Behavior of Foamed Concrete under Quasi State Indentation Test: Indenter Size Effects

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Abstract

Quasi static indentation test is a method consist of applying a compressive axial load using head of indenter to moulded cylinders at a rate which is within a prescribe range until failure occurs. The behaviour of foamed concrete under indentation test should behave like cellular material behavior. The Stress-strain behavior can be divided into three regimes, elastic regime, plateau regime and densification regime. There is still less research conducted toward foamed concrete under indentation test. It is stated that the standard method to obtain the compressive strength of foamed concrete based on ASTM C39 standard or BS 1881: Part 116:1983 is not captured the true compressive strength of foamed concrete. The compressive strength typically achieved low compressive strength and not behaves like a cellular material behavior. This result is due brittle collapse of the sample. Previous study has shows the compressive strength under indentation test is higher and created a localized deformation. Besides, there is a densified zone created below the indenter region which is end with hemi-spherical shape. . Tear line occur because of exrended in front of the indenter and perpendicular to the indenter surface. This study aims to investigate further about the behavior of foamed concrete. This study was look about effect of densities and size of indenter on behavior of foamed concrete under indentation test. The density used is low density, medium density and high density. Size of indenter used is 20mm, 30mm, 50mm and 70.5mm. Under indentation test, the higher densities, the higher compressive strength and the bigger size of indenter used, the strength is decreased due to the early crack initiation and propagation. It is important to know the ratio used to make sure indentation test is captured the true strength.

Keywords: *foamed concrete, brittle collapse, micro cracks, indentation test*

1.0 INTRODUCTION

Foamed concrete can be design within the range densities from as low as 300 kg/m^3 to 1800 kg/m^3 and its strength is depend on the densities which lower densities produced the lower strength. The entrained air reduces density of foamed concrete and the density would depend on the volume of foam injected into the slurry. Foamed concrete can be classified as a composite material which has a basic component in it mixture. The component of a basic foamed concrete mix is from Portland cement, water, sand and foamed which is produced from foaming agent. Normally concrete is made up of three basic components which is Portland cement, water and aggregate. The different between normal concrete and this foamed concrete, the aggregates is replaced by foam. This make foamed concrete more light. Compressive strength also reduces with decreasing the foamed concrete density. It is finding that the compressive strength of foamed concrete is mainly influenced by density [1]. Compressive strength of foamed concrete is depend on many factor such as sand – to cement ratio, curing condition, water to cement ratios and particle size distribution of sands. It also stress that the compressive strength inversely proportional to the sand to cement ratio [2]. Effect of foamed concrete density (function of foam addition rate), cement type and content, water/cement ratio, surfactant type, curing regime and bubble morphology(shape and size) on compressive strength reduce exponentially with decreasing foamed concrete density, it also reflecting the greater quantity of air bubbles present in the cementitious microstructure [3]. The main important thing when it related to cellular solid material is it relative density. Relative density become the main features when talk about cellular solids material. Relative density is related to the density of the material, ρ^* and density of the material that produced the cell wall, ρs. It can be defined as the density of the cellular material divided by density from which the cell was made.

$$\rho^*/\rho s \qquad (1)$$

Generally the fraction of pores spaces in foam is its porosity which is

$$1 - (\rho^*/\rho s) \qquad (2)$$

Normally cellular solid material have relative density which are less than about 0.3 and can be as low as 0.003[4]. When relative densities become higher, there is a change in cell. The cell wall is going to increase its thickness; the pore space is going to shrinks. This transformation wills changes the cellular solid material structure become more solid and contains isolated pores [4].

It is finding that indentation tests on brittle foams with open cell shows an unusual and surprising effect. They find that indentation pressure on zirconium foam can be equal to the compressive strength and it is depend on the size of the indenter where the force rises to the peak of the maxima sometimes significantly lower than initial peak and then fall back sometimes almost to zero. So it can be summarized the series of test from different indenter size, the maximum indenter force, F divided by the indenter area A (mm^2) where F is defined as the mean of the highest 10 maxima, excluding the first peak. It can conclude that F/A is inversely proportional to $A^{1/2}$. In indentation test, the near – zero effective poisson ratio during plastic collapse shows that the material beneath the indenter suffers simple compression not multi-axial compression [4].

Based on the stress-strain curve, the plateau regimes are starts from the crush strain, ε_y or crush stress, σ_y. These crush strain or crush stress representing the initiation of the new deformation mechanism of the cell wall or the cell wall failure and end at a critical strain, ε_{cd} which is representing the onset of densification. Cellular material is completely compacted when the strain reaches a complete densification strain, $\varepsilon_{d,}$ which cause a steep increase in the slope of the stress-strain curve. Onset of densification of cellular solids represents the start of the cell wall interaction, which enhance the compressive resistance of a cellular solid. Commonly method to determine the onset strain of densification is based on the energy absorption efficiency curves. Base on this method, it gives unique and consistent result. The energy absorption efficiency is defined by equation [5];

$$\eta(\varepsilon) = \frac{1}{\sigma(\varepsilon)} \int_{\varepsilon y}^{\varepsilon} \sigma(\varepsilon) d\varepsilon \tag{3}$$

based on the uni-axial stress-strain curve of the cellular material. The new method to calculate the energy absorption efficiency may lead to a slight increase of the onset strain of densification and slight decrease of the plateau stress which is defined by equation [5];

$$\sigma_{pl} = \int_{\varepsilon y}^{\varepsilon cd} \sigma(\varepsilon) d\varepsilon \Big/ \varepsilon_{cd} - \varepsilon_y \tag{4}$$

Where ε_y is the strain at the yield corresponding to the start of the plateau regime [5].

2.0 SAMPLE PREPARATION

In this study, foamed concrete is made of a combination of fine sand, cement, water and foam. There is three range of density in this research. The target density for this plain foamed concrete is within the range of 700 kg/m^3 - 900 kg/m^3, 900 kg/m^3 - 1200 kg/m^3, 1200 kg/m^3 – 1800kg/m^3 . Table 1 shows the mix proportion of foamed concrete sample while Table 2 shows the distribution of sample prepared for this research. Figure 1 shows the process of manufacturing the foamed concrete sample.

Table 1. Mix proportion of foamed concrete

Material	Mix		
	700 – 900 kg/m3	900 – 1200kg/m3	1200 – 1800kg/m3
Cement	1	1	1
Water/cement Ratio	0.6	0.6	0.6
Fine aggregate	1	1	1
Foam/Cement ratio	0	0	0

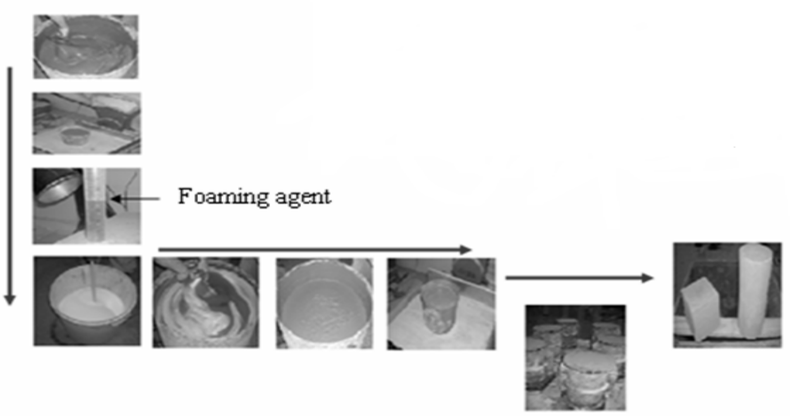

Figure 1. Manufacturing of foamed concrete

Table 2. Summary of the sample distribution

Density	Test			
	Indentation Test			
	Indenter size			
	Ø 20mm	Ø 30mm	Ø 50mm	Ø 70.5mm
700 - 900 kg/m3	3	3	3	3
	Sample Size			
	Ø 150mm x 100mm			
900 – 1200 kg/m3	3	3	3	3
	Sample Size			
	Ø 150mm x 100mm			
1200 - 1800 kg/m3	3	3	3	3
	Sample Size			
	Ø 150mm x 100mm			

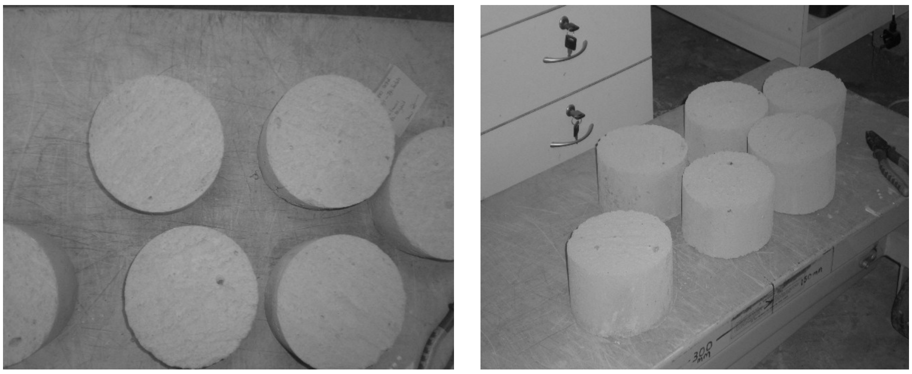

Figure 2. Foamed concrete sample

3.0 EXPERIMENTAL

3.1 Quasi Static Indentation Test

Indentation test is a mechanical testing process designed to determined the properties of foamed concrete by putiing an indenter in the surface of a faomed concrete sample. Indentation test is developed because to determine the properties of materials that, due to their configuration, could not be tested using other conventional methods. The mechanics of indentation test are simple in principle. The indenter defined geometry is forced into the surface of sample by using compressive test machine. This test procedure practice will be the same as specified in ASTM C39-Compressive Strength of Cylindrical Concrete Specimens. The indenter head is designed as flat nose indenter as in Figure 3. The penetration depth will be set to up to maximum 100mm. Here the consideration will be the size of indenter where the size used is 20mm, 30mm, 50mm and 70.5mm as in Figure 5. The sample diameter will be 150mm in diameter and 100mm thickness as in Figure 2. Indentation test will give the maximum load based on the indenter size and depth of penetration. Under this test, the displacement is control by the forced applied to the indenter. The force is set to 3mm/minute to the UTM machine. The force is applied continuously and indenter as it penetrates into the sample until it reaches the maximum load whereby the sample is failed as in Figure 4. Before start the indentation test, plug-in the designed head of indenter based on the size required into the universal testing machine. The indentation tests are made as soon as practicable after 28 days air curing. Wipe clean the bearing faces of the upper and lower bearing block of universal testing machine and of the test specimens. Then place the specimen on the lower bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated upper block. Then bring the upper block to bear on the specimen. Adjust the load to obtain uniform setting. Apply the load at a loading 0.05mm/second. Apply the load (at designed rate) until the specimen fails. Record the maximum load and depth of penetration of indenter. Calculate the indentation strength as the average of six specimens. The data is generated automatically from the UTM machine during the indentation test process are stored together in the memory of computer. The result consists of maximum load, depth of penetration and another parameter which is considerable to the test. The most universally accepted property determined from this test is linear elastic, other properties such as yield stress and strain-hardening characteristics can also be observed, the most important thing is we can observed the 3 regimes which is elastic regime, plateau regime and densification regime from the stress-strain diagram. In the indentation test, the nominal stress and strain are calculated as:

Nominal stress, $\sigma = P/A$

Strain $\varepsilon = \Delta h/h$

Where:

P = applied load

A = the cross-sectional area of the indenter

Δh = displacement of the indenter

h = length of the cylinder sample

Figure 3. Quasi static indenter

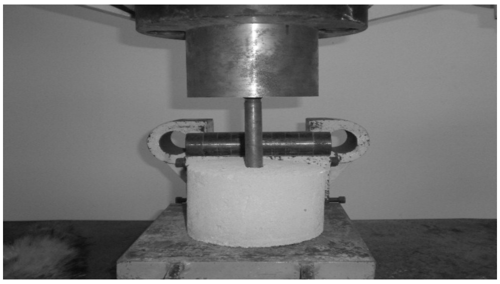

Figure 4. Indentation Test

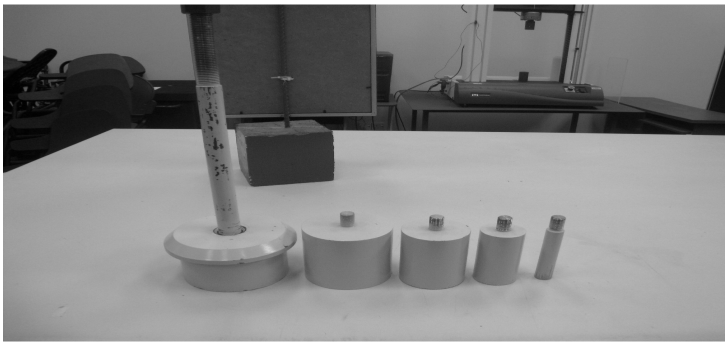

Figure 5. Size of Indenter

4.0 RESULTS AND DISCUSSION

4.1 Low Density

For low density sample, mechanical properties are tabulated in Table 3. Based on the statistical data on initial crushing stress and strain, plateau stress and strain of densification; it can divide the result into four sizes of indenter. For 20mm diameter, it shows that the sample has average crush stress about 1.707 Mpa with average crush strain 3.3%. Then the average critical strain is about 55.33%. The plateau stress average is 2.708 Mpa.

Table 3. Result of low density foamed concrete

Sample	Indenter Ø	Density Kg/m3	σy Mpa	εy %	σL Mpa	εcd %	Average σL
A1	20mm	700 - 900	1.691	3.000	2.181	45.000	2.708
A2			1.691	4.000	3.020	64.000	
A3			1.741	3.000	2.923	57.000	
A4	30mm		0.818	3.000	1.345	24.000	1.513
A5			1.149	3.000	1.555	27.000	
A6			0.508	3.000	1.638	48.000	
A7	50mm		0.468	0.200	1.010	1.658	1.342
A8			1.034	3.000	1.445	21.000	
A9			0.931	3.000	1.570	39.000	
A10	70.5mm		0.168	0.200	0.827	1.800	0.979
A11			0.256	1.000	1.076	11.000	
A12			1.016	1.000	1.035	5.906	

For 30mm diameter, it shows that the sample has average crush stress about 0.825 Mpa with average crush strain 3%. Then the average critical strain is about 33%. The plateau stress average is 1.513 Mpa.

For 50mm diameter, it shows that the sample has average crush stress about 0.811 Mpa with average crush strain 2.06%. Then the average critical strain is about 20.55%. The plateau stress average is 1.342 Mpa.

For 70.5mm diameter, it shows that the sample has average crush stress about 0.48 Mpa with average crush strain 0.733%. Then the average critical strain is about 6.23%. The plateau stress average is 0.979 Mpa.

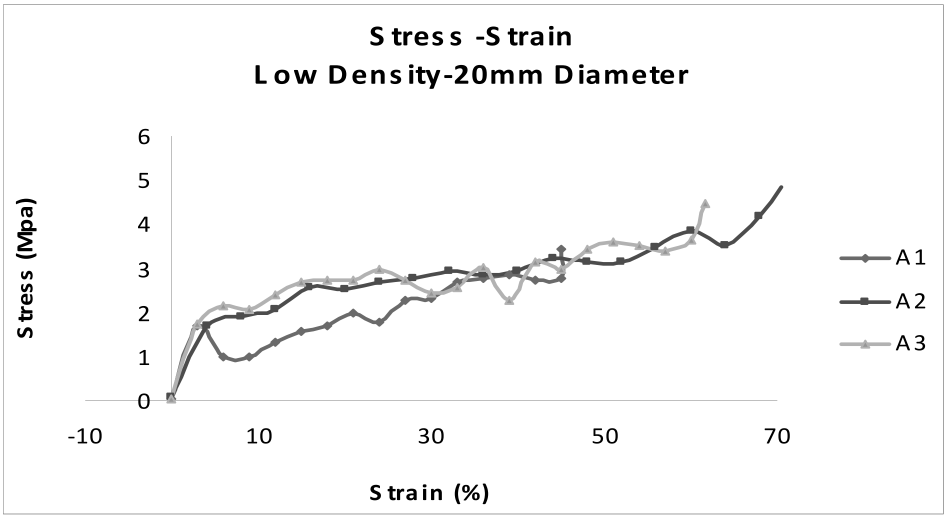

Figure 6. Compressive Stress-Strains curve

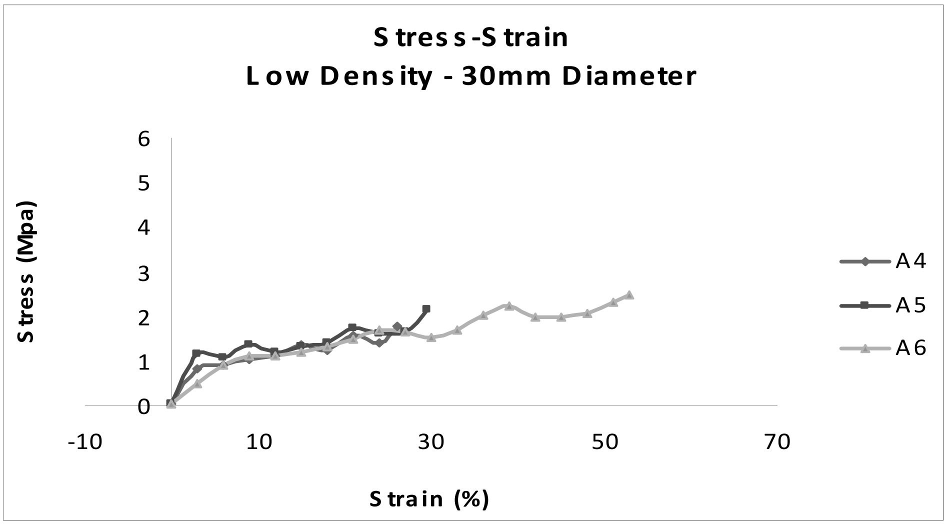

Figure 7. Compressive Stress-Strains curve

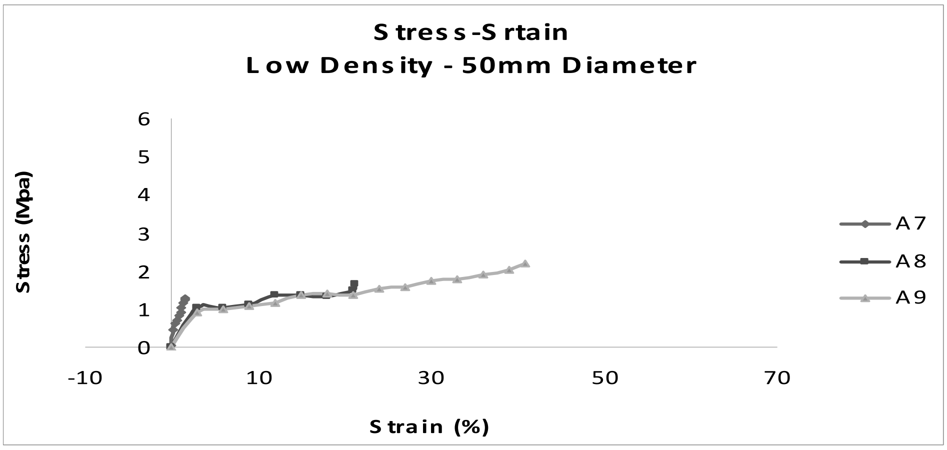

Figure 8. Compressive Stress-Strains curve

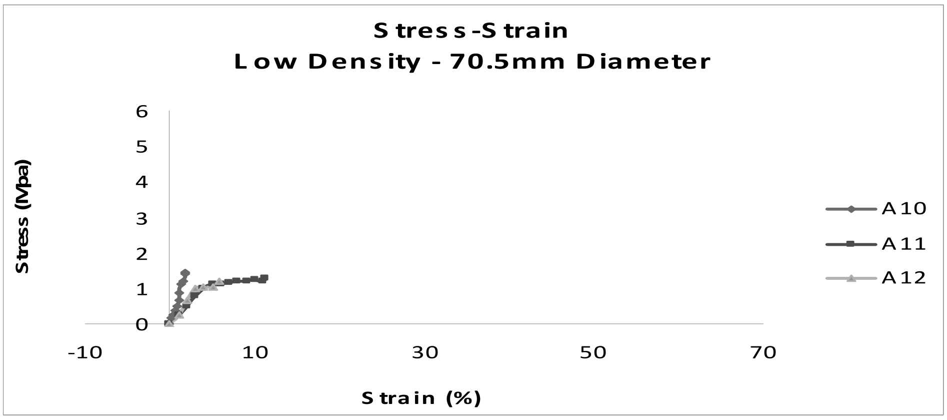

Figure 9. Compressive Stress-Strains curve

Figure 6, 7, 8 and 9 shows the stress-strain curve of the sample under different size of indenter in low density sample. In this study, 3 samples is test for every size of indenter. The compressive stress-strain is different from one size to another size. But all the sample experience all the three phase and from the graph, it can concluded that the distribution of the air voids in the sample can influence the critical strain of the sample. The average of plateau stress is higher when using 20mm diameter then when the size was increase, the plateau stress is reduced. This is because of the influence of critical strain. Another factor is because when the size increase, the sample is going too failed due to the early crack initiation and the samples become not stable when resist the compressive load.

4.2 Medium Density

For Medium density sample, mechanical properties are tabulated in Table 4. Based on the statistical data on initial crushing stress and strain, plateau stress and strain of densification; it can divide the result into four sizes of indenter. For 20mm diameter, it shows that the sample has average crush stress about 3.29 Mpa with average crush strain 3%. Then the average critical strain is about 29.97%. The plateau stress average is 6.53 Mpa.

Table 4. Result of medium density foamed concrete

Sample	Indenter Ø	Density Kg/m^3	σ_y Mpa	ε_y %	σ_{pl} Mpa	ε_{cd} %	Average σ_{pl}
B1	20mm	900 - 1200	2.785	3.000	5.066	26.959	6.538
B2			3.332	3.000	7.240	33.000	
B3			3.779	3.000	7.308	29.980	
B4	30mm		2.873	3.000	5.131	29.944	4.373
B5			1.812	3.000	3.605	27.000	
B6			2.475	3.000	4.382	24.000	
B7	50mm		0.437	1.000	2.408	7.000	3.237
B8			2.546	2.000	3.771	17.315	
B9			0.907	2.000	3.533	15.889	
B10	70.5mm		0.981	1.000	2.975	3.495	2.654
B11			0.500	1.000	2.557	11.562	
B12			0.612	1.000	2.430	6.508	

For 30mm diameter, it shows that the sample has average crush stress about 2.38 Mpa with average crush strain 3%. Then the average critical strain is about 26.98%. The plateau stress average is 4.37 Mpa.

For 50mm diameter, it shows that the sample has average crush stress about 1.29 Mpa with average crush strain 1.67%. Then the average critical strain is about 13.4%. The plateau stress average is 3.23 Mpa.

For 70.5mm diameter, it shows that the sample has average crush stress about 0.69 Mpa with average crush strain 1%. Then the average critical strain is about 7.18%. The plateau stress average is 2.65 Mpa.

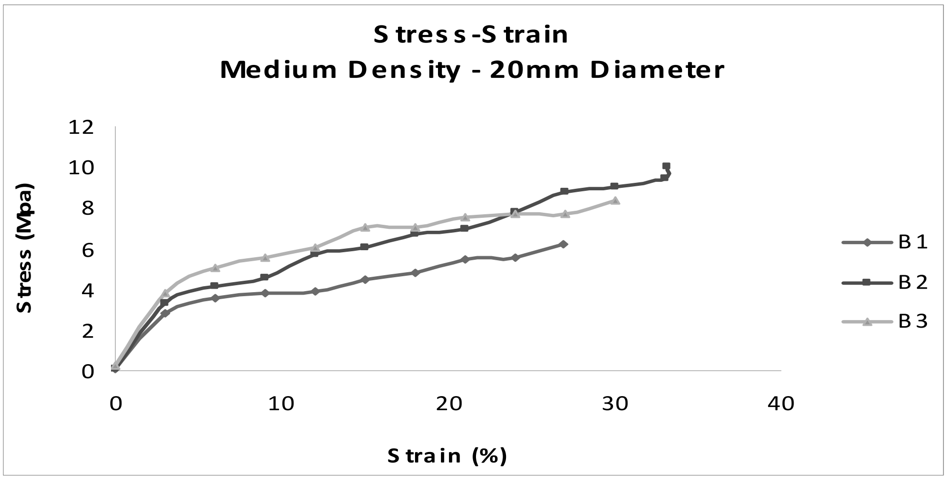

Figure 10. Compressive Stress-Strains curve

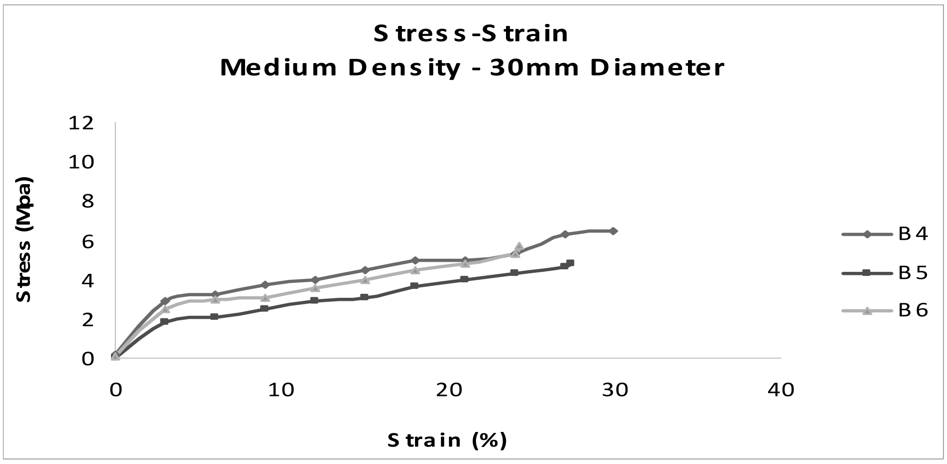

Figure 11. Compressive Stress-Strains curve

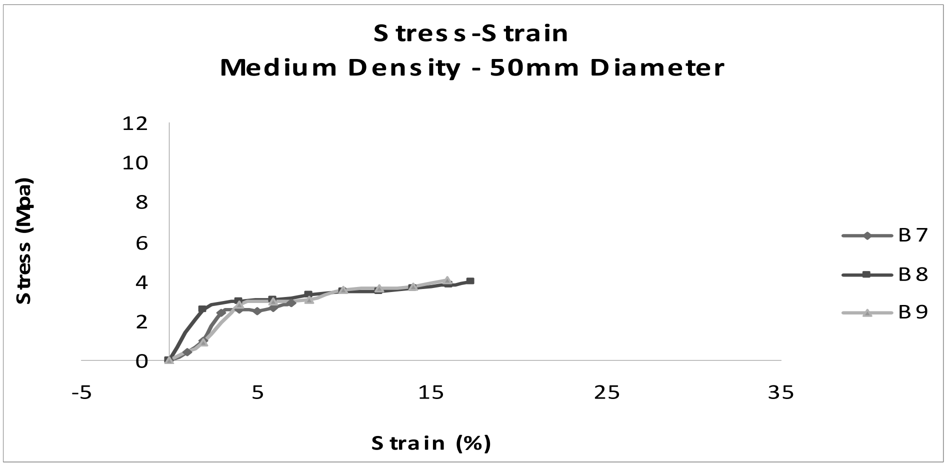

Figure12. Compressive Stress-Strains curve

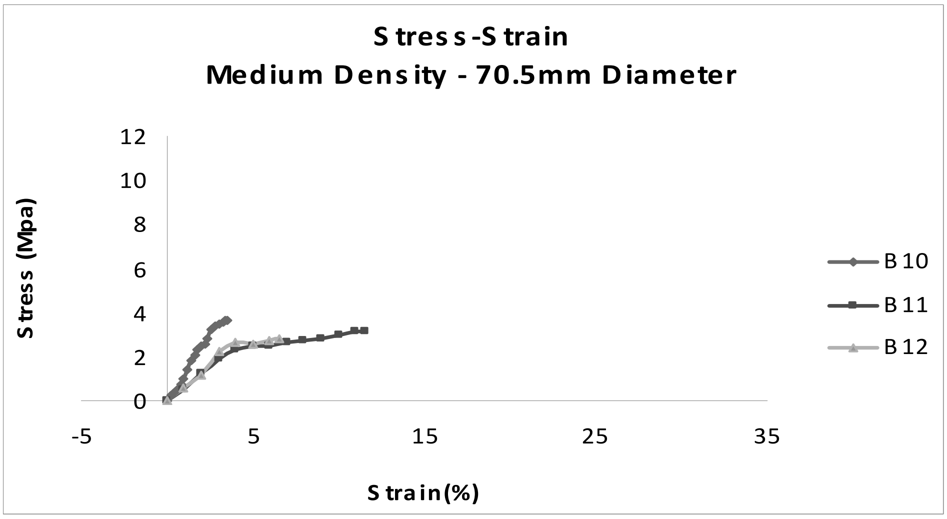

Figure 13. Compressive Stress-Strains curve

Figure 10, 11, 12 and 13 shows the stress-strain curve of the sample under different size of indenter in medium density sample. In this study, 3 samples is test for every size of indenter. The compressive stress-strain is different from one size to another size. But all the sample experience all the three phase and from the graph, it can concluded that the distribution of the air voids in the sample can influence the critical strain of the sample. The average of plateau stress is higher when using 20mm diameter then when the size was increase, the plateau stress is reduced. This is because of the influence of critical strain. Another factor is because when the size increase, the sample is going too failed due to the early crack initiation and the samples become not stable when resist the compressive load. This condition is same like low density sample but the plateau stress is higher. This is because more pressure is needed to compress the sample.

4.3 High Density

For high density sample, mechanical properties are tabulated in Table 5. Based on the statistical data on initial crushing stress and strain, plateau stress and strain of densification; it can divide the result into four sizes of indenter. For 20mm diameter, it shows that the sample has average crush stress about 12.39 Mpa with average crush strain 2%. Then the average critical strain is about 19.25%. The plateau stress average is 44.798 Mpa.

For 30mm diameter, it shows that the sample has average crush stress about 4.24 Mpa with average crush strain 2%. Then the average critical strain is about 11.15%. The plateau stress average is 13.004 Mpa.

For 50mm diameter, it shows that the sample has average crush stress about 0.184 Mpa with average crush strain 0.33%. Then the average critical strain is about 10.23%. The plateau stress average is 11.30 Mpa.

For 70.5mm diameter, it shows that the sample has average crush stress about 0.74 Mpa with average crush strain 2.66%. Then the average critical strain is about 10.23%. The plateau stress average is 6.23 Mpa.

Table 5. Result of high density foamed concrete

Sample	Indenter Ø	Density Kg/m^3	σ_y Mpa	ε_y %	σ_{pl} Mpa	ε_{cd} %	Average σ_{pl}
C1	20mm	1200 - 1800	0.099	0.000	56.811	18.962	44.798
C2			17.554	3.000	32.164	21.000	
C3			19.542	3.000	45.419	17.800	
C4	30mm		1.790	2.000	11.181	11.604	13.004
C5			3.310	2.000	13.078	8.450	
C6			7.624	2.000	14.754	13.386	
C7	50mm		0.474	0.500	12.147	3.996	11.299
C8			0.024	0.000	11.093	2.314	
C9			0.056	0.500	10.658	5.916	
C10	70.5mm		0.004	0.000	8.383	10.480	6.234
C11			1.228	2.000	7.815	11.610	
C12			1.001	6.000	2.504	8.610	

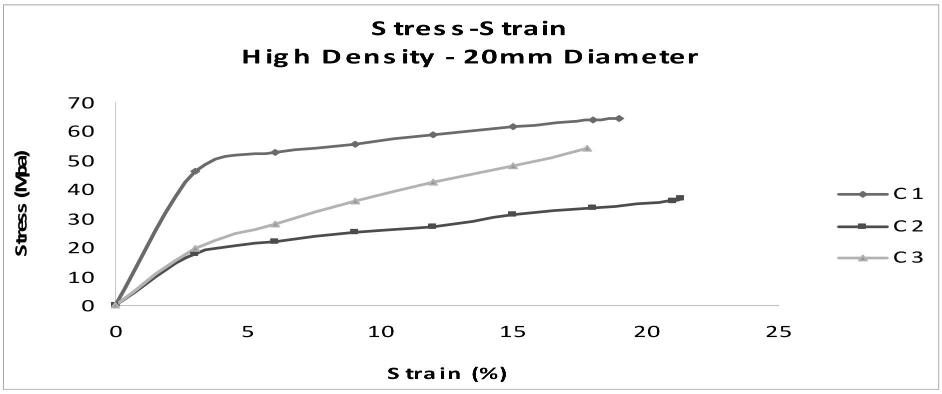

Figure 14. Compressive Stress-Strains curve

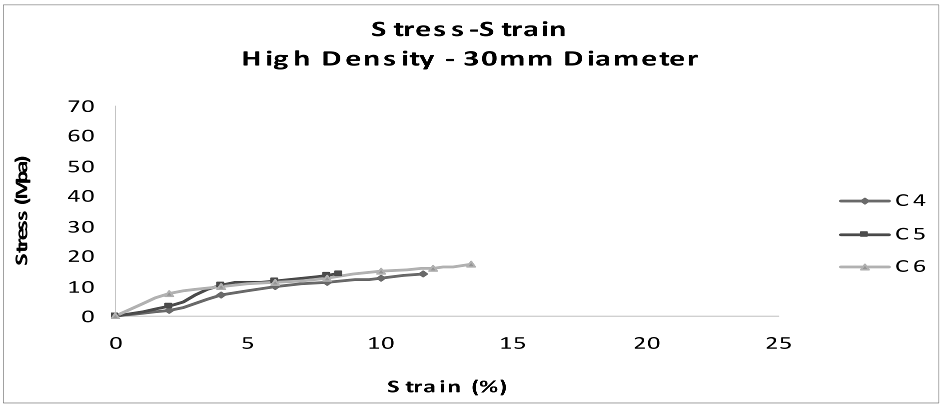

Figure 15. Compressive Stress-Strains curve

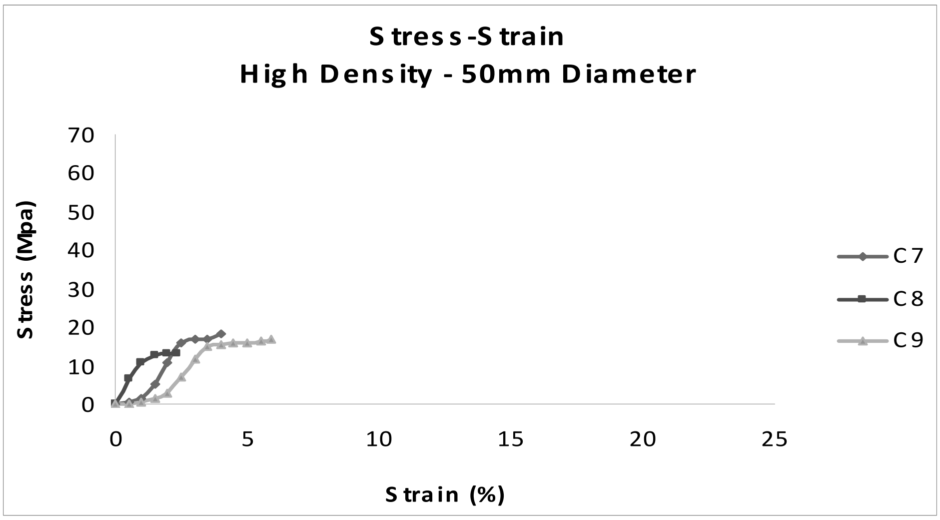

Figure 16 Compressive Stress-Strains curve

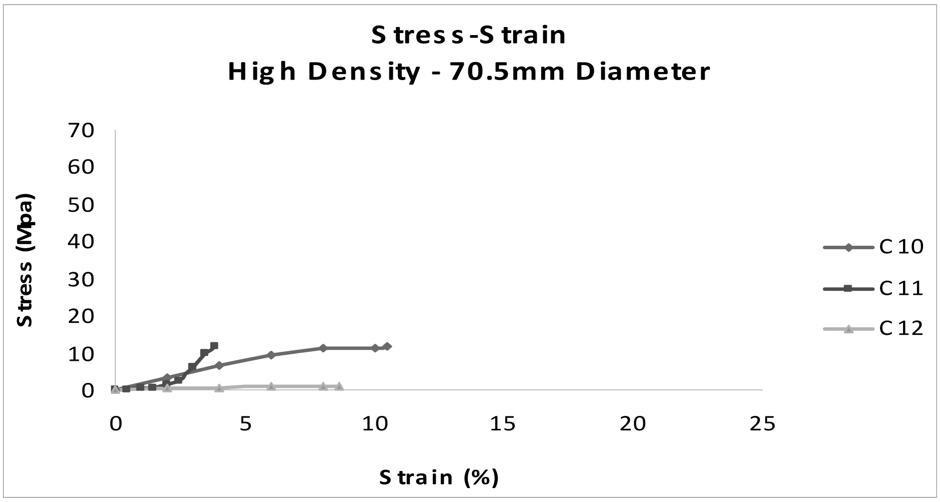

Figure 17. Compressive Stress-Strains curve

Figure 14, 15, 16 and 17 shows the stress-strain curve of the sample under different size of indenter in high density sample. In this study, 3 samples is test for every size of indenter. The compressive stress-strain is different from one size to another size. But all the sample experience all the three phase and from the graph, it can concluded that the distribution of the air voids in the sample can influence the critical strain of the sample. The average of plateau stress is higher when using 20mm diameter then when the size was increase, the plateau stress is reduced. This is because of the influence of critical strain. Another factor is because when the size increase, the sample is going too failed due to the early crack initiation and the samples become not stable when resist the compressive load. This condition is same like low density sample and medium density sample but the plateau stress is more higher compared to all the density.

4.4 Size of Indenter

Indentation test is produced to give natural confinement to the sample and provide sample from brittle failure. Sizes of indenter normally design 10 times more than the size of air voids. In this research, the minimum size of indenter is 20mm in diameter. The size of the sample is based on the standard cylindrical size which is 150mm in diameter. To find the suitable ratio, the sample were test using 20mm, 30mm, 50mm and 70.5mm in diameter size of indenter. This is to choose the ratio of indenter size to sample. Based on figure 7, it clearly shown that the indenter size of 20mm in diameter give the higher in compressive strength. This is because of it natural confinement. It can provide the sample from having brittle failure. When its go to 30mm in diameter, the compressive strength is going to reduce, the ratio size is going to have early crack initiate and then it will propagated to the sample which caused the sample failed due to brittle collapse. Increasing in size up to 50mm and 70.5mm in diameter totally reduce the compressive strength because the crack easily produced and propagated. The ratio size indenter to sample used in this research is 1:7.5, 1:5, 1:3, and 1:2.12. The ratio is calculated based on the diameter of indenter. It is found that the ratio 1:7.5 is suitable used to conducted indentation test to capture true behavior of foamed concrete. The bigger size used for indentation test, it will equally bringing the same condition like standard unconfined compressive test. Ratio indenter size to sample will make sure the indentation test can captured the true behavior of foamed concrete. Figure 8, 9 and 10 shows the strength of foamed concrete based on its densities and all indenter size pictures is representing in figure 11, 12, 13 and 14.

Figure 17. 20mm size of indenter

Figure 18. 30mm size of indenter

Figure 19. 50mm size of indenter

Figure 20. 70.5mm size of indenter

5.0 DISCUSSION

The important thing that should be in consideration is its relative density. This is because relative density is related to the density of the material and material that produced the cell wall. Based on literature review, when relative densities become higher, there is a change in cell. The cell wall is going to increase its thickness; the pore space is going to shrinks. This transformation wills changes the cellular solid material structure become more solid and contains isolated pores. In this research, foamed concrete with low, medium and high density were produced and test using variety size of indenter. Based on the indentation test, it is clearly showed that the higher density of the sample, the higher compressive strength it will achieved. This is due to its relatives density is higher. From the result in low density, medium density and high density, it is show when the density of foamed concrete becomes higher, the strength also increases. Overall it shows significantly the effect of the density towards the compressive strength and plateau stress based on their density. What happened is when the relative density of the foamed concrete increase, the structure of air voids slowly changes into isolated pores and finally become solid. So when compressive load is applied, more loads are needed to compress the sample until it failed.

6.0 CONCLUSION

Density is one of the factors that can affect the strength of foamed concrete. Normally foamed concrete is produced with low density, but sometimes it does also can be produced in high densities. From the research, it can conclude that foamed concrete densities can affect the compressive strength achieved under indentation test. It is found that higher density were produced higher strength due to the changing in cell structure where the cell become more solid and created isolated pores. Size of indenter also affects the strength of foamed concrete under indentation test. It is suitable to use the ratio than can give natural confinement where it can prevent the sample from early crack initiation and propagation and also to prevent the sample from brittle collapse. The suitable ratio in this research Is 1:7.5 (size indenter to sample). Finally it is important to know the true behavior of foamed concrete before it can use based on its final application.

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