



Dimensional Stability of Lightweight Foamed Concrete Containing Eggshell Powder and Calcium stearate

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Abstract: In order to reduce eggshell (ES) waste and reduce utilization of pure cement, various researches were conducted to study effects of eggshell powder (ESP) on properties of concrete when it partially replaces ordinary Portland cement (OPC). Dimensional stability is one of the properties that related to cracking issue and soundness of concrete, and it is generally guided by movement of moisture. This study was conducted to study the dimensional stability of lightweight foamed concrete (LFC) that containing eggshell powder and calcium stearate (CS), where, replacement level (RL) of eggshell powder ranged from 0% to 10% at interval of 2.5%, and additional of 1% calcium stearate as cement mass applied for the mixture containing 0% and 5% eggshell powder. Besides, sorptivity and initial surface absorption were tested to compare with dimensional changes, and compressive strength was tested to confirm the additives have no significant adverse effect on the strength. The result shows that incorporation of 5% eggshell powder improves sorptivity, initial surface absorption, and dimensional stability (outdoor R² value) of the lightweight foamed concrete by 33%, 55%, and 1.5% respectively, meanwhile, additional of 1% calcium stearate improves these properties by average 79%, 78%, and 7.2% respectively.

Keywords: Calcium Stearate, dimensional stability, eggshell powder, foamed concrete

1. Introduction

Dimensional changes of concrete occur with the movement of moisture, where increase water content by absorption cause expansion while decrease water content by evaporation cause shrinkage. Moisture loss occurs through evaporation and bleeding during the plastic stage cause plastic shrinkage. Moisture loss occurs after the plastic stage through evaporation cause drying shrinkage, drying shrinkage might only partially recover even moisture loss is fully compensated. The hydration process that utilized water content cause autogenous shrinkage, autogenous shrinkage is normally relatively small unless the water to cement ratio is extremely small. Shrinkage, especially differential shrinkage might cause cracking and weaken the concrete, for example, ununiform volumetric change between concrete and steel bar, cement paste and aggregate, concrete surface and concrete core, etc. will cause internal stress and cracking [1]. This study is focused on the dimensional stability of lightweight foamed concrete containing eggshell powder and calcium stearate as a respond to environmental changes such as rainfall and changes of temperature and relative humidity after the hardening process, by measuring dimensional changes, which is mostly drying shrinkage.

An abundance of eggshell (ES) waste is produced and its disposal might cause the environmental problem [2]. Eggshell powder (ESP) contains up to 99% of calcium carbonate as shown in Table 1 [2], while calcium carbonate powder can act as an inert filler to decrease porosity and increase the strength of concrete [3]. Based on previous researches, incorporation of ESP as partial replacement material of cement at a specific replacement level (RL) can increase the strength of mortar [4], reduces water absorption and thermal conductivity while increases compressive strength and hardness of mortar [5], improve water absorption properties and compressive strength of concrete [6]-[9]

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and lightweight foamed concrete (LFC) [2], [10], [11]. Besides improve compressive and flexural strengths, partially replace cement by using ESP at specific RL as well increase maximum capacity and deflection at the failure of reinforced one-way concrete slab [12]. Additionally, apply ESP to replace sand at RL of 5% to 50% was found to reduce compressive and flexural strengths but improve the radiation absorption property of mortar [13].

Table 1 - Chemical compositions of eggshell powder

Chemical Constituents (%)	Eggshell Powder [2]
Calcium Carbonate, CaCO ₃	99.19
Aluminium Oxide, Al ₂ O ₃	0.207
Ferric Oxide, Fe ₂ O ₃	0.093
Sulphur Oxide, SO ₃	0.467
Potassium Oxide, K ₂ O	0.029

According to Naseroleslami and Nemati Chari [14], “CS is a cost-efficient and easily processed damp-proofing admixture which is derived from the reaction of acid stearic and limestone”. Damp-proofing admixtures are able to form a water-repellent layer along with the pores and restrict moisture from transfer into capillary pores. Ma and Chen [15] studied the effects of water repellents including CS on 550kg/m³ LFC and found improvement in compressive strength and significant decrement in water absorption. Maryoto [16] studied the effects of CS on normal concrete as an additive and found very limited increment on compressive strength and found reduction on permeability by 50% with CS dosage of 4kg/m³, as well as a reduction on the level of corrosion.

Typical six months shrinkage of mortar and concrete stored at a relative humidity of 50% and temperature of 21°C can range from 200μ to 1200μ, in which higher aggregate to cement ratio and lower water to cement ratio contribute to lower shrinkage value, however, cellular concrete has higher shrinkage value ranged from 700μ for oven-dried density of 1600 kg/m³ to 3000μ for 400 kg/m³ [1].

Maryoto et al. [17] studied on drying shrinkage of concrete containing 0.1% to 0.3% of CS by cement mass. They concluded that CS could react with cement and water to form a hydrophobic layer on the pore surface and influences cement shrinkage behaviour, in which, the addition of CS reduces concrete shrinkage, and the shrinkage can be proportional to the water content of concrete.

This study was conducted to study the effect of ESP and CS on the dimensional stability of LFC with the fresh density of 1200 ± 50 kg/m³ under actual tropical indoor and outdoor nature weather. ES RL of 0%, 2.5%, 5%, 7.5%, and 10% were applied, and 1% CS added to LFC mixture containing 0% and 5% ES, in sum, total 7 mixtures were adopted for this study. The measurement of dimensional changes, i.e., shrinkage was performed up to 180 days with reduced measuring frequency. Besides, 28-day water absorption properties namely sorptivity and initial surface absorption of said LFC mixtures are measured to make comparison with dimensional changes result, meanwhile, the 28-day compressive strength was also tested to confirm the LFC fulfil compressive strength requirement of 2.8 MPa as specified by MS 76: 1972 [18].

2. Experimental Work Details

Experimental details included material preparation and specifications, LFC mix proportions, specimen preparation, and testing methods and specifications.

2.1 Materials

Materials used in this study including eggshell powder (ESP), 45.5N Ordinary Portland cement (OPC), 0.6mm sand, calcium stearate (CS), tap water, and foam agent.

The eggshell powder was prepared by referring to Tiong et al. [2]. The ES wastes were collected from local hawkers, washed and crushed by hand in a pail, blended by using a fruit blender and washed to remove the majority of the membrane that can float on water. After draining out the water, the eggshell flake was oven-dried and ground by high performance electric dry food grinder that has the grinding fineness of 30-300 mesh (around 45-600 μm). Finally, the ESP was sieved through a 63 μm sieve pan to obtain ESP and store in a moisture-proof container.

“Orang Kuat” branded Type I Portland Cement in accordance with MS EN 197-1 [19] was sieved through 300 μm to remove all lumps [20] and stored in a moisture-proof container. The sand was oven-dried and sieved through a 0.6mm sieve pan, and contain 10% to 15% particle passing 150 μm and 40% to 65% particle passing 300 μm. CS powder which is ready for use, and foam agent which is a blend of synthetic surfactants and polymer, were obtained from local suppliers. CS powder specifications obtained from the supplier are shown in Table 2. The foam used is categorized as pre-formed dry foam. It was produced by using a foam generator. In the foam generator, the mixture of water and foam agent at a ratio of 1:20 was passing through a series of high-density mesh with 0.5 MPa compressed air [10] and turn into foam.

Table 2 - Calcium stearate specifications

Properties	Calcium Stearate
Appearance	Powder
Ash (% , max.)	10.5
Free Fatty Acid (% , max.)	1.0
Melting Point (°C)	150
Moisture (% , max.)	4.0
Particle Size (% thru 200 mesh)	90
Specific Gravity (g/cm ³)	1.01

Note: 200 mesh = 74 μ m

2.2 Mix Proportions and Specimen Preparation

Mix proportions of the LFC with the density of 1200 kg/m³ are shown in Table 3, which are calculated by fixing cement to sand ratio (c/s) at 1 and water to cement ratio (w/c) at 0.6.

Before mixing of LFC, 100mm cubical mould, 100mm diameter by 200mm height cylindrical mould, and 400x200x100mm mould shall be ready with a thin layer of demoulding oil applied at inner and top surface, and strain disc stick on PVC sheet shall be placed in 400x200x100mm mould accordingly.

After casting, the specimen was demoulded on the second day. Cubical and cylindrical specimens were proceeding to water curing and subjected to 24-hour oven-drying at 105°C before 28-day properties testing, in which, the cylindrical specimen was cut to around 50mm thick before oven-drying. However, 400 x 200 x 100mm specimen was separated into 2 groups, 1 group placed in the outdoor garden area and the other group was placed at indoor sub-basement car-park area.

Table 3 - Mix proportions

Reference Name	Mix Proportions (per m ³)					
	Cement (kg)	¹ ES (kg)	² CS (kg)	Sand (kg)	Water (kg)	³ Foam (kg)
LFC- ⁴ 0ES	462	0	0	462	277	18.1
LFC-2.5ES	450	12	0	462	277	18.1
LFC-5ES	438	23	0	462	277	18.1
LFC-7.5ES	427	35	0	462	277	18.1
LFC-10ES	415	46	0	462	277	18.1
LFC-0ES ⁵ 1CS	462	0	4.62	462	277	18.1
LFC-5ES1CS	438	23	4.38	462	277	18.1

Note: ¹Eggshell; ²Calcium Stearate; ³Calculated amount of foam required to achieve target fresh density of 1200kg/m³ based on foam density of 45kg/m³; ⁴Percentage of ES as partial replacement material of cement, i.e., 5ES = 5% ES; ⁵Percentage of CS as additional material by mass of cement, i.e., 1CS = 1% CS

2.3 Compressive Strength, Sorptivity, and Initial Surface Absorption Test

A compressive strength test was conducted as referring to BS EN 12390-3 [21] at a loading rate of 2 kN/s, which is 0.2 MPa/s, by using a universal testing machine.

The sorptivity test was conducted as referring to ASTM C 1585 [22] to determine the sorptivity (rate of absorption) of water induced by capillary action. The cut specimen was placed on the steel rod and with 1 – 3 mm of specimen depth immersed in water. Then, the mass was measured at 5, 10, 15, 30, 60, 90, 120, and 150 minutes to calculate absorption (I, at mm), where absorption was calculated by the change of mass (at g) divided by area of specimen exposed to water (at mm²) and density of water (0.001 g/mm³). Then, the sorptivity (mm/s^{0.5}) was adopted as the trendline gradient of the absorption line plotted against the square root of time (\sqrt{t}).

Initial surface absorption test (ISAT) was conducted as referring to BS 1881- Part 208 [23] to determine the rate of flow of water into a concrete surface under a constant water pressure head of 200 \pm 20 mm. At 120 minutes after the surface starts to contact with water, the time required for the water in the capillary to flow for a certain number of divisions tube was recorded, and converted to a number of divisions per minute. Then the initial surface absorption will be 0.01 times the number of divisions per minute. As demonstrated by BS 1881-Part 208 [23], “if the movement over the 5 s period exceeds 30 scale divisions record the initial surface absorption as more than 3.60 ml/(m²s)”.

2.4 Measurement on Dimensional Changes

Measurement of dimensional change was conducted as referring to RILEM CPC9 [24] and Lim et al. [25]. Specimen size of 400 x 200 x 100mm was chosen to simulate the actual LFC block application. A total of 8 numbers or 4 pairs of strain discs were installed at each concrete block for strain measuring purpose. The centre of 400 x 200mm concrete surface was installed with 2 pairs of strain discs, in which, 1 pair parallel to, and the other pair perpendicular to 400mm edge of concrete block. The centre of 400 x 100mm and 200 x 100mm concrete surface also installed with 1 pair of discs perpendicular to 100mm edge. The locations of strain discs are shown in Fig. 1.

A strain gauge meter was used to perform the measurement starting from 24 hr after casting. The concrete block was subjected to indoor air curing or outdoor tropical natural weather curing after the first measurement. Then, the measurement was performed every day until 28-day, and approximately twice per week until 90-day, once per week until 120-day, and once per month until 180-day. The temperature and relative humidity were also being recorded during strain measurement.

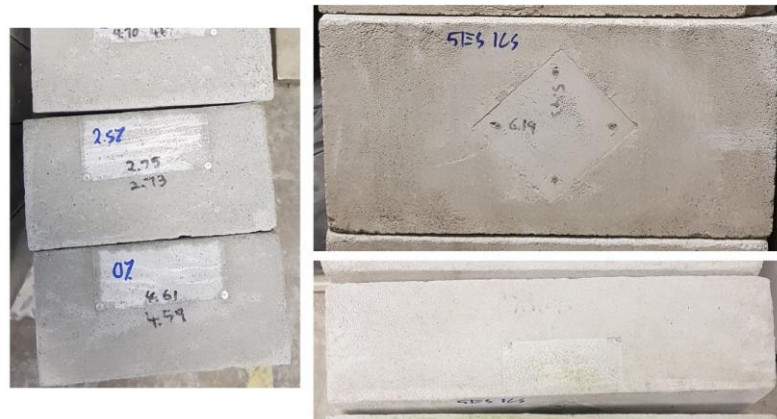


Fig. 1 - locations of strain discs on the specimen

3. Results and Discussions

3.1 Compressive Strength, Sorptivity and Initial Surface Absorption

Compressive strength, sorptivity, and initial surface absorption (flow) results are shown in Table 4 together with the actual average foam amount added and achieved fresh density.

The result shows that all the LFC fulfil strength requirement of 2.8 MPa as specified by MS 76: 1972 [18] and incorporation of ESP increases the compressive strength by up to 7%, the LFC with ES RL of 2.5% to 10% have a very close result and optimal result appear at 7.5% ES RL. The result also shows that incorporation of ESP reduces the sorptivity and flow of up to 33% and 57% respectively, LFC-5ES has the optimal sorptivity result, while, LFC-7.5ES has the optimal flow result, however, LFC-5ES also has a very close result with LFC-7.5ES. Therefore, it might be concluded that 5% shall be the optimal ES RL based on these results.

The improvement in compressive strength, sorptivity, and flow by incorporation of ESP might because ESP might act as an inert filler to block some interconnected capillary and noncapillary pores [2],[3]. Besides, calcium carbonate might also react with alumina phases of cement to produce monocarboaluminates that might enhance compressive strength [2], [26]. Hence, incorporation of ESP might improve micro-structure to increase the strength and meanwhile slow down the flow of water in the LFC.

The addition of 1% CS significantly improves the sorptivity and flow properties by average 79% and 78% respectively when compare LFC with CS to those without CS. For LFC containing CS, incorporation of ES might be unfavourable as the sorptivity and flow of LFC-5ES1CS are higher than those of LFC-0ES1CS by 35% and 4.4% respectively.

The improvement in sorptivity and flow by incorporation of CS might because CS can react with cement and water to form a hydrophobic layer on the pore surface [17]. The hydrophobic layer might able to reduce the diameter of pores or discontinue the pores, therefore sorptivity, and flow are greatly reduced.

When referring to the actual foam amount added during mixing, the required foam amount reduces when ES RL increase. It shows that ESP might be able to improve the stability of foam so that lesser foam is burst during the mixing process. On the other hand, the required foam amount increased by an additional 1% CS. It might because additional of CS make the mixture drier and stickier so that bursting percentage of foam increase. Bursting of foam shall result in continuous pore structure that leads to lower strength and higher sorptivity and flow, as shown by the result, the addition of 1% CS reduces compressive strength by 9%, however, favourable effects of CS had dominant these effects on sorptivity and flow.

Table 4 - Compressive strength, sorptivity, and 120 min flow of the LFC at the ages of 28-day.

Reference Name	¹ Foam (kg/m ³)	² Density (kg/m ³)	Compressive Strength (MPa)	Sorptivity (mm/ min ^{0.5})	120min Flow (ml/m ² s)
LFC-0ES	24.4	1225	4.39	0.3272	1.8336
LFC-2.5ES	23.4	1229	4.58	0.2552	1.0341
LFC-5ES	22.0	1236	4.63	0.2183	0.8238
LFC-7.5ES	21.1	1224	4.69	0.2733	0.7808
LFC-10ES	20.9	1231	4.65	0.2474	0.8894
LFC-0ES1CS	25.5	1214	3.99	0.0495	0.2864
LFC-5ES1CS	24.8	1215	4.22	0.0667	0.2989

Note: ¹Actual average amount of foam added during mixing; ²Actual average achieved fresh density controlled within 1200 ± 50 kg/m³

3.2 Dimensional Stability

The dimensional changes of the LFC that cured under tropical indoor and outdoor natural weather are shown in Fig. 2 and Fig. 4 respectively. In contrast, the measured temperature and relative humidity for indoor and outdoor are shown in Fig. 3 and Fig. 5 respectively. Actual foam amount added during mixing, achieved fresh density, and R² value (coefficient of determination) of shrinkage polynomial trendline at the order of 4 are shown in Table 5.

For indoor air curing condition, shrinkage of the specimen generally constantly increases at decreasing rate. It might because the moisture content keeps evaporated and lead to continuous shrinkage. The result also shows that there is some small expansion along the measuring period, and the specimen possesses better sorptivity and initial surface absorption properties namely LFC-0ES1CS and LFC-5ES1CS has greater shrinkage magnitude. It might because the specimen is absorbing the moisture in the air and slightly expands when subjected to higher relative humidity. The specimen with better sorptivity and initial surface absorption properties is less able to absorb moisture in air, therefore, the expansion along the measuring period is limited, hence a larger shrinkage amount is shown.

On the other hand, for outdoor natural tropical weather condition, the result fluctuates, in which the specimen shrink and expand depending on the weather with a larger amount, i.e., less dimensional stable, as compared to the indoor specimen. However, the shrinkage generally increases at decreasing rate at the earlier period as well but tend to maintain at the later age. The shrinkage is due to moisture loss by evaporating moisture content while the expansion is due to moisture gain by absorbing rainwater and air moisture. Similar to indoor specimen, those with better sorptivity and initial surface absorption properties, namely LFC-0ES1CS and LFC-5ES1CS, show around double the shrinkage amount of those without CS as the moisture is more difficult to penetrate in to compensate for some of the moisture loss throughout the measuring period. Moreover, because there is rainwater to compensate for the moisture loss partially, the outdoor specimen obviously experienced a smaller amount of total shrinkage compared to the indoor specimen along the measuring period.

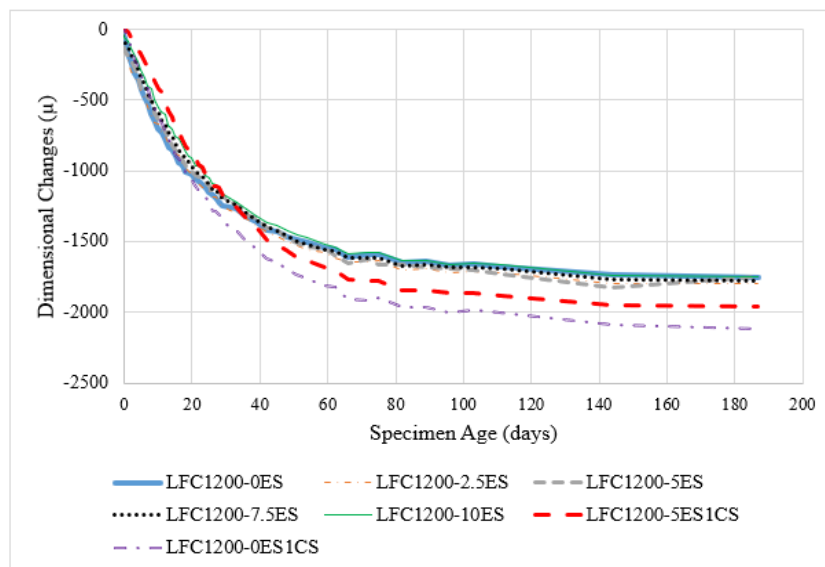


Fig. 2 - Dimensional change of the LFC under the tropical indoor condition

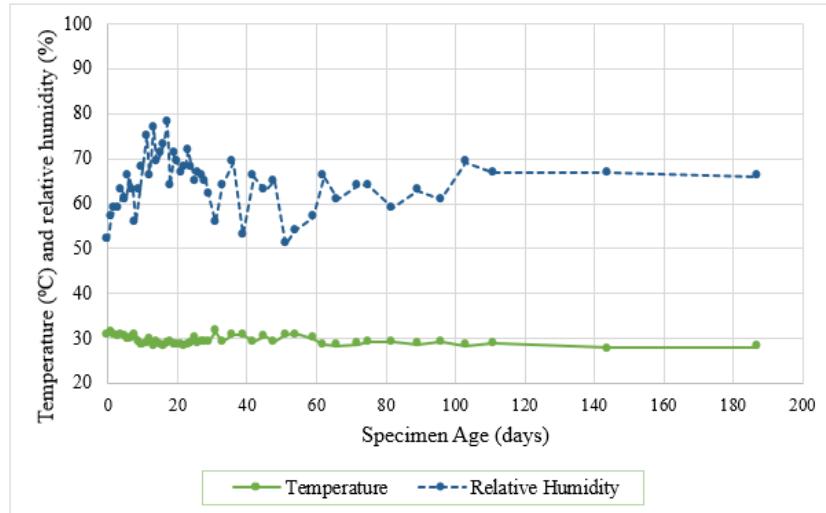


Fig. 3 - Temperature and relative humidity under the tropical indoor condition

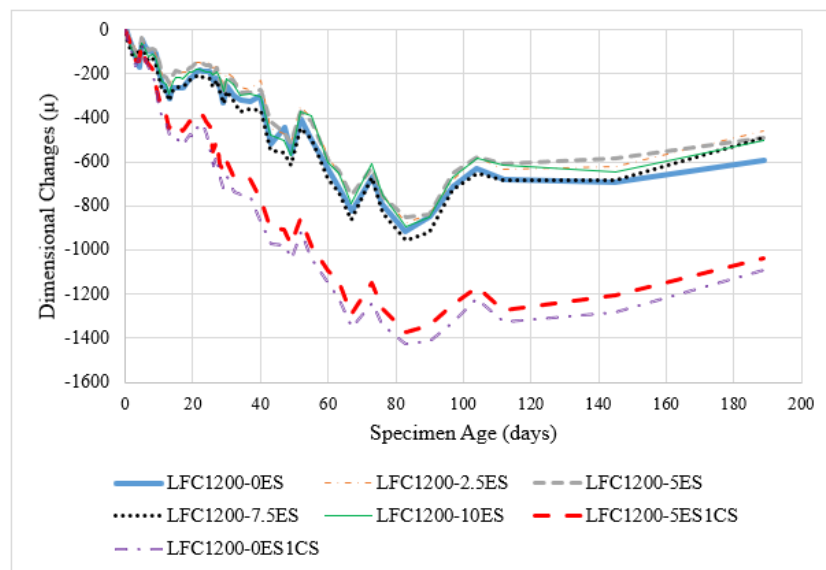


Fig. 4 - Dimensional change of the LFC under the tropical natural weather

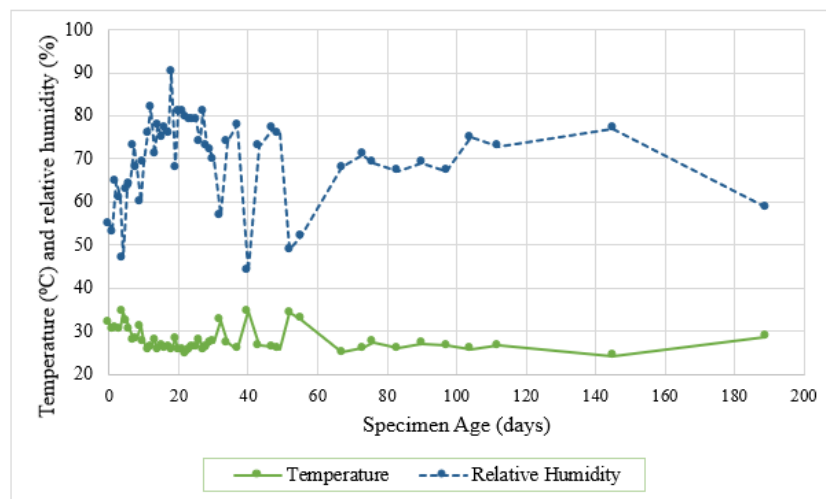


Fig. 5 - Temperature and relative humidity under the tropical natural weather

Both indoor and outdoor result shows that the incorporation of ESP has no obvious trend of changes on the shrinkage curve. However, the incorporation of CS does, which is significantly increase the magnitude of shrinkage strain. This result is contradicting the result obtained by Maryoto et al. [17] that shows reduced shrinkage magnitude with the incorporation of CS. It might because the researchers maintain the relative humidity and temperature of $50\% \pm 4\%$ and 22.8 ± 1.7 °C respectively indoor. Therefore, no absorption of moisture and expansion occur along the measuring period of up to 90 days. Moreover, the evaporation process might be slowed down by CS. Whereas in this study, the relative humidity fluctuates as the specimen was subjected to actual indoor condition, and the specimen with poor water absorption properties tend to absorb moisture to expand or reduce subsequent shrinkage when relative humidity increased, therefore the specimen with CS has larger shrinkage.

However, the large magnitude of shrinkage along the measuring period might not mean that the specimen is less dimensionally stable, as the dimensional stable shall mean that the specimen has smaller dimensional changes as a response to external parameters changes such as temperature and humidity, i.e., less fluctuation on shrinkage line. Hence, the R^2 value is introduced for analysis as the larger R^2 value that nearer to the value of 1 represents that the data are closer to the trendline, i.e., the data has less fluctuation, and it shall mean that the specimen is more dimensionally stable.

As refer to the R^2 value of indoor specimen, the result is closed to each other as the environmental changes are limited and no rainwater. However, as referred to the R^2 value of outdoor specimen, it can be observed that the specimen containing CS achieved a 7.2% higher R^2 value than those without, which means the dimension of the specimen is less fluctuated along the measuring period, which means better dimensional stability. Besides, incorporation of ESP at RL of 2.5% to 7.5% also slightly increase the R^2 value, while the increment is up to 1.56% at RL of 5% In other word, reduced sorptivity and flow result in a higher R^2 value that might represent better dimensional stability, regardless of the total magnitude of dimensional changes.

Table 5 - Actual foam amount, fresh density, and R^2 value of shrinkage polynomial trendline

Reference Name	¹ Foam (kg)	² Density (kg/m ³)	R^2 value of shrinkage polynomial trendline at the order of 4	
			Indoor	Outdoor
LFC-0ES	23.0	1210	0.9945	0.8989
LFC-2.5ES	22.9	1214	0.9970	0.9005
LFC-5ES	23.0	1217	0.9972	0.9129
LFC-7.5ES	23.1	1215	0.9985	0.9038
LFC-10ES	22.4	1223	0.9990	0.8876
LFC-0ES1CS	27.1	1198	0.9977	0.9702
LFC-5ES1CS	25.0	1219	0.9990	0.9719

Note: ¹Actual average amount of foam added during mixing; ²Actual average achieved fresh density controlled within 1200 ± 50 kg/m³

4. Conclusions

Some conclusions could be made according to the results:

- Lightweight foamed concrete containing calcium stearate possesses 7.2% higher dimensional stability compared to those without; for lightweight foamed concrete without calcium stearate, incorporation of eggshell powder at an optimal replacement level of 5% increases dimensional stability by 1.56%.
- The addition of 1% calcium stearate by cement mass reduces compressive strength by 9% but significantly improves sorptivity and initial surface absorption of lightweight foamed concrete by average 79% and 78% respectively.
- Incorporation of eggshell powder as partial cement replacement material at replacement level of up to 10% improves compressive strength, sorptivity, and initial surface absorption of lightweight foamed concrete by up to 7%, 33%, and 57% respectively, and optimal eggshell replacement level is 5%, however, incorporation of eggshell powder slightly decreases sorptivity, and initial surface absorption of lightweight foamed concrete that containing 1% calcium stearate.
- For lightweight foamed concrete subjected to weathering and fluctuated relative humidity and temperature, an improvement on sorptivity and initial surface absorption results in a larger shrinkage amount, however, it results in better dimensional stability.

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