



Influence of blowing agent on the fresh- and hardened-state properties of lightweight geopolymers



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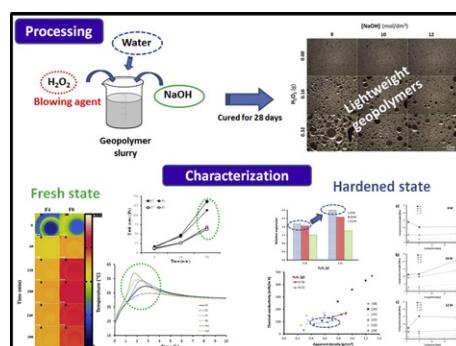
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HIGHLIGHTS

- The dominant factors affecting the fresh- and hardened-state properties of lightweight geopolymers were investigated.
- Geopolymers exhibiting very low thermal conductivity (up to 0.08 W/m K) and apparent density (440 kg/m³) were produced.
- Thermal conductivity values exhibited by these geopolymers suggest their use in thermal insulating applications.
- The incorporation of biomass fly ash waste mitigates the environmental problems associated with this waste disposal.

GRAPHICAL ABSTRACT



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ABSTRACT

The production of lightweight geopolymers is an emergent area, and the influence of the pore forming agent on geopolymer kinetics and the rheology of the pastes has been rather neglected up to now. In this work the influence of the blowing agent content, NaOH molarity and water content on the fresh and hardened-state properties of fly ash-containing geopolymers was evaluated. Results demonstrate that the blowing agent decreases the slurries yield stress, which extends the open time before in situ application. It was also found that the geopolymerisation rate is only slightly affected by the blowing agent, while a strong impact is exerted by the activator molarity. The proper association between NaOH molarity and blowing agent content leads to the production of lightweight geopolymers exhibiting very low thermal conductivity (up to 0.08 W/m K) and apparent density (440 kg/m³). The thermal conductivity shown by these innovative materials suggest their suitability for thermal insulating applications.

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1. Introduction

Increasing public awareness regarding the global warming exerts tremendous pressure on governments to significantly reduce their greenhouse gases emissions. Policy frameworks to address this concern

are already in place [1]. In this context a key criterion for the selection of construction materials is their sustainability. The production of Portland cement is becoming perceived as unsustainable [2] due to the massive CO₂ emissions (0.85 ton of CO₂/ton cement) [3]. The development of new building materials with reduced environmental footprints is a critical and pressing matter. Lightweight geopolymer concrete appears to be an excellent alternative combining performance [2] and environmental benefits [4]. Indeed the production of lightweight/porous

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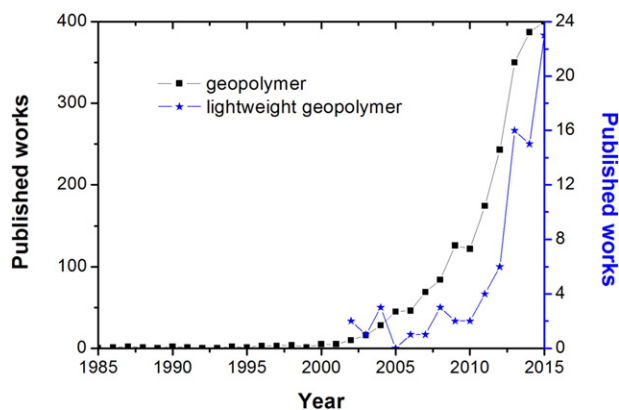


Fig. 1. Works published for “geopolymer” and “lightweight geopolymer”. (Data obtained from Scopus on April 2016)

geopolymer has attracted increasing attention [5,6] over the past years (see Fig. 1).

Geopolymers are aluminosilicate binders formed by alkaline activation of alumina- and silica-containing precursors at slightly elevated temperatures. Aluminosilicate by-products (e.g. fly ash, waste glass, red mud) [7–9] can be used as precursors which further reduce the carbon footprint of these binder materials. It is generally acknowledged that the mechanism of geopolymerisation involves dissolution, transportation or orientation, and polymerisation [10,11], this being an exothermic reaction [12]. Despite their known exothermicity, the research carried out on this topic is surprisingly scarce, as recently point out by Davidovits [13]. Nevertheless the influence of the curing temperature [14], activator type [15] and concentration [12], and nature of the starting precursors [16] has been evaluated by isothermal calorimetry.

Rheological properties such as viscosity and yield stress provide useful information regarding the kinetics and setting of geopolymers at the early age. For example, the solid/liquid ratio has been found to significantly affect the viscosity of the fresh pastes [17,18], while temperature affects mainly the yield stress [17]. The yield stress is also affected by the nature and dosage of the activator [19].

The production of porous geopolymers typically involves the addition of blowing agents (e.g. hydrogen peroxide (H_2O_2), aluminium and zinc powders) to the geopolymer slurry. Their incorporation in geopolymers production is expected to affect the geopolymerisation kinetics, as well as the rheology of the pastes, yet the latter has been rather ignored. Indeed the majority of studies focus on the geopolymers' properties after hardening [20–22], while their fresh state properties characterisation is uncommon.

In this work, lightweight biomass fly ash-containing geopolymers were produced using H_2O_2 as blowing agent. The influence of the blowing agent incorporation content, NaOH molarity and water content on

the fresh- and hardened-state properties of lightweight geopolymers was evaluated. To the best of our knowledge this is the first report considering the rheological and calorimetric characterisation of porous geopolymer slurries. This investigation aims to provide a deeper knowledge of the influence of the blowing agent on the fresh and hardened-state properties of lightweight geopolymers which is vital if the technology is to become widespread. Furthermore, the reuse of biomass fly ash (FA), as a partial replacement of metakaolin, reduces the production cost of the geopolymers while contributing towards sustainable construction.

2. Experimental conditions

2.1. Materials

Two raw materials were used as a source of aluminosilicate, namely metakaolin (MK) and biomass FA, with a MK:FA ratio of 2. MK is a commercial product bought under the name of Argical™ M1200S from Univar®, while biomass FA was supplied by a Portuguese industrial co-generation plant. The FA is generated from the biomass burning in a fluidised bed combustor.

Three different alkaline activators were prepared using hydrated sodium silicate (Chem-Lab, Belgium) and NaOH (reagent grade, 97%, Sigma Aldrich). The NaOH solutions (8, 10 and 12 M) were prepared by dissolution of sodium hydroxide beads in distilled water. The NaOH molarities were chosen according to previous works [8,18,20].

The foamed geopolymers were prepared with a 3% (wt./wt.) H_2O_2 solution.

2.2. Geopolymers preparation

To evaluate the influence of NaOH molarity, water and H_2O_2 content on the fresh and hardened properties of FA-containing geopolymers twelve compositions were prepared. The details of the mixture proportions and NaOH molarity are presented in Table 1.

The mixing involves: i) homogenisation of sodium silicate, NaOH solution and distilled water; ii) mixture of the alkaline solution with biomass FA and MK, and iii) addition of H_2O_2 (amount depending on the formulation) to the blend and mixture. Then, the slurry was transferred to plastic moulds and sealed with a plastic film. The samples were cured in controlled conditions (40 °C and 65% relative humidity) using a climatic chamber for 24 h. Afterwards, the specimens were demoulded and left at ambient conditions (temperature and humidity) until the 28th curing day.

2.3. Materials characterisation

The mineralogical compositions of MK, FA and geopolymer specimens (cured for 28 days) were assessed by X-ray powder diffraction

Table 1
Geopolymer preparation: mixture composition and NaOH molarity.

Sample name	Mixture proportion (g)						NaOH (mol/dm ³)	Study objectives
	FA	MK	Sodium silicate	NaOH	H ₂ O	H ₂ O ₂		
F1	3	6	8	3.5	1.44	–		
F2	3	6	8	3.5	2.88	–	8	
F3	3	6	8	3.5	1.44	0.16		
F4	3	6	8	3.5	2.88	0.32		
F5	3	6	8	3.5	1.44	–	10	
F6	3	6	8	3.5	2.88	–		
F7	3	6	8	3.5	1.44	0.16		Influence of water, H ₂ O ₂ content and NaOH molarity
F8	3	6	8	3.5	2.88	0.32		
F9	3	6	8	3.5	1.44	–	12	
F10	3	6	8	3.5	2.88	–		
F11	3	6	8	3.5	1.44	0.16		
F12	3	6	8	3.5	2.88	0.32		

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