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Lightweight geopolymer based on fly ash

Олекотени геополимери на основата на летяща пепел

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Introduction

The term "geopolymer" describes inorganic polymers composed of stable aluminosilicate material formed by alkali hydroxide or alkali silicate activation (Provis, Deventer, 2009). The geopolymers are X-ray amorphous materials, which possess good mechanical properties, chemical resistance, thermal and fire resistance (Davidovits, 2011). Over the last decades, the interest in geopolymers has increased. The research in this area has grown exponentially, influenced by modern environmental trends and the possibility of using waste products from various industries, including thermal power plants (TPP). The studies on the fly ash geopolymers are focused mainly on utilizing low calcium fly ash class F (according ASTM C618-91), due to its lack of self cementing properties and reduced use in concrete industry.

In order to improve the thermal and sound insulation properties of building materials, their density should be reduced. One of the methods is usage of gas forming substances in the preparation stage.

The aim of the present study is to demonstrate that local fly ash from TPP could be used for production of geopolymers. A lightweight porous geopolymer was prepared. Such material could find applications in building and construction industry as fire-resistant, thermal and sound insulation products.

Materials and methods

The raw material used in the present study was fly ash class F from TPP Maritsa East 2, Bulgaria. The typical chemical composition of the used fly ash is: SiO_2 52.66%; Al_2O_3 23.37%; CaO 5.75%; MgO 2.75%; Fe_2O_3 8.72%; CO_3 2.40% (Zgureva, Boycheva, 2015). The alkaline hardener was prepared by using solid KOH, tap water, and sodium silicate solution.

The powder XRD patterns were obtained by Bruker D-2 Phaser diffractometer with Bragg-Brentano geometry using a CuKα source. FTIR spectra were collected by Tensor 37 spectrometer (Bruker) with a 4 cm^{-1} resolution after averaging 72 scans on standard KBr pallets.

Results

Synthesis of geopolymers. Four series of geopolymers were prepared using different concentration of the alkaline hardener solutions. The composition of the geopolymer series is given in Table 1. All mixtures were prepared by water to solid ratio equal to 0.40. The fresh geopolymer mixtures were homogenized 1 minute with mechanical stirrer and poured into polypropylene moulds. The geopolymers were cured in plastic bags in laboratory conditions.

Absorption of water. At 90 day three specimens from each series were placed in containers with tap water. After watering to constant mass each specimen mass was measured. Then the specimens were placed in oven at 80 °C to constant mass to measure the dried mass. Water absorption was calculated and the average values with standard deviations are presented in Table 1. With decreasing the alkali concentration of the activator solution the water adsorption increased. The series B1 showed minimum water absorption.

Powder XRD. The X-ray diffractograms from the raw fly ash and geopolymer B1 are presented in Fig. 1. The mineral composition of the fly ash is represented

Table 1. Molar composition and water absorption of the prepared geopolymer

Series	Molar composition		Water absorption, %
	M_2O/Al_2O_3	H_2O/M_2O	
B1	1.4	10	20.0 ± 0.24
B2	1.1	12	24.8 ± 0.68
B3	0.8	15	28.1 ± 0.51
B4	1	12	28.2 ± 0.71

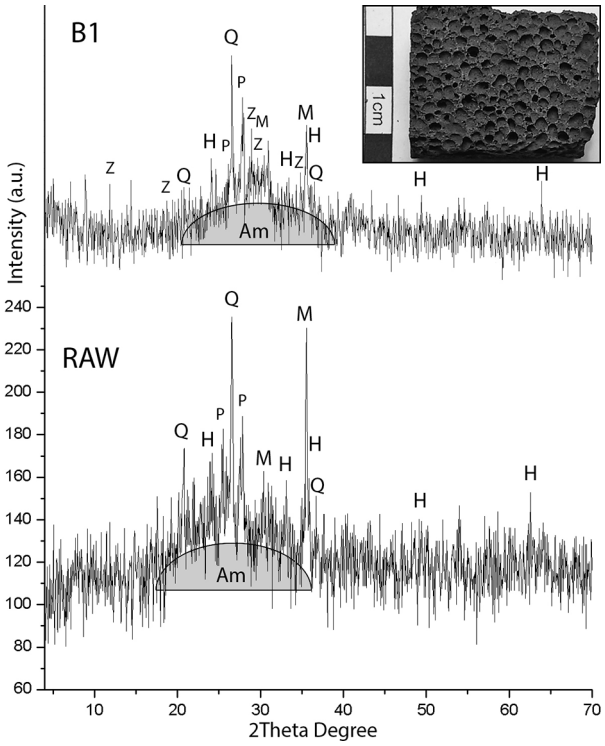

Fig. 1. Powder XRD results for the fly ash (raw) and the prepared geopolymer (B1); *Q*, quartz; *M,* magnetite; *H*, hematite, *P*, plagioclase, *Z*, $Na_8KSi_9O_{18}(OH)_9.19H_2O$. Rigth corner – image of piece from sample LB1.

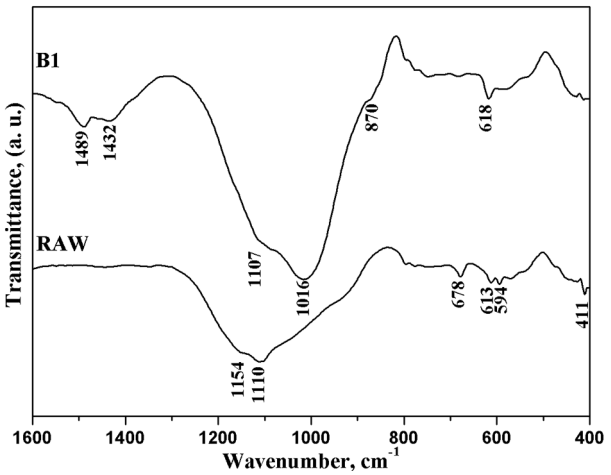

Fig. 2. FTIR spectra of the raw fly ash and geopolymer B1

by quartz, plagioclase, hematite, magnetite and amorphous phase. After the geopolymerization a new mineral phase $Na_8KSi_9O_{18}(OH)_9.19H_2O$ was formed. The amorphous halo was slightly shifted to higher two theta angles, which is typical for geopolymer materials.

FTIR. The main band in the spectrum of the fly ash at 1110 cm^{-1} also appears in B1 and reflects the asymmetric stretching vibrations of Si-O-T (Fig. 2). New strong band after geopolymerization is located at 1016 cm^{-1} and refers to Si–O–Si stretching vibration. Usually, this band is used for determination of the degree of geopolymerization. The peak at 618 cm^{-1} is assigned to six membered ring vibrations and refers to the participation of Si in more organized structures. The bands at 1489, 1432 and 870 cm^{-1} correspond to CO_3^{2-} ions, which are product of efflorescence processes.

Preparation of lightweight porous geopolymer. Porous fly ash-based geopolymer material was produced using recipe B1 and addition of 1% by mass H_2O_2 as gas forming agent. The decomposition of the peroxide produce oxygen and the mixture started to expand. After 30 seconds of mixing the expanding material was placed in plastic cups. The resulted porous geopolymer (LB1 – see Fig. 1, right corner) is characterized by 0.44 g/cm^3 density, 2.64 g/cm^3 absolute density and 83.3% relative porosity.

Fire-resistance test. Simple jet-torch test was conducted to observe the behavior of the porous geopolymer at high temperature and direct fire. The sample LB1 was exposed for 3 minutes to direct fire from butane jet-torch at 5 cm distance. During the exposure the color of the specimens in the hottest area turned into red-orange, which is associated to temperature about 1000 °C. After the fire test the specimen preserved its integrity, which indicates its potential as fire-resistance materials.

Conclusion

After the preliminary tests it can be concluded that mixing fly ash from TPP Maritsa East 2 with a suitable activating solution a hardened geopolymer material was obtained. The resulting geopolymer pastes were characterized by a partially amorphous structure and a relatively large porosity. Lightweight geopolymers could be also successfully prepared. The fire torch test indicates the potential as fire-resistance materials.

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