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Thermomechanical performance of blended metakaolin-GGBS alkali-activated foam concrete

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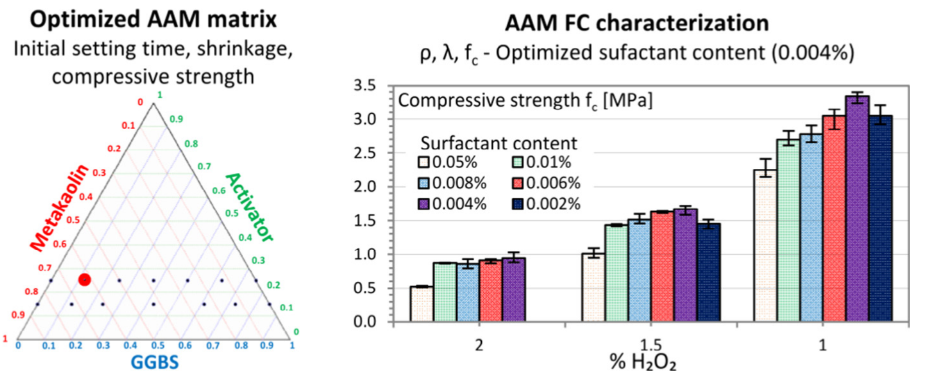
HIGHLIGHTS

- Optimized proportions between metakaolin, GGBS and activator were identified.
- H_2O_2 gas-off lasts 180 min. AAMs paste initial setting time must start after.
- Lightweight AAMs were obtained with density from 264 to 480 kg/m^3.
- The foam concrete porous structure depends on both H_2O_2 and surfactant contents.
- An optimized surfactant content (0.004%) maximized FC compressive strength.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to synthesize, at ambient temperature, blended metakaolin-ground granulated blast furnace slag (MK-GGBS) foam concrete (FC) presenting acceptable thermomechanical performance for use as self-bearing insulation material. First, a binder composition that could be used for MK-GGBS FC production was identified. Fourteen paste formulations were produced and analysed to determine the best proportions of MK, GGBS and activator to be used in an alkali-activated material (AAM) FC matrix. Certain requirements were specified for the fresh paste (initial setting time >180 min) and solid materials (high compressive strength and moderate shrinkage) to be used for FC production. The optimized mix was then employed for AAM FC production by using an H_2O_2 blowing agent (gas-foaming method). The influence of two main parameters (H_2O_2 and surfactant contents) on AAM FC properties (density, porous structure, thermal conductivity and compressive strength) were investigated. FC density mostly depends on H_2O_2 content. The FC porous structure depends strongly on both H_2O_2 and surfactant contents. High surfactant content FCs have a thin homogenous porous structure. At constant density, FC compressive strength depends on the surfactant content. An optimized surfactant content maximizing FC compressive strength at constant density was identified.

1. Introduction

During the last decades, there was a massive growing interest on research on alkali-activated materials (AAMs). These researches prove that these materials can be successfully used to produce

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load-bearing materials with good properties [1,2]. AAMs are produced by mixing aluminosilicate precursors (e.g. metakaolin (MK) or fly ash (FA)) or calcium aluminosilicate precursors (e.g. ground granulated blast furnace slag (GGBS)) rich in SiO_2, Al_2O_3 (and CaO) activated by a highly alkaline solution (usually NaOH, KOH or sodium silicate solution). Most of AAMs are based on aluminosilicate precursors that are industrial by-products. Using these precursors can reduce the embodied CO_2 if mix design and raw materials selection are carried out with a view towards optimisation of environmental performance [3]. Moreover using these precursors increase the use of waste materials, thus avoiding their storage in a landfill and the resulting pollution problems. AAMs present good mechanical properties and fire resistance [4]. A few studies showed that mixing GGBS and MK present some advantages. These studies were performed on MK-GGBS pastes [5–9] and mortar [10]. Adding GGBS to MK-based geopolymers provides an improvement in mechanical properties [5,9] and reduces shrinkage [9]. Samson et al. [9] produced and characterized blended AAMs based on flash-calcined MK and GGBS. The influence of compositions (MK, GGBS and activator contents) on initial setting time, shrinkage, mass loss and compressive strength were investigated.

The relatively new development of AAMs (compared to OPC) explains why only a few studies have been conducted on AAM FCs. Most FCs are made with Ordinary Portland cement (OPC) alone or with additions [11–13]. The main information on AAM FCs available in the literature is summarized in Table 1 (aluminosilicate precursors, alkaline activation, production method, surfactant, blowing agent, density, compressive strength and thermal conductivity). Most of the AAM FCs reported in the literature were produced with fly ash (FA) [14–21] and needed to be thermally cured. AAM FCs were also successfully prepared with a mix of FA and GGBS [22,23] and some were made with MK [24,25] or GGBS [26,27] but none have been made with blended MK-GGBS binder. The vast majority of AAM FCs are produced with the gas-foaming method [15–19,21,24,25,27–29].

This study aimed to synthesize and to characterize blended MK-GGBS FC presenting acceptable thermomechanical performance for use as self-bearing insulation material. The fact that some AAM FCs needs to be thermally treated to achieve reasonable properties is a major problem for industrial applications. Alternative binders proposed by researchers have to be produced under ambient conditions if they are to be economically and environmentally competitive. This explains why the AAM FCs presented in this study were produced at ambient temperature. The first step of this study was to identify a binder composition that could be used for MK-GGBS FC production. As far as we know, no blended MK-GGBS FC studies have been reported in the literature. This paste had to have controlled initial setting time, reasonable shrinkage and acceptable mechanical properties. The results obtained by Samson et al. [9] are summarized and used to identify the optimized binder for AAM FCs production. Once identified, this optimal binder composition was then employed to produce FC with controlled density and porous structure. The influence of two main composition parameters (H_2O_2 and surfactant contents) on AAM FC density, porous structure, compressive strength and thermal conductivity were investigated. The thermomechanical performances of the AAM FCs produced were then compared to the performances of FCs found in the literature.

2. Materials

2.1. Binders

The MK used in this study was produced in the south of France (Argeco Développement®). One of the main drawbacks of the MK AAMs is a tendency towards drying shrinkage and cracking [5,30]. MK density and specific surface are 2500 kg/m^3 and 14,000 m^2/kg (BET analysis) respectively. XRD, ICP and Rietveld analysis performed by Pouhet [30] show that this MK has a high impurity content (quartz, anatase, mullite, kaolinite). The different oxide contents were obtained by ICP analysis and are presented in Table 2. The analyses reveal that the amorphous proportions of SiO_2 and Al_2O_3 were respectively 29 and 24% (Table 2).

The GGBS used in this study was produced in France at Fos sur Mer (Ecocem®) and complied with EN 151-67-1. GGBS density and Blaine surface are 2900 kg/m^3 and 4450 m^2/kg respectively. The activity index at 28 days was 98% (EN 196-1). A diffusion hump seen on the XRD diagram confirmed that the GGBS was almost totally amorphous. Detailed physical properties as well as particle size distributions of MK and GGBS are given in [9].

2.2. Activator, blowing agent and surfactant

The alkali activation was performed with a commercial sodium silicate solution (Betol 47T – Woellner®) which composition is detailed in Table 2. The SiO_2/Na_2O molar ratio was 1.68. The dry extract (44.4%) corresponded to the material of the alkaline solution (commercial solution) that remained if all the water was evaporated (55.6%). A small amount of soda NaOH (3.2% of the mass of the alkaline solution) was added to improve the activation. The dry extract of the alkaline solution plus NaOH is referred to as the activator. The AAM FC porosity was created with hydrogen peroxide H_2O_2 (purity 50% – Solvay®) as blowing agent. A commercial surfactant was employed to stabilize the AAM FC porous structure until MK-GGBS matrix setting.

3. Methods

3.1. Mix design

Fourteen paste formulations were produced and analysed to determine the best proportions of MK, GGBS and activator to be used as the matrix for the AAM FC. The details of this mix-design was presented on [9] for three types of blended AAMs (26 compositions). MK was mixed with GGBS because pure GGBS AAMs are subject to high shrinkage [31,32]. These mixes are presented in a ternary diagram (Fig. 1) and in Table 3. It was built by changing the proportions of the three raw materials: MK, GGBS and activator (dry extract of alkaline solution + NaOH). Hereafter, the samples will be designated as: $A_iMK_jGGBS_k$ where A is the activator and i the associated percentage, j is the MK percentage, k is the GGBS percentage. Each sample verified $i + j + k = 100$. All the samples had the same water to binder mass ratio, $W/B = 0.36$. This minimum W/B ratio was evaluated with preliminary tests on the two samples that only contain MK ($A_{25}MK_{75}$ and $A_{15}MK_{85}$ – Table 3). MK particles led to higher water demand than GGBS or FA [33] because of the plate-like morphology of the MK particles. The minimum W/B ($W/B = 0.36$) corresponded to the minimum fluidity required to fill all the moulds without vibration.

The binder comprised the dry powders (MK and GGBS) and the activator (dry extract of the alkaline activator solution + NaOH). The water came from the alkaline solution and a suitable amount of water was added to satisfy the constant W/B ratio for each mix (Table 3). When the activator percentage was 15%, the percentage of water coming from the alkaline solution was 49.5% (50.5% from water addition). With 25% of activator, 84.2% of the water came from the alkaline solution.

3.2. AAM production

The production of the blended AAMs started with dry mixing of the MK and GGBS. Soda was diluted in the additional water and this solution was mixed with the alkaline solution. The resulting liquid was added to the powder (at the initial time, t = 0) and the liquid and powder were mixed together for 1 min at low speed then 2 min at high speed using an ordinary mixer (Automix 65 – Controls®). The paste was then cast in the different moulds (Table 4). To prevent water transfer, the moulds were covered with plastic sheets, which promote good mechanical properties. They were placed in a room at 20 °C for 24 h before unmoulding. The