E3S Web of Conferences **65**, 02010 (2018) https://doi.org/10.1051/e3sconf/20186502010
ICCEE 2018

Engineering Properties of 1200 kg/m³ Lightweight Foamed Concrete with Egg Shell Powder as Partial Replacement Material of Cement

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Abstract. This study presents the effects of egg shell powder on lightweight foamed concrete when partially replace the cement. At 2017, 12235 million eggs were consumed and around 85 thousand tonnes of egg shell waste was the yield in Malaysia. The waste might result in an environmental problem if it is not reused properly. Besides, large cement production also results in carbon dioxide emission and depletion of natural limestone. Therefore, studies on effects of egg shell powder on properties of lightweight foamed concrete as partial replacement of cement is attractive to be carried out by aiming to promote the application of lightweight foamed concrete as well as to mitigate the environmental issue by reducing the number of eggshell wastes and pure cement production. The objective of this study is to investigate the effects on engineering properties of lightweight foamed concrete with a fresh density of 1200 ± 50 kg/m³ when the cement is partially replaced by egg shell powder at replacement levels of 0%, 2.5%, 5%, 7.5%, and 10% by mass. The properties of the lightweight foamed concrete studied included workability, stability, compressive strength, flexural strength, water absorption, and sorptivity. The results show that the replacement of egg shell powder reduces the spread diameter, stability, and sorptivity, and improve the compressive and flexural strengths at replacement level of up to 5%. The eggshell powder is feasible to be used as partial cement replacement material for the production of the masonry unit.

1 Introduction

This study investigates on engineering properties of 1200 kg/m³ medium density lightweight foamed concrete (LFC) containing egg shell powder as partial replacement material of cement.

Lightweight foamed concrete, which is a mixture of base mix mortar and foam, can be applied widely and able to reduce building mass and save construction cost, and meanwhile

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promote better thermal and sound insulation [1-3]. However, the application of LFC is still considered unpopular in Malaysia.

Egg shell (ES) waste is produced abundantly; improper disposal of it might cause an environmental issue. As reviewed by Abdulrahman et al. [4], the management of agricultural wastes (included egg shell) is crucial as any kind of waste can become a critical factor for human animals, and vegetation when its concentration is in excess [5]; egg shell contains about 94% of calcium carbonate, 1% of magnesium carbonate, 1% of calcium phosphate, 4% of organic matter, and other insoluble proteins [6-7].

Malaysia consumed 20 million eggs daily in 2011 [8] but the utilization of egg shell is limited. According to the Department of Veterinary Services (DVS) Malaysia, the consumption of eggs is around 11906 million in 2016 and estimated at 12235 million eggs in 2017 in Malaysia [9].

John-Jaja et al. [10] measured the average weight of Bovan Nera Black laying chicken egg weight and egg shell weight at around 60g and 7g respectively. By multiplying the number of egg and egg shell weight, about 85 thousand tonnes of eggshell wastes was yield annually and it will result in an environmental problem [5]. Therefore, studies on eggshell as partial replacement of cement had been carried out to help in mitigating the environmental issue by reducing the eggshell wastes and production of pure cement.

Péra et al. [11] reported that calcium carbonate, which makes up around 94% of egg shell [4,6-7], can accelerate the hydration of tricalcium silicate (C_3S) and cement, the strength of mortar paste that containing 10% calcium carbonate is maintained or even increased; however, the strength is lower with higher calcium carbonate levels. Matschei, et al. [12] also reported that calcium carbonate will act as inert filler and fill pores in concrete and result in decreased porosity and increased strength.

Yerramala [13] and Gowsika et al. [14] studied the properties of concrete with eggshell powder as cement replacement and found that the 5% of replacement level results in optimal compressive strength, but for replacement level beyond 5%, the compressive strength is lower than the control mix.

As reviewed by Bakhtyar et al. [15], around 20 million ton of cement was produced yearly in Malaysia [16] and 0.9 ton of CO_2 is released to the environment with every ton of cement production [17], by simple multiplication, around 18 million ton of CO_2 was found released to the atmosphere yearly by cement industry in Malaysia; also, around 1.4 billion ton of CO_2 emissions were yield directly and indirectly by cement production in 2000, which is around 5% of global anthropogenic CO_2 emissions [18].

Besides, Cembureau [19] reported that around 1.27 ton of limestone is consumed with every ton of cement production. Based on 20 million ton of yearly production of cement [15-16], around 25 million ton of limestone was mined and consumed yearly by the cement industry in Malaysia.

Hence, this study was carried out by aiming to promote the application of LFC in the local construction industry and reduce egg shell waste, CO_2 emission, and mining of lime stone by incorporate egg shell powder to LFC as partial replacement material of cement. The objective of this study is to investigate engineering properties namely workability, stability, compressive strength, flexural strength, water absorption, and sorptivity of the LFC with fresh density of 1200 ± 50 kg/m³ and containing 0%, 2.5%, 5%, 7.5%, and 10% of egg shell powder as replacement material of cement.

2 Experimental procedures

2.1 Materials

Raw materials used for this study included cement, egg shell, sand, water, and foam agent. The cement used is "Buaya" branded Ordinary Portland Cement (OPC) complying with Type I Portland Cement in accordance with ASTM C 150 [20] and MS EN 197-1 [21]; it was sieved through 300 µm to remove all lumps [22] and stored in the moisture-proof container. The egg shell was collected from local food hawkers, washed, oven-dried to remove the moisture, grind and sieve through 63µm and stored in the moisture-proof container. The sand was oven-dried and sieve through 0.6mm; its gradation is shown in Fig. 1. The water used was tap water from the municipal water supply in accordance with ASTM 1602 [23].

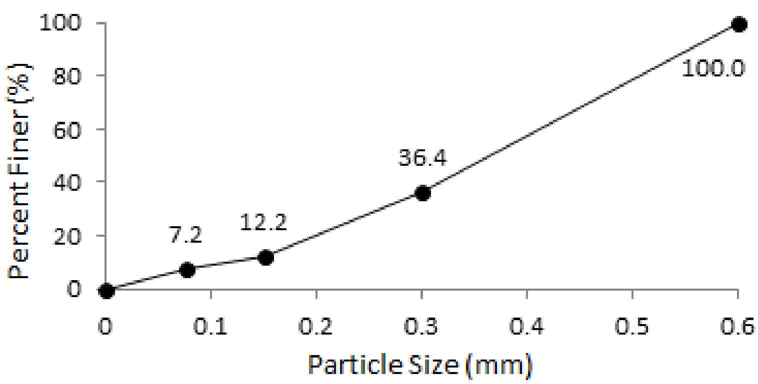

Fig. 1. Gradation of sand.

Petroleum base synthetic detergent was used as a foaming agent. The foam used was pre-formed dry foam that produced by forcing the foaming agent solution, mixture of water and foam agent at ratio of 1:20 in volume, through a series of high density restrictions by compressed air at pressure of 0.5 MPa; it is very stable and has size of smaller than 1mm [2,24].

2.2 Testing methods

The testing method used for this study include inverted slump test, compression, and flexural strength tests, the water absorption test, and sorptivity test.

Inverted slump test was performed as per ASTM C 1611 [25] to determine the workability of foamed concrete. The average spread diameter was measured; larger spread diameter represents higher workability.

The compressive test was conducted as per BS EN 12390-3 [26]. The 100mm concrete cubical specimens were tested at a loading rate of 3 kN/s.

The flexural test was performed using the centre-point loading method as per BS EN 12390-5 [27]. The specimens with 40mm x 40mm cross section were tested at a loading rate of 0.2 kN/s with an effective length of 100mm.

Water absorption (WA) was tested as per BS 1881-122 [28] by using 100 mm cubical specimen. Saturated surface dry (SSD) density was measured after water curing, oven-dried density was measured after one day oven-dried at a temperature of 105 ± 5 °C, then water absorption was calculated by the difference of both density divided by oven-dried density.

Sorptivity test was conducted as per ASTM C 1585 [29] by using 100mm dia. and 50mm height cut cylindrical specimen to determine the rate of absorption (sorptivity) of water that caused by capillary rise when one surface of the specimen contact with water. The cut surface of the specimen was placed on a steel rod and allowed 1 – 3 mm immersed in water. The increment of mass was then recorded at 5, 10, 15, 30, 60, 90, 120, and 150 minutes after the specimen is exposed to water. A graph of absorption (I, mm) was plotted against the square root of time (√t), where the absorption (I), is an increment of mass divided by the cross-sectional area of specimen and density of water of 0.001 g/mm³. The sorptivity was obtained by extracting the slope of the trend lines.

2.3 Mix proportions and screening

The lightweight foamed concrete (LFC) mix proportions and screening results are presented in Table 1 and Fig. 2. Water to cement ratios (w/c) of 0.56, 0.6, and 0.64 were tried on all mentioned replacement level namely 0%, 2.5%, 5%, 7.5%, and 10% to obtain the optimal w/c with optimal strength. Compressive strength with optimal w/c was underlined; with optimal replacement level was bolded.

Table 1. Mix proportions and screening results.

Reference Name	Mix Proportions					Screening Results	
	Cement (kg)	Egg Shell (kg)	Sand (kg)	Water (kg)	Foam (kg)	Hardened Density (kg/m³)	Compressive Strength (28-day, MPa)
LFC-ES 0[1]-0.56[2]	461.3	-	461.3	258.3	19.0	1243	3.04
LFC-ES 2.5-0.56	449.8	11.5	461.3	258.3	19.0	1191	3.34
LFC-ES 5-0.56	438.3	23.1	461.3	258.3	19.0	1238	**4.26**
LFC-ES 7.5-0.56	426.7	34.6	461.3	258.3	19.0	1180	2.17
LFC-ES 10-0.56	415.2	46.1	461.3	258.3	19.0	1229	2.78
LFC-ES 0-0.6	454.4	-	454.4	272.7	18.6	1222	3.97
LFC-ES 2.5-0.6	443.1	11.4	454.4	272.7	18.6	1196	3.34
LFC-ES 5-0.6	431.7	22.7	454.4	272.7	18.6	1212	**4.31**
LFC-ES 7.5-0.6	420.3	34.1	454.4	272.7	18.6	1173	2.55
LFC-ES 10-0.6	409.0	45.4	454.4	272.7	18.6	1161	3.28
LFC-ES 0-0.64	447.7	-	447.7	286.5	18.1	1172	3.40
LFC-ES 2.5-0.64	436.5	11.2	447.7	286.5	18.1	1292	3.28
LFC-ES 5-0.64	425.3	22.4	447.7	286.5	18.1	1203	**3.80**
LFC-ES 7.5-0.64	414.1	33.6	447.7	286.5	18.1	1177	3.14
LFC-ES 10-0.64	402.9	44.8	447.7	286.5	18.1	1180	1.36

Note:
[1] ES 0 or ES 2.5 = 0% or 2.5% of egg shell powder was replaced the cement by mass
[2] water to cement ratio (w/c)

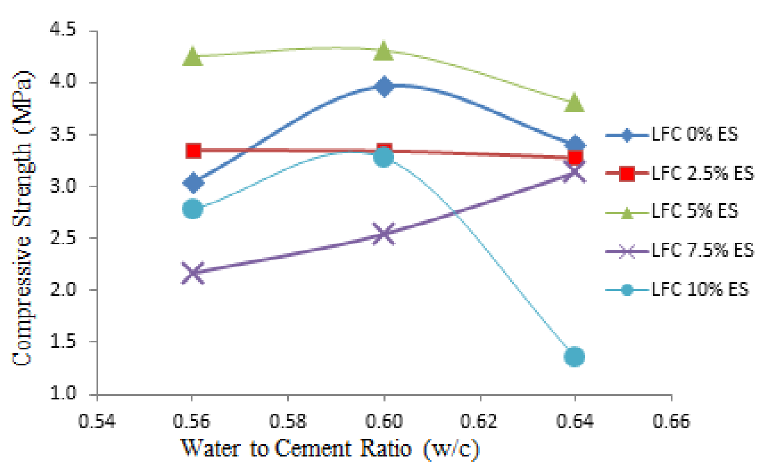

Fig. 2. Compressive strength results of screening mixtures.

Based on the compressive strength results, optimal replacement level is 5%; optimal w/c is 0.6 for most of the replacement levels namely 0%, 2.5%, 5%, and 10%. Hence, w/c of 0.6 is selected for further investigation on the effect of egg shell powder on the LFC.

3 Results and discussion

3.1 Workability and Stability

The result of the spread diameter and stability are shown in Table 2.

Table 2. Spread diameter and stability of the lightweight foamed concrete.

Reference Name	Spread Diameter (mm)	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Stability
LFC-ES 0-0.6	595	1214	1220	1.00
LFC-ES 2.5-0.6	575	1220	1197	1.02
LFC-ES 5-0.6	550	1222	1210	1.01
LFC-ES 7.5-0.6	550	1208	1190	1.02
LFC-ES 10-0.6	525	1216	1168	1.04

Note: Stability = proportion of measured fresh density to measured hardened density [30].

Spread diameter decreased with increased replacement level; therefore egg shell required more free water to achieve the same workability. Fresh density and hardened density measured on 100mm cubical specimens were fallen within the targeted density of 1150 to 1250 kg/m³. Stability decreased with increased replacement level; hence, larger fresh density is required to achieve same hardened density.

3.2 Compressive strength

Hardened density, compressive strength, and performance index (PI) of the lightweight foamed concrete with various replacement levels at various testing ages are shown in Table 3. Optimal strength was underlined and the 28-day result was bolded.

Table 3. The compressive strength of the lightweight foamed concrete.

Reference Name	Testing Age (day)	Hardened Density (kg/m³)	Compressive Strength (MPa)	Percentage of Corresponded 28-day Compressive Strength (%)	PI (MPa/1000kg/m³)
LFC-ES 0-0.6	7-day	1217	<u>3.53</u>	89	<u>2.90</u>
	28-day	**1222**	**3.97**		**3.25**
LFC-ES 2.5-0.6	7-day	1198	3.18	95	2.65
	28-day	**1196**	**3.34**		**2.80**
LFC-ES 5-0.6	7-day	1208	3.37	78	2.79
	28-day	**1212**	**<u>4.31</u>**		**<u>3.56</u>**
LFC-ES 7.5-0.6	7-day	1206	2.42	95	2.01
	28-day	**1173**	**2.55**		**2.17**
LFC-ES 10-0.6	7-day	1175	2.70	83	2.30
	28-day	**1161**	**3.28**		**2.82**

Note: PI represents performance index, calculated by strength divided by hardened density

It was found that the optimal replacement level is 5% for the 28-day result but is 0% for the 7-day result. It might because the replacement of egg shell had diluted the C_3S content that hardens rapidly and largely responsible for initial set and early strength; also, the egg shell might react slower in hydration process; hence the early strength was reduced with replacement level. However, at 28-day, the compressive strength was improved when the replacement level increased to up to 5%, but reduce thereafter to lower than the strength at 0% replacement level. Besides, the LFC was found has high early strength, which is around 78% to 95% of 28-day strength.

In addition, the compressive strength of the specimens with replacement levels of 0% to 5% had fulfilled the strength requirement of 2.8 MPa as a normal block as accordance to MS 76: 1972 [31].

3.3 Flexural strength

Hardened density, flexural strength, and performance index (PI) of the lightweight foamed concrete with various replacement levels at various testing ages are shown in Table 4. Optimal strength was underlined and the 28-day result was bolded. The relationship between 28-day flexural strength and corresponded compressive strength of the lightweight foamed concrete is shown in Fig. 3.

Table 4. Flexural strength of the lightweight foamed concrete.

Reference Name	Testing Age (day)	Hardened Density (kg/m³)	Flexural Strength (MPa)	Percentage of Corresponded 28-day Flexural Strength (%)	PI (MPa/1000kg/m³)
LFC-ES 0-0.6	7-day	1187	2.797	100	2.36
	28-day	**1158**	**2.803**		**2.42**
LFC-ES 2.5-0.6	7-day	1148	2.553	91	2.22
	28-day	**1124**	**2.806**		**2.50**
LFC-ES 5-0.6	7-day	1182	2.798	96	2.37
	28-day	**1168**	**2.900**		**2.48**
LFC-ES 7.5-0.6	7-day	1162	2.149	101	1.85
	28-day	**1136**	**2.135**		**1.88**
LFC-ES 10-0.6	7-day	1158	2.035	96	1.76
	28-day	**1142**	**2.126**		**1.86**

Note: PI represents performance index, calculated by strength divided by hardened density

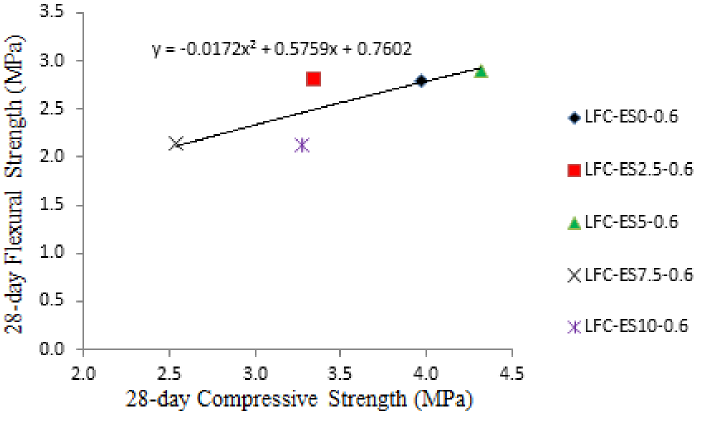

Fig. 3. The relationship between Flexural Strength and Compressive Strength.

It was found that the optimal replacement level is 5%, but the 7-day result for 5% replacement level is very close to that of 0% replacement level. As mentioned in section 3.2, it might because the egg shell dilutes C_3S content and might reacts slower in hydration process; hence there is no significant change in 7-day strength when replacement level increased from 0% to 5%. However, 28-day strength has increment when replacement level increased from 0% to 5%. Then, when the replacement level increased from 5% onward, the strength is reduced and is lower than the strength at 0% replacement level. Besides, the LFC was found has high early flexural strength, which is above 90% of 28-day strength.

The flexural strength was increased with corresponded compressive strength at a decreasing rate. The ratio of flexural strength to the corresponded compressive strength was found 68% to 83% as calculated by using the equation of trend line as shown in Fig. 3, for compressive strength between 2.55 MPa and 4.31 MPa.

3.4 Water Absorption

Water absorption results of the lightweight foamed concrete with various replacement levels at various testing ages are shown in Table 4. It was found no significant trend of changes in water absorption with different replacement level.

Table 5. Water absorption of the lightweight foamed concrete.

Reference Name	Testing Age	Hardened Density (kg/m³)	SSD Density (kg/m³)	Oven-Dried Density (kg/m³)	WA (%)
LFC-ES 0-0.6	7-day	1217	1271	1046	21.5
	28-day	**1222**	**1377**	**1087**	**26.7**
LFC-ES 2.5-0.6	7-day	1198	1238	1031	20.1
	28-day	**1196**	**1332**	**1037**	**28.4**
LFC-ES 5-0.6	7-day	1208	1243	1035	20.1
	28-day	**1212**	**1345**	**1053**	**27.7**
LFC-ES 7.5-0.6	7-day	1206	1241	1035	19.9
	28-day	**1173**	**1276**	**1003**	**27.2**
LFC-ES 10-0.6	7-day	1175	1210	1008	20.1
	28-day	**1161**	**1280**	**993**	**29.0**

Note: SSD = Saturated surface dry;
WA = Water absorption = (SSD Density - Oven-Dried Density) / Oven-Dried Density × 100%

3.5 Sorptivity

Sorptivity results of the lightweight foamed concrete with various replacement levels at testing ages of 28-day are shown in Fig. 4. Pitroda and Umrigar [32] reported that sorptivity shall be less than 6 mm/hr$^{0.5}$, which is equivalent to 0.774 mm/min$^{0.5}$, for laboratory concrete in order to fulfil the acceptable limits for durability index. Tiong et al. [33] also found that the lightweight foamed concrete containing steel slag and super-plasticiser with a density of 1600 ± 75 kg/m³ has sorptivity of 0.18 mm/min$^{0.5}$ to 0.43mm/min$^{0.5}$.

The results show that the sorptivity is decreased with the increased egg shell replacement level. Therefore, egg shell might act as inert filler and be able to reduce the capillary pore in concrete. By extracting the slope of trend lines in Fig. 4, 28-day sorptivity of the lightweight foamed concrete specimens with 0%, 2.5%, 5%, 7.5%, and 10% of egg shell replacement levels are 0.357 mm/min$^{0.5}$, 0.332 mm/min$^{0.5}$, 0.322 mm/min$^{0.5}$, 0.318 mm/min$^{0.5}$, and 0.278 mm/min$^{0.5}$ respectively. The results are lower than 0.774 mm/min$^{0.5}$; hence, sorptivity of these mixtures are in the acceptable range for durability index.

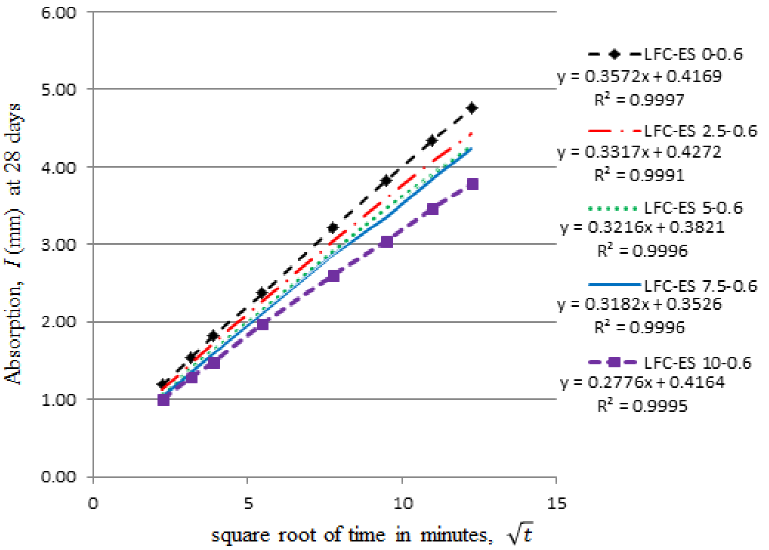

Fig. 4. Sorptivity of the lightweight foamed concrete at the testing age of 28 days.

4 Conclusions

Engineering properties of the lightweight foamed concrete with a density of 1150 kg/m³ to 1250 kg/m³ have been studied, in which cement was partially replaced by egg shell powder at various replacement level, namely 0%, 2.5%, 5%, 7.5%, and 10%. Some conclusions can be drawn as below:

1. The workability and spread diameter of the lightweight foamed concrete mixtures decreased with increased egg shell powder replacement level.
2. Egg shell powder reduces the early strength of the lightweight foamed concrete, i.e. 7-day compressive strength. However, the 28-day compressive and flexural strengths of the lightweight foamed concrete improved with increased egg shell replacement level of up to 5%.
3. The compressive strength of the lightweight foamed concrete with 0% to 5% egg shell replacement level achieves the minimum strength of 2.8 MPa for masonry application.
4. Egg shell powder has no significant trend of effect on water absorption of the lightweight foamed concrete.
5. Sorptivity of the lightweight foamed concrete improved with egg shell replacement level of up to 10% and is within the acceptable range for durability index.

The support provided by Universiti Tunku Abdul Rahman (UTAR) in the form of a research grant (Vote No. 6200/LL4) and effort of UTAR civil engineering students on laboratory work for this study are very much appreciated.

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