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## Compressive strength prediction of lightweight foamed concrete with various densities

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**Abstract.** A research has been undertaken to study the compressive strength of foamed concrete with various concrete density. This paper reports experimental investigation on lightweight foamed concrete of 300, 600, 800 and 1000 kg/m<sup>3</sup> densities and correlates compressive strength and density for further strength prediction. A total of 72 foamed concrete cubes with various densities and water cement ratio were prepared and tested for compressive strength at the concrete age of 7 and 28 days. Inverted slump and flow table spread value were obtained based on the test method stated in ASTM C1611. The foams were produced by using foam generator by mixing them with cement mortar (Ordinary Portland Cement, OPC and dry sand of size 850 $\mu$ m). The experimental results showed the highest compressive strength was recorded as 2 MPa for the density of 1000kg/m<sup>3</sup> and water cement ratio of 0.6. The results revealed that consistency of the foamed concrete is in the range of 0.97 to 1.03, whereas stability index is in the range of 0.98 to 1.19 which showed the bubbles in the foamed concrete were stable during casting and curing process. A prediction model with exponential equations were proposed for foamed concrete compression strength with different water-cement ratio and it can be preliminary used to predict the foamed concrete strength.

### 1. Introduction

In construction, self-weight of concrete represents large proportion to the total dead load on the structure. Foamed concrete is known as a lightweight, cellular concrete made by infusing a fresh concrete mixture with prepared foams or by generating bubbles within the mixture. Lightweight concrete is important and give advantages in reducing the total weight of a structure. The density of the foamed concrete usually varies from 300 kg/m<sup>3</sup> to 1800 kg/m<sup>3</sup>. Increasing amount of foams the concrete mixture can reduce the density of the foamed concrete. The main advantage of using lightweight foamed concrete is to reduce the weight of the structure by using low density concrete, thus eliminate heavy foundation system; and no compaction is needed as foamed concrete does not settle easily and it is free flowing, self-levelling to spread itself to fill all voids. Usage of foamed concrete eliminated vibration or compaction work on concrete, reduce usage of workers and speed up construction time.

Moreover, study by (Sach & Seifert, 1999) showed lightweight foamed concrete has improved thermal insulation, high flowability and high shock absorbing qualities, which are beneficial to building structure. However, it is showed that the compressive strength of foamed concrete is related to its concrete density and the foam volume. A reduction in density exponentially and adversely affects the compressive strength (Nambiar *et al.*, 2006; Cong & Chen, 2015). For an example, foamed concrete with densities of 600, 1000 and 1400 kg/m<sup>3</sup> had 28-days compressive strength of 0.5, 2.9 and



8.1 MPa respectively (Hamida *et al.*, 2005). In other words, the compressive strength of foamed concrete appeared to decrease with an increase in foam volume. This is because the foaming agent create artificial bubble in the mortar mix that caused air void in the hardened concrete to reduce the density of foamed concrete. However, too much air-void occurred in the foamed concrete might increase the porosity of the concrete and easily broken and fail once loading is applied. Lightweight foamed concrete is low in strength due to presence of void in the concrete. Therefore, it is less suitable to be used for structural purpose. An experimental work is conducted to investigate the performance of lightweight foamed concrete with various concrete densities. It is necessary to develop a mixture design that can increase the strength of foamed concrete for structural purpose. The main purpose of this research is to study the compressive strength of lightweight foamed concrete with 300, 600, 800 and 1000 kg/m<sup>3</sup> densities, and to develop a prediction model for the strength of foamed concrete.

In this study, the foamed concrete is prepared by mixing of Ordinary Portland Cement (OPC), sand, water and foams. The target densities of foamed concrete are 300, 600, 800 and 1000 kg/m<sup>3</sup>. The foams were generated by using foam generator (30-32 lit/min). The proportion of cement-sand ratio as 1:1 while water-cement ratio (w/c) were set at 0.4, 0.5 and 0.6. Foaming agent is diluted with water in a ratio of 1:25. All the foamed concrete samples were cured in water and tested for 7 days and 28 days with total of 6 samples for each mix design. The concrete are tested for their fresh properties, such as flow table test that based on ASTM C1437 (ASTM, 2015) and inverted slump test that based on ASTM C1611 (ASTM, 2014). The compression test was conducted in accordance to BS EN 12390-3 (BSI, 2001) to obtain compressive strength of foamed concrete. The results obtained from the tests were recorded and analysed.

## 2. Mix Design and Sample Preparations

Lightweight foamed concrete (LFC) was produced based on the mixture of base mix and stable foams. The water cement ratio for each type of mix proportion was prepared at 0.40, 0.50 and 0.60. Densities of LFC were based on 1 m<sup>3</sup> volume with the selection of targeted density of 300, 600, 800 and 1000 kg/m<sup>3</sup>. The sieved sand with particle size passing through 850 µm opening was used as fillers to produce cement mortar. The cement-sand ratio for base mix was kept to the ratio of 1:1. The foaming agent used to produce the stable foam is diluted with water in a ratio of 1:25. The cube samples were prepared in size of 100×100×100 mm.

Table 1 shows the proportion of material mix in the experiment. Preparation of foamed concrete consists of three stages where first stage is to obtain uniform base mix of OPC, sand and water; the second stage is the adding of foams to the base mix. Before the foams were added, flow table test was conducted for base mix mortar to check the workability of the fresh mortar. Flow table test was accordance with ASTM C1437-01. After that, foams were added into the base mix in accordance to the calculated amount until the base mix achieved the desired densities for 300, 600, 800 and 1000 kg/m<sup>3</sup>. Fresh foamed concrete was poured into a known 1 litre container and weighted to check for the required designated density. After that, inverted slump test was carried out before fresh lightweight foamed concrete was poured into the mould. The inverted slump test was carried out by using a slump cone and flat base plate as complied with ASTM C1611 (2014). Avoid any vibration or compaction once casting that can cause the bursting of air bubbles. The mould was removed after left overnight for 24 hours and cured under water until the respective testing age for 7 days and 28 days.

**Table 1.** Proportion of material mix in the experiment

Sample Type	sand/ cement	water/ cement	Target Density (kg/m <sup>3</sup> )	Fresh density (kg/m <sup>3</sup> )	Consistency	Hardened density (kg/m <sup>3</sup> )	Stability
LFC300-1	1:1	0.40	300	290	0.97	295	0.98

LFC600-1		600	600	1.00	595	1.01
LFC800-1		800	810	1.01	740	1.09
LFC1000-1		1000	990	0.99	930	1.06
LFC300-2		300	310	1.03	260	1.19
LFC600-2	0.50	600	590	0.98	580	1.02
LFC800-2		800	810	1.01	750	1.08
LFC1000-2		1000	1000	1.00	950	1.05
LFC300-3		300	300	1.00	250	1.20
LFC600-3	0.60	600	590	0.98	560	1.05
LFC800-3		800	780	0.98	740	1.05
LFC1000-3		1000	995	1.00	960	1.04

### 3. Fresh Properties and Hardened Properties

Flow table test was accordance with ASTM C1437-01. Flow table test or flow test is a method to determine the consistence of fresh concrete. Flow table test must be wetted. The cone was placed on the flow table and filled with concrete in two layers and each later with 20 times tamp with tamping rod. Scrap away excess mortar above the mould. After lifting the mould, the table was jolted 25 times in 15 sec and the average spread diameter from the edges was recorded.

The inverted slump test was carried out by using a slump cone and flat base plate as complied with ASTM C1611 (2014). The slump test carried out is to determine the consistency of concrete. The consistency indicates how much water has been used in the mix and the stiffness of the concrete mix should be matched with the requirement for the finished product quality. Slump cone was inverted and placed at the center of the flat base plate and filled with fresh lightweight concrete until it was fully filled. Excessive fresh lightweight foamed concrete was removed, and the inverted slump cone was lifted up to allow the foamed concrete to spread freely. The spread diameter was measured and recorded by using measuring tape at different four angle dimension. Average value of the data was taken to get know the fluidity consistency of the fresh foamed concrete.

The compression test is carried out on cube samples at 7 and 28 days curing period. The cubes were taken out from water tank and left it for air-dry for two hours before testing. The compressive strength test was performed accordance to BS EN 12390-3 by using a universal compression test machine with a constant pace rate of 0.1 kN/s. The compressive strength was obtained based on the average of three crush cubic specimens. The results obtained from flow table, inverted slump and compression tests are summarized in Table 2.

**Table 2.** Properties of foamed concrete

Specimens	w/c ratio	Flow table spread (cm)	Inverted slump spread (mm)	Compressive Strength (MPa)	
				7 Days	28 Days
LFC- 300-1		15.09	480.25	0.017	0.009
LFC- 600-1	0.4	17.13	461.25	0.026	0.047
LFC- 800-1		17.50	450.10	0.039	0.048
LFC- 1000-1		17.73	435.00	0.092	0.171
LFC- 300-2		25.00	639.75	0.022	0.019
LFC- 600-2	0.5	>25.00	534.50	0.111	0.238
LFC- 800-2		>25.00	563.75	0.263	0.483
LFC- 1000-2		>25.00	534.40	0.888	1.676

LFC- 300-3		>25.00	726.25	0.021	0.026
LFC- 600-3	0.6	>25.00	586.25	0.195	0.375
LFC- 800-3		>25.00	651.25	0.354	0.551
LFC- 1000-3		>25.00	627.00	1.132	2.011

#### 4. Discussion

Figure 1 shows the surface condition of LFC with different concrete density. More volume are presented in the concrete and eventually affect the strength of lightweight foamed concrete. Figure 2 shows the relationship between the compressive strength and density of LFC as per in the context of this study. The strength of the concrete increase exponentially with the increment of concrete density. The concrete strength reduces when the amount of foam increases. The lightweight foamed concrete become brittle and easily broken with large volume of foaming agent added into base mix.

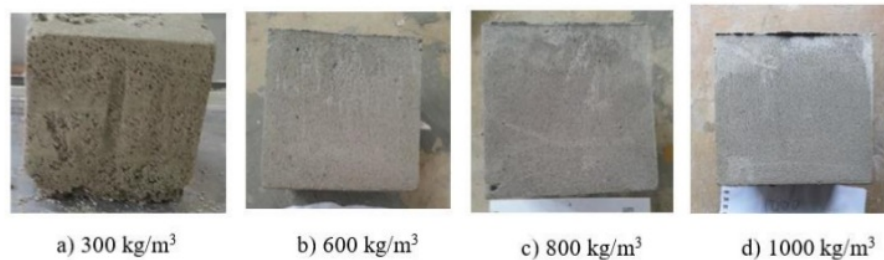


Figure 1. Surface condition of LFC with different density

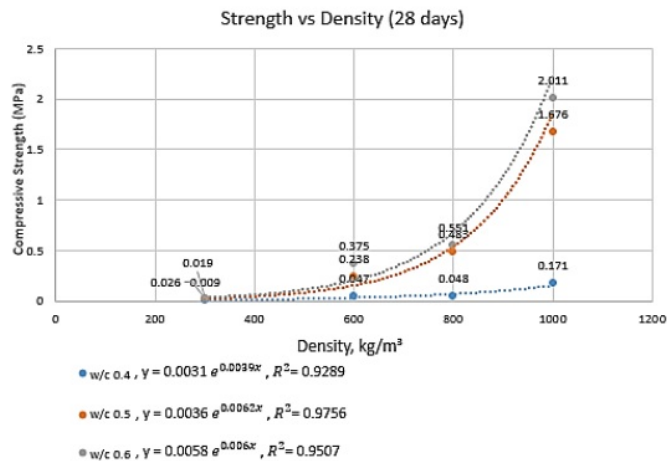


Figure 2. Strength prediction of foam concrete

On the other hand, the water-cement ratio also plays an important role in concrete strength where the higher water content (0.6) shows the highest compressive strength as compared to 0.4 and 0.5. Water cement ratio of 0.40 for 300 kg/m³ to 1000 kg/m³ with the compressive strength in between 0.009 MPa to 0.171 MPa. Water cement ratio of 0.50 for 300 kg/m³ to 1000 kg/m³ with the compressive strength in between 0.019 MPa to 1.676 MPa. Water cement ratio of 0.60 for 300 kg/m³ to 1000 kg/m³ with the compressive strength between 0.026 MPa to 2.011 MPa. The result shows the

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water cement ratio of 0.5 and 0.6 is more suitable to be used in preparation of base mix for LFC as the highest compressive strength was obtained.

The developed equations were obtained from the curve-fitting of current experimental data which are valid within the limitations of the studied range of concrete densities and water-cement ratio for concrete age of 28 days. The trends of the graphs as shown in Figure 2 are following the exponential behaviour of general expression of Eq. 1.

$$y = ae^{bx} \quad (1)$$

Where y represents the concrete compression strength, x is the densities, a and b are the equation constants of different water-cement ratio. With high R<sup>2</sup> values, it is believed that the prediction model is validly proposed. The increment of water-cement ratio has gradually increased the concrete strength of same density category. These proposed equations can be preliminary used to predict the concrete strength.

## 5. Conclusion

In this research work, prediction equations for foamed concrete compression strength were proposed based on a developed experimental program. The prediction model has general expression in exponential curve. The equation constants are increased as the water-cement ratio increased. These equation can be preliminary predicting the concrete strength of foamed concrete with limitations of similar concrete materials were applied.

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## Acknowledgement

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