



A classification of studies on properties of foam concrete

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ABSTRACT

Though foam concrete was initially envisaged as a void filling and insulation material, there have been renewed interest in its structural characteristics in view of its lighter weight, savings in material and potential for large scale utilization of wastes like fly ash. The focus of this paper is to classify literature on foam concrete in terms of constituent materials (foaming agent, cement and other fillers used), mix proportioning, production methods, fresh and hardened properties of foam concrete. Based on the review, the following research needs have been identified: (i) developing affordable foaming agent and foam generator, (ii) investigation on compatibility between foaming agent and chemical admixtures, use of lightweight coarse aggregate and reinforcement including fibers, (iii) durability studies, and (iv) factors influencing foam concrete production viz., mixing, transporting and pumping.

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1. Introduction

Foam concrete is either a cement paste or mortar, classified as lightweight concrete, in which air-voids are entrapped in mortar by suitable foaming agent. It possesses high flowability, low self-weight, minimal consumption of aggregate, controlled low strength and excellent thermal insulation properties. By proper control in dosage of foam, a wide range of densities (1600–400 kg/m³) of foamed concrete can be obtained for application to structural, partition, insulation and filling grades. Although the material was first patented in 1923 [1], its construction applications as lightweight non- and semi-structural material are increasing in the last few years. The first comprehensive review on cellular concrete was presented by Valore [1,2] in 1954 and a detailed treatment by Rudnai [3] and Short and Kinniburgh [4] in 1963, summarising the composition, properties and uses of cellular concrete, irrespective of the method of formation of the cell structure. Recently, Jones and McCarthy [5] have reviewed the history on use of foam concrete, constituent materials used, its properties, and construction application including some projects carried out worldwide. The functional properties like fire resistance, thermal conductivity and acoustical properties are also included in these reviews, while the data on fresh state properties, durability and air-void system of foam concrete are rather limited.

The production of stable foam concrete mix depends on many factors viz., selection of foaming agent, method of foam preparation and addition for uniform air-voids distribution, material selection and mixture design strategies, production of foam concrete, and perfor-

mance with respect to fresh and hardened state are of greater significance. With the above aspects in view, this paper classifies the studies on foam concrete related to its constituent materials, mix proportioning, production and fresh state and hardened properties.

2. Constituent materials

2.1. Constituents of base mix

In addition to Ordinary Portland cement, Rapid hardening Portland cement [6,7], high alumina and Calcium Sulfoaluminate [8] have been used for reducing the setting time and to improve the early strength of foam concrete. Fly ash [5,6,9–12] and ground granulated blast furnace slag have been used in the range of 30–70% and 10–50%, respectively [13,14] as cement replacement to reduce the cost, enhance consistence of mix and to reduce heat of hydration while contributing towards long term strength. Silica fume up to 10% by mass of cement has been added to intensify the strength of cement [15–17]. Alternate fine aggregates, viz., fly ash [18–20], lime [7], chalk and crushed concrete [21], incinerator bottom ash, recycled glass, foundry sand and quarry finer [22], expanded polystyrene and Lytag fines [23,24] were used either to reduce the density of foam concrete and/or to use waste/recycled materials. Concrete with densities between 800 and 1200 kg/m³ have been produced using lightweight coarse aggregate in foamed cement matrix [25].

The water requirement for a mix depends upon the composition and use of admixtures and is governed by the consistency and stability of the mix [26]. At lower water content, the mix is too stiff causing bubbles to break while a high water content make the mix too thin to hold the bubbles leading to separation of bubbles from the mix and thus segregation [20]. Water–cement ratio used

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ranges from 0.4 to 1.25 [15,27]. Though super plasticisers are also sometimes used [28], its use in foamed concrete can be a possible reason for instability in the foam [11] and hence compatibility of admixtures with foam concrete is of importance.

Chopped polypropylene fibers of 12 mm length in the dosage range of 1–3 kg/m³ has been reported to enhance the shear behaviour of foam concrete equivalent to that of normal concrete. Also the usage of fibers is reported to mitigate brittleness, while reducing its weight and cost [5,29,30]. Optimum combinations of strength, ductility, density, workability and also cost can be obtained by selecting a suitable fiber type, air content and w/c ratio of base mortar [31].

2.2. Foam

A description of commonly used natural material-based and synthetic foaming agents have been presented by Valore [1], Taylor [32], Perez and Cortez [33], Laukaitis et al. [34], Park et al. [35]. Most of the earlier studies have used proprietary foaming agents, viz., Neopar [36,37], Mearlcrete [38], Elastizell [39,40], and Foam tech [6,41–43]. Foam concrete is produced either by pre-foaming method or mixed foaming method. Pre-foaming method comprises of producing base mix and stable preformed aqueous foam separately and then thoroughly blending foam into the base mix. In mixed foaming, the surface active agent is mixed along with base mix ingredients and during the process of mixing, foam is produced resulting in cellular structure in concrete [16]. The foam must be firm and stable so that it resists the pressure of the mortar until the cement takes its initial set and a strong skeleton of concrete is built up around the void filled with air [44]. The preformed foam can be either wet or dry foam. The wet foam is produced by spraying a solution of foaming agent over a fine mesh, has 2–5 mm bubble size and is relatively less stable. Dry foam is produced by forcing the foaming agent solution through a series of high density restrictions and forcing compressed air simultaneously into mixing chamber. Dry foam is extremely stable and has size smaller than 1 mm, which makes it easier for blending with the base material for producing a pump able foam concrete [45]. Viscosity of liquid phase, surface effects such as Gibbs and Marangoni effects, disjoining pressure between adjacent interfaces due to adsorption of ionic and non-ionic surfactants and polymers and concentration of foaming agents are some of the factors influencing foam stability as identified by various researchers [46–50].

3. Proportioning and preparation of foam concrete

Often trial and error process is adopted to achieve foam concrete with desired properties [51]. For a given mix proportion and density, a rational proportioning method based on solid volume calculations was proposed by McCormick [38]. Based on this work, the design aid of ACI 523-1975 [52] relates plastic density and compressive strength, using which the cement content and water–cement ratio can be chosen for a given strength and density. ASTM C 796-97 [53] provides a method of calculation of foam volume required to make cement slurry of known water–cement ratio and target density. Kearsley and Mostert [54] have proposed a set of equations (density and volume of foam concrete), which are written in terms of the mixture composition, for calculating the foam volume and cement content. For a given 28-day compressive strength, filler–cement ratio and fresh density, typical mix design equations of Nambiar and Ramamurthy [55] determines mixture constituents viz., percentage foam volume, net water content, cement content and percentage fly ash replacement. Most of the methods proposed, help in calculation of batch quantities if the mix proportions are known. Even though the strength of foam con-

crete depends on its density, for a given density, the strength can be increased by changing the constituent materials. Also, for a given density, the foam volume requirement depends on the constituent materials [55]. Hence for a given strength and density requirement, the mix design strategy should be able to determine the batch quantities.

Pre-formed foaming is preferred to mix-forming technique due to the following advantages: (i) lower foaming agent requirement and (ii) a close relationship between amount of foaming agent used and air content of mix [1,16]. Most common types of mixers (tilt drum or pan mixer used for concrete or mortar) are suitable for foam concrete. The type of mixer and batching and mixing sequences of foam concrete depends upon pre-formed foam method or mix-foaming method [26].

4. Properties of foam concrete

Table 1 summarizes the fresh and hardened properties studied by researchers. The hardened properties are classified into physical (drying shrinkage, density, porosity and air-void system, sorption), mechanical (compressive and tensile strength, modulus of elasticity, prediction models), durability properties and functional characteristics (thermal conductivity, acoustical properties and fire resistance).

4.1. Fresh state properties

As foam concrete cannot be subjected to compaction or vibration the foam concrete should have flowability and self-compactability. These two properties are evaluated in terms of consistency and stability of foam concrete, which are affected by the water content in the base mix, amount of foam added along with the other solid ingredients in the mix [74].

4.1.1. Consistency

Flow time using marsh cone and flow cone spread tests are adopted to assess the consistency of foam concrete [10]. These measurements were also related to rheology and it was observed that coarse fly ash as filler exhibited 2.5 times higher spread compared to cement–sand mix. This enhanced consistence and rheology is attributed to difference in particle shape and size of fine aggregate. When replacing sand with fine fly ash by mass, the consistency of the mix is reduced due to higher fines content. Hence to satisfy the consistency requirement, an increase in water–solids ratio is required with an increase in fly ash replacement level. However fly ash mixes were also reported to affect foam stability, necessitating larger foam volume to achieve the design plastic density, which was attributed to the high fluid consistency in the base mix and high residual carbon in the ash [10]. The consistency reduces with an increase in volume of foam in the mix, which may be attributed to the (i) reduced self-weight and greater cohesion resulting from higher air content [26] and (ii) adhesion between the bubbles and solid particles in the mix increases the stiffness of the mix.

4.1.2. Stability

The stability of foam concrete is the consistency at which the density ratio is nearly one (the measured fresh density/design density), without any segregation and bleeding [20,74]. This ratio is higher than unity at both lower and higher consistencies due to either stiffer mix or segregation. The stability of test mixes can also be assessed by comparing the (i) calculated and actual quantities of foam required to achieve a plastic density within 50 kg/m³ of the design value and (ii) calculated and actual w/c ratios. The additional free water contents resulting from the foam collapse

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