

Geopolymers obtained from bottom ash as source of aluminosilicate cured at room temperature



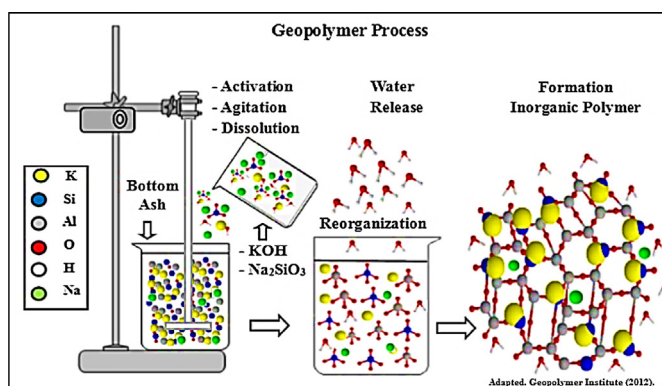
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HIGHLIGHTS

- Geopolymeric matrix from pure bottom ash from the burning of coal.
- KOH, NaOH and Na_2SiO_3 were used as activators.
- Cure at room temperature.
- Particle size and the activator influenced the formation of the geopolymers.

GRAPHICAL ABSTRACT



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ABSTRACT

Geopolymers may be considered as inorganic polymers, since they are obtained through chemical bonds between silicon (Si), aluminum (Al) and oxygen (O) composing polymer rings in tetrahedral coordination. In the geopolymeric synthesis, a large variety of materials may be used as a source of aluminosilicate in amorphous or semi-crystalline state. In this study, pure bottom ash obtained after the mineral coal burning was used, with the objective of evaluating the bottom ash potential as an only source of aluminosilicate for geopolymer synthesis. The used alkaline activator was a compound of potassium hydroxide (KOH), in the concentrations of 8 and 12 mol/L, sodium hydroxide (NaOH) in the concentrations of 5, 10 and 15 mol/L and sodium silicate (Na_2SiO_3), in the molar ratio between $\text{SiO}_2/\text{Na}_2\text{O}$ of 3.2. The cure was performed at room temperature. The characterization was performed by the X-ray diffraction (XRD), X-ray fluorescence (XRF), and Scanning Electron Microscopy (SEM) techniques. To evaluate the material strength, tests of compression strength were held. The use of bottom ash as a 100% residual raw materials for the geopolymer production exhibited good results, and the technology may be reproducible and environmentally viable in some samples. Moreover, it offers a new binding material option in order to complement the construction sector, due to the great global demand in cement business.

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1. Introduction

The growth of mankind has elevated the expenses with consumer goods and energy in the past years. Millions of megawatts per hour (MW/h) of electric energy are consumed worldwide. Cement is another type of high demand commodity. In 2013, the

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cement production has exceeded 4000 million tons worldwide [1]. The construction industry is responsible for most of raw material use among all types of economic activities, totalizing a sum of 60 billion tons of product per year [2].

In the last few decades, due to the environmental problems caused mainly by the improper use of natural resources, a mobilization is taking place in many countries for searching solutions that may reduce the greenhouse gases production in order to reduce global warming, these being responsible for, in every 10 years, an increase of 0.1–0.3 °C in the average temperature of the Earth [3].

The use of residues, which are available to disposal and do not need expensive treatments to be transformed in new products, decreases environmental pollutants.

Ashes are a residue generated in great proportions from burning mineral coal. Burning mineral coal produces 41% of global energy, and it is estimated that it will continue to produce great part of the energy consumed in the planet until 2040 [4].

The ashes generated by burning mineral coal may be classified as fly ash, which are transported by smoke and captured in precipitators, and bottom ash, which are deposited at the bottom of the boilers and are transported to sedimentation basins. In order to avoid that the ashes resulting from mineral coal burning are released in the environment, its capture and utilization as a byproduct is fundamentally important.

The fly ash is already being used, largely, as an additive in Portland cement. There are also several researches showing the potential of fly ash as a source of aluminosilicates in the production of alkaline active cements [5,6] named geopolymer by the scientist Davidovits [7]. However, bottom ash is still in great part available to be used as raw material and there are a few studies addressing bottom ash characteristics in the production of geopolymer cements, among which are Chindapasirt et al. [8]; Boca Santa et al. [9] among others.

Bottom ash differs from fly ash even when they are generated by the same source (mineral coal burning). Bottom ash possess bigger fragments, fewer fine particles and lower glassy phase [10]. According to Mehta et al. [11], bottom ash is part of the molten material which is transported to lower temperature zones, where solidifies in agglomerations of glass particles.

Some researchers consider that fly ash is more reactive than bottom ash, and others believe that both types of ashes are similar and the greatest difference is the particle size. In bottom ash, the particles are bigger, with pores and cavities; however, after being processed to adequate particle sizes, there is an increase in its surface area and, consequently, in its reactivity, making it feasible to be used as byproduct in the geopolymer production [8].

Therefore, it is evident that cement production using industrial residues generated through mineral coal burning for electric energy production is doubly favorable. Firstly, it absorbs part of the residue generated by mineral coal burning and produces cement to help the large demand from construction industry. Secondly, it reduces CO₂ emissions to the environment, since the production of geopolymer do not require the use of clinker used in cement production of the Portland type and which is responsible for the emission of millions of tons of greenhouse gases in the atmosphere [12,3].

In this manner, this research attempted to elaborate a geopolymeric formulation from 100% bottom ash as source of solid aluminosilicate, aiming to evaluate the potential of the use of pure bottom ash in the production of geopolymer.

Geopolymers may be produced from different sources of aluminosilicate, namely, residual or natural, which have been submitted to thermic treatments and stand in an amorphous or semi-crystalline state. To form a geopolymeric structure, aluminosilicate must be activated with one or more alkaline activators and with

elevated pH. Geopolymeric materials, depending on the form between the elements Si–O–Al, are described as polysialate, due to the polymer rings formed between Si⁴⁺ and Al³⁺ in tetrahedral coordination with four oxygens [7]. When aluminosilicate and alkaline solution are mixed, the reaction initiates and, after a short period of time, will result in an aluminosilicate chain [13]. The presence of aluminum in the chain generates a charge deficit of –5 in Al and –4 in Si, so a cation is necessary to compensate this deficit in order to maintain neutrality. Depending on the activation base used, an ion will be available, e.g. Na⁺, K⁺, Ca⁺⁺, which will balance the charges of Si⁴⁺ and Al³⁺ remaining in the structures' cavities [14].

Although there are plenty researches using different formulas for the production of geopolymers, some variables in the mechanisms of reaction are not completely explained. Geopolymer production from fly ash, metakaolin and blast furnace slag are among the most used. However, since there are few researches using bottom ash, it is difficult to comprehend all the variables involved in order to reach the ideal formulation.

This study has been held throughout six years, and the results that will be presented were considered, up until this moment, favorable in order to obtain a geopolymeric matrix from pure bottom ash, reproducible and with technologic potential. It is important to highlight that one of the objectives was the setting at room temperature to facilitate the use of this material in different areas. Many formulations were tested activating bottom ash with different alkaline reagents. However, many difficulties were found to obtain materials with good properties using only bottom ash solid material, especially in the drying period of the materials. Because the variation between Si/Al and Si/M in the formulation (where M is the cation of the alkaline metal) may influence in the result [15].

The bottom ash was activated using two formulations of activators, namely: potassium hydroxide (KOH) and sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH) and Na₂SiO₃. However, good results have been achieved only with the KOH formulations. Samples synthesized with NaOH presented elevated drying period at room temperature, 90 days, making the use of the tested material unfeasible as geopolymer cement in the construction industry.

2. Experiments

2.1. Materials and method

The materials used in the synthesis of the geopolymer samples were bottom ash from mineral coal burning as source of Si and Al and, as an alkaline activator, it was used KOH and Na₂SiO₃ and NaOH and Na₂SiO₃.

The bottom ash were obtained from a thermoelectric plant in the vicinity of this research, in South Brazil. The bottom ash was dried in temperature of 100 °C for approximately 24 h. After this period of time, weighings are carried out in the bottom ash at intervals of 1 h until constant weight is obtained. To reduce the size of the particles and increase the surface area, and in order to favor the alkaline activator's diffusion, the bottom ash was subjected to through ball milling for approximately 48 h with different ball sizes in porcelain jug, rotational speed of ±61 RPM. After 48 h of milling, tests are carried out on granulometric sieves of 325 mesh (0.044 μm). Since only 10% of the particles should be retained, otherwise the grinding time is prolonged until 90% of the particles are smaller than 0.044 μm. This step was considered fundamental to obtaining good results in the samples. The particle size distribution was performed by the laser diffraction method/PR-CC-062, default CILAS, carried out in the laboratory of SENAI, Criciúma-SC.

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