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Utilization of sodium waterglass from sugar cane bagasse ash as a new alternative hardener for producing metakaolin-based geopolymer cement

Hervé Kouamo Tchakouté[a,b,*], Claus Henning Rüscher[b], Malte Hinsch[b], Jean Noël Yankwa Djobo[c], Elie Kamseu[c,d], Cristina Leonelli[d]

[a] *Laboratory of Applied Inorganic Chemistry, University of Yaounde I, Faculty of Science, Department of Inorganic Chemistry, PO. Box 812, Yaounde, Cameroon*
[b] *Institut für Mineralogie, Leibniz Universität Hannover, Callinstrasse 3, D-30167 Hannover, Germany*
[c] *Local Materials Promotion Authority, P.O. Box: 2396, Nkolbikok, Yaoundé, Cameroon*
[d] *Department of Engineering Enzo Ferrari, University of Modena and Reggio Emilia, Via Vivarelli 10, 41125 Modena, Italy*

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ABSTRACT

Sugar cane bagasse ash from SOSUCAM company in Cameroon was used to synthesize sodium waterglass as a new alternative hardener. The new hardener was used to prepare metakaolin-based geopolymer cements. The compressive strength of the resulting geopolymer cement cured at room temperature for 28 days was 32.9 MPa. Samples soaked for 28 days in water in parallel experiments revealed a strength of 31.4 MPa. This shows that exposure of water does not lead to any weakening. The value of water absorption was 7.1% in the water-soaked cements, indicating the presence of fewer pores and voids than in the dry cements. However, in SEM micrographs, the microstructure of geopolymer cement appears rather homogeneous and compact without any change by water soaking. It can thus be concluded that sodium waterglass from sugar cane bagasse ash can be used as an alternative hardener or reactive ingredient for producing geopolymer cement with a high degree of cross-linking geopolymer framework. The use of this low-value silica-rich waste for producing sodium waterglass results in environmental benefits including a significant reduction of CO_2 emission and energy consumption compared to the production of commercial sodium waterglass.

1. Introduction

Sugar cane is one of the most produced crop in the world, with an estimated production of more than 2165 million tons in 2013 (Teixeira et al., 2014). Around 30% of world's sugar is produced in Brazil, with very large volumes also generated in other warm climate regions of the Americas and Asia. The production of sugar generates a huge volume of waste materials referred to as sugar cane bagasse. This fibrous matter is left over after sugar cane has been crushed to extract the juice. In Brasil, sugar cane bagasse is burned in boilers to produce electrical energy, resulting in a huge volume of ash (Teixeira et al., 2014). SOSUCAM Company ('*Société sucrière du Cameroun*') operating in Cameroon for over 40 years has developed various of products to satisfy the demanding clientele. For example it owns about 65,250 ha of agricultural land, a sugar factory with a crushing capacity of 12,300 tons of sugar cane per day, a refinery with a production capacity of 980 tons of white sugar per day, four sugar cube machines made by Chambon with a production capacity of 100 tons/day each, and will soon equip the plant to bag granulated sugar into sachets, five warehouses spread out in the country. Since the beginning, SOSUCAM has expanded many times, thus growing from 1,500,000 to 2,400,000 tons of sugar today. The last expansion done in 2006, will allow production to reach 3,500,000 tons of sugar before 2015 suggesting thus the availability of sugar cane bagasse produced by SOSUCAM. The wastes generated during the production of sugar are burned in open airspace and thus pollute the atmosphere. Therefore, the valorization of this waste material could be greatly interesting. Previous researchers (Souza et al., 2011) showed that sugar cane bagasse combustion produces a high amount of inorganic components such as silica associated with smaller amounts aluminum, iron, alkalis

* Corresponding author at: Institut für Mineralogie, Leibniz Universität Hannover, Callinstrasse 3, D-30167 Hannover, Germany.
E-mail addresses: htchak@yahoo.fr, hervetchakoute@gmail.com, htchakoute@uy1.uninet.cm (H.K. Tchakouté).

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Table 1
Chemical composition (wt.%) of BO1.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	K_2O	TiO_2	MgO	Na_2O	CaO	P_2O_5	MnO	LOI
BO1	41.46	31.47	7.65	0.51	1.50	0.65	0.69	0.15	0.09	0.06	15.76

LOI: Loss on ignition at 1000 °C.

and alkaline earth oxides. Sugar cane bagasse ash has been studied over the past decades as a potential additive to cement (Ganesan et al., 2007; Morales et al., 2009; Cordeiro et al., 2009a,b, 2012). Hariharan and Sivakumar (2013) and Teixeira et al. (2014) used also this waste material to produce nano silica and glass-ceramic materials, respectively. This waste material owing the presence of high amorphous SiO_2 content could be used as a strong potential silica source for the production of waterglass. The utilization of this waste material for waterglass synthesis could reduce the emissions of greenhouse gases during the production of commercial sodium silicate. For example, commercial sodium silicates are produced a potential additive to cement of silica from quartz sand and sodium carbonate treated at approximately 1400 °C (Turner and Collins, 2013) obtaining the solid sodium silicate as an amorphous compound (Turner and Collins, 2013). This amorphous compound is then dissolved in water to get solutions with various SiO_2/Na_2O ratios which are used in a large number of applications. It should be noted that the carbon footprint of such overall process to obtain a sodium silicate solution is extremely high due to melting and dissolution, often in a hydrothermal environment. Hence, the production of geopolymer cement has higher environmental impacts which are associated directly with the production of sodium waterglass. Due to this environmental problem related to the production of this chemical reagent, the utilization of sugar cane bagasse ash for producing it is necessary. It is important to note that some researchers (Tchakouté et al., 2016a,b,c, 2017) used rice husk ash and waste glass as low-value silica-rich wastes to produce sodium waterglass. Up to now no work has investigated the properties of geopolymer cement using sodium waterglass from sugar cane bagasse ash as an alternative hardener.

The main purpose of this work was to investigate the possibility to valorizing sugar cane bagasse provided by SOSUCAM company in the production of an alternative hardener known as sodium waterglass and use it to produce metakaolin-based geopolymer cements. In order to monitor the formation of uncondensed and condensed silica in the hardener, the infrared spectrum of sodium waterglass were measured using ATR method. To monitor the formation of geopolymer cement, the product was characterized by XRD, IR spectroscopy, water absorption, water resistance and compressive strength after 28 days at room temperature. The microstructural properties of geopolymer cement at least 28 days was determined using Scanning Electron Microscopy coupled to microanalysis by Energy-Dispersive X-ray analysis (SEM-EDX).

2. Materials and methods

2.1. Materials

Kaolin denoted BO1, used in this work was extracted from Bomkoul in the Littoral Region of Cameroon. This kaolin was previously used by Elimbi et al. (2011) to produce geopolymer cements. In this study, they reported that this raw material contained kaolinite, as aluminosilicate phases and quartz, illite, anatase, goethite as crystalline impurities. The obtained bulk chemical composition is given in Table 1. Sugar cane bagasse was provided by SOSUCAM (*Société Sucrière du Cameroun*), the largest sugar company in Cameroon. The sugar complex of SOSUCAM is settled in M'Bandjock along the Sanaga river valley, located at 150 km North-East of Yaoundé, the administrative capital of Cameroon. M'Bandjock is linked by road and railway to Yaoundé and Douala, the port giving access to the Atlantic Ocean. The sugar cane bagasse was dried under sunlight to reduce its moisture content in bagasse. After this process, the dry sugar cane bagasse and kaolin were calcined in a programmable electric furnace (Nabertherm, Mod_LH 60/14) for 2 h (for sugar cane bagasse) and 4 h (for kaolin) with heating/cooling rate of 5 °C/min at 600 and 700 °C to obtain sugar cane bagasse ash (SCBA) and metakaolin (MK), respectively.

2.2. Synthesis of sodium waterglass

Sodium waterglass from sugar cane bagasse ash was prepared by adding the powder of SCBA to sodium hydroxide pellets with SCBA/NaOH mass ratio of 1.4 in order to get a user-friendly hardener. The assembly was mixed with 200 mL of distilled water for 1 h at 150 °C using a magnetic stirrer to enhance the dissolution of silica from SCBA and the mixing was carried out at 1100 rpm. The solution was subsequently filtered and the filtrate was used as an alternative hardener.

2.3. Preparation of metakaolin-based geopolymer cements

Geopolymer cements were prepared by adding a fresh hardener gradually to metakaolin and mixing for 5 min. Afterward, the specimens were cast in cylindrical PE-containers (20 mm in diameter and 40 mm in height), which were closed in order to hinder water evaporation during the setting. The samples were allowed to set for 24 h in ambient condition before removing from the molds and then sealing in the plastic for 28 days prior to measuring the compressive strength and other characterizations. The obtained geopolymer cement was denoted GP. The hardener/MK mass ratio was kept constant at 0.83 obtaining a suitable workability.

2.4. Methods of characterization of raw materials, sodium waterglass and geopolymer cements

XRD patterns of the powders of raw materials and geopolymer cement were taken using CuKα radiation between 5 and 80° in 7 h in steps of 0.03° (Bruker D4). Infrared (IR) absorption spectra were collected by the KBr method (200 mg KBr, 1 mg sample, Bruker Vertex 80 v, 2 cm^{-1}, 32 scans). The water absorption tests were conducted according to ASTM C642-06 (2006). The percentage of water absorption of the sample was determined at 28 days by the following equation:

$$\%\ \text{Water Absorption} = \frac{(\text{Wet Weight} - \text{Dry Weight}) \times 100}{\text{Dry Weight}}$$

The compressive strength of the geopolymer was measured at 28 days staying under an ambient temperature of the laboratory using a manually driven testing machine (ENERPAC P392, USA). Six samples of synthesis geopolymer paste were tested and an average compressive strength values reported as the result. After compressive strength testing, some fragments of geopolymer were crushed and the obtained powders were used to measure XRD, infrared spectroscopy, and other fragments were used to characterize the microstructure. The amounts of binder content in geopolymers cured at room temperature and the one soaked in water were also determined. Pieces from the mechanical testing, the powders of sugar cane bagasse ash (SCBA) and metakaolin (MK), after gold coat-