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Effect of Specimen Shape and Size on the Compressive Strength of Foamed Concrete

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Abstract - Lightweight concrete, in the form of foamed concrete, is a versatile material that primarily consists of a cement based mortar, mixed with at least 20% volume of air. Its dry density is typically below 1600 kg/m^3 with a maximum compressive strength of 15MPa. The ASTM standard provision specifies a correction factor for concrete strength of between 14 and 42Mpa, in order to compensate for a reduced strength, when the aspect height-to-diameter ratio of a specimen is less than 2.0. However, the CEB-FIP provision specifically mentions a ratio of 150mm dia. x 300mm cylinder strength to 150 mm cube strength; though, both provision requirements do not specifically clarify the applicability and/or modification of the correction factors for the compressive strength to lightweight concrete (in this case, foamed concrete). The focus of this work is to study the effect of specimen size and shape on the axial compressive strength of concrete. Specimens of various sizes and shapes were cast with square and circular cross-sections i.e., cubes, prisms, and cylinders. Their compression strength behaviours at 7 and 28 days were investigated. The results indicate that, as the CEB-FIP provision specified, even for foamed concrete, 100mm cubes (l/d = 1.0) produce a comparable compressive strength with 100mm dia. x 200mm cylinders (l/d = 2.0).

1 Introduction

The differences between the types of lightweight concrete are particularly related to the aggregate grading used in the mixes. Foamed concrete is a type of porous concrete and referring to its features and use; it is quite similar to aerated concrete [1]. Lightweight concrete (or foamed concrete) is a versatile material that primarily consists of a cement based mortar, mixed with at least 20% volume of air. The characteristics of foamed concrete include high flowability, low self-weight, comparable compressive strength, and good thermal insulation properties. Its dry density is typically below 1600 kg/m^3 with a maximum compressive strength of 15MPa [2]. Typically, foamed concrete does not contain coarse aggregate, and is made by introducing a certain amount of air and fine sand into a cement slurry. Typical applications of foamed concrete (based on its fresh densities) include:

1. Density 300-600 kg/m^3 – used for tennis courts and inter-space filling between brickwork leaves in underground walls, insulating in hollow blocks, and any other situation where high insulating properties are needed. Other applications include roofs and floors; used as insulation against heat and sound.

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2. Density 600-900 kg/m^3 – used for the manufacture of precast blocks and panels for thermal insulation, soundproofing screed in multi-level residential and commercial buildings, curtain walls and partitions, and soffit of floor slabs as false ceiling.
3. Density 900-1200 kg/m^3 – used in concrete blocks and panels for architectural ornamentation, as well as partition walls, toppings of concrete slabs for roofing and floor screeds.
4. Density 1200-1600 kg/m^3 – used in lightly loaded structural concrete applications.

Generally, concrete compressive strength decreases with an increasing specimen section size. Meanwhile, a decreasing rate remains almost constant beyond a certain size limit. Cube compressive strength is normally higher than that measured from a cylinder, but the effect of specimen shape on the size effect is somewhat indecisive [3]. Therefore, ASTM standards specify a correction factor for concrete strength of between 14 and 42Mpa, in order to cover the decrease in strength; when the aspect ratio (height-to-diameter ratio) of the specimen is less than 2.0. Meanwhile, the CEB-FIP standard specifically mentions a ratio of 150 x 300mm cylinder strength to 150mm cube strength; though both standard requirements do not particularly explain the applicability and/or modification of the correction factors for the compressive strength to lightweight concrete [4].

This proposed laboratory work is intended to study the effect of specimen size and shape on the axial compressive strength of concrete. Specimens of various sizes and shapes were cast with square and circular cross-sections i.e., cubes, prisms, and cylinders; to investigate their compression strength behaviour at 7 and 28 days. Hypothetically, compressive strength will decrease with an increase of concrete specimen size, and cube shaped concrete specimens will yield comparable compressive strength to cylinders (100mm cube to 100mm dia x 200mm cylinder).

2 Experimental Works

2.1 Materials and mix design

Foamed concrete mixes, with a target dry density of 1250kg/m^3, were prepared containing Ordinary Portland Cement (OPC), sand (as fine aggregate), water, and stable foam. Three batches of mix were prepared for three types of samples with various sizes and shapes.

Table 1. Mix 1 for sample A

Volume, m^3	0.15
Target dry density, kg/ m^3	1250
Wet and dry density difference, kg/ m^3	+140
Wet density, kg/ m^3	1390
Solid mass, kg	208.5
Estimate foam mass, kg	3.59
Actual mass, kg	204.91
Mix ratio (C:S:W)	1:2.5:0.45 = 3.95
Cement mass, kg	51.88
Sand mass, kg	129.69
Water mass, kg	23.45
Water (during mixing), kg	7.3
Total mortar mass, kg	212.32
Slump	22cm
Mortar measured, kg/ m^3	2150
Mortar volume, m^3	0.099
Estimate foam volume, m^3	0.051
Foamed mix density, kg/ m^3	1420

Table 2. Mix 2 for sample B

Volume, m^3	0.03
Target dry density, kg/ m^3	1250
Wet and dry density difference, kg/ m^3	+140
Wet density, kg/m^3	1390
Solid mass, kg	41.7
Estimate foam mass, kg	0.72
Actual mass, kg	40.98
Mix ratio (C:S:W)	1:2.5:0.45 = 3.95
Cement mass, kg	10.37
Sand mass, kg	25.94
Water mass, kg	4.67
Add water (during mixing), kg	1.5
Total mortar mass, kg	42.48
Slump	22cm
Mortar measured, kg/ m^3	2150
Mortar volume, m^3	0.02
Estimate foam volume, m^3	0.01
Foamed mix density, kg/ m^3	1440

Table 3. Mix 3 for sample C

Volume, m^3	0.05
Target dry density, kg/m^3	1250
Wet and dry density difference, kg/ m^3	+140
Wet density, kg/ m^3	1390
Solid mass, kg	69.5
Estimate foam mass, kg	1.20
Actual mass, kg	68.3
Mix ratio (C:S:W)	1:2.5:0.45 = 3.95
Cement mass, kg	17.29
Sand mass, kg	43.23
Water mass, kg	7.78
Add water (during mixing), kg	1.9
Total mortar mass, kg	70.2
Slump	22cm
Mortar measured, kg/m^3	2150
Mortar volume, m^3	0.033
Estimate foam volume, m^3	0.017
Foamed mix density, kg/m^3	1430

Note 1:

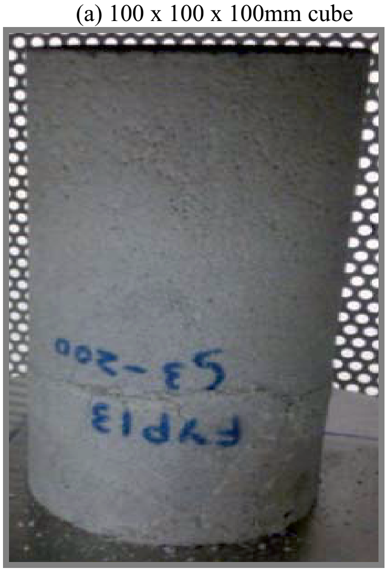
i. *Target dry density for all mixes was 1250kg/m^3.*
ii. *Cement-sand-water ratio for all mixes was 1:2.5:0.45.*
iii. *Foam liquid to water ratio was 1:30 for all mixes.*
iv. *Slump for slurry (mortar) should be in the range 22-25mm.*
v. *Wet density should be 140/150kg/m^3 higher than the target dry density.*

2.2 Specimens

Three different sample types were prepared consisting using (a) different specimen shapes (i.e., cubes, prisms, and cylinders), with l/d of 1.0 and 2.0, (b) same specimen size with different shapes, and (c) different cube specimen sizes and shapes; but with l/d = 1.0. Figure 1 shows an example of the samples prepared using different shapes and sizes.

(a) 100 x 100 x 100mm cube

(b) 100 x 100 x 200mm prism



(c) 100dia x 200mm cylinder

(d) 45dia x 100mm cylinder

Figure 1. Examples of the prepared samples

2.3 Curing

After de-moulding, samples were wrapped with a plastic sheet in air-tight conditions (as shown in Figure 2). Samples were unwrapped on day 6 (7 day strength) and day 27 (28 day strength) and further oven dry cured for another 24-hours (at 100-110°C) prior to testing.

Figure 2. Samples wrapped in plastic sheet for curing

3 Results and Discussions

The compression test was carried out in accordance with MS 26: Part 2: 1991. Testing was conducted using GOTECH GT-7001-BS300 (Figure 3), a closed-loop servo-hydraulic dynamic with a 3OOtan-capacity compression machine, with a loading rate of 0.3N/(mm^2.s).

Figure 3. GOTECH GT-7001-BS300, with a 300tan-capacity compression machine.

Table 4. Experimental results for samples A, B, and C.

Shape	Section, mm	Height, mm	Dry density, kg/m^3	Max load, kN	Compressive strength, kN/mm^2
Sample A (28 days test)					
Cube	100 x 100	100	1200	43.94	4.39
Prism		200	1189	36.68	3.67
Cylinder	100 (dia)	100	1223	30.64	3.90
		200	1267	36.22	4.61
Sample B (28 days test)					
Cube	40 x 40	50	1173	7.82	4.89
Prism		100	1230	8.00	5.00
Cylinder	43.0 (dia)	50	1190	6.80	4.68
	43.4 (dia)	100	1187	7.56	5.11
Sample C (7 days test)					
Cube	50 x 50	50	1216	8.38	3.35
	100 x 100	100	1209	40.01	4.00
	150 x 150	150	1179	78.89	3.51

Table 5. Compressive strength comparison between samples A

Sample A	Cube	Prism	Cylinder, d=100mm	Cylinder, d=200mm
Cube, d=100mm		+16.4%	+11.2%	-5.0%
Prism, d=200mm	-19.6%		-6.3%	-25.6%
Cylinder, d=100mm	-12.6%	+5.9%		-18.2%
Cylinder, d=200mm	+4.8%	+20.4%	+15.4%	

Table 6. Compressive strength comparison between samples B

Sample B	Cube	Prism	Cylinder, d=50mm	Cylinder, d=100mm
Cube, d=100mm			+4.3%	-4.5%
Prism, d=200mm			+6.4%	-2.2%
Cylinder, d=50mm	-4.5%	-6.8%		
Cylinder, d=100mm	+4.3%	+2.2%		

Table 7. Compressive strength comparison between samples C

Sample C	Cube, 50mm^3	Cube, 100mm^3	Cube, 150mm^3
Cube, 50mm^3		-19.4%	-4.8%
Cube, 100mm^3	+16.3%		+12.3%
Cube, 150mm^3	+4.6%	-14.0%	

From Table 5, there is 16.4% compressive strength reduction, when the l/d ratio of cube and prism increased from 1.0 to 2.0; however, for cylinder, the strength became 15.4% higher for the same l/d ratio. By referring to the CEB-FIP standard of comparison, when 100 x 100 x 100mm cube (l/d = 1.0) was compared to 100dia x 100mm cylinder (l/d = 2.0), there was only 5% difference in strength; which could be treated as a margin of error during sample preparation, curing, or testing.

By reducing the effective cross-sectional area difference between cube (prism) and cylinder during testing, a useful comparison can be made on the effect of specimen shape to its compressive strength [5]. The initial target cross-sectional area for cylinder was a 45mm diameter (1590mm^2), compared with 40 x 40mm (1600mm^2) cube. However, due to the frictional loss of the surface area during the curing process of 100 x 100 x 500mm prism to obtain a 45dia. x 50mm and 100mm cylinder, the effective cross-sectional cylinder tested gave an average of 43.5mm (1486mm^2). Nonetheless, as Table 4 shows, cube (and prism) were able to exhibit a higher loading than cylinder by 13.0%; if both depths were 50mm; but reduced to 5.5% when the depth was 100mm (see Table 6).

According to Tokyay et al. [6], compressive strength decreases as sample size increases. However, as Table 7 shows, for foam concrete, cube with a 100mm size had the highest compressive strength of all. Meanwhile, the 150mm cubes produced a higher compressive strength than that of the 50mm cube. For this reason, that size of test cube should be more representative, and the 50 mm cube seems to be unsuitable for testing the compressive strength of foam concrete.

4 Conclusions

The effect of size and shape (i.e., section shape and aspect ratio) of a specimen on the foamed concrete compressive strength was examined according to a unit weight of 1250kg/m^3. From the experimental test results, the following conclusions may be derived:

1. The cylinder specimen indicated a small change in compressive strength (f_{cu}) when the l/d ratio changed from 1.0 to 2.0; compared to cubes. In fact, f_{cu} for cylinder increased as l/d increased; whereas for cube, there was an 18.2% reduction in compressive strength.
2. Cube could carry a higher load than cylinder (both cross-sections remained identical).
3. At the same l/d ratio and shape (cube only), compressive strength of foam concrete, f_{cu} did not decrease as the specimen size increased.
4. For foam concrete, the 100mm cube (l/d = 1.0) produced a comparable compressive strength compared with that of the 100mm dia. x 200mm cylinder (l/d = 2.0).

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