Construction and Building Materials 165 (2018) 735–749

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation on the compressive strength of foamed concrete: Effect of curing conditions, cement type, foaming agent and dry density

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HIGHLIGHTS

- More than 100 foamed concrete specimens were experimentally tested in compression.
- Different behavior of foams arising from different foaming agents is observed.
- The type of foam affects the compressive strength development for fixed w/c ratio.
- A combination of curing conditions and cement types are analyzed.
- The presence of a superplasticizer in the concrete mix increased the strength.

ARTICLE INFO

Article history:
Received 30 October 2017
Received in revised form 22 December 2017
Accepted 29 December 2017

Keywords:
Foamed concrete
Compressive strength
Foaming agent
Density
Curing conditions

ABSTRACT

This paper presents the first results of an ongoing experimental campaign focused on foamed concrete. The dependence of the compressive strength upon dry density, water content, curing conditions, cement type and, most importantly, foaming agents employed in the cement paste is here investigated. In particular, this experimental study comprises more than 100 foamed concrete specimens with a fixed water/cement ratio and dry densities ranging from around 350 up to 850 kg/m^3, two cement types, three foaming agents with either protein or synthetic nature, and curing conditions in water at 30 °C, in air as well as within a cellophane sheet at environmental temperature. Unlike most of the research studies in which the water/cement ratio is adjusted on the basis of the stability and the consistence of the foam concrete mix, in this experimental investigation this ratio is fixed constant for all the analyzed design densities. This specimen preparation has made it possible to highlight different behaviors of the employed foaming agents having different nature, which is not fully described in other similar studies of the relevant literature, especially for the range of low densities analyzed in this work. The variability of the compressive strength measured is ascribed to a different stability behavior of the foams generated by foaming agents having different nature during the mixing phase with the cement paste. It is found that the increase of the compressive strength with the density is more or less described by a linear trend and is more pronounced when protein foaming agents are employed in the mix design.

1. Introduction

Foamed concrete, belonging to the wider class of lightweight concrete, is a special type of concrete that typically includes cement, water, preformed foam and fine sands, in conjunction with other sand-like fine particles such as fly ash or silica fume [1]. The foam components mixed with the cement paste give rise to the development of a system of air-voids in the underlying material microstructure. Consequently, the density of foamed concrete is generally ranging from 200 ÷ 2000 kg/m^3, thus being considerably lower than the values of 2200 ÷ 2500 kg/m^3 that are typically associated with ordinary concrete elements [2]. In particular, elements having density higher than 1600 kg/m^3 are employed as structural components in the buildings, whereas members with lower densities are mainly used for non-structural parts such as infill or internal partition walls.

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https://doi.org/10.1016/j.conbuildmat.2017.12.241
0950-0618/

The peculiar characteristics of foamed concrete elements are summarized as follows: 1) lightweight properties, which facilitate the transportation from the manufacturing plant to the construction site and make them suitable for applications to precast structures; 2) strictly related to the previous point, the inherent lower weight allows reducing the dimensions of the resisting frame structure, such as the size of the foundation, the beam and column sections, the thickness of the walls and so forth, which is advantageous in the scope of refurbishment or seismic retrofitting in seismically vulnerable areas; 3) cost-effectiveness due to the usage of rather simple ingredients that are easily available; 4) environmental sustainability when slags or recycled materials are employed in the mix design as a replacement of aggregates, for instance electric arc furnace slag [3], recycled glass, foundry slag [4], fly ash and ground granulated blast-furnace slag [5,6].

Additionally, other reasons have contributed to the growing interest in using foamed concrete members in civil engineering buildings that are more related to their physical properties: 1) their enhanced thermal insulating properties, especially when low densities are employed [6,7]; 2) the good resistance against fire as compared to ordinary concrete, which is due to the presence of air bubbles in the internal material microstructure [8,9]; 3) good acoustic shielding properties [7,9,10]; 4) the improved workability [11,12]. Despite their inherent low compressive strengths, which decrease almost proportionally with the decrease in density, it is however possible to achieve reasonably acceptable strength performance by modifying the cementitious matrix, in particular by incorporating fine particles such as silica fume and fly ash in the mix design [13–16], or polypropylene fibers [17]. Experimental evidence revealed that the water absorption and porosity are not significantly altered by the ash type or content [18,19].

Several experimental investigations on the compressive strength of foamed concrete can be found in the relevant literature. Most of the research studies focused on the correlation of the compressive strength with the concrete density [20,21], and with water/cement and air/cement ratios [22]. Some other studies aimed at increasing the typically low compressive strengths associated with low density by the introduction of fly ash and fine particles [23], or polypropylene and steel fibers [24]. Other research works attempted to correlate the development of compressive strength with the underlying material microstructure via microscopic scanning techniques, above all, by examining the porosity of foamed concrete with optical or electronic microscope [25,26]. The influence of different foaming agents having protein-based and synthetic nature was also investigated in [27] for medium-to-high density foamed concrete specimens, along with a characterization of the microstructure. In the latter study it was found that the foaming agents play a major role on the thermal resistance and sorptivity coefficient, but do not have a similar significant influence on the achievement of the strength. It seems interesting to check whether the previous experimental findings also apply to the range of low density (<800 kg/m^3) foam concrete.

1.1. Goal and outline of the paper

In line with this research subject, the aim of this paper is to present the first results of an ongoing experimental campaign focused on low-density foamed concrete specimens characterized by different physical, chemical and mechanical properties. In particular, in this work we only focus on the results of the compressive strength, more specifically on the influence of a few factors on the achievement of the 28 day compressive strength. More than 100 specimens were tested in compression and the main parameter investigated in this first paper is the dependence of the compressive strength upon: 1) cement type; 2) foaming agent; 3) density of the concrete specimen; 4) curing conditions. Unlike other studies, the experimental campaign was conducted by considering a fixed water/cement ratio and by varying the foam content to obtain a target dry density accordingly. This experimental campaign forms part of a wider study aimed at developing a new type of extrudable foam concrete that necessitates such low water/cement ratios. Although this study was motivated by comparative purposes against this new extrudable foam concrete, the experimental results that have been here found are interesting and useful for extending the knowledge on the traditional (non-extrudable) foam concrete in the range of low densities. It has been observed that different foam contents are necessary for foaming agents having different nature, due to the different stability behavior during the mixing phase with the cement paste. Interestingly, it has been noted that for the range of low densities analyzed in this work, the foaming agents do have a manifest influence on the achievement of the mechanical strength, which is different to other studies of the relevant literature [27] focused on medium-to-high density foam concrete. Considering traditional mixing procedures (specimen preparation with pre-forming methods) along with different curing conditions, different cement types and different foaming agents leads to an ensemble of quite general results that are not confined to the data set of the present work and that can be useful for future investigations in this field.

The outline of the paper is as follows. After this introductory section, in Section 2 the test setup will be described, along with the dimensions and characteristics of the tested specimens, the curing conditions and the testing procedures. In Section 3 the results of the experimental investigation will be presented. In this regard, physical and chemical justifications of the experimental results will be provided along with some qualitative observations regarding the hydration conditions and the compatibility of the foaming agent with the specific cement type employed. In Section 4 the coefficients of regression curves that best fit the experimental data are presented. These curves can be used for the prediction of the compressive strength of foamed concrete specimens having similar characteristics to those analyzed in the present study. Some concluding remarks will be drawn in the last Section 5.

2. Experimental campaign

The experimental campaign has comprised a set of 109 foamed concrete specimens. These specimens are cubes of 5 cm side, which were prepared as documented in Fig. 1. The choice of adopting cubes of 5 cm rather than typical 15 cm cubes is dictated by obvious savings of times and materials for the specimen preparation. Nevertheless, this simplification is meant to be on the conservative side, as the compressive strength of 5 cm cubes is usually found to be lower than analogous cubes having 15 cm side. In this context, in [28] an experimental study on the compressive strength of foamed concrete was carried out by varying the density and the shape of the cubic specimens, in particular cubes of 5, 10, 15 cm side were analyzed. It was found that the specimens having 5 cm side exhibited strengths of around 5% lower than the typical 15 cm specimens, whereas those characterized by a 10 cm side showed strengths of about 15% higher than the 15 cm specimens.

2.1. Materials

The cubic specimens were casted using two types of cement, namely Portland CEM I 52,5 R, and limestone Portland CEM II A-L 42,5 R. These cement types comply with the EN 197-1 (2006) standards with regard to the mix proportions of the main constituting elements. For each cement type, specimens were prepared using three different types of foaming agents. In particular, these three foaming agents are: 1) a protein-based foaming agent called