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Effect of carbon nanotubes on the mechanical fracture properties of fly ash geopolymer

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Abstract

Fly ash geopolymer is amorphous aluminosilicate material which is considered as alternative to Portland cement concrete. One of the limiting factors of its utilization is an increased shrinkage and related deterioration of fracture properties. This paper reports on a study of the application of multi-walled carbon nanotubes (MWCNTs) to improve the fracture properties of fly ash geopolymer. The amount of MWCNTs added varied in the range of 0.05–0.2% of the mass of fly ash. Mechanical fracture properties were determined via evaluation of three-point bending fracture tests. Specimen response during fracture tests was also monitored by means of acoustic emission, and this method was also used for the determination of cracking tendency occurring during the hardening process. Results show that the addition of MWCNTs increases the elastic modulus and compressive strength of fly ash geopolymer. However, basic fracture parameters (fracture toughness, fracture energy) firstly decreased with very small addition of MWCNTs and were regained or slightly exceeded the reference values with higher amount of MWCNTs.

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Keywords: Fly ash; alkaline activation; carbon nanotubes; fracture properties; acoustic emission

1. Introduction

Fly ash is generated in large quantities as a by-product from the combustion of coal-like fuel in power stations. Estimated worldwide production coal combustion products was 780 Mt in 2010, and approximately 80% of this amount is attributed to fly ash [1]. Only part of these ashes is used at present (40–60%); the rest is stored in the

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landfills giving a potential risk of groundwater contamination due to leaching. In building industry, most of the fly ash is used as supplementary cementing material in concrete production; however, other applications among which the most promising is geopolymer production were developed in last decades [2].

Geopolymers are two-component binders, where one of the components is an aluminosilicate material with considerable pozzolanic properties and the second component is an alkaline activator, mostly alkaline hydroxide, carbonate or silicate (water glass). Usually, natural pozzolanas (volcanic tuffs, diatomaceous earth etc.) or artificially produced materials such as fly ash can be used as a source of aluminosilicate [3,4]. These materials are quite easily accessible in large quantities and their properties can be controlled. The properties of fly ash geopolymer depend on several factors such as aggregate properties, alkaline solution and water content and the curing environment. A critical parameter for durability design of concrete is shrinkage of geopolymer concrete at early age. Deb et al. [5] reported that fly ash/slag blends showed much higher shrinkage than ordinary Portland cement (OPC) concrete. Higher shrinkage was also reported for the ambient-cured geopolymer concrete compared to heat cured geopolymer concrete [6]. A possible way to reduce shrinkage is the application of multi-walled carbon nanotubes (MWCNTs) as a shrinkage reducing admixture. Regarding the properties of MWCNTs, they have a great potential to reduce the cracking tendency of silicate-based materials caused by drying shrinkage [7,8].

Carbon nanotubes show extraordinary mechanical properties, with the elastic modulus of an individual nanotube being around 1 TPa and tensile strength being in the range of 65–93 GPa [9]. Since the production of multi-walled carbon nanotubes (MWCNTs) increases and the costs for their utilisation reduce, they become promising nanomaterials for enhancing the mechanical fracture properties of building materials, and their resistance to crack propagation. Some problems have appeared connected with the aggregation of MWCNTs, which reduces the efficiency of single nanotubes. Nevertheless, effective dispersion can be achieved by applying ultrasonic or high shear rate mechanical dispersion with the use of a surfactant [10].

Since microcracks have a strong negative effect on mechanical performance, the efficiency of MWCNTs as a potential nano-reinforcement and shrinkage reducing agent can be monitored by the fracture behaviour of the composite material and by acoustic emission methods. In this study, fracture tests and acoustic methods were applied to determine the performance of MWCNTs in fly ash geopolymer mortars.

2. Experimental part

2.1. Materials and sample preparation

Basic geopolymer mixture was synthesized from low calcium fly ash (ČEZ, Dětmarovice, CZ) and reagent-grade sodium silicate solution (Vodní sklo, CZ) having the molar ratio SiO_2/Na_2O = 1.6 and the content of dry mass 43%. The chemical composition is presented in Table 1. The average grain size of the fly ash obtained by laser granulometry was d_{50} = 15.5 µm and d_{90} = 38.3 µm. Quartz sand with a maximum grain size of 2.5 mm was used as fine aggregate in order to prepare geopolymer mortars. Multi-walled carbon nanotubes (Graphistrength® CW 2-45, Arkema, France) were used as admixture. Since MWCNTs are commonly not water-soluble, the product contains 55% of carboxymethyl cellusose as a dispersing agent for the stabilization of its aqueous dispersion. Carbon nanotubes were used in the form of 1% dispersion prepared following the procedure prescribed by the producer. MWCNT pellets were dissolved in hot water and dispersed bundles of MWCNTs were further disintegrated by mechanical homogenizer (3 h at 14000 rpm).

Table 1. Chemical composition of raw materials.

	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	S_{total} (%)
Fly ash	49.82	24.67	7.05	3.91	2.68	0.70	2.78	0.91
Sodium silicate	26.43	–	–	–	–	16.61	–	–

The content of MWCNTs was 0.05, 0.10, 0.15, 0.20%, respectively, with respect to the mass of fly ash. Geopolymer mixture without addition of nanotubes was also prepared and assigned as reference. The composition of mixtures is presented in Table 2. The mixtures were placed into prismatic moulds 40 × 40 × 160 mm and sealed