Geopolymer Concrete, a new approach towards green construction material: a Review

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Abstract

An environmentally responsible and long-lasting substitute for Portland cement concrete is geopolymer concrete. It is created by mixing alkaline chemical solutions like sodium silicate and sodium hydroxide with mineral admixtures like fly ash, GGBFS, metakaolin, micro silica, etc. The usage of mineral admixtures and chemical solutions acting as a binder is highlighted in this review paper's overview of the research on geopolymer concrete. Geopolymer concrete strength, durability and other properties are summarized in the study by summarizing key findings from several experiments. This work aims to support ongoing efforts to enhance and maximize the usage of geopolymer concrete in construction projects. The results of these investigations demonstrate the high-compressive strength, durability, and chemical resistance to corrosive acids, sulfates, and chlorides. The assessment concludes that geopolymer concrete shows promise as an alternative to conventional Portland cement concrete, highlighting the necessity for further research to improve its capabilities and explore its applicability in practical settings.

Keywords: Geopolymer concrete, GGBS, Alkaline solutions, Strength, metakaolin, micro silica, Optimization.

Introduction

Geopolymer concrete

Various types of adhesives are categorized as "cement," but the term is specifically reserved for the binders utilized in various civil engineering projects. These cement varieties are produced by finely grinding powders and mixing them with water to form a solid substance. While it can be used independently or as grout, cement is predominantly employed in mortar and concrete, where it is mixed with aggregate, an inert component. The combination of cement (often Portland cement), water, and aggregates results in concrete. Concrete is currently the most widely used construction material worldwide, making cement production a prevalent practice [1].

Concrete is internationally acclaimed for its remarkable flexibility and unmatched reliability, making it the go-to construction material across the globe. Following water, it is extensively utilized, with a significant demand for Portland cement. However, due to its current high cost and resource-intensive nature, an alternative must be sought. Geopolymer concrete, a cutting-edge building material, can be produced by the chemical interaction of inorganic compounds. Fly ash, a conveniently obtainable residue from coal in thermal power stations, is abundantly present worldwide [2].

This study seeks to minimize the need for traditional Portland cement and advocate for the use of alternative byproducts like fly ash. This substance is essential in decreasing the environmental impact linked to standard concrete. Moreover, it allows for the creation of durable concrete with fewer components. The study conducted investigated the development of geopolymer concrete blends to assess the impact of different factors on the characteristics of fly ash-derived geopolymer concrete, with a particular emphasis on compressive strength. These factors included the proportion of alkaline liquid to fly ash, the ratio of sodium silicate solution to sodium hydroxide solution, the concentration of sodium hydroxide solution, the amount of superplasticizer used, the duration of curing, and the temperature environment [3].

Concrete's compressive strength and % of tensile reinforcement were used as variables in work while keeping the cross-section constant. The initial crack load, service load, and ultimate load were used to study the behavior. The results revealed that the findings were on par with the performance of conventional reinforced beams made of cement concrete [7].

The excessive levels of fly ash produced when coal is burned result in a number of environmental issues, including air and water pollution. As a result, using fly ash as a stabilizer when making clay concrete will lessen these issues. To create an engineered block from the stable natural earth, mud concrete blocks are constructed. Fly ash mixed on its own did not produce much power [9].

In place of cement, different building materials such as geopolymers and black sands are being used more frequently. It has been demonstrated that using microwave characterization techniques can shed light on the electrical and reactional characteristics of such materials [10].

Ground Granulated Blast Furnace Slag (GGBFS)

An assessment is undertaken to examine the implications of utilizing fly ash and ground granulated blast furnace slag as alternatives to ordinary Portland cement. Four different binder compositions were tested across a set of 120 concrete cubes and cylindrical samples. Testing of above mentioned specimens at different ages showed that adding fly ash as a binding lowers the compressive strength at different ages. Additionally, it was observed that concrete containing GGBFS and fly ash demonstrated increased compressive strength during advanced stages in comparison to conventional concrete mixtures. The late activation procedure is to blame for this. On the other hand, geopolymer concrete durability testing, as demonstrated by the rapid chloride penetration test (RCPT), indicates that substituting GGBFS and fly ash for OPC in concrete results in significant improvements in durability at the different testing ages. Increasing the quantity of fly ash added leads to a reduction in both water absorption and the extent to which water penetrates the material. This means that the more fly ash is included, the less water the material will absorb and the shallower the water will penetrate. Finally, it is determined that environmentally benign elements like GGBFS and fly ash can be used as suitable substitutes for OPC in the binding component of concrete mixtures [20].

Geopolymer concrete is utilized as part of the initiative to encourage eco-friendly construction practices. It produces fewer carbon gases than regular concrete. The effects of rapid corrosion on Geopolymer concrete were also studied, along with the results with control concrete. The study revealed that geopolymer concrete has a smaller linear curve and is less porous than control concrete. The utilization of concrete in construction has rendered it susceptible to the detrimental effects of acidic environments. Concrete is constantly subjected to the corrosive impact of acids when utilized in an environment where it will come into contact with such substances [44].

This study evaluated the sorptivity of sustainable mortars without ordinary Portland Cement by using alkali-activated GGBS & fly mixes as binders. The results are presented in this publication. Sorptivity, a measurement of the matrix pore system, is a crucial sign of how long concrete will last. Three different binder combinations—GGBS as the only binder, a 3:1 of GGBS to fly ash, & similar mixture of GGBS to fly ash—were all successfully activated at ambient temperature without the use of heat. The 3:1 GGBS to fly ash ratio exhibited the lowest sorptivity among the 3 binder combinations at a 12M NaOH molarity, making it the most effective combination. Mortars with this ratio displayed decreased sorptivity after 7, 28, & 90 days of curing compared to mortars with only GGBS or equal amounts of GGBS & fly ash. The sorptivity of 100% GGBS binder mixes decreased as NaOH concentration increased from 10M to 16M in 2M increments. Mortars with a 50% GGBS with 50% fly ash binder showed optimal sorptivity at a sodium silicate to sodium hydroxide ratio of 2.0, outperforming ratios of 1.5 & 2.5 [45].

One of the main components in the majority of civil engineering constructions, concrete surely contributes to environmental pollution, either directly or indirectly, especially during cement production. Keeping this in mind, researchers from all over the world are working to find ways to utilize less cement or to substitute other materials in their place without sacrificing the strength & the concrete's standard. Substantial investigation has been carried out in this specific field, the principal objective of this research is to comprehend the impact of substituting cement with GGBS on the compressive & flexural strengths of concrete within the higher range of medium workability (80-100mm slump) as per the guidelines outlined in IS 456-2000. Research has shown that even though there is a decrease in compressive strength of concrete at different replacement levels, compressive strengths can still surpass the target mean strength of concrete up to 50% replacement level. Additionally, Replacing over 30% of cement with Ground Granulated Blast Furnace Slag results in an improvement in the flexural strength of the material. This substitution has been shown to enhance the structural integrity and durability of the final product, making it a popular choice in construction projects where strength is a key factor [46].

This research investigates the impact of fly ash & ground granulated blast furnace slag on the mechanical properties, porosity, & chloride penetration of sand concrete. W/B ratio of 0.36 & 0.32 were used to make two batches of concrete. Sand that has been crushed and has a modulus of fineness of 3.2 and 1.7, respectively, makes up the aggregate used. In each series, one batch of reference sand concrete (RSC) and two other batches containing 40% GGBFS and 35% GGBFS, & 20% FA, respectively, were examined.

The research findings indicated a significant increase in the strength of sand concretes containing 40% GGBFS after a week of curing. Additionally, these concretes exhibited reduced porosity and chloride penetration when compared to RSC. Sand concrete with 35% GGBFS & 20% FA showed reduced strength at 28 days but caught up by 56 days. In addition, their permeability and resistance to chloride ingress were significantly reduced when compared to RSC and sand mixes containing 40% GGBFS [11].

This study aimed to enhance the durability of fine-grained concrete (FGC) against sulfuric acid attack by incorporating ground granulated blast furnace slag (GGBFS) and fly ash (FA) as partial replacements for cement. Two series of FGC were constructed using water-to-binder ratios of 0.36 & 0.32. Each series consisted of a control FGC mixture and two additional mixtures: one with 40% GGBFS replacement (GS40) and the other with a combination of 35% GGBFS & 20% FA (GS35FA20).

The research findings revealed that in a water environment, FGC made with GS40 exhibited the highest compressive and flexural strengths, while FGC made with GS35FA20 demonstrated the absorption rates were the most minimal across all experimental ages. Notably, at 90 days, FGC with a replacement rate of GS35FA20 showcased the highest compressive and flexural strengths and the lowest absorption rates. The acid resistance of the control FGC was found to be lower in comparison to FGC with GS40 and FGC with GS35FA20 [13].

Cement production generates a significant quantity of carbon dioxide. The encouragement of utilizing alternative waste products from diverse industrial operations as a partial substitute for cement is driven by environmental concerns and specific technical requirements. With this plan, it should be possible to lower cement prices, save energy, and cut waste production [15].

This research investigates the impact of fly ash & GGBFS on the slump, mechanical properties, absorption, & sulfate resistance of fine-grained concrete produced with sea sand. The work's findings demonstrated that FGCR-SS had greater strength than FGCR at 7, 28, and 90 days but less strength loss than FGCR at the same time points. Throughout all test stages, FGCSSs utilizing GGBFS to substitute cement by 30–50% demonstrated enhancements in both compressive strength & splitting tensile strength [16].

In the realm of Alkali Activated Binders, fly ash & GGBFS have been utilized as eco-friendly substitutes for traditional Portland cement for soil improvement. Alkali solutions were utilized to activate these AABs [18].

Utilizing industrial waste for concrete production offers a practical answer to the problem of growing industrial waste in emerging towns where there is no strategic waste management plan in place. This study evaluates the alkalinity and strength properties of concrete that includes GGBFS & macro silica [19].

Industrial waste

Industrial waste ash is generated in large quantities by sectors such as the power generation industries, timber, iron & steel industries, rice mills, mining industries, & other sectors. This is primarily due to concerns related to the environment, health, land availability, & various other factors etc. have presented a significant challenge to the aforementioned industry players. Promoting extensive recycling and reuse of these waste products is the greatest strategy for solving the aforementioned waste management issues. Recent research and development on geopolymer binders has highlighted their immense potential in addressing waste management challenges associated with solid aluminosilicate waste materials generated by different industries. Additionally, geopolymer offers a promising solution to mitigate environmental degradation caused by the prevalent use of OPC as the primary binder in construction [21].

Over the past few years, there has been a notable drive to explore alternative and sustainable building materials such as geopolymer cement/concrete, with the aim of reducing CO2 emissions. Industrial by-products has pozzolanic minerals that can be used to create sustainable materials like geopolymers based on aluminum silicate. Examples of industrial waste that contains minerals that are used to make geopolymer cement or concrete include fly ash, red mud, GGBFS, rice husk ash, & bagasse ash. In order to analyze different mechanical properties of GPC produced utilizing various industrial wastes and to study the chemical makeup of these materials, which is essential for making geopolymer cement, a review of the literature was conducted [22].

The rising need for sustainable construction materials is driven by the escalating consequences of environmental degradation and global warming, which are intricately connected to the production of Portland cement used in the construction sector. Consequently, in order to produce geopolymer concrete (GPC) through ambient curing, this study employed GGBFS & corncob ash (CCA). The corncob was subjected to de-hydroxylation at a temperature of 600 °C and then substituted for GGBFS at different proportions ranging from 0% to 100%. The activation process involved the use of both sodium silicate (SS) & sodium hydroxide (SH), with varying molar concentrations of sodium hydroxide at 12, 14, & 16 M. Additionally, the chosen samples' mechanical characteristics, micro structural behavior, and mineralogical phases were studied. The findings showed that Portland cement concrete had lower strengths than concrete with up to 40% CCA replacement. Additionally, there is a strong correlation between the experimental findings & the suggested model equations. These suggested models could be useful in creating GPC and PCC strength designs that incorporate agro-industrial wastes. The work also demonstrates the viability of producing GPC by combining CCA with GGBFS and the achievement of curing GPC for structural applications under ambient circumstances [23].

Aggregates source effect on concrete properties

The properties of OPC and GPC, which contain recycled Portland cement concrete aggregates, were thoroughly investigated and compared. The study focused on examining the effects of different proportions of course geopolymer recycled aggregates (ranging from 0% to 100% replacement of natural coarse aggregates) on the characteristics of both types of concrete. The findings indicate that substituting as much as 20% of traditional coarse aggregates with recycled geopolymer concrete aggregates has a negligible effect on the compressive strength, flexural strength, and volume of permeable voids in Portland cement concrete [25].

Recent studies have focused on investigating the distinctive characteristics of concrete by utilizing recycled aggregates sourced from building & demolition waste. This research aims to gain a deeper understanding of how these recycled materials can be effectively incorporated into concrete mixtures to enhance sustainability and reduce environmental impact. A novel cementitious material called geopolymer composite seems to have the ability to take the place of traditional cement concrete. This publication provides a summary of previous studies that have explored the use of recycled aggregate as a substitute for traditional aggregates in geopolymer concrete. The research conducted in this study offers a comprehensive evaluation of how the addition of recycled aggregate impacts both the initial & final properties of GPCC [26].

An assessment will be conducted to evaluate the effects of varying percentages of RCA & the manner in which they are replaced. Alkaline activators, the alumino-silicate material & the curing process will all be assessed for their effects. Additionally, the features of this concrete that relate to durability will be examined. Comprehensive reviews of the effects of greater temperature exposure, freezing & thawing cycle, marine environments, and acid & alkali attacks will be given. According to a survey of the literature, the hardened GC is improved by adding more alumina silicates, like slag & metakaolin, as well as up scaling the Na2SiO3 to NaOH ratio & alkali activator to binder ratio. Its workability is negatively impacted by slag & metakaolin content as well as the Na2SiO3 to NaOH ratio. Therefore, it's crucial to determine the best mix design while employing RCA in GC. Additionally, there is potential for creating a self-compacting GC that uses RCA and is cured at room temperature [28].

Types of aggregates

Alkali-activated binders have been the subject of a lot of recent studies; however, certain important parameters are still unresolved, which limits the commercial use of AAMs to standard building activities. Alkali-activated concrete's new characteristics, mechanical strength, and durability performance using a variety of aluminium silicates as base materials are discussed. The alkaline solution's concentration plays a vital role in the formation of alkali-activated concrete, making it a critical factor to consider, which affects several qualities including mechanical strength, setting time, and durability. The research investigates and documents the impact of various concentrations, ranging from 6 to 16 M, on these characteristics. This essay primarily focuses on the characteristics of widely accessible base materials like fly ash and slag as well as ways to enhance their performance by adding different industrial and agricultural by-products as additives. AAMs' practical application to typical building activities is a problem that is also underlined [30].

The environmentally friendly geopolymers made from industrial waste have the potential to replace cementitious binders. By utilizing this type of polymer, it is possible to lessen the need for cement, thereby helping to mitigate the negative impact of its carbon emissions on the eco-system. The use of palm oil fuel ash (POFA) geopolymer as a sustainable building material has received much research. Through cycles of mixture optimization, they investigated in this work the impacts of various material design parameters on the performance of a POFA-based geopolymer as a construction material product [31].

The samples of geopolymer concrete were evaluated for different mechanical properties using different ratios of GGBFS, fly ash, & silica fume with variable concentrations of alkaline solution. The pozzolanic substance used for concrete preparation affects the test results for GPCC. The experimental investigation yields specific conclusions. With increasing fineness, pozzolanic material's consistency rises. Since silica fume is finer than GGBFS and Fly ash, consistency will also rise as the percentage of silica fume increases. Initial and final setting times rise as fly ash percentage rises, while they fall as silica fume levels rise. The soundness of GGBFS is 2 mm, however, it will decrease as fly ash levels rise and rise with silica fume levels, respectively. With an increasing NaOH concentration up to 12M and further rising molarity of NaOH strength getting lowered, the strength of geopolymer mortar increases. As the temperature rises to 1200C, the strength of the geopolymer mortar increases; however, as the temperature rises after that, the strength decreases. Within seven days of curing without water at 1200°C in an oven with a 0.32 binder ratio and 12 M NaOH, the GGBFS-based geopolymer concrete reached its maximal strength [32].

Testing:

Cement is an essential material that is widely utilized in the construction industry for its strength & durability. Thanks to a variety of cement types, concrete may be utilized for a wide range of functions. On the construction site, cement is regularly tested for a number of qualities to establish its quality before use. Cement is crucial in the construction industry. There has seldom ever been a structure built without it. The material that holds other components together must be tested in order to ensure the endurance of any construction project. Cement testing is a procedure employed to evaluate the various attributes of cement in order to ascertain its suitability for a construction endeavor. These examinations adhere to set guidelines, regulations, and technical factors to analyze the chemical and physical traits of the construction material [32].

For numerous years, steel fiber reinforced concrete (FRC) has been a popular choice for construction projects in the field of civil engineering. FRC is used in military engineering to build some protective constructions due to its suitability. Non-destructive testing has recently attracted a lot of attention in the area of building diagnostics. Numerous studies using common non-destructive methods have been conducted in an attempt to determine their applicability to the testing of structural elements constructed of fiber-reinforced concrete due to the complete lack of recognized methods and procedures for testing fiber-reinforced concrete. The article outlines a study that examines the compression strengths achieved through both destructive and non-destructive methods, highlighting the differences between the two approaches (hardness, ultrasonography) [35].

The experimental findings of the wave interaction between the ultrasonic pulse velocity (UPV) and concrete structures are givenThe examination utilized the testing equipment provided by Pundit Lab to analyze mortar mixtures with varying Water-Cement ratio of 0.4, 0.5, & 0.6. The investigation involved measuring the Ultrasonic Pulse Velocity (UPV) of concrete samples with travel path lengths of 150 mm and 100 mm, using a frequency of 54 kHz. Direct and indirect methods of measurement, respectively, were used. Each test's UPV curves were provided, and the results demonstrated the importance of the measurement type and W/C ratios in keeping track of concrete's structural health. A proportional relationship between the water cement ratio, UPV, & the increase in UPV is also demonstrated by the results [36].

The caves and faults are not longer than 10mm in linear measure, according to the non-destructive method used to examine the internal structure of concrete. However, the faults are actually more pronounced in three-dimensional directions. To discover every defect, many defect detection techniques are used. Due to the calculation time, larger flaw detection than 30 mm is not used. The next step in the inquiry is to look at the faults with larger dimensions. The larger size will provide a more accurate and thorough picture of the flaws under examination and could result in the discovery of new essential information in the field of non-destructive testing of concrete [37].

Types of testing

- *Slump Test:* Slump measurement is popular since it's easy to use. This is also a helpful quality control tool that aids in identifying variations in the concrete mixture, Alterations in the quantity of water within the blend, specifically referring to variations in the water content of the mixture [38]. The modified slump test can be used to track the evolution of viscosity. This test may be used as a field test if its validity is established. As a result, this test aims to quantify viscosity. The initial technique was timing how long it took for a plate lying on top of concrete to descend 100 seconds' worth of concrete. Using the second technique, the slump height is measured after 60 seconds. The slump height between these two techniques was determined to be 60 seconds [38].
- *Compressive Strength test:* The objective of the present investigation is to assess how well inexpensive GFRP encloses concrete cylinders with low strength. Eight concrete cylinders were cast, and they were then compressed uniaxially until they broke. Under compressive loading, concrete with 1 to 3 GFRP layers of standard strength (15 MPa) and low strength (5 MPa) was tested. In each series, the GFRP performed remarkably similarly while constraining cylinders. The compressive strength of a cylinder with a 5 MPa compressive strength was found to increase by 2.27 MPa, 3.96 MPa, & 4.31 MPa,

respectively, when one, two, & three layers of GFRP wrapping were applied, compared to the controlled specimen. Similarly, for a cylinder with a 15 MPa compressive strength, the compressive strength of the specimens increased by 1.32 MPa, 1.72 MPa, & 2.22 MPa for one, two, and three layers of GFRP wrapping, respectively, in comparison to the controlled specimen. The test results clearly indicated that utilizing low-cost GFRP wrapping is one of the most effective and economical methods to enhance the compressive strength of weak concrete specimens. [39].

- *Water permeability test:* Permeability of cement mortar or concrete is important for structures that retain water and resist deterioration. Permeability is linked to concrete durability and its ability to resist progressive deterioration and leaching due to exposure to severe climate and prolonged water seepage containing aggressive minerals or gases. In order to determine permeability, a mortar or concrete specimen of known dimensions is placed in a specially designed cell and subjected to a known hydrostatic pressure. The quantity of water entering and leaving the specimen is measured over a given interval, & the coefficient of permeability is calculated. This test is essential for measuring the water percolating through the specimen and determining its permeability characteristics [40].
- *Water Absorption test*: In order to conduct the water absorption test, the specimens undergo a drying process in an oven at a specific temperature & duration. Once dried, they are transferred to a desiccators to cool down. The specimens are then weighed immediately after cooling. Following the initial weighing, the specimens are immersed in water at a predetermined temperature, usually around 23 °C, for a period of 24 hours or until equilibrium is reached. Once removed from the water, the specimens are carefully dried using a lint-free cloth and weighed again [42].
- *Initial Surface Absorption test*: A plastic cap is secured to the concrete surface during the initial surface absorption test (ISAT) using modeling clay. The cap has a water area of 5000 mm2 and it is essential to secure it tightly in position either by bolting or using another suitable method when working on a vertical surface. To conduct the test, water is introduced into the cap through a connecting point and maintained at a head of 200 mm by utilizing a filter funnel. Additionally, a horizontal capillary tube is attached to the cap at a different location. The connection to the reservoir is closed off, and the absorption is determined by monitoring the movement of the water line's end in the capillary tube over a specific duration of time [43].

Discussion

The experiments detailed in this paper have revealed that geopolymer concrete shows great potential as a substitute for conventional Portland cement concrete, offering numerous benefits in terms of strength, durability, and sustainability. The research has demonstrated that the mechanical properties of geopolymer concrete, particularly its compressive strength, can be improved by incorporating mineral admixtures like fly ash, GGBFS, metakaolin, and micro silica as partial replacements for cement. The ideal replacement ratios for these mineral admixtures vary depending on the specific type of admixture used and the conditions under which the concrete is cured.

The chemical compositions utilized in the production of GPCC, like sodium silicate and sodium hydroxide, play a crucial role in determining its mechanical properties & durability. The concentration of the solution and the molar ratio of SiO_2/Na_2O are key factors that greatly impact the strength & lifespan of Geopolymer concrete. The strength of the Geopolymer concrete can be increased but its durability could be decreased by a high molar ratio of SiO_2/Na_2O. On the other hand, a low molar SiO_2/Na_2O ratio can increase the strength of the GPCC while decreasing its durability.

Since it has been discovered that geopolymer concrete has good resistance to acid, sulfate, and chloride attacks, it can be used in difficult situations. By incorporating fibers or nanoparticles, such as carbon fibers or silica nanoparticles, into the mixture, geopolymer concrete's endurance can be increased even further. More study is required to best utilize these additives because their impact on the mechanical characteristics of GPCC is still being researched.

Finally, there is currently a limited amount of practical application for Geopolymer Concrete, & further study is required to see how it will hold up over time in various environmental settings. It will be crucial to increase the acceptance of Geopolymer Concrete in the Construction Industry through the optimization of the Geopolymer Concrete Mix Design as well as the establishment of Standards and Guidelines for its Production and Use. As an alternative to standard Portland cement concrete, geopolymer concrete has a lot of potential, and there are ways to enhance its qualities by using chemical and mineral binders. To maximize its functionality and investigate its potential for useful applications, more study is required.

Conclusion

The analysis of geopolymer concrete has concluded that it is a promising substitute for conventional Portland cement concrete. It has been shown that using chemical and mineral binders as admixtures can increase the strength, resilience, & sustainability of geopolymer concrete. To improve the mix design, evaluate the long-term performance of Geopolymer concrete, and define market guidelines for its manufacturing and use, more study is necessary. Geopolymer concrete has the capacity to transform the construction industry by offering a durable, eco-friendly, and sustainable option in place of traditional concrete. When taking everything into account, this innovative material has the potential to revolutionize the way buildings are constructed, ensuring long-lasting and environmentally conscious structures for the future.

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