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Aerated Concrete Produced Using Locally Available Raw Materials

Faris Matalkah [a*], Harsha Bharadwaj [a], Anagi Balachandra [b], Parviz Soroushian [b]

[a] *Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI (48824), United States.*

[b] *Metna Co., Lansing, MI (48906), United States.*

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Abstract

Aerated concrete materials were developed with abundant natural materials. Aerated concrete can provide insulating qualities complemented with secondary structural attributes when used as core in sandwich composites for building construction. A hybrid binder that comprised lime and gypsum was used. Different foaming agents were considered for production of aerated concrete, including saponin that is found abundantly in different plants. Different formulations were considered, and the stability of the foam structure as well as the density and early-age compressive strength of the resulting aerated concrete were evaluated. One formulation comprising lime-gypsum binder with saponin foaming agent, with a density of 0.53 g/cm^3, was further characterized through performance of thermal conductivity, split tension, flexure, elastic and shear modulus and sorptivity tests. The results pointed at the satisfactory balance of qualities provided by the aerated concrete when compared with alternative aerated concrete materials.

Keywords: Aerated Concrete; Foaming Agent; Lime-Gypsum Binder; Density; Mechanical Properties.

1. Introduction

Aerated concrete comprises an inorganic binder in which a relatively high concentration of air voids that are introduced using a foaming agent to produce distinctly low bulk densities when compared with normal-weight or even structural light-weight concrete materials. The binder composition and the method of curing influence the microstructure and thus the physical and mechanical properties of aerated concrete [1, 2]. Aerated concrete provides a high degree of thermal insulation and savings in the costs of structural support systems, which are due to its low bulk density [2-4]. It can also provide viable structural qualities for use as the core of sandwich composites in building construction. The purpose of this work was to develop aerated concrete materials with low-cost, energy-efficient and abundantly available binder materials and foaming agents. A hybrid lime-gypsum binder was used in this investigation. Past work on sustainable binders (used without aeration) has relied upon biomass ash and natural materials (e.g., laterite soils and pumice) to produce, via simple and energy-efficient processing techniques, hydraulic binders for concrete production [5-7]. A common theme here is to avoid the high processing temperatures of Portland cement, which can be achieved only in industrial settings [8, 9].

Aerated concrete comprises foams that are formed and stabilized in the mixing water of concrete using a surfactant (surface active) foaming agent [10]. Foaming agents stabilize the air bubbles formed in water during (intense) stirring. Foaming agents comprise surfactants with polar (hydrophilic) and non-polar (hydrophobic) ends. The hydrophilic ends of the surfactant molecules cluster in air bubbles, with their hydrophilic ends pointing at water, thereby stabilizing the air bubbles formed in water [11]. In this capacity, the surfactant acts as an emulsifier, which refers to molecules that help normally repulsive ingredients (like water and air) to mix. Considering the breadth of surfactant applications, they are available abundantly across the world.

* Corresponding author: matalkah@msu.edu

Alternative cementitious binders were developed in this project using formulations incorporating gypsum. Some surviving ancient buildings point at the improvements made in the moisture resistance and durability of gypsum binders via introduction of calcium and aluminum compounds which produce moisture-resistant calcite and ettringite [12, 13]. Parallel with gypsum, lime produced by calcination of limestone emerged as another binder used in construction of ancient buildings [14-16]. The work reported here used inorganic binders formulated with gypsum and lime; surfactants were used to transform these binders into aerated concrete. Two surfactants were evaluated in this project: (i) saponin, a major constituent of plants such as caryophyliaceae, sapindus, aceracease, hippocastanaceae, gynostemma pentaphllum and ginseng; and (ii) liquid soap.

2. Materials and Experimental Methods

The binder considered in this work comprised lime: gypsum at 20:80 weight proportions with different dosages of foaming agents. Gypsum, calcium oxide (Lime) and saponin were purchased in powder form from Sigma Aldrich at 99% purity, and liquid soap was purchased from a local grocery store in Lansing (Michigan). The mix designs considered in the experimental program are presented in Table 1. These mix designs were devised after preliminary trials which led to selection of viable dosages of different foaming agents.

Table 1. Mix designs of aerated concrete materials

Mix	Binder Composition by Weight	Foaming Agent	Foaming Agent	Water/Binder Ratio
1	0.2Lime:0.8Gypsum	Saponin	0.001	0.6
2	0.2Lime:0.8Gypsum	Saponin	0.002	0.6
3	0.2Lime:0.8Gypsum	Saponin	0.003	0.6
4	0.2Lime:0.8Gypsum	Saponin	0.004	0.6
5	0.2Lime:0.8Gypsum	Liquid Soap	0.02	0.6
6	0.2Lime:0.8Gypsum	Liquid Soap	0.04	0.6
7	0.2Lime:0.8Gypsum	Liquid Soap	0.05	0.6

Foam was generated in water by adding the foaming agent (saponin or liquid soap) to water, and stirring the solution at high speed (Figure 1a.). Mixing was continued until all water assumed the appearance of foam. Half of the mixing water was used for generating the foam. Other mix ingredients were mixed separately in a mortar mixer; the foamed water was then added, and mixing was continued until a homogeneous aerated concrete was achieved (Figure 1b.).

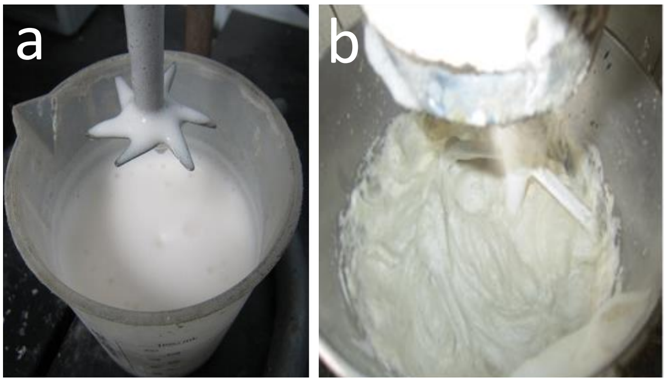

Figure 1. (a) Generation of foam in water, (b) Mixing of aerated concrete

Cube specimens were used to measure the compressive strength of aerated concrete using Forney test equipment with 2,227 kN force capacity. Density of aerated concrete was calculated as weight divided by volume of cubes, and length change was measured as percent change in cube dimensions; these measurements were made at 7 days of age after 4 days of storage at room temperature and 50% relative humidity. The assessment of shear modulus was made by performing compression tests on 50 mm cube specimens where the compression force and deformation in the loading direction were measured together with transverse deformation (Figure 2.). The test data was used to calculate the elastic modulus and Poisson’s ratio, and the shear modulus of aerated concrete. This test was performed after 14 days of room-temperature curing on specimens of Mixes 3 and 7 in Table 1.

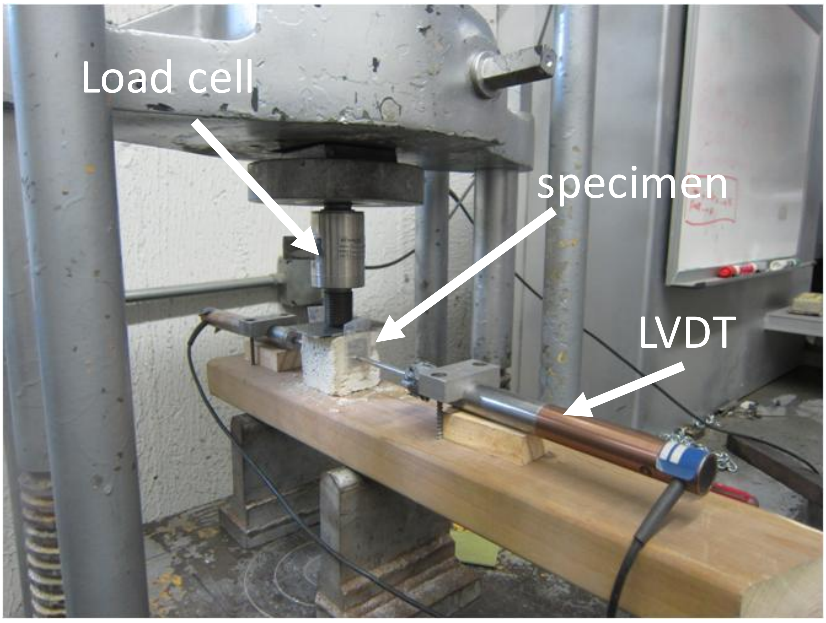

Figure 2. Compression testing of cube specimens with instrumentation for measurement of longitudinal force and deformation as well as transverse deformation

Thermal conductivity tests were performed per ASTM C177 and C1045 on plate specimens with 13 mm thickness and $200\ mm \times 200\ mm$ planar dimensions made with Mix 3 in Table 1. In this test (Figure 3.), two plate specimens were sandwiched between cold and metered hot plates (with a guard plate). Steady-state temperatures were chosen to be 40oC for the measured area, and 25°C for the cold plates. When steady-state conditions were achieved, three successive readings were made, that were separated by at least 30 minutes. Heat flux and thermal conductivity were calculated using Equations 1 and 2.

$$q = \frac{Q}{2A} \quad (1)$$

$$\lambda = \frac{q}{\Delta TL} \quad (2)$$

Where, q represents heat flux (W/m^2), Q is power in Watt, A is the total metered area (m^2), λ is thermal conductivity ($Wm^{-1}°C^{-1}$), ΔT is temperature difference between the metered hot plate and the cold plate surfaces (°C), and L is the thickness of the specimen (m).

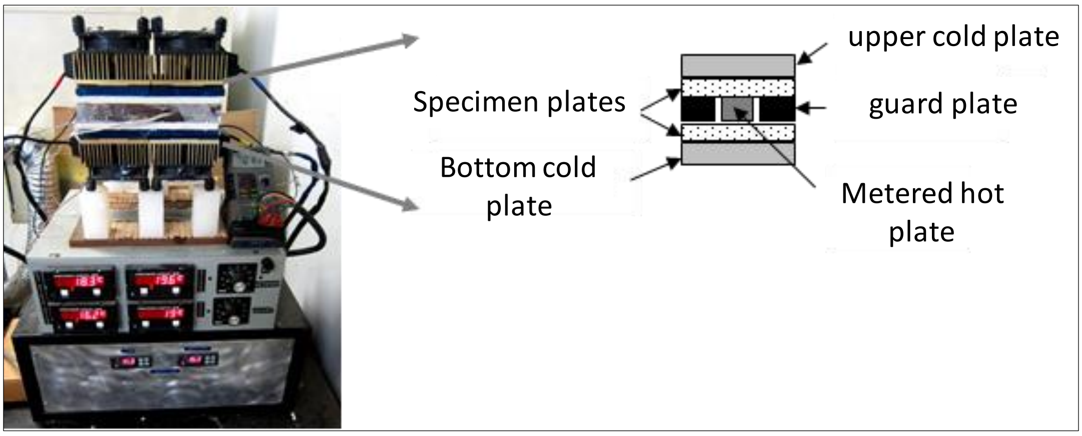

Figure 3. Thermal conductivity test setup (insulation removed to show specimens)

Split tension tests (Figure 4a.) were performed on specimens prepared with Mix 3 per ASTM C496, using cylindrical specimens of 152 mm diameter and 72 mm height. This test was performed using Forney test equipment with 2,227 kN force capacity. Flexure tests (Figure 4b.) were also performed on specimens made with Mix 3 per ASTM C78 using prismatic specimens of $50\ mm \times 50\ mm$ cross-section and 285 mm total length. The test was performed using servo valve-controlled hydraulic MTS equipment, and flexural load and deflection data were collected using a load cell and a displacement transducer. Sorptivity (rate of water absorption) tests were performed on 10 cm height by 5 cm diameter cylindrical specimens per ASTM C 1585. Sorption tests were performed on specimens made with Mixes 3 and 7.

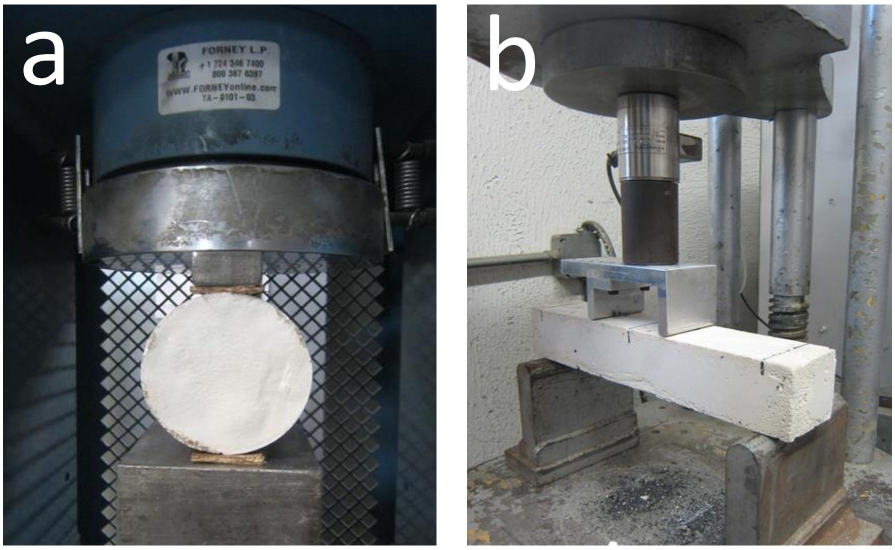

Figure 4. (a) Split tension, (b) Flexural tests setups

3. Results and Discussion

Aerated concrete specimens exhibited ductile failure modes in compression. Figure 5. shows a compression test cube prior to and after testing. The compressive strength, density and length change test results for different aerated concrete mixtures are presented in Table 2. Stability of the foam structure during curing is also a key requirement in development of aerated concrete. Among mixtures considered in the experimental work on aerated concrete, Mix 3 (comprising a lime-gypsum matrix with saponin used as foaming agent) provided a desired balance of properties. The 7-day compressive strength of this aerated concrete formulation is comparable with those reported in the literature (or deducted from the reported 28-day values) [17]. The measured value of thermal conductivity for Mix 3 with 0.53 g/cm^3 density was 0.546 W m^{-1} $^oC^{-1}$, which is of the same order of magnitude as those reported in the literature [17]. The 7-day split tensile and flexural strengths of the Mix 3 aerated concrete were 0.256 and 1.32 MPa, respectively. Both these values exceed the 7-day compressive strength of this aerated concrete. The ratio of flexural-to-split tensile strength of aerated concrete (at 7 days of age) is also high when compared with normal concrete. These observations point at the ductility of the aerated concrete (Mix 3), and its fundamentally different qualities (at 7 days of age) when compared with normal concrete. Figure 6. presents the flexural load-deflection behavior of the Mix 3 aerated concrete at 7 days of age.

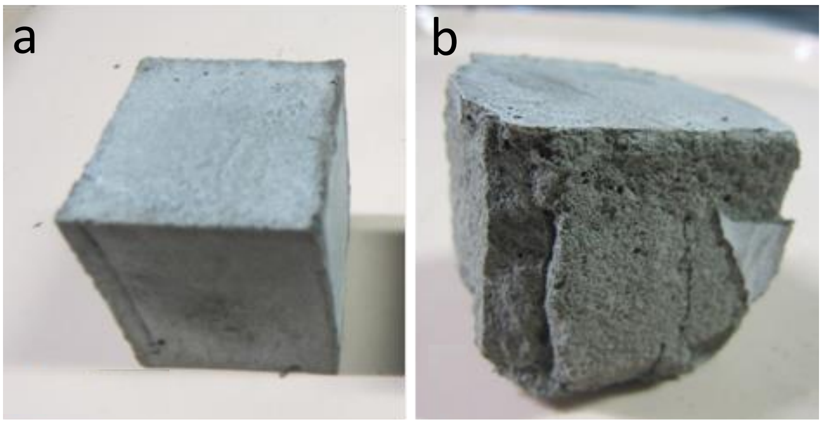

Figure 5. Compression test cube before (a) and after (b) failure

Table 2. Compressive strength, density and length change test results

Mix	7-Day Compressive Strength, MPa	Density, g/cm^3	Length Change, %
1	3.65	091	Minor*
2	2.82	0.82	Minor*
3	0.14	0.53	Minor*
4	0.20	0.49	Minor*

5	2.19	0.82	Minor*
6	1.05	0.76	Minor*
7	1.18	0.70	Minor*

* less than 3%

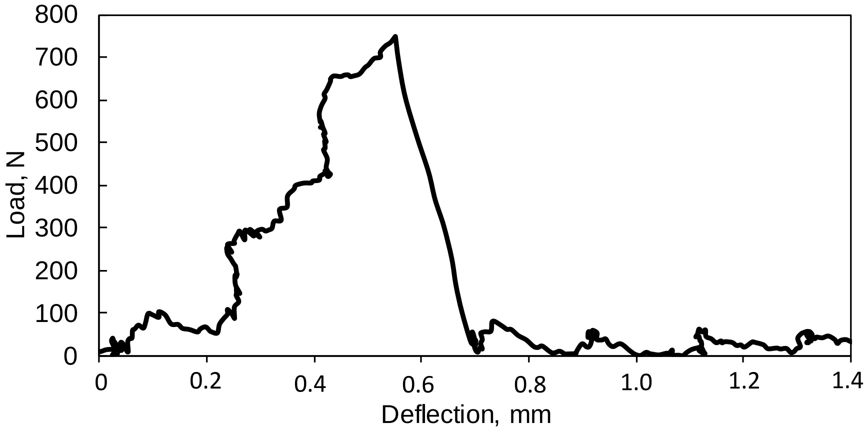

Figure 6. Flexural load-deflection behaviour of aerated concrete (Mix 3)

The measured shear moduli of aerated lime-gypsum Mixes 3 and 7 were 11 and 23 MPa, respectively. Judicious selection of indigenous cementitious matrices could further increase the shear modulus of aerated concrete materials. This shear modulus is two orders of magnitude greater than polyurethane foams used in aerospace-grade sandwich composites (with fiber reinforced composite skins). The elastic moduli of Mixes 3 and 7 were 16 and 36 MPa, respectively, and the corresponding Poisson's ratios were 0.24 and 0.22.

Sorption test results for Mixes 3 and 7 are presented, as a function of the square root of time ($Sec^{1/2}$), in Figure 7, and the initial and secondary sorptivity values are presented in Table 3. With saponin as foaming agent, Mix 3 has a higher initial sorption rate than Mix 7 with liquid soap foaming agent. The secondary sorption rate of Mix 3, however, is smaller than that of Mix 7.

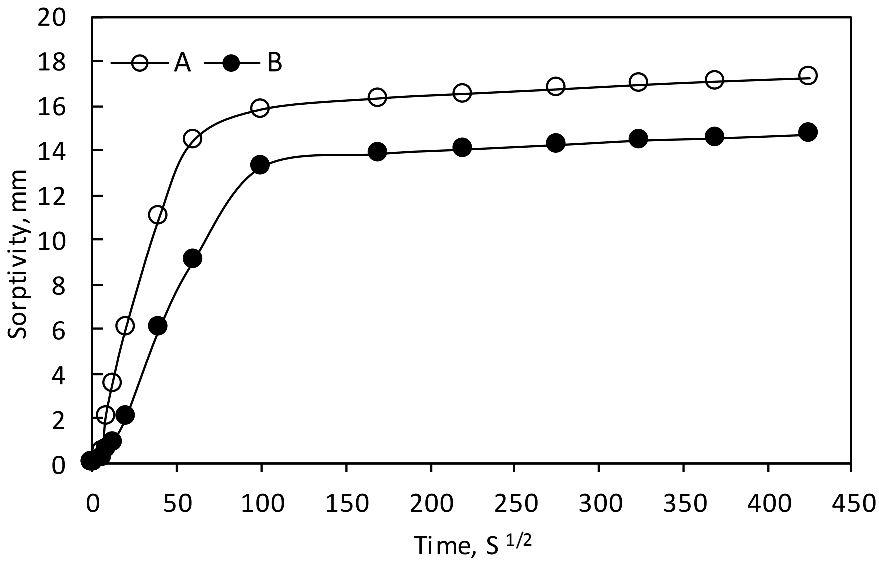

Figure 7. Sorption versus square root of time for Mix 3 (A) with saponin and Mix 7 (B) with liquid soap

Table 3. Initial and secondary sorption rates of Mixes 3 and 7

	Initial sorptivity ($mm/s^{1/2}$)	Secondary sorptivity ($mm/s^{1/2}$)
Mix 3	0.377	0.0029
Mix 7	0.239	0.0036

4. Conclusion

- Aerated concrete can provide a desired balance of insulation and structural attributes for use as core in sandwich composites that offer both insulation and structural qualities for building construction. In this application, aerated concrete is expected to provide moderate levels of mechanical properties (e.g., shear strength and modulus, tensile strain capacity) to enable efficient sandwich composite structural action. The aerated concrete core should also provide adequate insulation qualities. Aerated concrete comprises a cementitious matrix within which air bubbles are introduced (as replacement for aggregates in normal concrete) using a foaming agent. It comprises foams that are formed and stabilized in the mixing water of concrete using a surfactant.
- An experimental program was conducted where different foaming agents (saponin and liquid soap) were used at different dosages within cementitious matrices based on lime-gypsum binder. The stability of the resulting foam, and its impact on the density as well as the physical and mechanical properties of aerated concrete incorporating the foam were investigated.
- Several indigenous aerated concrete materials were developed successfully. One with lime-gypsum matrix and saponin foaming agent was selected for further characterization. It was found to provide a viable balance of compressive, tensile and flexural strengths, density, thermal conductivity, stability of the foam structure, elastic and shear moduli and sorptivity for use as the core in sandwich composite construction modules.

5. Acknowledgment

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