



Production of Geopolymer Cement Using Lateritic Clay and Rice Husk

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ABSTRACT

The production of geopolymer cement using locally sourced raw materials (laterite and rice husk ash, RHA) was explored. Chemical analysis carried out showed that the laterite and the RHA contain 18.87 wt. % Al_2O_3 and 47.95 wt. % SiO_2 , respectively. The XRD patterns showed sharp peaks associated with gibbsite and iron oxide at $18^\circ - 2$ Theta and $20^\circ - 2$ Theta, respectively. The noisy background observed in the patterns is due to the presence of amorphous silica and alumina in the clay. A mix ratio of 8 M alkaline liquid or activator comprising of a solution of sodium hydroxide and sodium silicate (water glass) ratio of 3:1 was used. The strength of the geopolymer concrete was investigated using laterite to RHA ratios of 1:1 (batch BA) and 1:3 (batch BB), respectively. Compressive strength tests were carried out on 100 x 100 x 100 mm cube geopolymer concrete specimens cured at room temperature and the strength tested for 7, 14 and 28 days, respectively. The effect of RHA: laterite mix ratio and curing period on the compressive strength of the geopolymer concrete formed was evaluated and compared to that of ordinary Portland cement-based concrete. The results reveal that as RHA mass ratio increases, the compressive strength of the geopolymer concrete also increases. In addition, an increase in curing period increases the compressive strength of the geopolymer concrete. The results of the maximum compressive strengths obtained from this study after 28 days of curing at ambient temperature for batches BA and BB are 22.62 (3280 psi) and 25.58 (3710 psi) MPa, respectively. These compressive strengths are higher than 3000 psi which is the minimum compressive strength of concrete recommended for load bearing applications.

Keywords: Geopolymer, laterite, rice hush ash, compressive strength, curing.

1. INTRODUCTION

The manufacturing of ordinary Portland cement (OPC) involves the utilization of enormous resources and energy, and eventual release of greenhouse gases (e.g., CO_2) to the environment. In addition, OPC is very poor in the control of pollutants and other impurities, hence the concretes made from it are susceptible to atmospheric corrosion [1]. In the search for new binders and possible replacement for traditional OPC, geopolymer cement stand tall as a potential alternative, hence novel and cost effective. A geopolymer cement is a binding material made by activating source materials containing silica and alumina, e.g., fly ash (FA), red mud, etc. with alkali solutions and sodium silicate, Na_2SiO_3 [2]. Geopolymers have received significant attention due to their low cost, outstanding mechanical and physical properties, low energy consumption and reduced greenhouse gas emissions [3].

The name “geopolymer” was coined by a French Professor Joseph Davidovits in 1978 [4] to represent a broad range of materials characterized by networks of inorganic molecules. Geopolymer derives its source of aluminosilicate from raw materials such as metakaolinite, or industrial by-products e.g., fly ash, slag etc. These aluminosilicates become binders by dissolving in alkaline reactive medium (known as alkaline reagent or hardener) and polymerize into molecular chains, and this process is known as geopolymerization.

Geopolymerization therefore, is a chemical reaction between an alkali solution and source material containing aluminosilicate, e.g. fly ash thereby giving a 3D polymeric chain and a ring structure consisting of Si–O–Al–O bonds [1]. The synthesis of geopolymer binder and the reactions taking place during geopolymerization are summarized in Figures 1 and 2, respectively [1]. Hence, a geopolymer cement is a binder formed as a result of polymerization process [5]. The mixture of the binder and aggregate with water forms the geopolymer concrete.

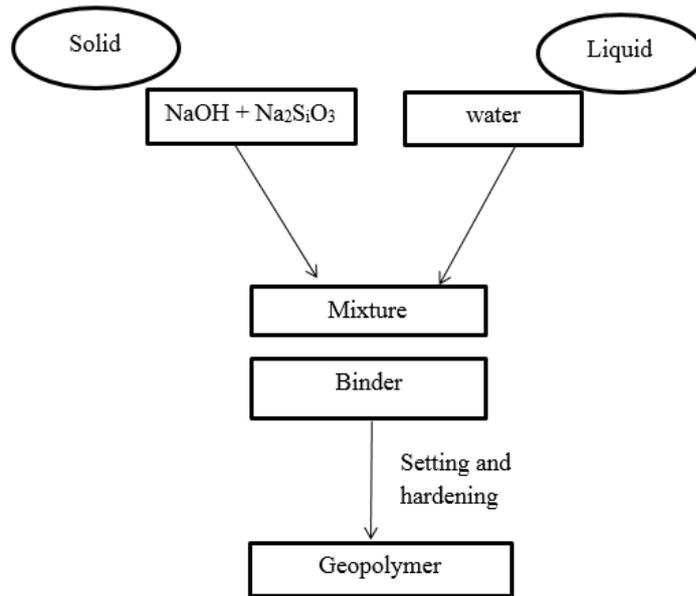


Figure 1. Schematic of geopolymer cement synthesis [1].

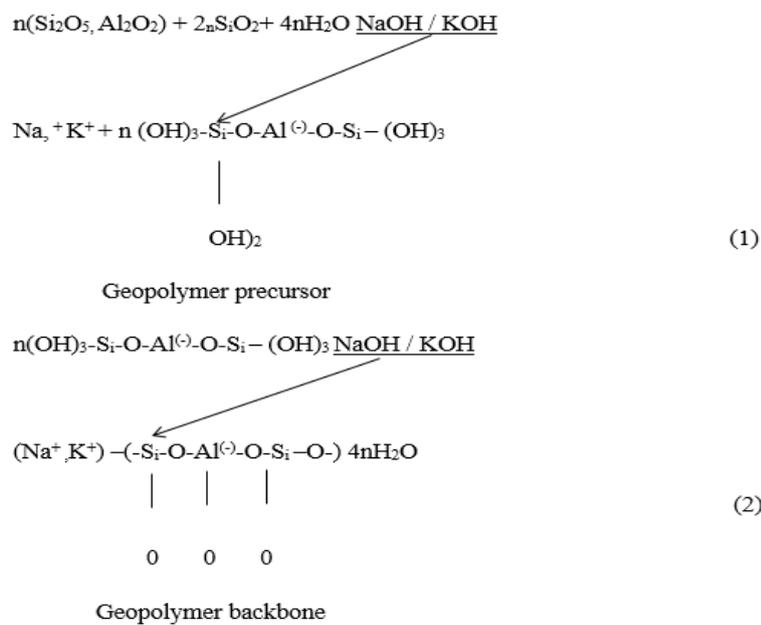


Figure 2. Geopolymerization reactions [1]

As observed in Figure 2, reaction 1 shows that the Si and Al atoms present in the source material (e.g., fly ash, slag, etc.) dissolve by the actions of the OH⁻ ions while the precursor ions convert into monomers, leading to polycondensation of the monomers into a polymeric structure. Reaction 2 indicates that during polymerization, water is eliminated, contrary to hydration of OPC where water is absorbed [6].

In this research, the geopolymer cement was synthesized using a locally sourced aluminosilicate materials (laterite and rice hush ash, RHA) referred to as source materials. Laterite is a soil category usually seen in tropical regions [7]. The red color of laterite soils is due to the presence of iron oxides. Oxide composition (%) of a typical laterite soil is as follows: 25.46 % SiO₂, 31.10 % Al₂O₃, 35.53 % Fe₂O₃ and 7.91 % CO₂ [7]. Rice husk ash (RHA) is a high silica material made from burning rice husk. It contains about 15-20 % SiO₂, cellulose and lignin [8]. RHA provides high silica oxides utilized in different industries, e.g. plastics, rubbers, steels, building materials, etc.

2. MATERIALS AND METHODS

The source materials are lateritic clay and rice husk ash obtained from Oguta in Imo State and Afikpo in Ebonyi State, respectively both in the Eastern part of Nigeria. They were used to produce the geopolymer cement via a wet method by utilizing two different formulated stoichiometric ratios: 1:1 and 1:3, respectively of laterite to rice husk ash. An alkaline activator used was formed by mixing a solution of sodium hydroxide, NaOH and a solid sodium silicate (water glass), Na_2SiO_3 in the ratio of 1:3. The lateritic clay and rice husk were dried, thereafter the rice husk was burnt to ashes, forming rice husk ash (RHA). The source materials (lateritic clay and RHA) were separately ground, ball milled and sieved using 125 μ sieve mesh in the Ceramic workshop of Ceramic and Glass Technology department, Akanu Ibiam Federal Polytechnic Unwana, Nigeria. The source materials were characterized for chemical and mineral (phase) compositions using x-ray fluorescence (XRF) and x-ray diffraction (XRD), respectively. Proportions of the formulated geopolymer binders (wt. %) and weight (g) of the batched geopolymer binders are presented in Tables 1 and 2.

Table 1. Proportions of formulated (wt. %) geopolymer binders

Mix ratio	Batch code	Source materials	Alkaline activator
1:1	BA	75	25
1:3	BB	85	15

Table 2. Weight (g) of batched geopolymer binders

Materials	Batch code	
	BA	BB
Lateritic clay	375	212.5
Rice husk ash	375	637.5
Alkaline activator	250	150

100 x100 x 100 mm geopolymer concrete cube specimens were prepared with the source materials mixed with fine and coarse aggregates for compressive test. The blended source materials (laterite and RHA) and the aggregates were first dry mixed in a pan mixer for five minutes. Thereafter, the prepared alkaline activator was added to the mixture and mixed for another five minutes. In order to improve the workability of the fresh geopolymer concrete, naphthalene sulphonate based superplasticizer was added into the geopolymer concrete mixes.

Prior to compressive test, the green geopolymer concrete specimens were demolded and cured for 7, 14 and 28 days, respectively at room temperature. The specimens were compacted in two layers by tamping with about twenty-five strokes per layer. The mix proportions are shown in Table 3.

Table 3. Weight (g) of batched geopolymer concrete

Raw materials	Batch BA (1:1 mix ratio)	Batch BB (1:3 mix ratio)
Lateritic clay	5000	5000
Rice hush ash	5000	15000
Fine aggregate (sand)	12800	12800
Coarse aggregate (chippings)	29800	29800
Super plasticizer	169	169
Alkaline solution	4000	4000
water	800	800

4. RESULTS AND DISCUSSION

Table 4 shows the results of the chemical composition of the source materials (lateritic clay and rice husk ash). Al_2O_3 and SiO_2 are the main oxides required from lateritic clay and rice husk, respectively for the production of cement. The least weight percent (wt. %) of Al_2O_3 and SiO_2 oxides required for OPC production is 6.9 and 21.9 wt. %, respectively [9] while the percentage of both oxides (Al_2O_3 and SiO_2) needed in green cements should be at least 23 wt. % Al_2O_3 and 52 wt. % SiO_2 , respectively [10]. The total quantity of Al_2O_3 (37.42 wt. %) and SiO_2 (77.68 wt. %) oxides obtained from both lateritic clay and RHA (Table 4) in this work suggests they can be used for the production of cement since they contained the required oxides in the right amount.

As shown from the XRD patterns of lateritic clay and RHA (Figure 1), evidence of amorphous silica and alumina was observed as described by the noise at the bottom hump of the XRD spectrums. Sharp peaks associated with crystalline minerals of gibbsite ($Al_2O_3 \cdot 3H_2O$) at $18^\circ - 2\theta$ angle and iron oxide (Fe_2O_3) at $20^\circ - 2\theta$ angle in XRD pattern of lateritic clay (Fig. 1a) and cristobalite (SiO_2) in XRD spectrum of RHA (Fig. 1b) are observed. However, the amorphous compositions are necessary conditions to conduct geopolymerization for lateritic clay based geopolymer materials. Hence, lateritic clay and RHA serve as the reactants in the geopolymerization process.

Table 4. Chemical composition of the lateritic clay and rice husk ash (RHA)

Materials	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ag_2O_5	CaO	K_2O	Na_2O	MgO	Others
Lateritic clay	29.73	18.87	28.26	4.69	3.72	1.89	3.81	0.17	0.37	5.43
RHA	47.95	18.55	11.76	4.69	4.45	2.76	2.33	0.51	0.47	6.54

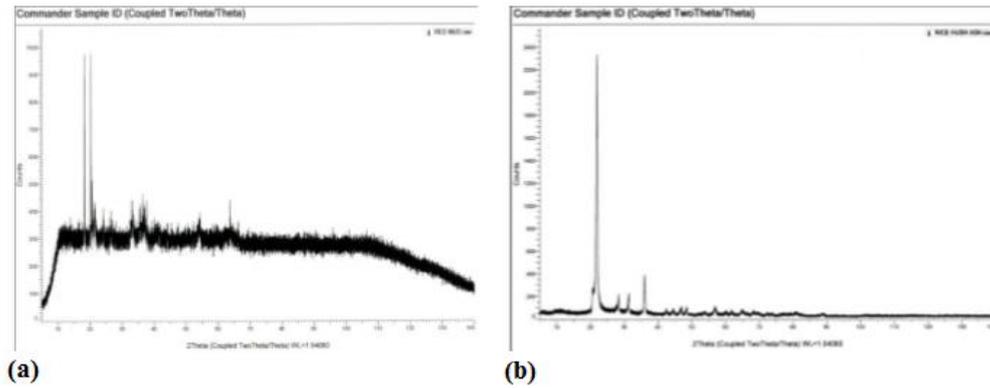


Figure 1. XRD patterns of (a) lateritic clay (b) rice husk ash

The result of the compressive test conducted on the prepared geopolymer concrete specimens after 7 to 28 days of curing at ambient temperature are shown in Table 5. From the results, it was observed that the compressive strength of all batches increased with an increase in curing period and RHA content. Rice husk ash (RHA) introduces silica (SiO_2) into the mix, hence batch BB (1:3 mix ratio) contains more silica which results in high compressive strength in every curing period under study when compared to batch BA (1:1 mix ratio) following a maximum average compressive strength of 25.58 MPa at 28 days curing. These results are similar to the results obtained by Nagral *et al* [11] for OPC at 28 days curing (15-26 MPa).

The geopolymer concretes obtained in this work possess high early compressive strength (14.8 – 17.4 MPa) at 7 days curing and reaches a maximum of 25.62 MPa at 28 days curing period, while an OPC concrete gave compressive strengths of 13 MPa and 25 MPa at 7 days and 28 days, respectively [12], Figure 5. Furthermore, the compressive strengths, 22.58 MPa (\approx 3280 psi) for 1: 1 mix ratio and 25.62 MPa (\approx 3710 psi) for 1:3 mix ratio achieved in this study are more than 3000 psi that is approved as a minimum standard for structural applications [11].

Table 5. Compressive strength of the geopolymer-based concrete

Batch code	Mix ratio	Average Compressive Strength (MPa)		
		7 days	14 days	28 days
BA	1:1	14.8	18.6	22.58
BB	1:3	17.4	22.8	25.62

CONCLUSIONS

The production of a geopolymer cement using locally sourced lateritic clay and rice husk ash

(RHA) was studied. The results obtained from the chemical and mineral analyses showed that lateritic clay and RHA utilized in this research contained the required amount of Al_2O_3 and SiO_2 oxides by wt. % needed for cement production. From the compressive strength test, the higher the compressive strength, the longer the curing time. Hence longer curing period produces higher compressive strength of lateritic clay- rice husk ash-based geopolymer concrete. In addition, the compressive strength of the geopolymer concrete increases with increase in RHA. Overall, the maximum compressive strength of geopolymer concrete achieved in this study is 25.58 MPa (3709 psi) and this is higher than 3000 psi which is the approved minimum standard for structural applications.

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