and Properties of Foamed Synthetic Lightweight Aggregates," 2007.

[12] K. Ramamurthy, E. K. Kunhanandan Nambiar, and G. Indu Siva Ranjani, "A classification of studies on properties of foam concrete," *Cem. Concr. Compos.*, vol. 31, no. 6, pp. 388–396, 2009.

[13] A. Raj, D. Sathyan, and K. M. Mini, "Physical and functional characteristics of foam concrete: A review," *Constr. Build. Mater.*, vol. 221, pp. 787–799, 2019.

[14] N. M. Mhedi, A. A. Hilal, and Abdulkader Al-Hadithi., "Re-use of waste plastic as fibers in production of modified foamed concrete," in *11th International Conference on Developments in eSystems Engineering (DeSE)*, 2018, pp. 295–299.

[15] ASTM C513, "Standard Test Method for Obtaining and Testing Specimens of Hardened Lightweight Insulating Concrete for Compressive Strength."

[16] F. Raupit, A. Saggaff, C. S. Tan, Y. L. Lee, and M. Tahir, "Splitting Tensile Strength of Lightweight Foamed Concrete with Polypropylene Fiber," vol. 7, no. 2, pp. 424–430, 2017.

[17] ASTM C157, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and concrete."

[18] U. E-journal and C. Engineering, "The Effect of Reinforcement, Expanded Polystyrene (EPS) and Fly Ash On The Strength of Foam Concrete," vol. 2, no. 2, pp. 1–7, 2011.

[19] M. R. Jones and A. Mccarthy, "Preliminary views on the potential of foamed concrete as a structural material," no. 1, pp. 21–31, 2005.

[20] J. B. Hernández-zaragoza, T. López-lara, J. Horta-rangel, C. López-cajún, E. Rojas-gonzález, and J. Adue, "Cellular Concrete Bricks with Recycled Expanded Polystyrene Aggregate," vol. 2013, 2013.

[21] A. A. Hilal, "Effect of Aggregate Roughness on Strength and Permeation Characteristics of Lightweight Aggregate Concrete," *J. Eng.*, vol. 2021, p. 9505625, 2021.

[22] A. A. Sayadi, J. V. Tapia, T. R. Neitzert, and G. C. Clifton, "Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete," *Constr. Build. Mater.*, vol. 112, pp. 716–724, 2016.

[23] P. K. Mehta and P. J. M. Monteiro, *"concrete microstructure, properties and materials"*. 2005.

[24] S. M. Abd and D. Ghalib, "Improving the Mechanical Properties of Lightweight Foamed Concrete Using Silica Fume and Steel Fibers Introduction :," *Al-Nahrain J. Eng. Sci.*, vol. 21, no. 2, pp. 300–307, 2018.

[25] A. A. Hilal, N. H. Thom, A. R. Dawson, and A. Materials, "The Use of Additives to Enhance Properties of Pre-Formed Foamed Concrete," vol. 7, no. 4, 2015.

[26] B. T. R. Naik, R. N. Kraus, and Y. Chun, "Effect of Different Types of Aggregates on Shrinkage in Concrete Containing Shrinkage-Reducing Admixtures," *CANMET/ACI Int. Conf.*, no. November 2005, p. 16, 2006.

[27] P. Chindaprasirt and U. Rattanasak, "Shrinkage behavior of structural foam lightweight concrete containing glycol compounds and fly ash," *Mater. Des.*, vol. 32, no. 2, pp. 723–727, 2011.

[28] M. T. Scholar, R. Tukdoji, and M. Nagpur, "Experimental study on foam concrete," vol. 4, no. 1, pp. 145–158, 2014.

[29] O. Kayali, M. N. Haque, and B. Zhu, "Drying shrinkage of fibre-reinforced lightweight aggregate concrete containing

fly ash," vol. 29, pp. 1835–1840, 1999.

[30] W. C. Tang, Y. Lo, and A. Nadeem, "Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete," vol. 30, pp. 403–409, 2008.