Foam geopolymers: State of the art and preliminary experimental results

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Abstract. Buildings are responsible for more than 40% of the energy consumption and greenhouse gas emissions. Thus increasing building energy efficiency is the most cost effective way to reduce emissions. The use of thermal insulation materials constitutes the most effective way of reducing heat losses in buildings thus reducing heat energy needs. These materials have a thermal conductivity factor, k (W/m.K) lower than 0.065 while other insulation materials like for instance aerated concrete can go up to 0.11. Current insulation materials are associated with negative impacts in terms of toxicity. Polystyrene, for example contains anti-oxidant additives and ignition retardants, additionally, its production involves the generation of benzene and chlorofluorocarbons. Polyurethane is obtained from isocyanates, which are widely known for their tragic association with the Bhopal disaster. Besides current insulation materials releases toxic fumes when subjected to fire. This paper reviews literature on foam geopolymers that could constitute a lower toxicity alternative to current commercial insulator. Current methods use foaming agents (blowing agents) such as hydrogen peroxide (H_2O_2), sodium perborate ($NaBO_3$), silica fume, powder alumina. Results of an experimental research on foam hybrid alkaline cements are reported.

Keywords. Foam agents, hybrid alkaline cements, compressive strength, thermal conductivity, density.

Introduction

Energy consumption is one of the greatest problems of the human civilization being responsible for high greenhouse gas emissions. Energy efficiency is the most cost effective way to reduce emissions. Since buildings are responsible for more than 40% of the energy consumption it´s reduction is of paramount importance not only environmental speaking as well as to reduce electric bills [1].

In this context the development of innovative thermal insulators constitutes a research priority [2].

Current insulation materials are associated with negative impacts in terms of toxicity. Polystyrene, for example contains anti-oxidant additives and ignition

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retardants, additionally, its production involves the generation of benzene and chlorofluorocarbons. Polyurethane is obtained from isocyanates, which are widely known for their tragic association with the Bhopal disaster [3].

Foamed materials are produced by using either cement paste or mortar in which large volumes of air are entrapped by using foam agents.

Giannakau and Jones explored the potential of foam concrete to enhance the thermal performance of low rise building has shown that the foam concrete ground supported slab foundation possess better thermal insulation and lower sorptivity properties while producing satisfactory strength [4].

Using foam concrete instead of inner leaf leads to increase thermal insulation of brick wall by 23%. Furthermore, insulation is more or less inversely proportional to density of foam concrete [5]. The heat transfer at high temperature is done through porous materials which are affected by radiation. Heat transfer is an inverse function of the number of air–solid interfaces traversed [6].

In this context the first part of this paper reviews the state of the art of these materials followed by the disclosure of some preliminary experimental results on the influence of several foam agents on the properties of hybrid alkaline cements.

1. State-of-the-Art

Proportioning and the preparation process of foam concrete are usually achieved by a trial and error process to obtain the desired mechanical properties of foam concrete [7]. Most proposed methods result in calculation of batch quantities. In this direction, McCormick based on solid volume calculations proposed a rational proportioning method [8].

Kearsley and Mostert have proposed a set of equations for calculating the foam volume and cement content [9].

Porosity network, permeability and pore size distribution affect compressive strength and durability properties of foam concrete [10]. The porosity of foam concrete consists of gel pores and capillary pores which is affected by volume, size, size distribution, shape and spacing between air-voids. Narrower air-void distribution leads more compact foam concrete which subsequently higher compressive strength is achieved. Using finer filler materials such as fly ash results in more uniformity of air void distributions. The compressive strength of foam concrete is significantly functioned to the density [10].

Therefore, the density of composition for foam concrete is adjusted by compressive strength. The type of mixer and batching and mixing sequences of foam concrete depends upon pre-formed foam method or mix-foaming method [11].

Pre-formed foaming is preferred to mix-forming technique due to the lower foaming agent requirement and a close relationship between amount of foaming agent used and air content of mix [12].

Foam concrete with density 1000 kg/m^3 has one-sixth thermal conductivity of typical cement-sand mortar [13].

The name ‘geopolymer’ was introduced by Davidovits in the 1970s, however the technology of alkali-activation predates this terminology by more than 60 years [14]. According to the rigorous definition of Provis [14] these materials “*are produced through the reaction of an aluminosilicate—normally supplied in powder form as an industrial by-product or other inexpensive material—with an alkaline activator, which* *is usually a concentrated aqueous solution of alkali hydroxide, silicate, carbonate or sulphate*".

Despite all the investigations published on these materials in the last decades some aspects still needed to be further investigated especially concerning durability performance [15].

Foam geopolymer constitutes a recent research field with high potential in the development of low toxicity thermal insulators with thermal conductivity value around 0.22 W/mK [16].

The discovery of one-part geopolymers (also known as hybrid alkaline cements) is considered a key event on the evolution of low carbon geopolymer technology, however they were associated with very low compressive strength [17].

Some authors recently investigated these materials having reported a 28 days curing compressive strength of 27 MPa by using fly ash and 30% OPC [18]. These mixtures are used in this paper to produce foam materials. The influence of the foam agent is highlighted.

2. Experimental

Hybrid alkaline cements are based on kaolin, fly ash, ordinary Portland cement (OPC), sodium hydroxide, calcium hydroxide ($Ca(OH)_2$), water and superplasticizer (Table 1). As previously reported [18] the kaolin and sodium hydroxide were calcined in a furnace at 650 ºC during 140 minutes being termed as calcined stuff.

Table 1. Mixture proportions (%)

Cement	Fly ash	$Ca(OH)_2$	Calcined stuff	Water/Powder	SP/Powder	Sand
30	58.3	7.7	4	35	0.8	80

Two foam agents in three percentages (1%, 2% and 3%) were used, namely hydrogen peroxide (H_2O_2) and sodium perborate ($NaBO_3$). Figure 1 shows how foaming agents induce the increase in open porosity.

1.1. Testing description

To study foamed hybrid alkaline cement four parameters were considered bulk density; open porosity (water absorption); thermal conductivity and compressive strength.Bulk density was assess according to the ASTM C 373-78.

For water absorption the specimens were immersed in water until their their weights become stable. After they were then rolled lightly on a wet cotton cloth to remove all excess water from their surfaces to reach the status of saturated-surface-dry (SSD), and were weighed and denoted by W_{SSD}.

Furthermore, the saturated IPF specimens were dried to constant weight by heating in an oven at 150 ºC, and the resulting oven-dry (OD) specimens were then weighed and recorded as W_{OD}.

The water absorption of each specimen can be calculated from the relation of $W^* = (W_{SSD} - W_{OD})/W_{OD}$.

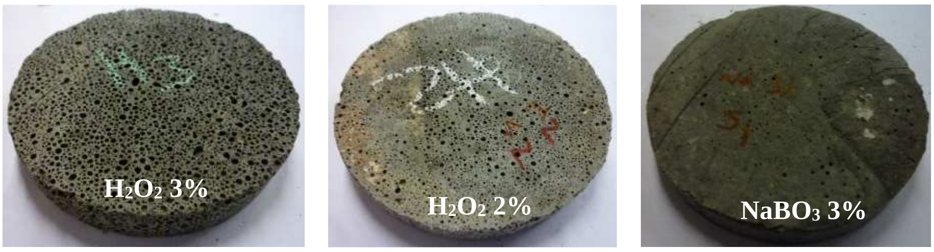

Figure 1. Porosity aspect in hybrid alkaline cement with different foam agents

Compressive strength were performed on 50×50×50 mm^3 concrete specimens according to NP EN 195-1. The specimens were located in the chamber room at 23 ºC for 28 days. Compressive strength for each mixture was obtained from an average of 3 cubic specimens. The compressive strength after exposure to high temperatures was also assessed. The specimens were exposed during two hours at 600 ºC and 800 ºC. After two hours the specimens were removed from the furnace.

2. Results and discussion

Figure 2-4 shows the open porosity (water absorption), bulk density and thermal conductivity results of mixtures with hydrogen peroxide (H_2O_2) and sodium perborate ($NaBO_3$).

Sodium perborate addition shows a more higher influence on the increase of open porosity than hydrogen peroxide. The increase of sodium perborate content from 1% to 2% leads to just a minor increase in the open porosity while the increase to 3% even reduced it.

A higher reduction in open porosity is noticed when hydrogen peroxide content increases from 2% to 3%.

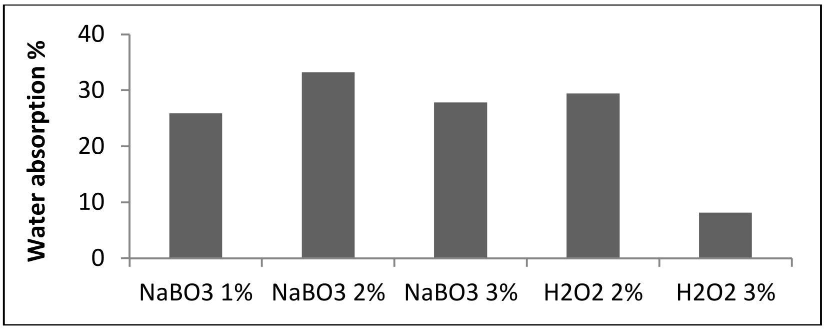

Figure 2. Water absorption (open porosity)

Concerning bulk density the increase in the sodium perborate from 1% to 3% content seems to had little influence on the bulk performance.

A not very different behaviour takes place when hydrogen peroxide content increases from 2% to 3%.

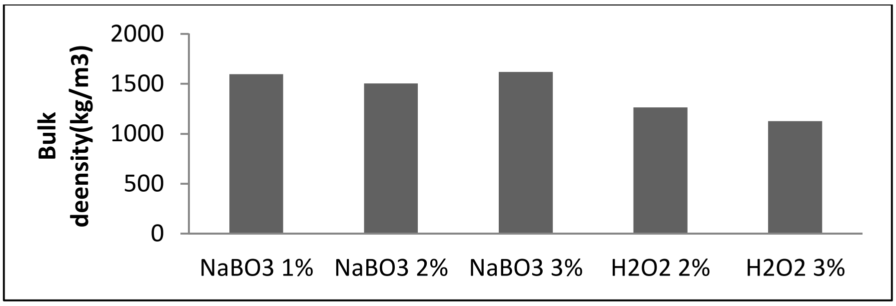

Figure 3. Bulk density

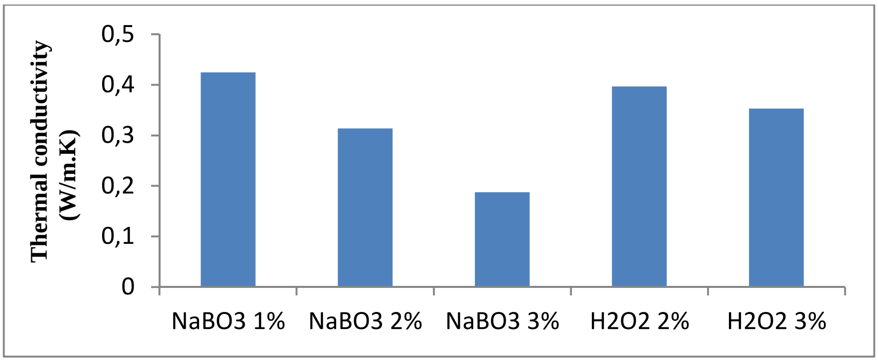

Figure 4. Thermal conductivity

The best thermal conductivity performance was obtained in the mixture with 3% sodium perborate. Still this performance is unsatisfactory because the thermal conductivity of commercial foamed masonry blocks (Ytong) are below 0.2 W/m.K and some aerated concrete mixtures have a thermal conductivity around 0.11 W/m.K. Further investigations concerning the use of higher contents of sodium perborate are therefore needed.

Figure 5 shows the 28 days compressive strength at ambient temperature and after the specimens were submitted to a high temperature (600 º C and 800 ºC).

Only the mixtures with 1% hydrogen peroxide and mixtures with 2% and 3% sodium perborate have a 28 days compressive strength above 6MPa.

The exposure to high temperature leads to a severe compressive strength reduction for the reference mixture while the reduction sis much less severe for foam mixtures.

3. Conclusions

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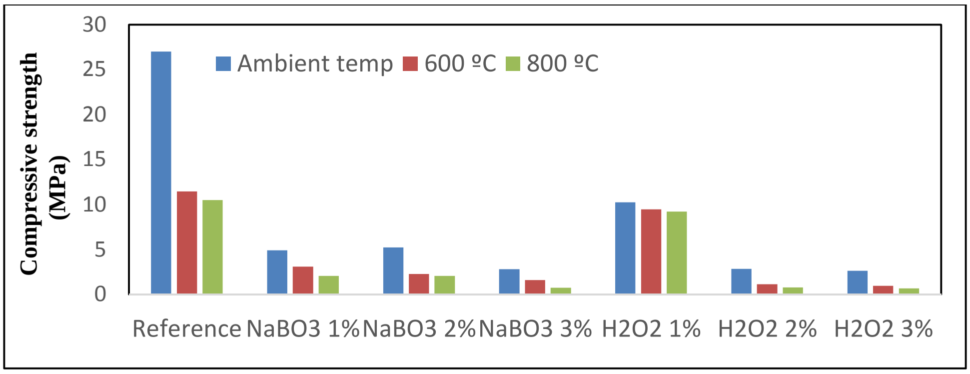

Figure 2. Compressive strength of specimens at 23 ºC, 600 ºC and 800 ºC

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