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Effect of slag addition on mechanical properties of fly ash based geopolymers

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Abstract

This work describes improvement of mechanical properties of alkali activated binders – geopolymers made of fly ash from coal combustion in fusion boiler. The effect of addition of amorphous phase on physico-mechanical properties of geopolymers was examined. The studied properties were: flexural strength, compressive strength and water absorption. Effect of preparation process on the final properties of samples was also discussed. Amorphous phase was added in form of slag from the same coal combustion boiler. Samples were tested after 7, 28 and 90 days. With increasing amount of slag, the ascending trend of compressive strength was observed at the early stages of maturing. Compressive strength values measured after 90 days of maturing were found almost the same for all slag concentrations, and outperformed the compressive strength value of reference sample. On the contrary, the flexural strength was not positively affected by addition of the slag. Regarding the water absorption, the higher the slag addition, the lower water absorption was measured.

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Keywords: Fly ash; slag; alkali activation; geopolymers; mechanical properties

1. Introduction

At present, most of the worldwide production of energy is made in heating plants by using combustion of fossil fuels, most of it coal. This process produces substantial part of solid and gaseous wastes. These products include fly ash, slag, clinker and gypsum. Combustion is the oldest and most common way of using coal. The combustion

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process is based on the exothermic reaction between carbon in fuel and oxygen from the atmosphere. The product of reaction is not only heat but also water vapor and carbon dioxide [1].

The combustion of coal in power plants and heating plants occurs most often in powder form and in three types of boilers, whether it is a fusion boiler, granulation boiler or fluid boiler. The granulation boilers use less valuable fuels and operation is well below the melting point of ash. In the core of the flame, temperature depends on the type of fuel being in the range of 1100 – 1300 °C and the formation of molten slag is undesirable [2].

In fusion boilers, temperatures higher than the melting point of ash are used, about 1400 – 1600 °C. Ashes are melting and are removed in the liquid form from the boiler. This creates slag and only a small amount is collected from electrostatic precipitators as fly ash [1,3].

Fly ashes can be used as alkali activated materials and utilized in synthesis of geopolymers. The term geopolymer was first used by Joseph Davidovits. He defined the material that is formed in inorganic polycondensation called geopolymerization. In geopolymerization reaction, three-dimensional structures of AlO_4 and SiO_4 tetrahedra are created. According to him, only material with peak at about 55 ppm in 27Al NMR spectrum may be called geopolymer. Only materials produced by alkaline activation of metakaolin comply with this condition. Later the term geopolymer was used for all alkali activated aluminosilicate. Nowadays, research in field of geopolymers is focused mostly on using secondary raw materials like fly ash [4,5,6].

Geopolymers now represent a new group of organic substances, because they have significant environmental and energy potential. They belong in a group of the inorganic polymer covalently bound macromolecules with the chain consisting of -Si-O-Al-O-. Geopolymers are obtained from the chemical reaction of alumino-silicate oxides with sodium silicate solutions in a highly alkaline environment. As an alkali activating solution, strongly alkaline aqueous solution of sodium or potassium hydroxide is most commonly used [5,7,8].

Geopolymer structure is created by sialate network which is composed of SiO_4 and AlO_4 tetrahedron, which are connected to each other through its own oxygen atoms. The empirical formula of geopolymers, also known as poly(sialates) is $Mn\{-(SiO_2)z-AlO_2\}n \cdot wH_2O$, where M is a cation such as K^+, Na^+, or Ca^{2+}; n is the degree of polycondensation and z is 1, 2, or 3 [4,9].

Geopolymerization is a complex multi-stage process. The reaction rate and chemical composition of the final reaction products is dependent on a numbers of factors which can be properties of the feed material, such as chemical and phase composition, grain size, and material composition of the activating solution, such as, the water content and the presence of soluble silicates [10].

Geopolymers are materials with many excellent properties such as high mechanical strength, resistance to low and high temperatures, resistance to aggressive environments or flame resistance [11].

This paper describes the effect of addition of amorphous phase – slag from coal combustion in fusion boiler on the physico-mechanical properties of geopolymers based on fly ash. Two different procedures were used to prepare the samples – the first one was stirred immediately after addition of the activating solution, the second one after one-hour exposure to activation solution. Effect of preparation process on the final properties of samples is also discussed.

2. Materials and methods

Material used for alkali activation was fly ash (FA) and slag (S) from the same combustion process from District Heating Plant in Košice (Slovakia). Combustion temperature is 1400–1550 °C. Slag was used as a filler to a fly ash based binding material. Material was homogenized before alkali activation. No other treatment was applied to material. Partial chemical analyses of the fly ash and slag are indicated in Table 1. The fly ash and slag are characterised by a SiO_2/Al_2O_3 ratio of 2.59 for FA and 2.63 for S.

Table 1. Partial chemical composition of used materials.

(*Wt. %*)	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	LOI
Fly ash	45.26	17.46	5.61	9.10	3.22	15.48
Slag	58.22	22.17	2.82	7.95	7.29	0