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Review JoPC

A Systematic Review on Laterite Based Geopolymer

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Abstract

Laterite based geopolymer has been widely studied as a sustainable alternative to Portland cement in construction industry. However, its thermal performance is still a challenge due to the low thermal conductivity and low temperature resistance. In this paper, recent studies on the improvement of thermal performance of laterite based geopolymer using additives are reviewed. The additives studied include organic materials, metal oxides and natural fillers. The effect of these additives on the thermal conductivity and temperature resistance of geopolymer is analyzed. The limitations and challenges in the application of these additives in laterite based geopolymer are also discussed. Finally, the conclusion is drawn that the use of these additives can effectively improve the thermal performance of laterite based geopolymer and make it more competitive in the construction industry. As a partial replacement for OPC clinker, a lot of supplemental cementitious materials (SCMs) (industrial and agricultural wastes) are employed nowadays. SCMs cannot be regarded as a universal replacement for cement due to their restricted availability. Recently, efforts have been made to substitute waste materials (SCMs) with naturally occurring materials like clay, which contains significant amounts of alumina and silica and can, under the right circumstances, trigger a pozzolanic reaction. Nearly all nations have large amounts of clay.

Keywords: Laterite soil, additives, geopolymer, elevated temperature

INTRODUCTION

One of the oldest and most significant industries in the world is construction. It predates civilisation. The construction sector currently dominates all market economies. A wide range of materials, including cement, concrete, aggregates, clay, wood, metals, and bricks, are used in the building business [1]. The pricing and characteristics of these materials influence the decision. Binders are the most popular building material in use today among all other materials. Cement and concrete rank as some of the most significant binders. The primary binder is Portland cement (OPC), which has a variety of components and compositions [3]. OPC production uses a lot of energy and raw resources, while also producing roughly 7% of the CO_2 gas that causes global warming as shown in Figure 1 [2]. Another serious reason behind cement replacement is to reduce carbon dioxide emissions to the atmosphere to dissuade the global warming problem worldwide [16]. From the perspectives of performance and environmental concern, geopolymeric binders is an ideal alternative to Portland cement [15].

Laterite based geopolymer has been recognized as a promising alternative to traditional Portland cement. It has several advantages, such as low CO_2 emissions, low energy consumption, and low raw material cost. However, one of the major challenges in the widespread application of laterite based geopolymer is its low thermal performance, which is characterized by low thermal conductivity and low temperature resistance [11].

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To overcome this limitation, researchers have attempted to improve the thermal performance of laterite based geopolymer by adding various types of additives. Laterite soil is a type of soil found in tropical regions and is widely distributed in India, covering around 50% of Kerala, 25% of Karnataka, 20% of Goa, 15% of Maharashtra and other places as shown in Figure 2. The soil is characterized by its reddish-brown color and high iron oxide content and is widely used for agriculture, particularly in hilly regions due to its high fertility.\

Figure 1. CO_2 emissions from a typical industry.

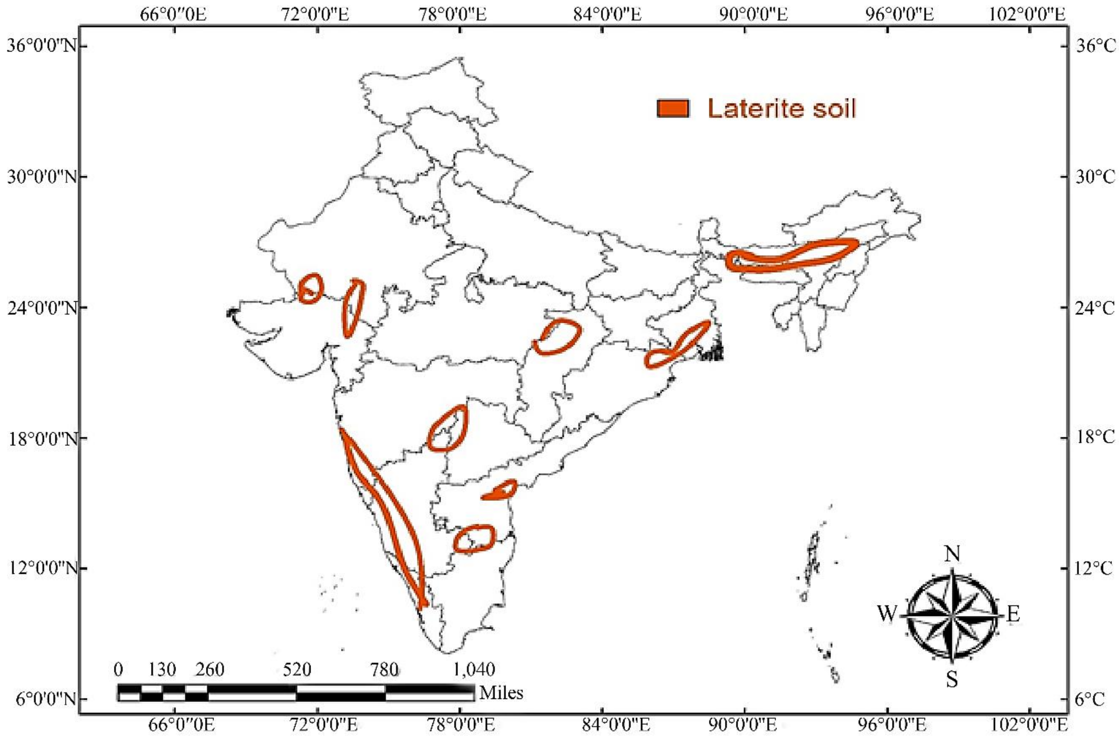

Figure 2. Details of laterite soil availability state wise.

Studies on the Improvement of Thermal Performance of laterite Based Geopolymer Using Additives

Organic materials: Some studies have shown that the addition of organic materials, such as fly ash and rice husk ash, can improve the thermal conductivity and temperature resistance of laterite based geopolymer [11]. The organic materials provide a porous structure that enhances the heat transfer and reduces the thermal resistance.

Metal oxides: Metal oxides, such as iron oxide, aluminium oxide, and titanium dioxide, have been found to have a positive effect on the thermal conductivity of laterite based geopolymer. These metal oxides provide a high thermal conductivity and improve the temperature resistance of the geopolymer.

Natural fillers: Natural fillers, such as quartz and perlite, have been studied as additives to improve the thermal performance of laterite based geopolymer. These fillers increase the thermal conductivity and improve the temperature resistance of the geopolymer by providing a continuous network of pores that enhances heat transfer.

Limitations and Challenges in the Application of these Additives

Despite the potential benefits of these additives, there are some limitations and challenges in their application in laterite based geopolymer. One of the challenges is the difficulty in controlling the particle size and distribution of the additives, which affects the thermal performance of the geopolymer [4]. Additionally, some additives may have a negative impact on the strength and durability of the geopolymer, which needs to be carefully considered.

Lateralization Process or Lateritic Soils Formation

Lateralization is the process of formation of lateritic soils. Lateritic soils are soils that are rich in iron oxide, aluminium oxide, and other minerals. They are formed due to intense weathering and leaching of rock minerals under tropical conditions. The formation of lateritic soils is a slow and gradual process that takes place over thousands of years.

The lateralization process involves the following steps:

1. *Weathering of rocks:* The first step in the formation of lateritic soils is the weathering of rocks. Rocks are exposed to the elements and undergo physical and chemical weathering. Physical weathering occurs due to the expansion and contraction of rocks due to temperature changes and the action of wind, water, and ice. Chemical weathering occurs due to the reaction of rocks with water and air, leading to the dissolution and breakdown of minerals.
2. *Leaching of minerals:* The minerals in the weathered rocks are leached away by the rainwater. This process is known as leaching. The rainwater carries away the soluble minerals, such as silica and calcium, leaving behind the insoluble minerals, such as iron oxide and aluminium oxide.
3. *Formation of iron oxide and aluminium oxide:* The iron oxide and aluminium oxide in the weathered rocks are further oxidized by the air and water, forming iron oxide and aluminium oxide. These minerals are very resistant to weathering and leaching and form a hard and dense layer over the weathered rocks.
4. *Accumulation of lateritic soils:* The hard and dense layer of iron oxide and aluminium oxide accumulates over time and forms a layer of lateritic soil. This layer is typically several meters thick and covers the weathered rocks below.
5. *Soil formation:* The lateritic soils undergo further weathering and decomposition, leading to the formation of different soil layers. The top layer is rich in organic matter and is known as the topsoil. The subsoil layer contains the residual minerals from the weathered rocks, and the underlying layer is composed of the original rock material [4].

In general, the lateralization process involves the weathering of rocks, leaching of minerals, formation of iron oxide and aluminium oxide, accumulation of lateritic soils, and soil formation. The process occurs over a long period of time and is most commonly found in tropical regions.

Chemistry and Mineralogy of Lateritic Soils

Lateritic soils are soils that are rich in iron and aluminium oxides and are formed by the weathering of underlying rocks in tropical and subtropical regions. The weathering process involves chemical reactions that break down the minerals in the rock into smaller particles, and changes the chemical composition of the soil. The end result is a soil that is rich in iron and aluminium oxides, with a low content of essential nutrients such as nitrogen, phosphorus, and potassium. Mineralogy of lateritic soils is characterized by the presence of aluminium and iron oxides, such as goethite, hematite, and gibbsite [2]. These minerals are the result of the breakdown of feldspar and other minerals in the parent rock. In addition, lateritic soils also contain hydrous oxides of aluminium, such as kaolinite, which are the result of the weathering of silicate minerals in the parent rock.

Chemistry of lateritic soils is characterized by a high content of aluminium and iron oxides, and a low content of essential nutrients such as nitrogen, phosphorus, and potassium. The high content of aluminium and iron oxides makes these soils highly acidic, with a pH ranging from 4 to 5.5 [2]. This acidic environment is unfavourable for most crops, and can limit plant growth. In addition, the low content of essential nutrients can also limit plant growth, and may require the application of fertilizer to improve soil fertility.

In conclusion, lateritic soils are characterized by their mineralogy and chemistry, which are the result of weathering processes in tropical and subtropical regions. The high content of aluminium and iron oxides, and low content of essential nutrients, make these soils unique, and require special management practices to support agricultural production [2].

GEOPOLYMERIZATION OF LATERITIC SOILS

Geopolymerization is a process of transforming a mixture of inorganic materials into a solid, ceramic-like material using an alkaline solution. This process is particularly applicable to the treatment of lateritic soils, which are soils formed from the weathering of volcanic rock and rich in aluminium and iron oxides. In the geopolymerization of lateritic soils, the lateritic soil is first crushed and ground into a fine powder. The powder is then mixed with an alkaline solution, typically sodium hydroxide or potassium hydroxide, to activate the reaction [14]. The mixture is then cured, typically at elevated temperatures, to allow the reaction to proceed.

The reaction between the alkaline solution and the lateritic soil produces a solid material that is resistant to degradation and has many of the properties of ceramics, including high strength and durability. This material can be used as a building material or as a component in other construction materials. The main benefits of geopolymerization of lateritic soils are that it is a low-energy, low-emissions process that can help to reduce waste and conserve resources. In addition, the resulting material has low permeability and is resistant to chemical and biological degradation, making it ideal for use in a variety of construction and engineering applications.

Overall, the Geopolymerization of lateritic soils shown in Figure 2 and 3 offers a sustainable and environmentally friendly solution for the treatment and utilization of these soils, with many potential applications in the construction and engineering industries.

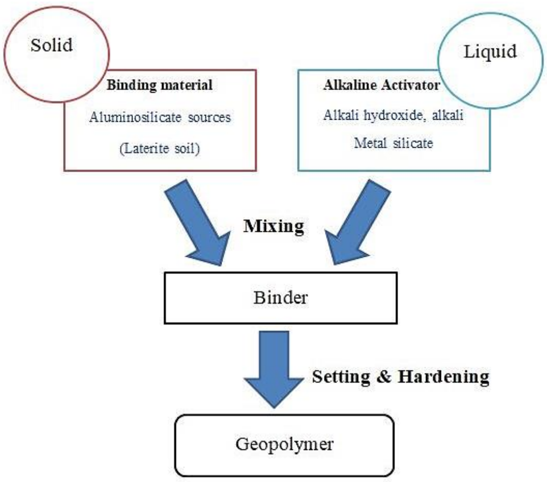

Figure 3. Geopolymerization Process of Laterite Soil.

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Reactivity of Lateritic soils for Geopolymer Synthesis

Lateritic soils are known for their high reactivity towards geopolymer synthesis. This reactivity is due to the high concentration of reactive silica and aluminium in the soil. During the geopolymer synthesis process, the silica and aluminium in the soil react with an alkaline solution to form a network of interconnected silicate and aluminate species [6]. This reaction results in the formation of a highly cross-linked, three-dimensional structure with a high level of mechanical strength and durability.

Additionally, the presence of iron in lateritic soils can also contribute to the reactivity of the soil during geopolymer synthesis. The iron present in the soil can react with the alkaline solution to form iron-rich species that further reinforce the geopolymer network. The reactivity of lateritic soils towards geopolymer synthesis makes them a highly promising material for use in construction and engineering applications. Geopolymers made from lateritic soils have been shown to have good mechanical strength and durability, making them suitable for use in load-bearing structures and as a replacement for traditional Portland cement-based materials. It is worth noting that the reactivity of lateritic soils towards geopolymer synthesis can vary depending on several factors, including the composition of the soil, the presence of impurities, and the conditions of the synthesis process [8]. As such, it is important to carefully evaluate the reactivity of a given soil sample before using it for geopolymer synthesis.

Microstructural Characteristic of Lateritic Soil Based Geopolymer

Lateritic soil-based geopolymers are inorganic, cement-like materials made from the reaction of an alkaline solution with lateritic soils, which are soils formed from the weathering of volcanic ash or other rock materials. The microstructural characteristics of these materials can be studied using various techniques, such as electron microscopy, X-ray diffraction, and infrared spectroscopy [10]. At the microscale, lateritic soil-based geopolymers have a dense and homogeneous structure, with well-defined, regular arrangements of silicate and aluminate units. These units are responsible for the material's strength and durability and are held together by a network of chemical bonds that give the material its high mechanical stability.

One important microstructural characteristic of lateritic soil-based geopolymers is the presence of an amorphous phase, which acts as a filler material between the silicate and aluminate units, improving the material's overall mechanical properties. The amorphous phase also contributes to the material's high resistance to thermal and chemical degradation. Another important microstructural feature of lateritic soil-based geopolymers is the presence of nanoscale pores and voids, which play a crucial role in determining the material's properties such as strength, porosity, and water permeability. These pores and voids can be controlled through the use of different alkaline activators, curing conditions, and particle size distribution of the lateritic soil.

The microstructural characteristics of lateritic soil-based geopolymers, such as the presence of an amorphous phase and nanoscale pores and voids, are critical factors that determine the material's mechanical and physical properties, making it an attractive alternative to traditional building materials.

Use of Laterite in Geopolymers Without Pre-treatment

Laterite is a soil type rich in iron and aluminium oxide minerals, commonly found in tropical regions. In the field of geopolymer science, laterite is often used as a raw material for the production of building materials due to its low cost and abundant availability [6]. In geopolymer production without pre-treatment, the laterite is typically crushed, dried and ground into a fine powder before being mixed with an alkaline solution (usually sodium or potassium hydroxide) to form a slurry. The slurry is then allowed to cure and harden into a solid geopolymer.

The use of laterite in geopolymer production offers several benefits. Firstly, it is an environmentally friendly alternative to traditional building materials such as cement and concrete, as the production of geopolymers releases significantly less greenhouse gases. Secondly, the high iron and aluminium oxide content of laterite gives the resulting geopolymer improved mechanical and fire resistance properties. Finally, the use of laterite in geopolymer production is an important step towards reducing the dependence on finite resources such as cement and sand, as well as improving sustainability and reducing the carbon footprint of the construction industry.

However, it is worth noting that the properties of the resulting geopolymer can be greatly affected by the composition of the laterite, and it is important to carefully select and characterise the raw materials used in production.

Improving the Geopolymeric Reactivity of Laterite Soils

Improving the geopolymeric reactivity of laterite soils refers to the process of increasing the ability of laterite soils to undergo a chemical reaction with geopolymeric materials. Geopolymeric materials are a type of composite material made from natural minerals and industrial waste materials, and they are used in construction and civil engineering applications due to their high strength and durability. However, in order to be effective, the soil must be capable of reacting with the geopolymeric materials.

The reactivity of laterite soils can be improved by several methods, including:

1. *Increasing the soil's alkalinity:* The reactivity of laterite soils can be improved by increasing its alkalinity, which can be done by adding alkaline substances such as sodium hydroxide or sodium silicate.
2. *Adding activators:* Activators are substances that increase the rate of the chemical reaction between the geopolymeric material and the soil. Common activators used for laterite soils include sodium hydroxide, sodium silicate, and potassium hydroxide.
3. *Grinding the soil:* Grinding the soil to a finer particle size can also increase its reactivity by increasing the surface area available for the reaction to occur.
4. *Increasing the temperature:* The reactivity of laterite soils can also be improved by increasing the temperature at which the reaction occurs, which can be done by heating the soil or adding heat-generating activators.
5. *Mixing the soil with other materials:* Mixing the soil with other materials such as fly ash or slag can also improve its reactivity by introducing new components that can participate in the chemical reaction.

Overall, improving the reactivity of laterite soils is important for ensuring the effectiveness of geopolymeric materials in construction and engineering applications. By following these methods, the soil can be made more receptive to the chemical reaction, resulting in stronger and more durable structures.

Incorporation of Secondary Materials

The incorporation of secondary materials in laterite-based geopolymer refers to the process of adding waste or by-product materials to the laterite-based geopolymer mixture to improve its properties and reduce the environmental impact of its production. This process can include a variety of materials such as fly ash, slag, silica fume, and recycled glass, among others [5].

Incorporation of secondary materials has several benefits in the production of laterite-based geopolymer, including:

1. *Improving the properties of the geopolymer:* Secondary materials can improve the strength, durability, and other properties of the geopolymer, making it more suitable for construction applications.

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2. *Reducing the environmental impact of production:* Using secondary materials can reduce the need for primary raw materials, which are often associated with significant environmental impacts, such as mining and extraction.
3. *Cost savings:* Using secondary materials can reduce the cost of production as they are often readily available and cheaper than primary raw materials.

The incorporation of secondary materials in laterite-based geopolymer requires careful consideration of their chemical and physical properties, as well as the specific properties desired in the final product. For example, the presence of certain impurities in the secondary material can affect the properties of the geopolymer, and therefore, careful selection and processing of these materials is important.

The incorporation of secondary materials in laterite-based geopolymer has several benefits, including improved properties, reduced environmental impact, and cost savings. However, careful consideration of the chemical and physical properties of the secondary materials is required to ensure the desired properties are achieved in the final product.

Application of Blended Laterite Without Thermal Activation

Blended laterite is a mixture of laterite and other materials, often used as a construction material or as a filler in various industrial applications. It is unique from traditional laterite, as it does not require thermal activation, which refers to a heating process used to improve the properties of the material. Instead, blended laterite relies on its composition and processing to deliver the desired properties.

The application of blended laterite without thermal activation is quite versatile, and it can be used in several areas including:

1. *Road construction:* Blended laterite can be used as a base or sub-base material in road construction. It offers improved stability and drainage compared to traditional laterite.
2. *Landfilling:* Blended laterite can be used as a lining material in landfills to reduce the permeability of the soil and prevent the release of toxic chemicals.
3. *Agriculture:* Blended laterite can be used as a soil conditioner to improve soil structure and fertility.
4. *Environmental remediation:* Blended laterite can be used to treat contaminated soil and water by adsorbing pollutants.
5. *Construction industry:* Blended laterite can be used as a building material, particularly for low-cost housing or in areas with limited access to conventional building materials.

The application of blended laterite without thermal activation is growing, as it offers a low-cost and sustainable solution for various industrial, and construction needs.

ACID ACTIVATION

Acid activation is a process used to improve the reactivity of clay minerals in laterite-based geopolymers. This process involves treating the laterite material with a strong acid such as hydrochloric or sulfuric acid, which breaks down the silicate framework and creates reactive silica and alumina species. The resulting material has a higher surface area and a more positive charge, which enhances the interaction with the alkaline activators used in geopolymerization.

In the acid activation process, the acid is typically added in a controlled manner to the laterite material to achieve a desired degree of reactivity. The reaction between the acid and the laterite material is exothermic and generates heat, which needs to be carefully managed to avoid damaging the material. After the reaction, the material is usually washed to remove any residual acid and then dried to a suitable moisture content.

The acid activation process can significantly improve the properties of laterite-based geopolymers, including strength, setting time, and durability. This is because the increased reactivity of the material leads to a more rapid and complete reaction with the alkaline activators, resulting in a denser and stronger final product. Additionally, the increased surface area of the material can also increase the adsorption of pozzolanic components, which can improve the overall properties of the geopolymer.

Acid activation is a crucial step in the production of high-performance laterite-based geopolymers, as it enhances the reactivity of the clay minerals and improves the properties of the final material.

Acid Resistance

The chemical durability of geopolymer products using laterite as a solid precursor has been studied in a few research studies. Kwasny et al. conducted a study to compare the durability of conventional Portland cement mortars (PCMs) with geopolymer mortars (GPMs) in acidic environments (solutions of 5% H_2SO_4 and 1.9% HCl). After 32 weeks of immersion in the acidic solutions, it was found that the laterite-based geopolymer mortars showed better resistance compared to the Portland cement mortars. The mass loss for geopolymer mortars was 4–5%, whereas it was 7–12% to 28–35% for PCMs. This was due to the dissolution of C-S-H and C-A-S-H binder phases in PCMs which are less stable in acidic environments compared to the N-A-S-H gel produced in geopolymer systems, which is more stable.

Another study by Kaze et al. investigated the behavior of calcined iron-rich laterite-based geopolymer mortars cured at 27°C and 80°C upon exposure to a sulfuric acid medium of pH = 1. The results showed that the geopolymer mortars cured at 80°C developed better acid resistance compared to those cured at 27°C. This was attributed to the compact and dense microstructure of the samples cured at higher temperatures. The compressive strength and mass losses of the geopolymer mortars cured at 27°C and 80°C were 28.40% to 78.09% and 12.20% to 42.04%, respectively. The high strength loss recorded on samples cured at room temperature was linked to the release of ferrisilicates which is not stable in an acidic environment resulting in the formation of sodium jarosite, which in turn had a destructive effect on the formed geopolymer network and reduced the compressive strength.

Overall these studies suggest that the chemical durability of laterite-based geopolymer products is better compared to Portland cement mortars in acidic environments. The curing temperature also plays a role in the acid resistance of the geopolymer mortars, with higher curing temperatures leading to better resistance.

Sulphate and Chloride Resistance

Ghani et al. carried out a pioneering study on the durability of laterite-based geopolymer formulations. The team prepared four different samples by curing them in an oven for 24 hours at 80°C and adjusting the Al(OH)3 content to maintain a Si to Al ratio between 1 and 3. The samples were then subjected to a solution of 8 % wt chloride and sulphate for 35 days and the results were evaluated in terms of mass loss, compressive strength, and morphological changes [13]. The study revealed that a higher Si/Al ratio resulted in lower mass loss and improved compressive strength. However, the aggressive environment caused significant cracks and voids in the microstructure of the geopolymer, impacting its overall strength. This was confirmed through SEM analysis, which showed noticeable surface erosion and the appearance of voids.

LITERATURE REVIEW

Based on Fire Performance on Geopolymer Concrete v/s Portland Cement Concrete

Fire performance is an important aspect of building design and construction, as it determines the safety of the building and its occupants in the event of a fire. In the case of concrete, fire performance is dependent on several factors, including the type of concrete used, the composition of the concrete mixture, and the presence of any fire-resistant additives or treatments.

When comparing fire performance of geopolymer concrete and Portland cement concrete, several factors should be considered:

1. *Heat of Hydration:* Geopolymer concrete has a lower heat of hydration compared to Portland cement concrete, which means that it releases less heat during the curing process and therefore, is less likely to ignite.
2. *Density:* Geopolymer concrete is typically denser than Portland cement concrete, and a higher density is generally associated with improved fire resistance.
3. *Thermal Conductivity:* The thermal conductivity of geopolymer concrete is generally lower than that of Portland cement concrete, meaning that geopolymer concrete is a better insulator and less likely to transfer heat to the internal structure of a building.
4. *Fire Resistance:* The fire resistance of concrete is primarily determined by the type of aggregate used, the thickness of the concrete layer, and the presence of any fire-resistant additives. Geopolymer concrete has been shown to have improved fire resistance compared to Portland cement concrete, as it is less prone to cracking and spalling during exposure to high temperatures.
5. *Toxicity:* In the event of a fire, the smoke produced by concrete can be toxic. Geopolymer concrete produces less toxic smoke compared to Portland cement concrete, making it a safer option for building occupants.

It is important to note that fire performance is not the only factor to consider when choosing between geopolymer concrete and Portland cement concrete. Other factors such as sustainability, durability, and cost should also be taken into account. Portland cement concrete and geopolymer concrete have different properties when it comes to fire performance.

Portland cement concrete is made by mixing Portland cement, water, aggregates (such as sand, gravel, and crushed stone), and sometimes other materials such as fly ash, slag cement, or silica fume [9, 5]. When exposed to fire, Portland cement concrete can withstand high temperatures for a short period of time. However, when the temperature gets too high, the concrete can start to crack and spall, which is when small pieces of the concrete break off.

Geopolymer concrete is made from a mixture of materials such as fly ash, ground granulated blast furnace slag, and alkaline activators [7]. It has been shown to have better fire performance than Portland cement concrete. Geopolymer concrete can withstand higher temperatures for a longer period of time without significant cracking or spalling. This is because geopolymer concrete has a different chemical structure than Portland cement concrete, which allows it to retain its strength at higher temperatures.

Based on Effect of Fire on Geopolymer Concrete

The effect of fire on geopolymer concrete depends on several factors, including the composition of the concrete mixture, the temperature and duration of exposure, and the presence of any fire-resistant additives or treatments [12].

1. *Strength:* Like most materials, the strength of geopolymer concrete decreases as the temperature increases. However, compared to Portland cement concrete, geopolymer concrete has been shown to have improved fire resistance and to maintain its strength to a greater extent during exposure to high temperatures.
2. *Cracking and Spalling:* One of the most significant effects of fire on concrete is cracking and spalling, which occurs when the surface of the concrete deteriorates and flakes off due to exposure to high temperatures. Geopolymer concrete has been shown to have improved fire resistance and to be less prone to cracking and spalling compared to Portland cement concrete.
3. *Thermal Conductivity:* The thermal conductivity of geopolymer concrete is generally lower than that of Portland cement concrete, meaning that geopolymer concrete is a better insulator and less likely to transfer heat to the internal structure of a building. This can help to reduce the spread of fire and protect the internal structure from damage.

4. *Toxicity:* In the event of a fire, the smoke produced by concrete can be toxic. Geopolymer concrete produces less toxic smoke compared to Portland cement concrete, making it a safer option for building occupants.
5. *Durability:* Geopolymer concrete has been shown to have improved durability compared to Portland cement concrete, meaning that it is less likely to degrade over time due to exposure to high temperatures [9].

It is important to note that while geopolymer concrete has improved fire resistance compared to Portland cement concrete, it is not fireproof as shown in Table 1. In the event of a fire, it is still important to take appropriate fire safety measures, such as providing fire escapes and installing fire alarms and sprinklers, to ensure the safety of building occupants as shown in Table 2.

Table 1. Comparing the Fire Resistance of Portland Cement Concrete and Geopolymer Concrete

Particulars	Portland cement concrete	Geopolymer concrete
Combustibility	Incombustible, does not burn	The property of being incapable of burning has been noted in various sources, including J. Davidovits et al. (1991), R.E. Lyon et al. (1997), and J. Davidovits et al. (1989).
Thermal conductivity	As per G.A. Khoury's findings in 2018, the thermal conductivity of concrete typically ranges between 1–4 W/mK, which is at least one order of magnitude less than that of steel, which is 46 W/mK.	According to J. Davidovits in 2008, Geopolymer binder typically exhibits a thermal conductivity ranging between 0.2–0.4 W/mK.
Spalling resistance	Can experience spalling during fire (A.Z.M. Ali et al,2018)	Better spalling resistance than OPC concrete
Microstructural damage	Apart from the loss of free water and the initial release of chemically-bound water at temperatures nearing 80ºC, the disintegration of calcium hydroxide commences at approximately 300º–400ºC. Furthermore, under high temperature conditions, calcium silicate hydrate undergoes a progressive breakdown. When exposed to temperatures exceeding 600ºC, both the cement paste and aggregates experience a decrease in strength, rendering the concrete structurally unfit for use.	Although both evaporable and chemically bonded water are lost in Geopolymers, their microstructure remains stable when compared to that of Portland cement concrete. Geopolymers maintain their chemical bonds even when subjected to high temperatures, and may undergo a transformation from the amorphous phase to the crystalline phase at temperatures near 1000ºC.
Strength loss	Concrete experiences a reduction in strength as temperature increases. However, by choosing appropriate aggregates, this strength loss can be limited to a certain extent, typically up to 600ºC. However, at even higher temperatures, the loss in strength can become more pronounced, as noted by G.A. Khoury in 2018.	According to J. Davidovits in 2008, Geopolymer concrete can exhibit exceptional fire-resistant properties up to 1200ºC when appropriate aggregates are used.

Table 2. "Assessing the Fire Endurance of Geopolymer Concrete: A Systematic Review and Meta-Analysis of Previous Research"

Author's Observations	Critical Temperature level, ºC
According to H.Y. Zhang et al (2016), GPC mortar exhibited more degradation in tensile and bending strength with increasing temperature than OPC mortar, but showed less degradation in bond and compressive strength.	300º–700º
A study by A. Hosanetal et al (2016) found that a Na_2SiO_3/NaOH ratio of 3 considerably improved the compressive strength of GPC, and increased the residual compressive resistance to 600ºC.	600º
In P. Duanetal's study (2017), the compressive resistance of GPC decreased with increasing heat cycles between 200ºC and 800ºC. Loss of mass and compressive strength were observed to increase with rising temperatures.	200º–800º

H.Y. Zhang et al (2014) reported that even after exposure to high temperatures, GPC samples based on MK/FA exhibited bending and compressive performance similar to OPC specimens, indicating that GPC based on MK/FA is a feasible alternative to normal OPC.	500º
In M. Lahoti's study (2018), the strength of combined sodium and potassium GPC (30%–40%) remained unchanged after exposure to elevated temperatures, while the strength of GPC produced with sodium decreased by 10%.	100º–900º
D.L.Y. Kong et al (2010) identified 10 mm aggregate size and GPC matrix as the two most important characteristics for GPC activity at high temperatures (800ºC). They observed that a large loss of GPC concrete at high temperatures is due to thermal instability between the GPC matrix and aggregates at low and high temperatures.	800º
P.K. Sarker et al (2014) found that following fire exposure, GPC samples suffered less damage in terms of cracking than OPC concrete specimens. For exposure between 800ºC and 1000ºC, significant spalling was observed in the OPC samples, but not in the GPC samples.	800º–1000º
According to Z. Panet et al (2014), the strength of GPC paste increased by 192% at 550ºC, compared to the original strength value, while the strength of OPC paste only changed slightly. However, the proportion of residual strength of GPC and OPC after heating to 550ºC was similar.	550º
M. Lahoti et al. (2018) and A. Rudenko et al. (2021) reported that all GPC specimens presented reduced compressive strength after being exposed to a high temperature of 900ºC. Although the GPC mixtures exhibited excellent chemical stability at the micro scale, their volume was weakly maintained at the micro scale, and thermal shrinkage was extremely high.	900º
S. Luhar et al (2018) observed that GPC beams had the same deformation characteristics as reinforced cement beams at room temperature, but the strain compatibility technique underestimated the deformation behavior of enhanced GPC beams when subjected to high temperatures.	800º
L.M. Kljajevi´c et al (2017) found that the amount of Si-O-Na bonds in GPC samples was reduced via cross-linking polymer modifications at 600ºC. After the occurrence of large morphological changes, such as the formation of a complex pore structure, thermal action at 900ºC considerably reduced oxygen and articulated sodium.	600º–900º
According to M. Sivasakthi et al (2018), the linear dimensional stability of GPC paste and mortar remains unaltered until 800ºC. The inclusion of 10% micro silica increased the filling effect, improving compressive strength, but compromising the integrity of the bulk GPC specimen	800º
According to Luhar et al. (2018), the control GPC and rubberized GPC experienced a similar decrease in strength as temperature increased from 200º to 800º. However, the thermal expansion of certain materials in the rubberized GPC caused irregularities and may have contributed slightly more to the loss of strength compared to the control GPC.	200º–800º

CONCLUSION

1. The best techniques for examining its microstructure are Mossbauer, EPR, and N-A-S-H, N-F(A)-S-H, and N-P(A)-S-H gels, which are the binder phase generated during the laterite-based geopolymerization.
2. The dissolution of solid precursor can be improved for high polycondensation and the development of a compact and strong matrix by increasing the curing temperature and concentration of alkaline or acid activator.
3. There have been few reports on studies and mix designs using secondary source materials to enhance the reactivity and properties of geopolymers from laterite soils.
4. The fresh properties of mixtures blended with secondary source materials have not been explored through rheological behavior investigations.
5. The laterite-based geopolymer products synthesized exhibit good performance in acidic and salty media.
6. Although laterite soils are suitable for the synthesis of geopolymers or alkali-activated materials, further research is needed to conduct other durability tests such as carbonation, alkali-silica reaction, freeze-thaw resistance, etc., for their potential applications.
7. When exposed to high temperatures, the compressive strength of GPC tends to decrease. Nevertheless, incorporating 10% micro silica can improve its filling effect and increase

compressive strength. However, this may lead to a compromise in the integrity of the bulk GPC specimen. The linear dimensional stability of GPC paste and mortar remains unchanged up to 800ºC.

8. In the temperature range of 800ºC to 1000ºC, GPC samples tend to suffer less damage in terms of cracking as compared to OPC concrete specimens. However, after being subjected to a high temperature of 900ºC, all the GPC specimens demonstrated a reduced compressive strength, and the thermal shrinkage was exceptionally high.

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