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Freezing and thawing resistance of cellular concrete containing binary and ternary cementitious mixtures

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HIGHLIGHTS

- The compressive strength of cellular concrete was primarily affected by porosity and density.
- Higher porosity did not necessarily result in higher water absorption.
- Air-voids smaller than 300 μm played a critical role in increasing freeze-thaw resistance.

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ABSTRACT

Cellular concrete (CC) is a foamed low-density and low-strength material made with cement and/or lime, silica-rich material (sand, slag, or fly ash), water, fine aggregate and a foaming agent. The CC containing millions of evenly distributed, uniformly sized macroscopic air-voids of approximately 0.1–1 mm in size is considered to have good freeze-thaw (F-T) resistance. In the present study, the CC of binary and ternary cementitious mixtures with varying proportions of portland cement, fly ash, and lime were explored in a comprehensive laboratory test program related to porosity, water absorption, dry density, compressive strength, and resistance to F-T including durability factor and loss of mass. For selected mixtures, air-void spacing factor and air-void distribution had been determined. Test results showed that compressive strength of CC was primarily as a function of the porosity and density regardless of type of cementitious material with respect to the combination of binary and ternary cementitious mixture. It was also found that higher porosity did not necessarily result in higher water absorption. CC was generally found to present good F-T resistance compared to non-aerated concrete although the CC with high porosity did not necessarily result in higher resistance of F-T. The addition of fly ash to mixture led to a decrease in the number of air voids smaller than 300 μm. It was also found the F-T resistance of CC was more affected by the size of the air-void. The number of air-voids smaller than 300 μm played a critical role on reducing the F-T damage in CC.

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1. Introduction

Cellular concrete (CC) or sometimes called foamed/aerated concrete is defined as a foamed low-density and low-strength material made with cement and/or lime, silica-rich material (sand, slag, or fly ash), water, fine aggregate and a foaming agent to form a uniform cellular structure of air voids [1]. The process of forming air bubbles in the CC is divided into two groups: (1) mechanical foaming procedure and (2) chemical expansion foaming procedure [2]. In the mechanical foaming procedure, the air void system in the CC is created by mixing a mortar mixture and the foam created by diluting a liquid foaming agent with water in predetermined proportion through a foam generator. On the other hand, the chemical expansion foaming procedure is to use expansion agent such as aluminum powder to generate the foam. As shown in Fig. 1, the reaction between aluminum powder and calcium hydroxide from cement (lime) paste results in the hydrogen gas generation in the mixture, and thus microscopic air bubbles are produced in the matrix [3].

Due to high air void content having millions of evenly distributed, uniformly sized air bubbles or cells (up to 80% of the volume), the CC can have a thermal conductivity as low as 0.15 to

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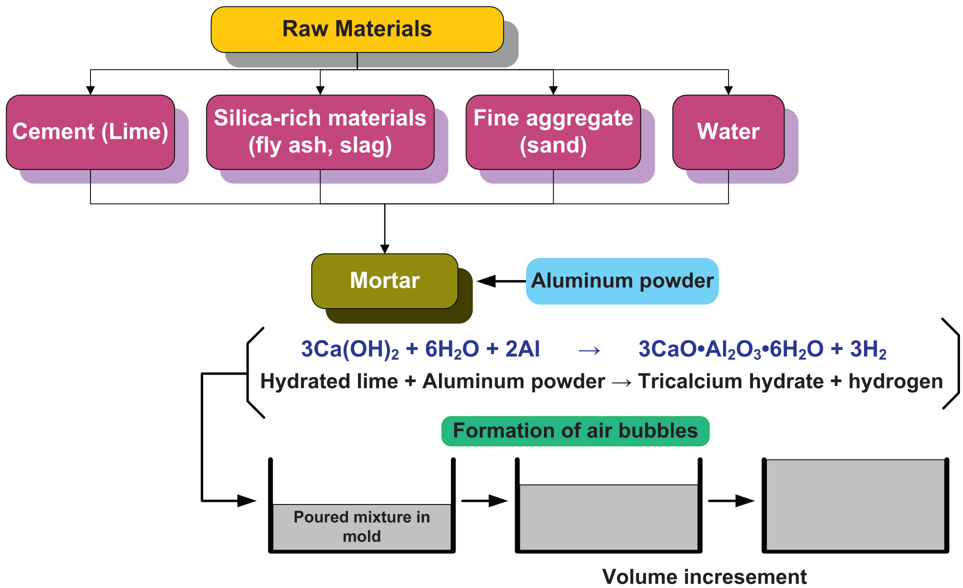

Fig. 1. Chemical expansion foaming procedure.

0.20 W/m·K, oven dry density between 240 and 1900 kg/m^3, and low compressive strength between 2.5 and 10 MPa [4,5]. These unique properties of the CC make it a suitable material for lightweight-based insulation, fire walls, and structural backfill. Besides being utilized as an insulating concrete, precast bricks and blocks made with CC can replace normal weight concrete and burned-clay masonry units commonly used as filler panels in concrete framed structures. Such a replacement is considered for economic reasons and results in more energy efficient air conditioning of the structure [6–8]. However, the use of CC as construction materials in many applications is still limited because of the lack of information about its durability, testing standards, acceptable performance criteria of the material. For example, little data are available on the performance and role of air-void system of CC on freezing and thawing (F-T) resistance.

Narayanan and Ramamurthy [9] and Visagie and Kearsely [10] reported that the pore structure of CC consists of gel pores, capillary pores as well as air-voids (air entrained and entrapped voids) in a similar fashion with normal concrete. However, most of previous researches [10–12] have been focused on the relationship between air-void system and compressive strength including empirical modeling that allows to predict the strength of CC. Few reports have discussed the performance of F-T resistance of CC. The most common and critical failure modes of CC exposed to F-T were surface scaling and spalling because CC contained large amount of free and absorbed water due to its high water absorption characteristics [13]. Tikalsky et al. [14] reported that compressive strength, depth of initial penetration, absorption capacity and absorption rate are important variables in F-T resistance of CC. However, as previously noted, little data are available on the physical performance and the relationship between capillary porosity and F-T resistance of CC.

The purpose of this study is to evaluate and to characterize a role of air-void system (capillary porosity) in F-T resistance of CC. The CC with varying proportions of portland cement, fly ash, and lime were explored from comprehensive laboratory experiments related to porosity, water absorption, dry density, compressive strength, and F-T resistance including scaling resistance and durability factor. Air contents of CC were set at 30, 40, and 50 percent. A set of plain cement concrete and binary cementitious concrete were also tested in conjunction with ternary CC mixtures.

2. Experimental program

2.1. Materials and mixture proportions

Cementitious materials used in this study included an ASTM Type I Portland cement, ASTM Class F fly ash, and lime. The specific gravity (G_x) of cement, fly ash, and lime are 3.15, 2.30, and 2.25, respectively. Masonry sand meeting the specification of ASTM C 144-03 [15] was used in the mixture. The sand had 100 percent passing of No. 8 (2.36 mm) sieve, an absorption capacity of 1.01%, and a G_{sand} of 2.57. The foaming agent was diluted with water at a ratio of 1–60 (by volume) and then aerated under pressure to create the foam using a foam generator. The foaming rate was set at 0.05 m^3/min.

A total of 16 mixtures were evaluated. The mixture proportions are given in Table 1. Test mixtures were prepared under ambient laboratory conditions. To evaluate the effect of air content on F-T resistance and its fresh and hardened properties of CC, these mixtures were further categorized into 3 series; Series I, II, and III. Four mixtures in Series I did not contain forming admixture and was combined with cement, fly ash, and lime and water to cementitious material ratio (w/cm) of 0.60. Series II mixtures were cement-lime binary cementitious blends with 30, 40, and 50% air contents with the same w/cm as Series I. Finally, series III mixtures were ternary cementitious mixtures with varying proportions of cement-lime-fly ash and with the same air content and w/cm of series II.

2.2. Mixing procedure

The CC preparation was carried out in the laboratory using a commercial paddle mixer. As there is no standard for CC preparation, the mixing was carried out by following sequence. The total amount of water was first placed in the mixer. The dry cementitious materials such as cement, fly ash, and lime were then introduced and mixed at medium speed for 30 s. The required amount of aggregate was then added to the mixer over a period of 30 s while the mixer continued to operate. The resulting mortar was then allowed to mix for an additional 30 s at medium speed. The foam was produced by the foam generator and was added to the mixture over a 60 s period until all foam was uniformly

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