Application of Laterite-Based Geopolymer Mortar for Masonry Bedding

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Abstract. This paper explores the production and properties of geopolymer cement mortar using laterite soils. The aim was to evaluate the laterite-based geopolymer mortars for masonry bedding applications. The testing programme encompassed three series of mixes tested to determine setting times, flowability, flexural strength and compressive strength. Two types of sands were used including standard sand and natural sand. The effect of water-to-laterite ratios, activating agent concentration, and cement-to-sand ratio were established. The properties of standard cement paste, and mortar were used as a reference. The study found that geopolymer mortar made from laterite meets the requirements for masonry bedding.

Introduction

Geopolymer cement is produced by mixing materials that contain aluminosilicate (also called precursor materials), such as fly ash, slag, laterite and other natural or by-product materials, with either an alkaline solution (NaOH, Na_2SiO_3, and K_2SiO_3) or an acidic solution (H_3PO_4). Geopolymer cement has been used as a binder in various construction applications [1, 2]. Laterites are found in many parts of the world, with a particular abundance in intertropical regions such as Africa, Australia, India, Southeast Asia, and South America [3]. Laterite soils were found to exhibit pozzolanic behaviour due to the high concentration of silica, alumina and iron oxide and therefore was used in some applications, including pavement layers, and building blocks [4]

Existing studies on laterite-based geopolymer cement have shown that appropriate calcination temperatures range from 500 to 800 °C [5, 6 ,7]. The investigation by [8], stated that all volatile materials disappear at a temperature of 700 °C, hence, this is assumed to be the optimum temperature for calcination.

To produce geopolymer cement, in a paste form, calcined precursor must be activated with either alkali or acidic solution. As outlined by [9], the parameters that influence the setting time, flowability and strength of geopolymer cement are the molarity of the activator, the water-to-binder ratio (e.g., water-to precursor material), the alkali solution-to-binder ratio, and the precursor material utilised. To obtain the desired flowability, shortest setting time and highest strength, a combination of one part of NaOH with two parts of Na_2SiO_3 (i.e., NaOH: Na_2SiO_3 is 1:2) was recommended [10, 9]. Also, the investigation by [10] suggested a water-to-fly ash precursor ratio of 0.15, while a ratio of 0.3 was adopted by [9] and 0.25 to 0.35 recommended by [11]. Moreover, the alkali-to- precursor material ratio was found to be in the range of 0.4 to 0.6 [12, 13]

There is little research on geopolymer mortar produced from naturally occurring materials such as laterite soil. Likewise, assessmentof mortar properties was overlooked. This paper involves laboratory testing to investigate the use of geopolymer mortar for masonry bedding. The results indicate that laterite-based geopolymer has good potentials for masonry bedding application.

Aim and Objectives. The aim of this research is to evaluate laterite-based geopolymer mortar for masonry binding application. The objectives of this paper are to: (a) determine the flowability, setting time, compressive and flexural strengths, and bulk density of mortar mixes manufactured using standard or natural sands and binders including laterite-based geopolymer cement and Portland cement, and (b) study the effect of water-to-binder ratio on flowability, mechanical strength, and the influence of activator's molarity on setting times.

Research Significance. The production of Portland cement is known for its impact on worldwide carbon emissions, presenting a substantial environmental hazard. Bedding mortars made with laterite-based geopolymer cement offer a sustainable option as compared to conventional Portland cement mortars. Furthermore, using natural materials like laterite soils to produce geopolymer mortar can provide advantages to rural areas in developing nations by allowing the production of construction materials at the construction site.

Experimental Programme

The study was centred on testing laboratory-scale samples of laterite-based geopolymer cement paste and mortars by mixing laterite-based geopolymer cement with varying binder-to-sand ratios and water-to-laterite ratios. Conventional Ordinary Portland Cement (OPC) mortar was produced and used as a control material. Specimens made from both geopolymer and OPC mortars were subjected to standard tests including flowability, setting time, and compressive and flexural strengths.

Materials. A sample of laterite soil was obtained from a construction site in Johannesburg, South Africa. The soil that passed through a 150 μm sieve was calcined at 700°C for four hours. Also, the soil was analysed using X-ray fluorescence spectrometer (XRF) and showed, among other oxides, contents of 61.1% silica dioxide (SiO2), 20% aluminium oxide (Al2O3), and 6.6% iron oxide (Fe_2O_3). This chemical composition makes the laterite soil appropriate for manufacturing geopolymer cement.

The activator used was created by combining solutions of sodium hydroxide (NaOH) and sodium silicate (Na2Si3O7) at a ratio of 1: 2. The solution of Na2Si3O7 formed from 47% of H2O and 53 % of solid. The NaOH, available as pellets with a purity of 99.45%, was mixed with water to make three solutions with molar concentrations of 8, 10, and 12 M. The blend of NaOH and Na2Si3O7 solutions was subsequently stored in a tightly sealed container for 24 hours before application.

Two different types of sands were utilised for producing the mortar mixes. These are standard sand as specified by the SANS 196-1: 2006[14] and natural sand often used for masonry bedding in South Africa, obtained from a local supplier. The bedding mortar sand has a specific gravity of 2.06, a fineness modulus of 1.7, and a water absorption of 10.85%.

Mixes. Three series of mixtures were produced for the purpose of this study. The first series involves a control mix of OPC that was prepared (500g of CEM I 52.5N and 150g of water) and tested according to the methods described in the SANS 196-3:2005 [15]. Taking into consideration the lack of a comparable guideline for geopolymer cement, the paste is created by mixing 500 g of laterite with 275 g of the alkali activating agent, which consists of 92g of NaOH and 183g of $Na_2Si_3O_7$. The geopolymer paste mixes made with laterite and NaOH activator molarities of 8, 10, and 12M were labelled as GPCL8M, GPCL10M, and GPCL12M.

In the second series, a control mortar, designated OPCM, was produced and tested using the methods described in the SANS 196-1:2005 [14]. The control mix contains 450g of CEM I 52.5N, 1350g of standard sand and 225g water as specified by the SANS 196-1: 2006 [14]. This resulted in water-to-cement ratio of 0.5 and cement-to-standard sand ratio of 1:3. For the geopolymer mortar mixes with standard sand (GPMCLs), the amounts of laterite and standard sand were kept unchanged as 450g and 1350g. This resulted in a laterite soil-to-standard sand ratio of 1:3. However, varying amounts of water were added to the mixes which resulted in water-to-laterite (w/L) ratios that were different from the control mortar (OPCM). Alternatively, water in the mortar mix can be expressed as water-to-binder (w/b) ratio which is total mass of water in the mortar (i.e., added water plus the water in the activating agent solution) divided by the total mass of the geopolymer paste (mass of laterite soil plus the mass of activating agent). The activator-to-laterite (A/L) ratio was kept constant at 0.55. In the third series, natural sand was mixed with laterite soil-based geopolymer cement paste to produce three mixes (i.e. GPMCLn). The A/L ratio was kept constant at 0.55. The size of the laterite soil sample varied in the three mixes due to the mass being determined by the volumes of mortar needed to fill the three moulds for each mix. The second and third series were devoted to determining the flowability, flexural strength and compressive strength of mortars. Based on the findings from tests in series 1, it was decided to keep the NaOH molarity constant at 10 M for both series1 and 2. Table 1 shows the details of the geopolymer mortars incorporating standard and natural sands.

Table 1. Mix proportion of geopolymer mortar mixes with standard sand.

Mix label	L (g)	Standard sand (g)	Added water (g)	w/L	Water in activating agent (g)	w/b	NaOH (g)	$Na_2Si_3O_7$ (g)	A/L
GPMCLs0.20	450	1350	96	0.21	127.35	0.39	83 (*)	165	0.55
GPMCLS0.15			72	*0.16*		*0.35*			
GPMCLS0.10			48	0.11		0.31			
GPMNLS0.20			96	0.21		0.39			
GPMNLS0.15			72	0.16		0.35			
GPMNLS0.10			48	0.11		0.31			

L: Laterite soil, calcined or un-calcined.

w/L: water-to-laterite ratio (mass of added water divided by mass of laterite soil). For example: 72/450 = *0.16*

(*): the mass of NaOH solution prepared by adding 49.8g of water to 33.2g of NaOH pellets.

w/b: water-to-geopolymer cement paste ratio (mass of total water divided by mass of geopolymer paste).

For example: (72 +127.35)/ (450+33.2+87.5) = *0.35*

Typical bench-scale mechanical mixer used for Portland cement mortar was used to prepare the laterite-based geopolymer mortar. During the mixing process, the calcined and un-calcined laterite soils were mixed with alkali for approximately 3 minutes. Subsequently sand was added and mixed for 6 minutes. Finally, the specified amount of water was added and mixed for 3 minutes.

Specimens and Testing. The initial and final setting times test were determined for the OPC and laterite-based geopolymers paste using the VicatDB apparatus aided with Tonic techniK software at a controlled temperature. Flowability tests were conducted on the fresh mortar immediately after mixing in accordance with the methods described in ASTM: C 1437-07 [16]. The workability was evaluated by measuring the mortar flow diameter on a flow table. Metal prism moulds, measuring 40 mm x 40 mm x 160 mm were used to cast three specimens for each mortar mix and the prisms were demoulded after 24 hours. The laterite-based geopolymer mortar prisms were exposed to open-air curing while the OPCM mortars were subjected standard water curing. All produced prisms specimens were tested after 28 days in accordance with the SANS-196-1:2005[14] methods.

Result and Discussion

Setting Times. Table 2 shows the results of initial and final setting times of the OPC paste and laterite-based geopolymer cement paste with varying activating agent's molarity. Although there are no specific setting time requirements for bedding mortar, the initial and final setting times for geopolymer cement paste made from laterite appear to be satisfactory as they align with the results obtained for the OPC paste (i.e., the control material). Furthermore, increasing the concentration of the activator from 8M to 10 M results in a significant reduction in the initial and final setting times by 21% and 19% respectively. Going above 10M in activator molarity tends to have a less impact.

This finding aligns with [17], who obtained the same trend in their experimental study on the effect of alkali concentration on slag-based geopolymer concrete produced from alkali activator. Their investigation revealed initial setting time is reduced by 73.3% when the molarity of NaOH increased from 8M to 12M. Similar trend was observed by [18], the initial and final setting time of fly ash based geopolymer paste was reduced by 33% and 16% when the NaOH molarity increased from 10M to 16M, respectively. In general, these findings indicate that NaOH molarity has a significant impact on the degree of reactivity of the precursor material of geopolymer cement paste and eventually setting times. It is worth noting that higher molarity of activating agents may have negative effect on the economy of the geopolymer cement.

Table 2. Initial and final setting times.

Mix label	Average initial setting time (min)	Average final setting time (min)
OPC	230.8	341.0
GPCL8M	469.0	502.0
GPCL10M	395.1	422.4
GPCL12M	370.1	408.4

Mortar Flowability. Table 3 shows the flowability test results. It is not surprising that the flow diameter of the mortar mixture was influenced by w/L, leading to a 12% to 15% decrease in flow diameter for every 0.05 w/L reduction. The workability of calcined laterite-based geopolymer paste of w/L below 0.16 (GPMCLs0.1) is not feasible for masonry bedding mortar applications. The un-calcined laterite-based geopolymer mortar is considered not acceptable not only for the extended setting times, but also for lack of workability. This result correlates well with the findings by [9]. In their experimental testing on fly ash-GGBS based geopolymer concrete, found that increasing water-to-biner ratio from 0.9 to 0.15 increases workability. The effect of water-to-binder ratio on workability was affirmed by [19], who found noticeable increase in the flow diameter with increasing water-to-binder ratio. However, it should bear in mind that increasing water-to-binder ratio adversely influences some other properties.

Table 3. Flow diameter and workability level.

Mix label	Flow diameter (mm)	Workability
OPCM	220	Good
GPMCLs0.2	200	Good
GPMCLs0.15	170	Medium
GPMCLs0.1	150	Stiff

Mortar Strength. Refer to Table 4, the effect of w/L is evident in GPMCLs and GPMNLs mixes. The compressive strength, flexural strength, and density decreased with the increase in w/L, the same trend is often observed for conventional mortars. Conversely, the geopolymer mortar made with un-calcined laterite has higher flexural strength compared to the geopolymer mortar made with calcined laterite. This correlates well with the findings by [9] who revealed the adverse effect of higher water-to-binder ratio on the strengths of hardened geopolymer concrete. To the authors' opinion, water can have dual effect on geopolymer mortar, these includes the dilution of the activator (i.e., lower molarity) which reduces geopolymerisation and voids developed in the hardened mix (i.e., lower bulk density) due to evaporation of water during the curing of the mixture.

Table 4. Flexural and compressive strength properties of tested mortar mixes.

Mix label	Bulk density (kg/m^3)	Average flexural strength (MPa)	Average compressive strength (MPa)
OPCM	2346	7.9	72.8
GPMCLs0.2	1979	2.6	11.8
GPMCLs0.15	2068	5.0	21.9
GPMCLs0.1	2139	8.7	38.3
GPMCLn1:1	1926	8.9	39.8
GPMCLn1:2	1923	4.6	25.3
GPMCLn1:3	1912	2.4	13.6

According to SABS 0164 [20] there are three categories of masonry bedding mortar, with Class I utilized for heavily stressed loadbearing masonry, Class II for typical load bearing uses, and Class III designed for lightly stressed loadbearing walls. A minimum compressive strength of 14.5 MPa, 7 MPa, and 2 MPa must be met by laboratory prepared specimens for Class I, Class II, and Class III, respectively. The results depicted in Table 4 suggest that geopolymer mortar incorporating natural sand in ratios of 1:1 and 1:2 is suitable for the three mortar classes, but the mix with a 1:3 ratio falls slightly short of the compressive strength requirement for Class I.

Conclusions and Recommendations

The setting times of geopolymer cement paste made from laterite was satisfactory and reasonably compares with those of OPC. The molarity of the alkali activator affected the setting times, with setting times decreasing as the activator molarity increased.

The flowability of mortar mixes were influenced by water-to-laterite soil ratio. The workability of laterite-based geopolymer paste with water-to-laterite soil ratio below 0.16 was not feasible for masonry bedding mortar applications due to unworkable mixtures.

The compressive and flexural strengths, as well as the density of laterite-based geopolymer mortar decreased as the water-to-laterite ratio increased. The geopolymer mortar showed significantly weaker strength values compared to the Portland cement mortar.

The laterite-based geopolymer mortar incorporating natural sand was found to meet the minimum strength requirements for mortar used for masonry bedding.

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