Construction and Building Materials 125 (2016) 998–1004

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of activated foaming agent on the foam concrete properties

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HIGHLIGHTS

- Stability of foam is dependent on concentration of protein foaming agent (FN1).
- Improved foam concrete stability gained by microwave and ultrasonic treatment of FN1.
- Effect of foam and foam concrete stability on final properties of foam concrete.

ARTICLE INFO

Article history:
Received 1 August 2014
Received in revised form 2 August 2016
Accepted 28 August 2016

Keywords:
Foam concrete
Foaming agent
Ultrasonic treatment
Microwave treatment
Solid particle stabilization

ABSTRACT

Different volumes of liquid foam and constant water-cement ratio (0.55) were used to prepare a set of foam concretes via pre-formed foaming. The liquid foams consisting of protein foaming additive, water and air, produced by using foam generator, were mixed with Portland cement – water suspensions. The effect of the foaming agent concentration and its microwave and ultrasonic treatment was examined in relation to the foam stability, bulk density, microstructure and resulting compressive strength. Micrographs from scanning electron microscope (SEM) were used to determine an average pore size. The crystalline phase composition of the samples was assessed by XRD analysis and simultaneous TG-DTA was used to study their thermal stability. Decreased pore size that accounts for compressive strength improvement was determined in the samples prepared with lower concentration of microwave and ultrasonic treated foaming agent. Lower concentration of foaming agent itself also had positive effect on the stability of the foam. However, its influence was not so distinguished.

1. Introduction

In comparison with ordinary concrete, foam concretes show many advantages, including better manipulation, possibility of treatment and repairing. They can be used for roof insulation, floor leveling, void filling etc. [1]. The foam concretes exhibit good mechanical strength and low thermal conductivity, resulting from their low weight. Low specific density together with the saving of input material, as well as environmental aspect, which are the important characteristics of these materials, are ensured by encased character of air voids within their porous structure [2].

Contrary to the air-entraining methods, where a cellular structure is attained by gas generation from gas-forming chemicals (predominantly aluminium power), the foaming method is reported as more economical and controllable pore-forming process because there are no related chemical reactions involved [3]. Volume, size and air-void spacing impact on the strength and the density of the foam concrete was investigated by many authors [4–6]. It was confirmed that the more narrow distribution of air-void size, the higher strength values can be achieved, whereas larger voids result in lower strength. Previously mentioned pore parameters and microstructure together with the composition are the most important factors influencing final properties of the foam concrete and thus their particular usage. Considering the foam concretes prepared via pre-formed foaming, the porosity and the pore-related parameters of material result predominantly from the porosity, stability of the foam and water-cement ratio.

Stability of the foam is threatened mainly by the drainage, the coalescence and the Ostwald ripening (disproportionation) that relate together. Initial stability of the liquid foam is ensured by foaming agents that reduce the surface tension. Both synthetic and protein foaming agents are used in preparing cellular concrete. Their mechanism of air entraining differs from each other [7]. The foaming additive FN1 chosen for this study is commonly used and belongs to the protein group. This type of formers produces air bubbles as a result of proteins degradation. In addition to the

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http://dx.doi.org/10.1016/j.conbuildmat.2016.08.122
0950-0618/

Table 1
Wet density (WD) vs. theoretical density (TD) of the samples prepared with different volume of the liquid foam.

V_{foam}/l	Normal	Low concentration	Treated	
	WD/kg m^{-3}	WD/kg m^{-3}	WD/kg m^{-3}	TD/kg m^{-3}
1	880	860	860	850
1.5	690	700	730	690
2	580	580	620	580
2.5	480	500	530	510

reduction of the surface tension and the creation of interface between bubbles, protein foaming agents help to develop stable air bubbles via hydrogen bonds between molecular groups [7].

The effect of ultrasonic and microwave treatment on the functional properties of proteins is commonly discussed in the literature related to the food technology. Among many applications, the ultrasound is used to enhance the surface chemistry of proteins. The positive effect of ultrasound is mainly attributed to the physical, mechanical and chemical results of acoustic cavitation. Acoustic pressure cavitation leads to formation, growth and violent collapse of small bubbles in liquid and thus increases diffusion rates, disperses aggregates and breaks down small particles. Lower frequencies of ultrasound (from 20 kHz to 100 kHz) are used to produce cavitation, because at very high frequencies, i.e. above 1 MHz, cavitation becomes more difficult to occur, and above 2.5 MHz the cavitation does not appear [8].

Acoustic cavitation causes the following effects that are important for the foam formation (a) extremely high local temperatures, which result in increased solubility and diffusivity (b) large shear forces and jetting, which favor penetration and transport at liquid/liquid or liquid/solid matrix, and (c) formation of highly oxidizing radicals during sonolysis of the solvent (hydroxyl and hydrogen peroxide for water). As a result, the foam capacities and the foam stabilities are improved after ultrasonic treatment [9].

Heating of proteins using microwave energy is accomplished by both – absorption of microwave energy by rotation of the bipolar water molecules, and translation of ionic components of the proteins. This energy is converted into heat [10]. Microwave heating causes denaturation of proteins, i.e. the violation of their quaternary, tertiary and secondary structures, while their primary structure remains unchanged [8,9]. It is commonly considered that the denaturation of proteins could expose hydrophobic regions, necessary for adsorption of molecules, on the air/water interface. Foaming stability is affected by the denaturation level, thus by the duration of microwave treatment [11,12].

Despite the above mentioned advantages of microwave and ultrasonic treatment on the foaming ability of proteins, the investigation or the use of such treatment in order to improve the properties of protein foaming agents in relation to the foam concrete technology, are absent. These processing treatments are commonly used in food industry and could present simple and available way to improve foam concrete materials. The aim of the present article is, therefore, to examine their influence on the foaming agent and consequently on the foam concrete properties.

Among others, the concentration of the foaming agent is an important factor influencing stability of the foams. According to Cases et al. [13], a suitable concentration of foaming agent is essentially lower than the critical micelle concentration (CMC). On the contrary, other authors [14] stated that foaming agent concentration should be higher than CMC to produce stable foam. In general, optimal foaming agent concentration depends on its type and the particle size. In the present study, two concentration levels – the first commonly used in practice and the second significantly lower, were investigated. Density and compressive strength as the main characteristics of the foam concrete constructive materials were also investigated in relation to the volume of the liquid foam.

Table 2
Foaming properties after different treatment of FN1.

Treatment	Foam expansion/%	Foam stability/%
Normal	83	100
Low concentration	87	130
Treated	85	140

2. Experimental

The set of the samples comprised of cement, water and different volumes of the liquid foam (1 L, 1.5 L, 2 L, 2.5 L) was prepared. In all the mixtures, the amount of cement (1000 g; Portland cement CEM I 42.5 R, Považská cementáreň, a.s., Ladce, Slovakia) and water (550 g) were maintained constant to produce a water-cement ratio of 0.55. Mixing was carried out until a homogenous base mix without lumps of undispersed cement was achieved. Special foaming additive FN1 was used to prepare the liquid foam with bulk density of approximately 70 kg m^{-3} by using the foam generator.

After the cement paste mixing, the chosen amounts of the foam were added gradually along with the continual stirring. Following the homogenization (3 min), such prepared mixtures were poured into the plastic vessels (volume of 0.5 L) and left to hydrate and harden in the air at laboratory temperature of 21 ± 1 °C.

The effect of cumulative microwave and ultrasonic treatment on the properties of the foam and the foam concrete was evaluated as follows. In the series denoted as "Normal", the foaming agent was applied without the additional treatment, thus in the original state and concentration (1.4 wt.% of foaming agent in the liquid foam) that are commonly used in practice. The second series denoted as "Low concentration" was prepared with foaming agent diluted to the half of its original concentration (0.7 wt.%). Subsequently, in series denoted as "Treated", the diluted FN1 was subjected to the effects of microwave oven (2 min at 500 W) and ultrasonic treatment (6 min). Sonication was performed in the Tesla UC 405 BJ-1 ultrasonic bath (25 kHz).

Foam expansion was evaluated according to Jambrak et al. [8]. Suspensions of "Normal", "Low concentration" and "Treated" FN1 were whipped at room temperature with a household blender at the maximum speed setting for 10 min. The whipping was interrupted after 2 min intervals. Plastic vessels with the volume of 290 ml were filled up with the prepared foams and weighted. Foam expansion was calculated using the Eq. (1):

$$\text{Foam expansion } (\%) = \frac{\text{Unwhipped suspension (g)} - \text{Foam (g)}}{\text{Unwhipped expansion (g)}} \quad (1)$$

For determination of the foam stability, the foams produced by the foam generator were inserted into the Pyrex filter funnel with the inner top diameter of 6.8 cm, the inner stem diameter of 1 cm and the stem length of 7.3 cm. Volume of the liquid released from the foam as a result of drainage was determined 6 h after the foam preparation.