



# Production of lightweight aerated alkali-activated slag pastes using hydrogen peroxide



Murat Şahin<sup>a,b,\*</sup>, Sinan Turhan Erdoğan<sup>b</sup>, Özgür Bayer<sup>c</sup>

<sup>a</sup> Department of Civil Engineering, Bozok University, Yozgat, Turkey

<sup>b</sup> Department of Civil Engineering, Middle East Technical University, Ankara, Turkey

<sup>c</sup> Department of Mechanical Engineering, Middle East Technical University, Ankara, Turkey

## HIGHLIGHTS

- Production of aerated alkali-activated slag concrete using H<sub>2</sub>O<sub>2</sub> was investigated.
- > 480 kg/m<sup>3</sup> aerated pastes with > 0.117 W/m · K thermal conductivity were produced.
- Average pore size increased with increasing H<sub>2</sub>O<sub>2</sub> or decreasing water-to-slag ratio.
- H<sub>2</sub>O<sub>2</sub> was useful up to 0.75% by mass of slag.
- Ambient curing was detrimental to strength development due to efflorescence.

## ARTICLE INFO

### Article history:

Received 1 December 2017

Received in revised form 2 May 2018

Accepted 30 May 2018

### Keywords:

Aerated paste  
Alkali-activated slag  
Aerated concrete  
Hydrogen peroxide  
H<sub>2</sub>O<sub>2</sub>  
Thermal conductivity

## ABSTRACT

This study investigated the production of lightweight aerated alkali-activated slag pastes (LAAASP) using hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). A mixture of sodium hydroxide and sodium silicate solution was used for the activation of slag. Physical, mechanical, and thermal properties of samples cured under different curing conditions were investigated. Various water-to-slag ratios (W/S) and H<sub>2</sub>O<sub>2</sub> contents were used to explore the expansion mechanism of fresh mixtures and to investigate their effect on apparent density. The LAAASP produced were in the apparent density range of 516–1199 kg/m<sup>3</sup> and had 0.5–30.0 MPa compressive strength. Thermal conductivities of aerated samples varied from 0.117 to 0.206 W/m · K in the dry density range of 480–1098 kg/m<sup>3</sup> and were lower than thermal conductivities reported for autoclaved aerated concrete. The use of more than 0.75% H<sub>2</sub>O<sub>2</sub> by mass of slag was found to be non-essential to achieve low-density pastes.

© 2018 Elsevier Ltd. All rights reserved.

## 1. Introduction

Lightweight, porous cement-based materials, comprising macroscopic air voids formed by adding foam or by generating gas in the fresh state, have been around for more than 100 years as alternatives to normal-weight concrete [1]. Names like aerated, cellular, gas, or foam concrete are widely used, despite the lack of coarse aggregates in most of these materials. The low densities and superb workability in the fresh state of these lightweight pastes and mortars distinguish them from normal-weight concrete. While workability allows for self compactability, low density allows for a significant reduction in structural weight, amounts of binder and

fillers used, thermal conductivity, handling and transportation costs, and construction time [2]. Different types of cements have been used with or without addition of cement replacement materials or fillers to produce lightweight materials with desired properties such as reduced setting time and high early strength [3], or enhanced consistency and low cost [4]. Such properties may also be achieved using alkali-activated materials without the use of hydration-accelerating, water-reducing or viscosity-enhancing admixtures [5,6], the addition of fillers [7,8], or the application of autoclave curing [9–11]. Hence, recently there has been a growing interest in the production of aerated concrete using different kinds of gas-releasing agents such as aluminum powder [12–18], H<sub>2</sub>O<sub>2</sub> [16,19–24], or sodium perborate [19] via alkali activation of different powders such as fly ash [13,14,16,18,19,21,22,25], blast furnace slag [18,26], perlite [24], metakaolin [12,15,20], or blends of these [12,17,23,27].

\* Corresponding author at: Department of Civil Engineering, Bozok University, Yozgat, Turkey.

E-mail addresses: [murat.sahin@bozok.edu.tr](mailto:murat.sahin@bozok.edu.tr) (M. Şahin), [sinante@metu.edu.tr](mailto:sinante@metu.edu.tr) (S. T. Erdoğan), [bayer@metu.edu.tr](mailto:bayer@metu.edu.tr) (Ö. Bayer).

Alkali-activated slag (AAS) systems have become the most popular high-calcium alkali-activated materials [28] owing to their potential environmental advantages [29], and their superb mechanical and durability properties [30]. They have been used in several applications in building and civil infrastructures. A detailed summary can be found in Shi et al. [31] or Provis and van Deventer [28]. The first attempt to produce autoclaved aerated alkali-activated slag concrete dates back to 1978. With the activation of several types of slags using a waste alkali hydroxide solution, aerated alkali-activated slag samples in the apparent density range of 300–1200 kg/m<sup>3</sup> with 1.1 to 35.8 MPa compressive strength were produced [31]. Bean and Malone [32] patented the production of foamed concrete with the activation of high-calcium amorphous slags using sodium peroxide which forms oxygen upon decomposition, and also suggested the use of alkali hydroxides as activators to reduce the amount of sodium peroxide used. Vlček et al. [17,18] produced pastes based on the activation of ground granulated blast furnace slag (GGBFS), and GGBFS and fly ash blends, aerated using aluminum powder. The bulk densities and compressive strengths were reported as 520–1150 kg/m<sup>3</sup> and 1.4–5.1 MPa. Esmaily and Nuranian [26] used aluminum powder with bubble stabilizer agents to produce aerated alkali-activated slag pastes in the apparent density range of 681–1127 kg/m<sup>3</sup>, with 1.0 to 15.3 MPa compressive strength. Tarameshloo et al. [33] performed a preliminary study on the production of aerated alkali-activated slag pastes using H<sub>2</sub>O<sub>2</sub>. Lightweight concrete with densities as low as 890 kg/m<sup>3</sup>, and 3.3 MPa compressive strength were obtained with 3.0% H<sub>2</sub>O<sub>2</sub> (by mass of slag) after curing at 85 °C. However, only small samples were produced, and details about the production process or the mixtures were not provided.

The majority of past studies on aerated alkali-activated slag mixtures focused on the use of aluminum powder as a gas-releasing agent even though aluminum powder is not only a high-cost material but also its production requires a significant amount of energy with high carbon dioxide emissions. Industrial-grade pure aluminum powder is generally produced by atomizing molten aluminum [34]. Hao et al. [35] estimated the greenhouse gas emission from the production of one ton of aluminum to be in the range of 8.2 t–21.7 t CO<sub>2</sub> equivalent in China which is responsible for about 55% of the global aluminum production [36]. Furthermore, aluminum production is responsible for about 3.5% of the global energy consumption [35]. Therefore, the use of alternative lower-environmental-impact gas-releasing agents such as H<sub>2</sub>O<sub>2</sub> for the production of aerated products is important. H<sub>2</sub>O<sub>2</sub> generates oxygen gas during its decomposition. It is generally available in liquid form at various concentrations which makes it easier and more practical to work with than aluminum powder. Production of one ton of H<sub>2</sub>O<sub>2</sub> by the Anthraquinone process emits about 3.7 t CO<sub>2</sub> equivalent [37]. Furthermore, H<sub>2</sub>O<sub>2</sub> is much less expensive than aluminum powder [38].

In this study, lightweight aerated alkali-activated slag pastes (LAAASP) were produced using H<sub>2</sub>O<sub>2</sub> as a gas-releasing agent. The effects of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) dosage and water-to-slag ratio (W/S) on the physical, mechanical, and thermal properties of LAAASP are presented.

## 2. Experimental

### 2.1. Materials

The granulated slag used was received in ground form from Kardemir Iron and Steel Plant, in Karabük, Turkey. The oxide composition of the slag determined using X-ray fluorescence (XRF) spectroscopy and its physical properties are given in Table 1. The slag is observed to be mostly amorphous with a characteristic hump at about 30°2θ with some of the peaks of akermanite, calcium carbonate, and quartz after performing X-ray diffraction analysis. A combination of sodium hydroxide solution and sodium silicate solution was chosen as the alkaline activator

**Table 1**  
Oxide composition and physical properties of the slag used.

Oxide	wt (%)
SiO <sub>2</sub>	38.20
Al <sub>2</sub> O <sub>3</sub>	10.00
Fe <sub>2</sub> O <sub>3</sub>	1.16
CaO	36.70
MgO	6.09
SO <sub>3</sub>	1.46
Na <sub>2</sub> O	0.25
K <sub>2</sub> O	1.10
Blaine fineness (cm <sup>2</sup> /g)	4150
Specific gravity	2.95

based on a previous study [30] that reported rapid strength gain with this activator type and concentration. Laboratory grade flakes of NaOH with >99% purity were used. NaOH was dissolved in distilled water using a magnetic stirrer to obtain a concentration of 8 M. A commercially available sodium silicate solution (40–42° Baume) with a chemical composition of Na<sub>2</sub>O = 8.9%, SiO<sub>2</sub> = 28.6% and H<sub>2</sub>O = 62.5% (SiO<sub>2</sub>/Na<sub>2</sub>O ratio of 3.2) was used. The solutions were mixed 24 ± 0.5 h prior to mixing with the slag at moderate speed using a magnetic stirrer for 2 min at room temperature, and kept in a climate-controlled room at a temperature of 21 ± 1 °C. Sodium silicate solution-to-slag ratio and sodium hydroxide solution-to-slag ratio were kept at 0.25 and 0.11, respectively. Thus, the solution contained 4.46% Na<sub>2</sub>O, by mass of the slag for all mixtures.

A 35% w/w H<sub>2</sub>O<sub>2</sub> solution (Merck, Germany) was used as the gas-releasing agent for aeration of mixtures. Decomposition of H<sub>2</sub>O<sub>2</sub> is an exothermic reaction which forms water and oxygen (Eq. (1)). The rate of decomposition of H<sub>2</sub>O<sub>2</sub> depends on its concentration, temperature, and pH [39].



### 2.2. Methods

The initial and final setting times of mixtures prepared with no H<sub>2</sub>O<sub>2</sub> were determined using a Vicat needle in accordance with ASTM C191 [40] but at W/S = 0.40, 0.425, 0.45 and 0.50, instead of at normal consistency. A standard flow cone [41] was used for the determination of flowability of mixtures. After preparation of the mixtures, the cone was filled with the mixture and pulled up. Unlike in the standard, tests were performed without raising and dropping the flow table [42,43]. Since some of the mixtures had a flow value greater than the diameter of the flow table, a wider platform was placed on the flow table and the tests were performed on it. The flow tests were completed within approximately 30 s of mixing. The apparent density of samples was measured by dividing the mass by the volume. The volumes of samples were calculated by measuring their edge lengths using a digital caliper.

Mechanical tests were performed on samples cured under three different curing regimes; humid-oven curing at 80 °C, sealed curing, and ambient curing. The motivation for choosing three different curing regimes is monitoring strength development under different conditions which may be useful for large scale manufacturing. In sealed curing, after demolding each sample was sealed with clear plastic wrap and placed into a clear plastic bag, then kept at 21 ± 2 °C until testing. Ambient curing in the laboratory was performed at 21 ± 2 °C and a relative humidity of 40 ± 5%. Ambient-cured and sealed-cured samples were tested directly after curing, but samples cured in the humid oven for 12 h, 24 h, and 48 h were kept at ambient temperature for 3 days prior to testing, as described in ASTM C495 [44]. Compressive strength was measured using a 250 kN-capacity automatic universal testing machine with a loading rate of 1.5 kN/s for samples prepared without any H<sub>2</sub>O<sub>2</sub>. A manually-controlled universal testing machine with an adjustable loading capacity of 100 kN was used for compressive testing of samples prepared using H<sub>2</sub>O<sub>2</sub> and flexural testing of all samples due to the low strengths expected. Three samples were used for flexural testing. Compressive strength tests were performed on the six half samples remaining after the flexural strength tests. The averages of three and six measurements are presented as the compressive and flexural strengths. Necessary care was taken to prevent shock loading by adjusting the rate of loading at the beginning of tests. Failure loads were reached in not less than 20 s, as stated in ASTM C513 [45].

Water absorption was determined on sealed-cured samples for 28 days in accordance with ASTM C796 (2012) with the minor modification of using cylindrical samples and exposing the samples to air drying from day 25 to day 28, and using cylindrical samples. The motivation was to avoid possible carbonation of samples. Samples were directly immersed in 23-°C water for 24 h. Then, the samples were taken out, allowed to release excess water for 30 s, and their wet masses measured. The difference between the wet and initial mass of a sample gives the amount of water absorbed in 24 h. Water absorption was expressed by volume instead of

Download English Version:

<https://daneshyari.com/en/article/6712377>

Download Persian Version:

<https://daneshyari.com/article/6712377>

[Daneshyari.com](https://daneshyari.com)