Materials and Design 65 (2015) 529–533

Contents lists available at ScienceDirect

Materials and Design

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

Short Communication

Development of porous fly ash-based geopolymer with low thermal conductivity

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ARTICLE INFO

Article history:
Received 16 July 2014
Accepted 9 September 2014
Available online 17 September 2014

ABSTRACT

Porous fly ash-based geopolymer material was produced using fly ash and sodium water glass as original material and H_2O_2 as foaming agent. The changes caused by the geopolymerization and decomposition of H_2O_2 on the properties of the final products were investigated by applying curing on geopolymer mortars with different amounts of sodium water glass (60, 80 and 100 g) and H_2O_2 (4, 6 and 8 g) added at various curing temperatures. The samples were cured at two different temperatures (55 and 85 °C). Physical properties such as porosity, density and thermal conductivity and mechanical property were determined from the completely dried samples. As a result, this study confirmed that the amount of sodium water glass, H_2O_2 and curing temperature had effects on properties of the samples. Given the compressive strength obtained and the environmental and economic effect, the optimal thermal curing temperature and the amount of sodium water glass and H_2O_2 were 55 °C, 80 g and 6 g, respectively. Sample synthesized at this condition had porosity of 79.9%, thermal conductivity of 0.0744 W/m K and compressive strength of 0.82 MPa. Therefore, it shows promise as thermal insulation material in some situations.

1. Introduction

The name "geopolymer" was originally introduced by Davidovits [1] to describe the inorganic aluminosilicate polymers produced by synthesizing natural materials such as metakaolin [2] or industrial by-products such as fly ash [3–6] and blast furnace slag [7] with highly alkaline activators. Geopolymers exhibit a wide variety of properties and characteristics, including high compressive strength, low shrinkage, high temperature resistance [8] and acid and fire resistance [9,10], and seem to be a desirable alternative to ordinary Portland cement and environmentally sustainable characteristics [10,11]. Besides, the CO_2 emission due to production of fly ash-based geopolymer is at least 80% less compared to manufacture of ordinary Portland cement [11,12].

Throughout the world, numbers of researches are being carried out on the use of waste materials [13] in order to either avert an increasing threat to the environment or to streamline current disposal techniques by making them more affordable and environmentally friendly [14]. Fly ash is an industrial waste with pozzolanic properties obtained from thermal power plants and a large portion of it is disposed in landfills or ash lagoons, which produces endangering consequences to the environment and people's health [15]. Containing high levels of amorphous silica and alumina, fly ash, which has favorable size and shape, is recently often used as an original material to produce geopolymer. The main factors affecting the properties of fly ash-based geopolymers include the particle size of the utilized ash, curing temperature, curing time and alkaline activating solution [16]. Results of previous investigations [17,18] showed that the finer the particle size, the better properties. Furthermore, literature [16] has validated that curing time was not an important factor to determine the compressive strength.

Up to present, scores of works [14,19–22] have been conducted on fly ash based geopolymers and have gained some achievements. However, almost all of these literatures focused on the effects of some parameters on the compressive strength of geopolymers and few researches have emphasized on adding foaming agent into the polymer pastes to produce porous geopolymer materials and taken the thermal conductivity of them into consideration. In this study, H_2O_2 was added to the polymer pastes to make porous geopolymer materials through the decomposition of H_2O_2 at alkaline environment before the pastes were concreted. Considering the fact that the organic thermal insulation materials widely used today are flammable and the inorganic thermal insulation materials need complex processing conditions and high sintering temperature, which is a big component in manufacturing cost, the porous fly ash-based geopolymer material synthesized in this study has good application potential as thermal insulation material in some situations.

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http://dx.doi.org/10.1016/j.matdes.2014.09.024
0261-3069/

Table 1
Chemical composition of FA.

Oxides	Fe_2O_3	SiO_2	K_2O	CaO	Al_2O_3	TiO_2	Na_2O	MgO	SO_3
Contents (%)	6.68	46.77	1.48	11.15	25.22	1.58	1.57	1.37	3.0

2. Materials and method

2.1. The characterization of the original materials

Coal fly ash (100 meshes), obtained from the coal fired power station at Hefei, was used as the original material and the XRF result showed that SiO_2 and Al_2O_3 account for over 75% (mass ratio, as shown in Table 1). Sodium silicate solution (water glass) with SiO_2:Na_2O weight ratio of 3.55 was used as activator for the activation of fly ash in the process of geopolymerization and for the decomposition of H_2O_2 without following modification. The water used is the ordinary domestic water to minimum the production cost.

2.2. Mixing procedure

The mass of fly ash and water used was constant as 80 g and 60 g, respectively. Among the 60 g water, 10 g was used to dilute the H_2O_2 because in our previous study we found that diluted H_2O_2 was more likely to synthesize specimens with homogeneous pores. The weighed fly ash, water and water glass were mixed for 2 min to give complete homogenization. Afterwards, the diluted H_2O_2 was added to the mixture and mixed for another 1 min. Then the pastes were poured into plastic moulds.

2.3. Preparation of the porous geopolymer mortar

Different amounts of water glass were used to determine the effect of water glass dosage on the porous geopolymer materials, so were the different additive amounts of H_2O_2.

The pastes were shaped in 140 mm × 70 mm × 50 mm plastic moulds. The mixtures were then placed at ambient temperature to precure for 24 h because this precuring time has been proved to be beneficial to strength development [23]. And after this precuring process, the mixtures were completely foamed and the specimens were placed in a laboratory-type oven (DHG101-00) for 24 h to cure thermally. The prepared samples are shown in Table 2. The samples cured at 55 °C were coded as A and those cured at 85 °C were coded as B. When a prepared porous geopolymer specimen was activated by 60 g water glass with 4 g H_2O_2 and cured at 55 °C, this set of samples was coded as 60A-4. Other specimens were also encoded depending on the dosage of water glass, additive amounts of H_2O_2 and curing temperature.

Table 2
Prepared samples and curing temperature.

Porous geopolymer	Dosage of water glass (g)	Curing temperature (°C)	Dosage of H_2O_2 (g)
60A-4	60	55	4
60A-6	60	55	4
60A-8	60	55	4
80A-4	80	55	6
80A-6	80	55	6
80A-8	80	55	6
100A-4	100	55	8
100A-6	100	55	8
100A-8	100	55	8
60B-4	60	85	4
60B-6	60	85	4
60B-8	60	85	4
80B-4	80	85	6
80B-6	80	85	6
80B-8	80	85	6
100B-4	100	85	8
100B-6	100	85	8
100B-8	100	85	8

2.4. Physical and mechanical tests

The thermal conductivity was measured using a hot-disc thermal analyzer (DRE-2c, Instrument and meter Co., Xiangtan, China) at room temperature, adopting the transient plane source technique. To achieve a relatively precise result, we measured each pair samples three times and got the average value.

The principles of Archimedes were used to determine the physical property of apparent porosity using water as immersion medium.

Compressive strength was obtained by a universal testing machine (MST809, USA) with a cross-head speed of 0.5 mm/min, which required the specimens to be Φ20 mm × 20 mm.

Pore morphology of samples was carried out using SAMSUNG ST200F on fractures of samples to observe the effects of parameters on pore morphology.

3. Results and discussion

3.1. Density, porosity and thermal conductivity

Figs. 1–3 represent the density, porosity and thermal conductivity of samples cured at different temperatures. At the same curing temperature, when adding same amount of sodium water glass, increases in H_2O_2 amount lead to a reduction in density and thermal conductivity and increase in apparent porosity. H_2O_2 can be easily decomposed in alkaline environment. However, if the basicity is too strong, H_2O_2 will be decomposed in a shorter time even before the suspensions begin to solidify. Similarly, the decomposition of H_2O_2 cannot be finished while the suspensions start to solidify if the basicity of suspensions is not enough. This can explain why the properties of samples with 80 g sodium water glass added are more desirable than samples with 60 g and 100 g sodium water glass added. For instance, porosities of samples 60A-4, 80-4 and 100A-4 are 78.5%, 79.1% and 76.3%, respectively. And the corresponding thermal conductivities are 0.0886, 0.0816 and 0.0902 W/m K, respectively.

In addition, with the increase of H_2O_2 amount, numbers of voids inside the material with air contained could be generated, thus resulting in the reduction of density and thermal conductivity and increase in apparent porosity. Density and apparent porosity are generally correlated with thermal conductivity. For one thing, some references has confirmed the opposite relationship between density and thermal conductivity [24]. Meanwhile, the higher the porosity, the lower is the thermal conductivity. This is because higher porosity means more voids and the thermal conductivity of air within the voids is much lower than that of solid substance, thus leading to a comparatively lower thermal conductivity of the whole material [25]. Take 80A-4, 80A-6 and 80A-8 for example, thermal conductivity of them are 0.0816, 0.0744 and 0.0721 W/m K, respectively. And the relevant density and apparent porosity are 335, 260 and 239 kg/m^3 and 79.1%, 79.9% and 81.2%, respectively.

Comparing the thermal conductivity of this porous fly ash-based geopolymer material with other thermal insulation materials, it can be seen that the thermal conductivity of this material is bigger than those of expanded perlite and kenaf insulation board