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Framework for Assessing the Viability of Laterite as a Source of Aluminosilicates In Geopolymerisation

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ABSTRACT

As the search for eco-friendly and affordable cement intensifies, geopolymer technology has become a viable option. Geopolymer technology offers a greener and cheaper means of producing cement-based materials which exhibit performance comparable to Portland cement. This technology could be instrumental in addressing the needs for adequate housing and other civil infrastructures in middle- and low-income countries. However, the utilisation of geopolymer technology depends on the accessibility of a steady source of aluminosilicates. One material that meets such a criterion is laterite. Laterite is abundantly found in most countries, situated in the tropical and subtropical regions of the world. Despite this, the potential of laterite as a source of aluminosilicates is yet to be exploited, and one of the limitations impeding the acceptance and development of geopolymer cement derived from laterite is the lack of information regarding its durability performance.

Consequently, this paper presents the framework of an ongoing study on the viability of laterite as a source of aluminosilicates in geopolymerisation, with emphasis on the transport properties and corrosion of steel in laterite-based geopolymer concrete. For this investigation, imaging analysis and nano-analytics will be employed to probe the microstructure. It is envisioned that the findings of this study will fill the current gap in knowledge regarding the afore-mentioned properties and further the use of laterite as a source of aluminosilicates in producing green and affordable cement.

Keywords: Geopolymer, Laterite, Microstructure, Steel Corrosion, Transport.

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1. INTRODUCTION

The need for eco-friendly and affordable cement is the current driving force behind the research and development of alternative cements, such as those based on alkali or acid activation technology. One novel class of materials that falls in this category is geopolymer. Geopolymers are inorganic polymeric materials synthesised from the reaction of aluminosilicate materials (usually called the precursors) with an alkaline or acidic reagent. These materials consist of chains or networks of molecules linked by covalent bonds and have a broad range of applications [1].

Geopolymer technology presents a promising opportunity of producing low cost and green cement-based materials, which is much needed in the least developed and developing countries, where the needs for low-cost housing, road infrastructure, water reticulation system, to name a few, are ostensible. However, the utilisation of this technology strongly depends on the accessibility of a steady source of aluminosilicates, as the availability of locally sourced precursors is an essential factor in determining the acceptance and utilisation of alkali-activated binders [2].

Considering that access to industrial wastes in underdeveloped and less-industrialised countries is a major problem, the need for other sources of aluminosilicate materials is self-evident if geopolymer technology is to be utilised. Thus, the only available source of aluminosilicates that should be exploited in these regions is geological materials [3]. One potential geological material that could be used as a source of aluminosilicates and exists in vast quantities exceeding the likely global production of cement-based materials [2], but has not received the deserved attention, is laterite or lateritic soil.

Laterite is a reddish or rust-coloured soil found mostly in the tropics and subtropics, developed as the result of long and intensive weathering of the underlying parent rock. This material is poorly crystallised, rich in iron and aluminium; and mainly consists of goethite, hematite, kaolinite, and gibbsite minerals. Laterite has long had a history of being used as a construction material. Dating back as far as 1000 years ago in Southeast Asia, laterite soil was cut in the form of large blocks and used in the construction of temples [4]. Apart from being used as a compressed stabilised earth block (CSEB) in modern time [5], laterite has also found usage in road construction, as road base material and road surface pavement [6], in the development of earth dams and the concrete industry as Portland cement replacement material. It has been proven that calcined laterite has pozzolanic properties and can be used as cement replacement in the production of Portland cement-based materials [7], [8]. Laterite or lateritic soil, as a construction material, suits the context of sustainability and is promising for middle- and low-income countries, most notably regarding chemical activation.

Despite being a potential source of aluminosilicates, laterite has received less attention from researchers. There are scant publications on the use of laterite as an aluminosilicate precursor compared to the vast publications and reviews available on the properties, characterisations and performance of alkali-activated binders based on metakaolin, fly ash, and blast-furnace slag [9], which are considered the most-used aluminosilicate precursors [10]. Although there is a substantial amount of information on the mostly used aluminosilicate precursors, knowledge of these materials is not easily transferable, given that the properties and performance of alkali-activated binders strongly depend on the chemical and mineralogical compositions of the aluminosilicate precursors as well as the mix design, activators, and the curing process. Thus, other potential sources of aluminosilicates, such as laterite, must be subjected to full scrutiny.

2. LATERITE AS A SOURCE OF ALUMINOSILICATES

Laterite, as a source of aluminosilicates, has just attracted attention in recent time, and most of the publications on the use of laterite as a source of aluminosilicates are under the name geopolymer. It is worth mentioning that this review only captures work on lateritic material sourced from the tropics or subtropics. Results from previous investigations indicate that laterite-based geopolymer is suitable for construction purposes. However, these investigations lack comprehensive information about the durability performance of laterite-based geopolymer. Obonyo et al. [11] investigated the suitability of using laterite as a solid precursor in geopolymerisation. In their study, portions of the laterite ranging from 15 – 35% by weight were calcined at 700 °C to serve as nucleation sites for the geopolymerisation. The authors examined the final product for stability in water, biaxial flexural strength, pore size distribution and the microstructure. They found that the final product exhibited excellent stability in water, low porosity and water absorption, and flexural strength comparable to that of conventional concrete. Lamougna et al. [12] examined the influence of curing temperature and the amount of sodium hydroxide (NaOH), the sole activator, on the compressive strength of laterite-based geopolymer. The authors reported that both the curing temperature and alkali concentration influenced strength development.

Similarly, studying the potential of utilising laterite as a raw material in geopolymerisation, Gualtieri et al. [13] studied the mechanical and microstructural properties of phosphoric acid activation and sodium silicates activation of laterite and found that the laterite-based geopolymer synthesised with phosphoric acid exhibited better mechanical properties and low porosity than the sodium silicates activation. Lamougna et al. [14] investigated the effects of replacing laterite with slag and calcite on the development of laterite-based inorganic polymer. The replacement level ranged from 5 – 50% and 2 – 20%, for the slag and calcite, respectively. The authors reported the calcite to have little influence while the replacement of the laterite with slag from 20% and above, had significant improvement on the compressive strength and the microstructure.

Studying the influence of calcination temperature on fully indurated laterite, Kaze et al. [15] examined water absorption, flexural strength, and the microstructure of laterite-based geopolymer. The authors reported 500 °C to be the optimum calcination temperature in terms of flexural strength and dense microstructure. Still concerned with the performance of laterite-based geopolymer, Kaze et al. [16] investigated the flexural strength, water absorption, porosity and microstructure of laterite-based geopolymer containing rice husk ask (RHA) at 10 – 40% replacement level, cured at room temperature and 90 °C. The authors reported significant improvement in the mechanical properties and microstructure of the laterite-based geopolymer containing RHA at higher replacement level and curing temperature. Kaze et al. [17] also investigated the effect of silicate modulus with varying NaOH concentration on the initial and final setting times, compressive strength and microstructure of laterite-based geopolymer cured at room temperature and found the setting times to decrease with increasing NaOH concentration while the compressive strength and microstructure improved with increasing concentration of NaOH and decreasing silicate modulus.

As stated above, the current research on the activation of laterite as a cement-based material has focused chiefly on strength development, the influence of curing temperature, soundness in water, and the microstructure. None has detailed neither the flow behaviour of the fresh mix nor the durability performance regarding corrosion of steel, the most common deterioration mechanism associated with reinforced concrete [18] or the transport properties, which often serve as indicators of durability [19]. These are essential aspects that should be understood if alkali- or acid-activated laterite is to be utilised as cement-based material.

3. SCOPE OF THE ONGOING INVESTIGATION

The focus of this investigation is on the durability aspects of steel corrosion in laterite-based geopolymer concrete and its transport properties. However, the scope of this investigation also covers the rheology, setting times (initial and final) and reaction kinetics of the fresh mix, as well as strength development and microstructural analyses of the hardened laterite-based geopolymer concrete.

4. EXPERIMENTAL FRAMEWORK

4.1 Laterite Characterisation

Various techniques will be employed in characterising the physical and chemical properties of the laterite. The physical properties of interest are the particle size distribution, specific gravity, surface area and SEM micrography, while those of the chemical are the oxide composition, mineralogical phases, and elemental composition.

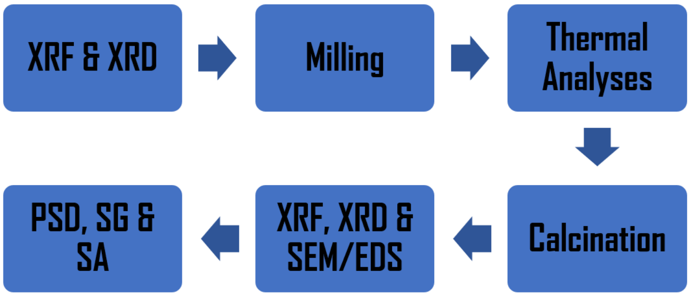

Figure 1: Flowchart of the Laterite Characterisation Process.

As illustrated in Figure1, the characterisation of the laterite will begin with preliminary chemical analyses (XRF & XRD) to establish whether the material is suitable for this investigation. Subsequently, the laterite will be milled to pass a sieve size of 45 µm, and thermal analyses (DSC-TGA) will be conducted to determine the dehydroxylation temperature, followed by the calcination of a portion of the milled laterite. Next, the final chemical analyses (XRF, XRD and SEM/EDS) will be conducted for both calcined and uncalcined parts of the laterite. Then, the particle size distribution (PSD), specific gravity (SG), surface area (SA) and SEM micrography will be obtained.

4.2 Concrete Mix Designs

Two (2) categories of mixes will be considered in this investigation, Geopolymer Mixes and Hybrid Mixes. Each category will comprise two mixes: consisting of calcined and uncalcined laterite. The geopolymer mixtures will consist solely of laterite as the precursor (100% laterite), while the hybrid will consist of 70 – 80% laterite & 20 – 30% Portland cement.

All mixes will be activated with the same activator(s). The optimum mix design of the geopolymer mixtures will be achieved after several trial mixes, and the critical factors to be considered during the mix design process are the workability, setting at ambient temperature and strength development. The liquid-to-solid ratio, type of activator(s) and concentration will be determined during the trial mixes. Once the optimum mix design is established, the hybrids will be tailored to suit the sole laterite mixes in terms of consistency and workability.

4.3 Rheology, Setting time and Reaction Kinetics

The rheology of the fresh mix will be examined by a free flow test (slump) which will evaluate workability and consistency. Vicat apparatus will be used for the determination of the initial and final setting times, and the reaction kinetics (heat evolution) will be studied by measuring the heat released during the geopolymerisation process with an isothermal calorimeter.

4.4 Strength Development

The strength development of the mixes will be explored using the compressive strength and splitting tensile strength tests. The compressive and splitting tensile strengths tests will be conducted in accordance with the South African National Standards, and the trend of strengths development will be tracked up to 52 weeks after casting.

4.5 Microstructural Analyses

The microstructural analyses cover phase identification of the products of geopolymerisation and analyses of the pore structures (porosity, pore size and pore size distribution). The pore structures will be analysed by SEM imaging and mercury intrusion porosimetry (MIP), whereas the phase identification involves XRD and EBSD in combination with EDS. EDS and EBSD will consist of both micro- and nanoscale analyses. The TGA technique will also be employed in the microstructural characterisation to complement results of the XRD and EBSD/EDS analyses.

4.6 Durability Performance

4.6.1 Transport Properties

The transport properties of the laterite-based geopolymer concrete will be studied from the perspective of resistance to penetration. The resistance to penetration will be evaluated against gas permeation, moisture absorption, and chloride diffusion, and these will be assessed by the South African Durability Indexes.

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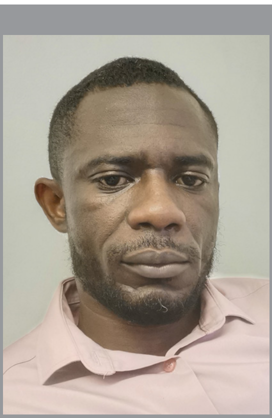
4.6.2 Steel Corrosion Resistance

The steel corrosion resistance of laterite-based geopolymer concrete will be evaluated based on chloride-induced corrosion since chloride is the most aggressive corrosion-inducing species in the environment. This corrosion resistance study involves the depth of chloride penetration, the electrical resistivity, the half-cell potential, the corrosion rate, and the mass loss of the rebars. A Coulostat meter will be employed to measure the corrosion rate, electrical resistivity of the specimens and the half-cell potential of the rebars. The mass loss of the rebars will be evaluated by gravimetric analysis. A resistivity meter and half-cell meter will also be used to verify or complement the electrical resistivity and half-cell potential measurements, respectively, obtained from the Coulostat meter.

5. CONCLUDING REMARKS

This study seeks to examine the viability of laterite as a source of aluminosilicates with emphasis on the durability performance of laterite-based geopolymer concrete, which covers steel corrosion and the transport processes of gas permeation, moisture absorption, and chloride diffusion. These are essential durability aspects that should be understood if alkali- or acid-activated laterite is to be utilised as cement-based materials.

It is anticipated that the findings of this study will fill the current gap in knowledge regarding the corrosion of steel in laterite-based geopolymer concrete and its durability-related transport properties and promote the use of laterite as a source of aluminosilicates in producing green and affordable cement. **CB**



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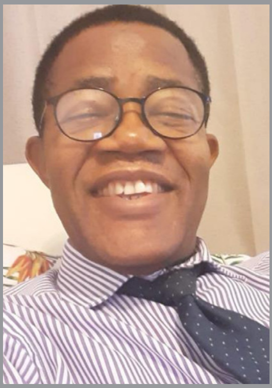

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