ANALELE UNIVERSITĂȚII
“EFTIMIE MURGU” REȘIȚA
ANUL XIX, NR. 1, 2012, ISSN 1453 - 7397

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Elastic Modulus of Foamcrete in Compression and Bending at Elevated Temperatures

This paper will presents the experimental results that have been performed to examine and characterize the mechanical properties of foamcrete at elevated temperatures. Foamcrete of 650 and 1000 kg/m^3 density were cast and tested under compression and bending. The tests were done at room temperature, 100, 200, 300, 400, 500, and 600°C. The results of this study consistently demonstrated that the loss in stiffness for cement based material like foamcrete at elevated temperatures occurs predominantly after about 95°C, regardless of density. This indicates that the primary mechanism causing stiffness degradation is microcracking, which occurs as water expands and evaporates from the porous body. As expected, reducing the density of LFC reduces its strength and stiffness. However, for LFC of different densities, the normalised strength-temperature and stiffness-temperature relationships are very similar.

Keywords*: foamed concrete, compressive strength, flexural strength, elevated temperature, modulus of elasticity*

1. Introduction

Foamcrete has principally been employed throughout the world for bulk filling, trench reinstatements, backfill to bridge abutments and retaining walls, insulation to foundations and roof tiles, sound insulation, stabilising soils, grouting for tunnel works, sandwich fill for precast units and pipeline infill. Nevertheless, in the last few years, there is developing interest in using foamcrete as a lightweight non-structural and semi-structural material in buildings to take advantage its lightweight and good insulation properties. Figure 1 shows the use of foamcrete at roof and wall for insulation purpose while Figure 2 visualizes the process of pouring of foamcrete for foundation.

Foamcrete is a cementitious material having a minimum of 20 per cent by volume of mechanically entrained foam in the mortar slurry [1] where the air-pores are entrapped in the matrix by means of a suitable foaming agent. With the integration of the air-pores into the base matrix, it gives a low self-weight, high workability, excellent insulating values, but lower strength in contrast to normal strength concrete. Foamcrete can be manufactured anywhere in several shape or building unit size.

Figure 1. Pouring foam concrete to roofs and walls.

Figure 2. Foamcrete lightweight foundations

Degradation mechanisms ofr cement-based material like foamcrete upon exposure to elevated temperatures comprise of mechanical damage as well as chemical degradation; where each mechanism is dominant within a specific temperature range. Lin et al. [2] performed studies to scrutinize the microstructure of concrete exposed to elevated temperatures in both actual fire and laboratory conditions with the assistance of Scanning-Electron-Microscopy (SEM) and stereo microscopy. They established that the absorption of moisture from the surrounding medium provides a mechanism for the rehydration of calcium oxide and unhydrated cement grains that refilled the void spaces. They observed that long irregular fibers of C-S-H gel combined with ettringite and C-H crystals and formed as a result of rehydration.

Schneider and Herbst [3] carried out research to study on the chemical reactions and the behaviors of calcium hydroxide, calcium carbonate, calcium silicate hydrate, non-evaporable water and micropores under various temperatures. They established that the major increase of concrete permeability and porosity at high temperature was principally produced by arising microcracks and by changes of material inner structure, as well as by crack opening due to high gas pressure values. As a result, the permeability of concrete depends not only on temperature levels, moisture content and gas pressure but also upon the degree of cracks development.

As a two phase material with solid cement and air voids, the degradation mechanisms of LFC are principally caused by deprivation of the cement paste. Even though both mechanical and chemical degradation result in degradation of mechanical properties, the mechanisms take place at considerably different temperature ranges. The dehydration process in the cement paste becomes significant at temperatures above about 110 °C [4] and diminishes the calcium silicate hydrate (C-S-H) links which provide the primary load-bearing formation in the hydrated cement. Furthermore, due to low permeability of the cement paste, internal water pressure is built up during dehydration of the hydrated C-S-H, which increases internal stresses and induce microcracks in the material from about 300°C, resulting in decreased strength and stiffness of the material [5].

At higher temperatures around 450°C, calcium hydroxide ($Ca(OH)_2$), which is one of the most vital compounds in cement paste, dissociates, resulting in the shrinkage of LFC [6]. If the hot LFC is exposed to water, as in fire fighting, CaO in LFC turns into $Ca(OH)_2$ to cause cracking and destruction of LFC. It is still extremely difficult to accurately predict these mechanisms and experimental investigation remains essential.

Thus, the aim of this study is to experimentally examine and characterize the elastic modulus of foamcrete at elevated temperatures. Tests were carried out at different temperatures up to 600°C. Extensive compressive and bending strength tests will be performed for foamcrete of densities of 650 and 1000 kg/m^3.

2. Mix Design

The foamcrete used in this study will be made from Portland cement SEM1, fine sand, water and stable foam and Table 1 lists details of the constituent materials. The aims of this research are to determine the elastic modulus of foamcrete at high temperatures therefore only a constant cement-sand ratio of 2:1 and water-cement ratio of 0.5 will be used for all batches of LFC samples made for this research. A higher cement-sand ratio (2:1) was chosen to achieve better compressive strength and water-cement ratio of 0.5 was found acceptable to achieve adequate workability [7]

Table 1. Constituent materials used to produce LFC

Constituents	Type
Cement	Portland cement SEM1
Sand	Fine sand with additional sieving to eradicate particles greater than 2.36 mm
Stable foam	Noraite PA-1 (protein based) surfactant with weight of around 70 to 80 gram/litre produce from Portafoam TM2 System

3. Test set-up

For this research, the unstressed test method was adopted for convenience. In the unstressed test, the sample was heated, without preload, at a steady rate to the predetermined temperature. While maintaining the target temperature, load was applied at a prescribed rate until sample failure. Because the temperature is unchanged, the test is also referred to as steady state test, as opposed to transient test in which the specimen temperature changes with time

Electric furnace was used for heating the foamcrete specimens to the various steady-state temperatures. The furnace temperature exposure profiles were produced by a programmable microprocessor temperature controller attached to the furnace power supply and monitored by a Type K thermocouple located in the furnace chamber. Pre-testing checking of the furnaces showed that the furnace controller and furnace power system could maintain furnace operating temperatures within ±1°C over the test range.

The compressive strength tests were carried out on 100 x 200 mm cylinders. To monitor the strain behaviour at ambient temperature during loading, two strain gauges was fitted on each sample for the ambient test only. Since no strain measurement was made at elevated temperatures, the ambient temperature strain measurements were used to confirm that the strain calculated based on the displacement of the loading platen was of sufficient accuracy. Four Type K thermocouples were installed in the central plane of each cylinder specimen. Loading was applied using an ambient temperature compression machine (Figure 3) after removing the test samples from the furnace. To minimise heat loss from the specimen to atmosphere, each specimen was wrapped with insulation sheets immediately after being removed from the electric furnace. For each set of test, three replicate tests were carried out to check consistency of results.

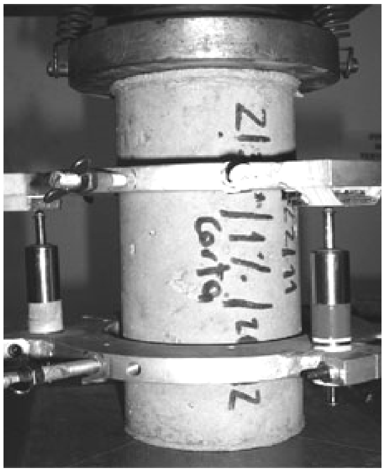


Figure 3. Compression test using ambient temperature machine

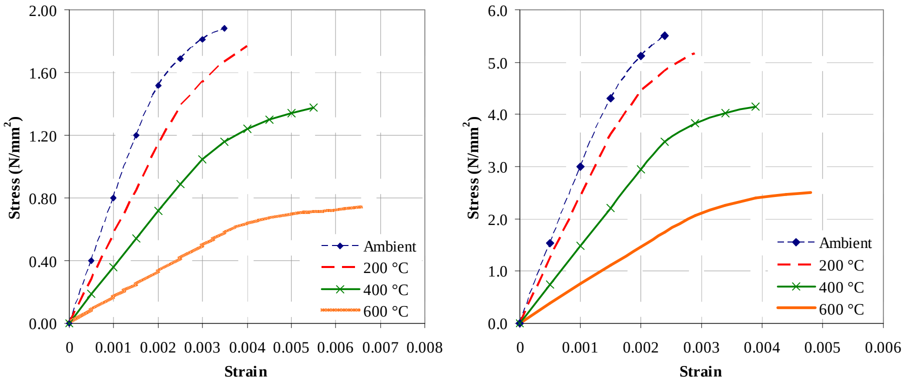
Three point bending test was carried out for convenience in this study. The preparation of samples followed a similar procedure as delineated above for the compression tests. The specimens were rectangular parallelepipeds of height *(h)* 25 mm, width *(w)* 125 mm and length L *(l)* 350 mm. As shown in Figure 4, the LFC specimen was simply supported and was subjected to point load at the centre point. The length between the supports was L_s = 200 mm, giving a L_s/h aspect ratio of 8 and sufficient to ensure predominance of bending behaviour. The load-deflection was recorded for the evaluation of flexural tensile strength.

Figure 4. Bending test set up

4. Experimental Results

4.1. Compressive stress-strain relation of foamcrete

Figure 5 (a-b) displays the average stress-strain curves at all different testing temperatures for the two densities. It can be seen from Figure 5 that for both densities at all temperature levels, the ascending branch was linear for stress up to 75% of the peak strength. The strain corresponding to the peak strength increased at increasing temperatures. For foamcrete of 650 kg/m^3 density, the maximum strains were 0.0034, 0.0039, 0.0055 and 0.0066 at ambient temperature, 200, 400 and 600°C in that order; for the 1000 kg/m^3 density, the corresponding values were 0.0024, 0.0029, 0.0039 and 0.0048 at ambient, 200, 400 and 600°C correspondingly. The increase in strain results from opening of cracks initiated by the heating at higher temperatures.

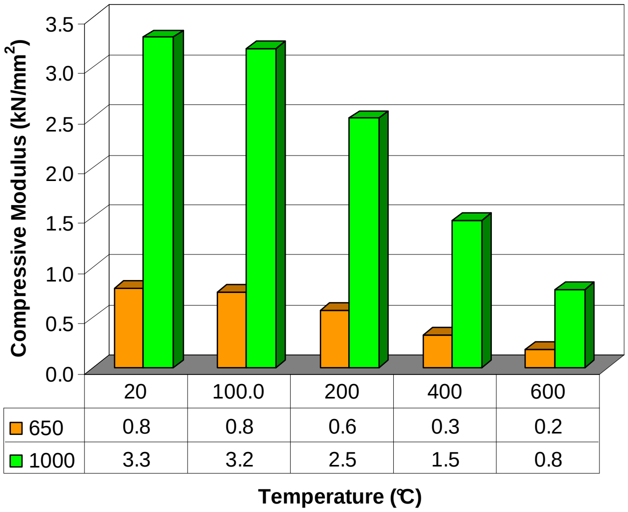


a) 650 kg/m^3 (b) 1000 kg/m^3

Figure 5. Average foamcrete stress-strain relationships at different temperatures

4.2. Elastic modulus of foamcrete under compression

Figures 6 and 7 show the changes in modulus of elasticity of foamcrete in compression as a function of temperature. The modulus of elasticity was taken as the secant modulus at the point where the material changed from elastic to plastic behavior from the experimental compressive stress–strain curve. Compared to the reduction in foamcrete strength, the reduction in elastic modulus is greater. Both figures show that the loss in modulus of elasticity began immediately upon heating when the samples began to dry. The modulus of elasticity at 200°C, 400°C and 600°C was respectively about 75%, 40% and 25% of the original value for both densities. As with changes in normalised strengths of foamcrete of both densities at elevated temperatures, the normalised modulus of elasticity of foamcrete of both densities at the same temperature are almost the same.



	20	100.0	200	400	600
🟧 650	0.8	0.8	0.6	0.3	0.2
🟩 1000	3.3	3.2	2.5	1.5	0.8

Figure 6. Compressive modulus of foamcrete as a function of temperature

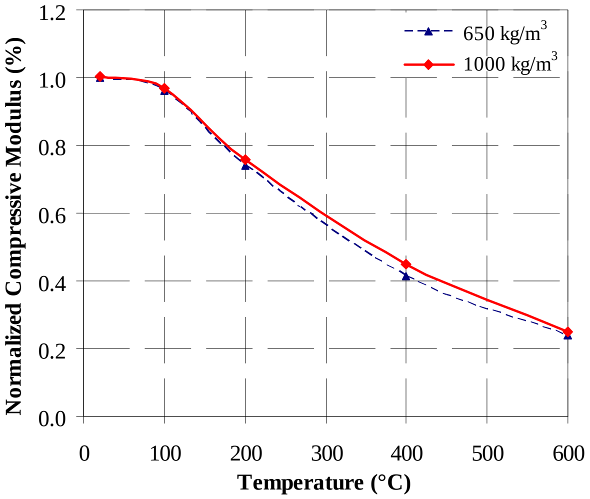


Figure 7. Normalized compressive modulus of foamcrete as a function of temperature

4.3 Elastic modulus of foamcrete under bending

Figures 8 and 9 show the changes in bending modulus of foamcrete as a function of temperature and compare the flexural modulus with the compressive modulus obtained from the cylinder tests. Although there are some differences, the compressive modulus and flexural modulus values are very similar for both densities and at different temperatures.

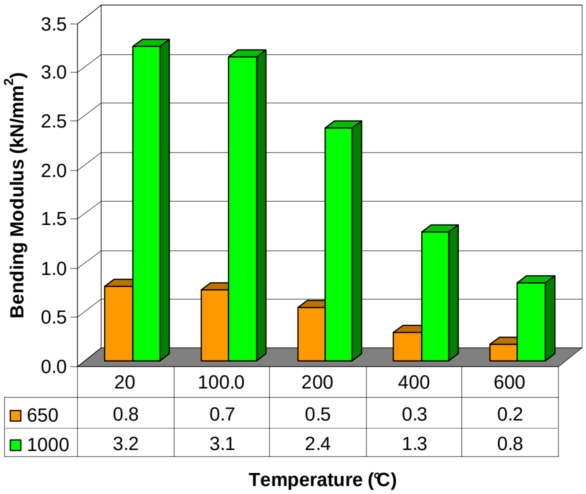


Figure 8. Bending modulus of foamcrete as a function of temperature

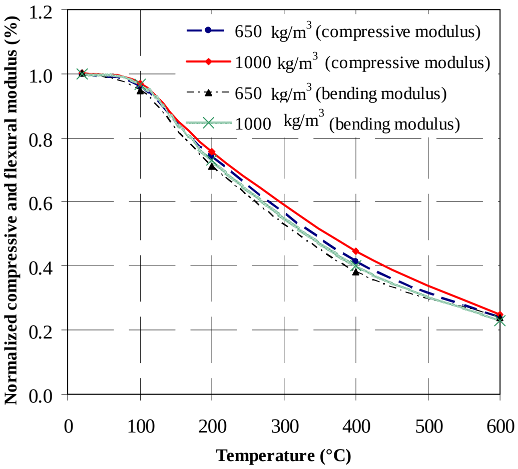


Figure 9. Comparison of normalized compressive modulus and flexural tensile modulus of foamcrete as a function of temperature

5. Conclusion

This paper has presented the results of a series of experimental studies to obtain compressive and bending modulus of foamcrete from ambient up to 600^{o}C. The experimental results demonstrated that the loss in stiffness for cement based material like foamcrete at elevated temperatures occurs predominantly after about 90°C, regardless of density. This indicates that the primary mechanism causing stiffness degradation is microcracking, which occurs as water expands and evaporates from the porous body. As expected, reducing the density of foamcrete reduces its strength and stiffness. However, for foamcrete of different densities, the normalised strength and stiffness (ratio of elevated temperature value to ambient temperature value) – temperature relationships are very similar.

Acknowledgement

The author would like to thank Universiti Sains Malaysia and Ministry of Higher Education Malaysia for their financial supports under Fundamental Research Grant Scheme (FRGS). No. 203/PPBGN/6711256

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