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Mechanical properties of geopolymer composites reinforced with natural fibers

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Abstract

Geopolymer composites have recently become a promising ecological alternative to the traditional cementitious materials. They are cost-effective, environmentally friendly and their production involves relatively small amount of energy. They have also good compressive strength, durability and thermal properties being highly resistant to flame and heat. However, these composites have relatively low tensile and flexural strength, which limits their use in many areas. This paper describes the mechanical properties of the geopolymer based on fly ash and reinforced with short natural fibers such as cotton, sisal, raffia and coconut. The study is intended to analyze the influence of addition of various natural fibers on the mechanical properties of the geopolymer. The empirical part of the research was based on the compressive strength tests, flexural strength tests and detailed microstructure examination. The results show that the appropriate addition of natural fibers can improve the mechanical properties of geopolymer composites.

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Keywords: Fly ash-based geopolymers; geopolymer composites; natural fibers; cotton fiber; sisal fiber; raffia fiber; coconut fiber; coir

1. Introduction

Nowadays, the fiber-reinforced composite materials, including those produced on the basis of alkali-activated materials, play an important role in many branches of the industry e.g., in advanced technological solutions used in the aerospace and automotive industry, naval architecture and ground transportation [1,2]. They have a lot of advantages in comparison to the traditional materials. The addition of fibers is an efficient method for improving such

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mechanical properties as fracture toughness [3]. The presence of fibers reduces the general effect of cracking, limits the widths of the occurring cracks (exemplary reduction of the propagation of microcracks), suppresses all brittle behavior and enhances ductility [4]. Thanks to it damage caused by cracking may be mitigated.

The other reason for using fiber-reinforcement is the fact that it increases the flexural strength of composites [5,6]. The fibers can also improve those properties of geopolymers that are connected with their energy absorption and resistance to deformation [7]. Here, the introduction of short fibers may particularly contribute to the improvement of the physical and mechanical properties of the particular geopolymer [8,9]. In fact, it is one of the most effective ways of strengthening and toughening geopolymer materials through reinforcement [10], especially because of easy fiber dispersion and fiber aspect ratio. The most common fiber reinforcements added to geopolymer composites are nowadays inorganic fibers such as carbon or glass fibers [10,11].

It is quite new solution to add natural fibers as a reinforcing material to the composites based on geopolymer matrix. Growing environmental awareness and the need to ensure sustainability of construction materials has led many researchers to look for some alternative fibers to reinforce those materials. In this respect natural fibers are attractive because they are reproducible, have low density, high specific strength and are cheap to obtain. They do not pose any problems in terms of closing important life cycles (especially CO_2) of the products based on natural fibers [7]. The replacement of the synthetic fibers with their natural counterparts is desirable not only for the environmental but also economic reasons, because the production of artificial fibers is an energy-consuming process as opposed to the farming and harvesting natural ones [12].

While reinforcing traditional cement and cementitious materials with natural fibers is popular, only few studies focused on reinforcing geopolymer-based composites with them. In this area researchers have studied various natural fiber additives such as: sweet sorghum [7], cotton [8,9], wool [13] and celulose [14] as well as others such as peat-wood [15], wood flour [16] or sawdust [17]. Promising results have been obtained. This paper describes the research on the specific geopolymer made from fly ash and reinforced with four short natural fibers i.e. cotton, sisal, raffia and coconut.

2. Experimental

2.1. The material: geopolymer matrix

The specific fly ash from the CHP plant in Skawina (Poland) was thoroughly investigated as a possible raw material for the production of the geopolymer matrix being a base for various composites. SEM observations, EDS analysis and the previous research [5,6,16] confirmed its suitability for such matrix. The chemical composition of the mentioned ash consists of approx. 56% SiO_2, 23.5% Al_2O_3, 6% Fe_2O_3, 3.5%, K_2O, below 3% CaO and MgO, and less than 1% of other components e.g., TiO_2, Na_2O, P_2O_5 and BaO [16]. The fly ash density amounted to 2.22 g/cm^3. The morphology of the particles of fly ash was typical of such by-products of coal combustion. Regarding the particle size distribution of the examined fly ash, the size of approx. 60% particles was <56 μm [16].

The matrix of the composites was 8M sodium hydroxide solution combined with the sodium silicate solution (liquid glass at a ratio of 1:2,5). In order to manufacture the composites flakes of technical sodium hydroxide were used and water solution of sodium silicate R–145 whose modulus was 2.5 and density 1.45 g/cm^3. Tap water was used as batched water instead of the distilled one. The alkaline solution was prepared by means of pouring the aqueous solution of sodium silicate and water over solid sodium hydroxide. The solution was mixed and left until its temperature became stable and the concentrations equalized. Then, the solution was mixed with fly ash.

2.2. The material: fibers

To reinforce the geopolymer matrix cotton fibers were used whose length was approx. 30 mm and diameter approx. 1 mm. Mechanical properties of bulk fibers: Young's modulus approx. 4.8 GPa tensile strength approx. 400 MPa [8,9].

Sisal fibers (made from agave sisalana) are stiff fibers used to manufacture various products. Mechanical properties of bulk sisal fibers: Young's modulus of 9.0–38 GPa, tensile strength of 363–700 MPa and total elongation 2.0–7.0%