COMPRESSION TEST AND FINITE ELEMENT ANALYSIS OF FOAMED CONCRETE CUBE

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ABSTRACT

Foamed concrete is one of the most economical and industrialized construction materials in modern building construction market either for conventional construction technique or precast construction technique. However, the damage behavior of foamed concrete had not been explored deeply by researchers especially for its continuum damage mechanics and plasticity. This paper presents the results of compressive tests and finite element analysis of foamed concrete cubes. The focus of this paper is on the compressive behavior of foamed concrete. Three dimensional- nonlinear finite element model was developed and analyzed by the aquasi static technique using the ABAQUS explicit module. The input parameters of the model were obtained from experimental results. Concrete damaged plasticity was chosen as damaged criteria. Results show that the proposed finite element model is able to predict the damage behavior of the foamed concrete cube accurately. Thus, finite element method can be used as an economical tool for studying the structural behavior of foamed concrete in compression.

KEYWORDS: *Foamed concrete; Finite element analysis; Concrete damage plasticity; ABAQUS*

1.0 INTRODUCTION

Foamed concrete is a lightweight construction material consisting of Portland cement, sand and water with a homogeneous void or the pore structure created by introducing air in the form of small bubbles. The pore system in the foamed concrete does not influence the strength of concrete through its pores, although these pores are directly related to creep and shrinkage (Kunhanandan Nambiar & Ramamuthy, 2007). The air bubble was used to reduce the density of base mix and have a

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strong plasticizing effect. In the presence of air bubbles, the lightweight concrete can be produced by dry density of 400 to 1600kg/m^3 and seven days compressive strength approximately from one to 10MPa. Foamed concrete is good for fire resistant, and its thermal and acoustical insulation properties make it suitable for a wide range of applications, from insulating sub-bases and roof screeds to void filling etc. Based on these advantages, it gradually becomes a popular construction material in order to produce sustainable building all over the world (British Cement Association, 1997). Despite being widely used as construction material, the damage or failure behavior of foamed concrete had not yet been explored deeply by previous researchers, especially for its continuum damage mechanics and plasticity. Material damage criteria and analysis technique are very important to be considered in nonlinear finite element analysis in order to obtain a good result up to the ultimate load bearing capacity of the material.

In this paper, we present a 3D nonlinear finite element model to analyze foamed concrete cube subjected to compression load to obtain its ultimate compressive strength. Considering the brittle nature of the foamed concrete material, explicit dynamics analysis procedure was employed using ABAQUS/Explicit module. The concrete damaged plasticity model as depicted in Figure 1 was used for foamed concrete material property. It uses stress-strain relationships to correlate parameters for relative concrete damage for both tension and compression. The concrete damaged plasticity model provides a general capability for modeling concrete and other quasi-brittle materials in all types of structures. This model uses the concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete (Abaqus 6.9, 2009).

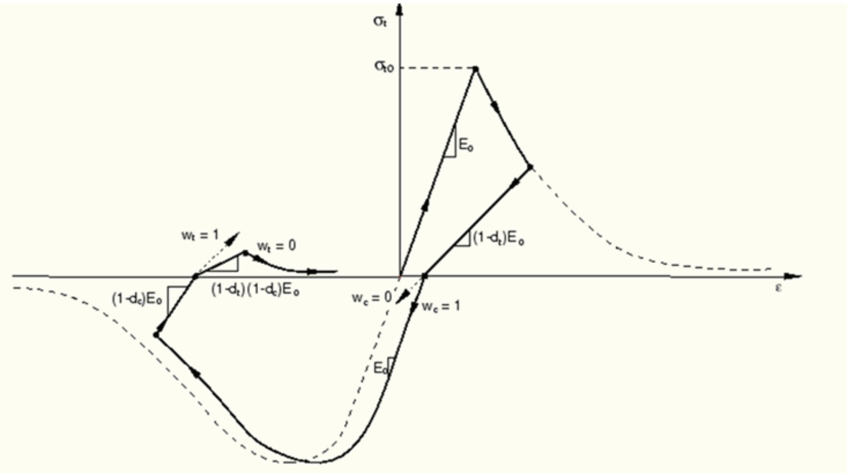


Figure 1. Concrete damaged plasticity modified stress/strain curve. (Abaqus 6.9,2009, Jankowial & Lodygowski, 2005, Jason et al., 2004, Lee & Fenves, 1998, Mokhatar & Abdullah, 2012)

2.0 EXPERIMENTAL PROCEDURE

2.1 Mix Proportion for producing foamed concrete

Materials used in the foamed concrete are ordinary Portland cement, fine sand passing through No. 5 sieve and foam agent. The ratios of the materials are listed in Table 1. The foam used was produced by foam generator by diluting the foam agents with water. The ratio of foam concentrates with water is one to twenty. The foam agent was a synthetic foam agent based on protein hydrolyzates. The air bubbles produced by the foaming agent were stable and able to resist physical and chemical forces imposed during mixing, placing and hardening of the concrete. The foamed concrete was cast into cubes and cylinders. The compression test was conducted over 28 days of casting.

Table 1. Mixture ratio for casting of foamed concrete cube

	Sand : Cement	Foam : Cement	Water : Cement
Ratio	2 : 1	0.65	0.55

2.2 Test Configuration & Instrumentation

The compressive strength of foamed concrete was obtained from the compression test on cubes which was carried out using Universal Testing Machine according to BS 1881: Part 116: 1983. The tensile strength of foamed concrete was determined from split test on cylinders according to BS 1881: Part 117: 1983 and ASTM 496-90. The Young's Modulus, E and poison ratio values were obtained from compression test on the concrete cylinder by using the Universal testing Machine according to BS 1881: Part 116 and ASTM C39-86. Two units of 30mm strain gauges were glued on the cylinder and connected to the data logger which recorded the strain values. The load was applied to failure and strain at each load stages were recorded for analysis. Graph of stress versus strain were plotted from the recorded stress and strain values. The Young's Modulus, E was determined from the slope of graph as shown in Figure 2. Results from the testing are listed in Table 2.

Table 2. Properties of foamed concrete of PLFP

Dimension (mm^3)	P_c (MPa)	F_c (kN)	F_t (kN)	*E* (MPa)	Mass Density, *p* (kg/m^3)	Poisson Ratio, *v*
100 x 100 x 100	10	103	1	12000	1600	0.2

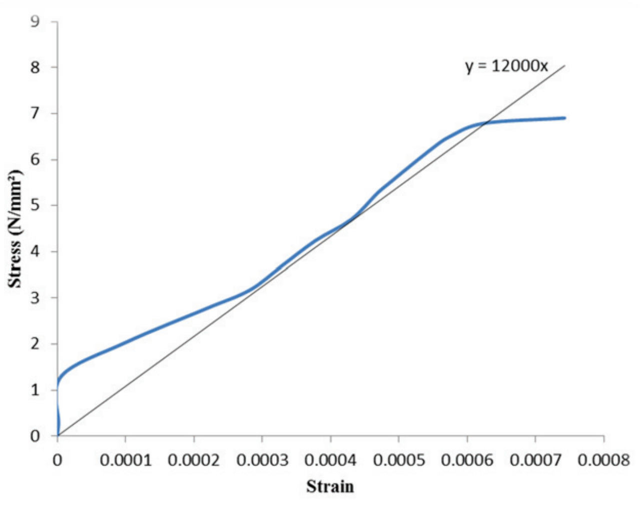


Figure 2. Modulus Young of foamed concrete from experiment

3.0 FINITE ELEMENT ANALYSIS

3.1 Material Properties

A 3D nonlinear quasi static finite element model was developed using ABAQUS/Explicit module to study the behaviour of the foamed concrete cube under compression. Material properties of foamed concrete obtained from the experiment were used to calculate the concrete damage plasticity parameters as input to the model. The parameters were calculated based on the stress-strain relations under uniaxial tension and compression loading in equation 1. Where *D* is the damage parameter of foamed concrete in compression and tension, E_0 is the initial (undamaged) elastic stiffness and E is the damaged elastic stiffness of the foamed concrete.

$$D = 1 - \left(\frac{E}{Eo}\right) \qquad (1)$$

Table 3 shows the constitutive parameters used in concrete damaged plasticity model for both compressive and tensile behaviour of foamed concrete material. The parameters listed in Table 3 that are not measurable from the experiment mentioned in paragraph 2 above were assumed using values from normal strength concrete (Abaqus 6.9, 2009, Jankowial & Lodygowski, 2005, Jason et al., 2004, Lee & Fenves, 1998, Mokhatar & Abdullah, 2012, Sourav Basak & Paul, 2012). Due to the concrete damaged plasticity of foamed concrete had not been identified by previous research, the concrete damaged plasticity parameters were assumed based on the parameters of normal strength concrete.

Table 3. Concrete damaged plasticity of foamed concrete

Concrete Damaged Plasticity (assumed)					
Dilatation Angle	**Eccentricity**	**Initial biaxial/ uniaxial ratio, σ_{c0}/σ_{b0}**	***K***	**Viscosity**	
27°	**0.1**	**1.16**	**1**	**0**	
Compressive Behavior from Experiment			Tensile Behavior from Experiment		
Yield Stress, (MPa)	Inelastic Strain	Damage Parameter, *D*	Yield Stress (MPa)	Cracking Strain	Damage Parameter, *D*
8.751	0	0	0.861	0	0.000
9.850	0.0017	0	0.776	0.00159	0.204
10.356	0.0033	0	0.605	0.00409	0.476
10.032	0.0041	0.215	0.518	0.00526	0.582
9.714	0.0047	0.337	0.431	0.00638	0.673
9.357	0.0055	0.456	0.345	0.00746	0.752
8.734	0.0066	0.577	0.259	0.00854	0.824
7.725	0.0078	0.682	0.173	0.00966	0.889
5.450	0.0127	0.862	0.086	0.01082	0.947
3.962	0.0194	0.934	0	0.01202	1.000

3.2 Modeling of Concrete, Interaction, Loading and Analysis Control

Foamed concrete was modeled with eight-node continuum elements (C3D8R) and rigid bodies were used to represent the load cell at the top and support at the bottom. Constant displacement was applied at the rigid body on top until the failure occurred. Surface to surface contact was defined for interaction between the rigid body and foamed concrete cube; kinematic contact method for mechanical constraint formulation was employed in defining the contact property option. Concrete crushing issue and spalling were neglected. In order to reduce the impact and inertia effects from explicit dynamic procedure and to ensure the equivalent static response is obtained, the loading period was adjusted until the kinetic effect become minimum. Loading period was fixed at 1 second after the process of trial and error with the initial trial value based on the natural frequency of the foamed concrete cube.

4.0 RESULTS AND DISCUSSION

4.1 Effectiveness of Mesh Density

Models with different mesh refinement were analysed to determine the best mesh density that gives reasonable accuracy of results and reasonable analysis time. Results of compressive force, *Fc* for various refined element meshes are shown in Table 4 and plotted in Figure 3. From the comparison of compressive strength with experimental results, mesh density with 1000 elements provided the same result as the experiment with reasonable computing time.

Table 4. Result of mesh refinement study

ABAQUS Mesh Type	Total Elements	Total Nodes	F_c (kN)	% Difference from Experiment
Experimental Data	-	-	103	-
C3D8R – 1	64	125	115	-11.65
C3D8R – 2	216	343	107	-3.883
C3D8R – 3	512	729	104	-0.971
C3D8R – 4	1000	1331	103	0
C3D8R – 5	1728	2197	102	0.9709
C3D8R – 6	2744	3375	102	0.9709
C3D8R – 7	4096	4913	101	1.9417
C3D8R – 8	8000	9261	101	1.9417
C3D8R – 9	16900	18954	101	1.9417
C3D8R – 10	39304	42875	101	1.9417
C3D8R – 11	125000	132651	101	1.9417

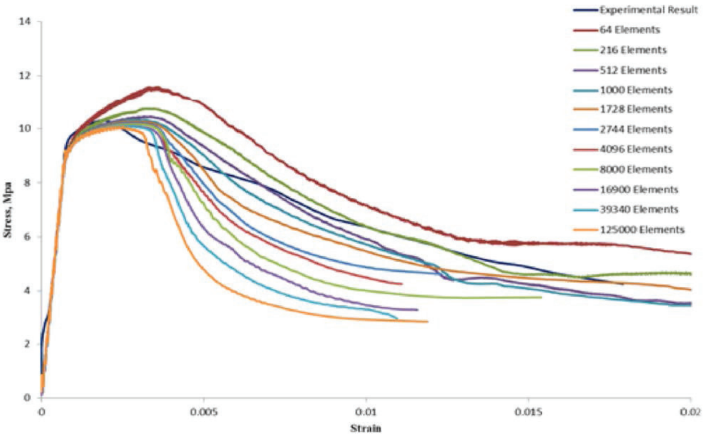


Figure 3. Mesh density study of finite element analysis

4.2 Failure Behavior and Crack Pattern

The stress-strain curves from FE analysis (1000 elements model) and from the experiment were plotted in Figure 4. It can be seen that both results achieved same ultimate compressive stress with similar strain value at both the elastic and plastic stages until the failure stage. Failure modes were compared as shown in Figure 5(a) and 5(b). It can be seen that the crack in the experiment had occurred at one corner and along the height of the cube which is identical to the contour plot of the analysis. In the experiment, imperfection of the test specimen, such as uneven cube surface and uneven distribution of foam might had caused the crack to occur only at one corner of the cube.

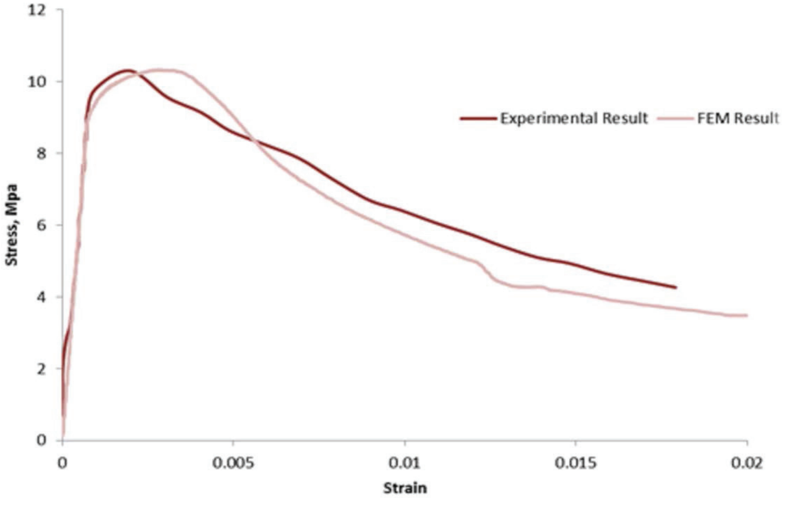
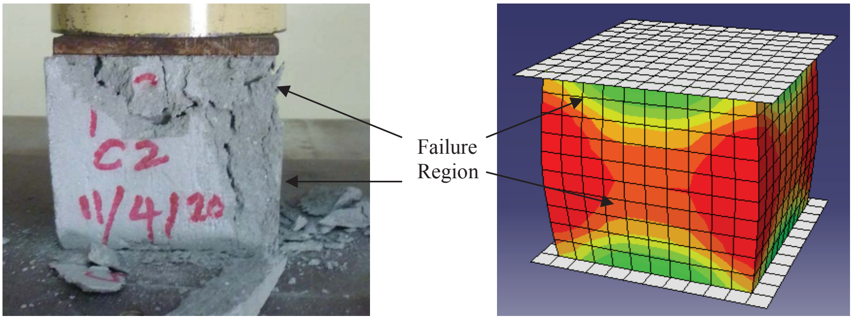


Figure 4. Comparison between experimental result and finite element analysis result



(a) Experimental result (b) Numerical result

Figure 5. Comparison of failure mode for foamed concrete cube

Crack propagations in the foamed concrete cube model are shown in Figure 6 (a), (b), (c), and (d). In Figure 6 (a), the first crack appears near the edge and along the height of concrete and propagating towards the center of the cube. Then, as shown in Figure 6 (b) to (d), the concrete cube expended at the middle height due to the compression force applied to it. The maximum load was achieved on stage 1 when the damage occurred. Figure 6 (b) to Figure 6 (d) are the condition beyond the maximum load.

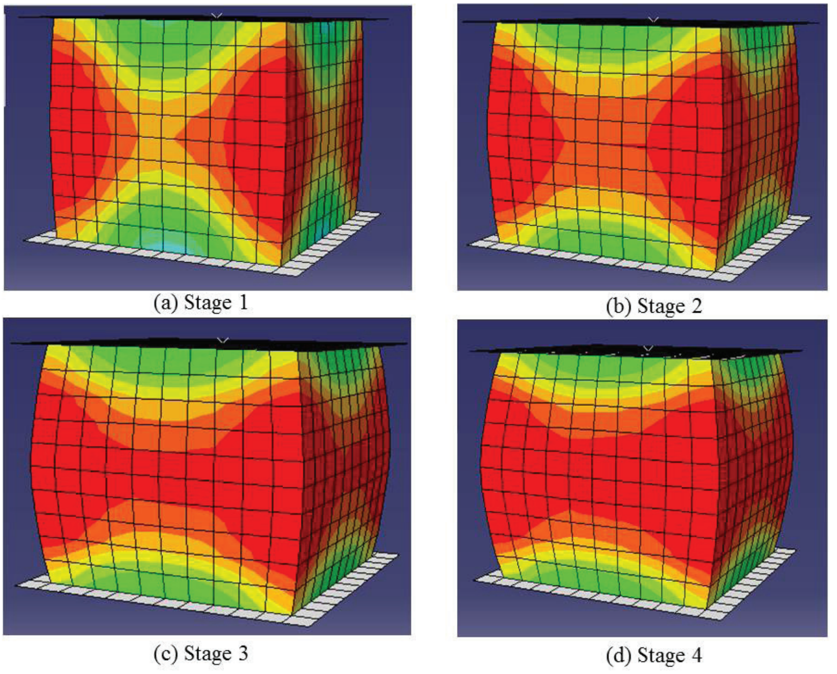


Figure 6. Damage wave propagation of cube from failure, (a) to post failure, (b) to (d)

5.0 CONCLUSION

Compression test of the foam concrete cube was modeled and analyzed using finite element method. The concrete was modeled with the linear brick element. The damage criterion for the foam concrete was modeled with concrete damage plasticity and the material property parameters were obtained from experiment. Quasi static analysis using ABAQUS/ Explicit was employed and the equivalent static result was ensured by controlling the loading period. The result of the study shows that finite element procedure employed in this study can simulate the compression test of the foam concrete cube accurately. The concrete damaged plasticity model is suitable for modeling the compression damage of foam concrete. The model and analysis method employed in this study can be used as a guide in modeling the foam concrete under compression

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