Experimental Study on Environmental Friendly Wall Panels for Structural and Non- Structural Use

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Abstract—**The pursuit of sustainable construction materials has intensified the search for alternatives to Ordinary Portland Cement (OPC), a major contributor to global carbon emissions. Geopolymer concrete, derived from industrial by- products such as fly ash and activated with alkaline solutions, has emerged as an eco-friendly and high-performance substitute for conventional cement. This study focuses on developing and evaluating geopolymer-based wall panels for structural and non-structural applications. An optimized geopolymer mix was formulated and compared with traditional OPC concrete through laboratory tests conducted in accordance with IS and ASTM standards. The experimental investigations included compressive and flexural strength, water absorption, dimensional accuracy, and full-scale wall performance under axial and diagonal loading. The results revealed that geopolymer blocks and panels exhibited superior strength, reduced water absorption, and improved dimensional stability. Overall, the study confirms geopolymer concrete as a sustainable, durable, and technically viable alternative for wall panel construction, promoting environmentally responsible and energy-efficient building practices.**

Index Terms—**Geopolymer concrete, Fly ash, Sustainable construction, Wall panels, Compressive strength, Durability, Ordinary Portland Cement (OPC) alternative, Eco-friendly materials**

I. INTRODUCTION

Previous studies have shown that fly ash can partially replace cement in concrete mixtures, typically between 15–25% by weight, depending on material properties and application requirements. Higher replacement levels, up to 60%, have been effectively used in structural applications, improving durability and mechanical strength. However, excessive fly ash content may slow setting times and early strength development, potentially affecting construction progress.

Ordinary Portland Cement (OPC) remains the most widely used construction material but poses serious environmental and durability challenges. Its production results in high CO_2 emissions, consumes large quantities of natural resources, and contributes to long-term performance issues, emphasizing the need for sustainable alternative binders.

Portland cement concrete typically contains a small percentage of OPC by mass, yet its production emits nearly one ton of CO_2 per ton of cement produced. Additionally, OPC concretes suffer from durability problems such as sulphate attack, corrosion, and poor fire resistance, leading to high maintenance and repair costs in infrastructure projects.

To overcome the limitations of OPC, researchers are developing alkaline-activated cements (AACs), which use aluminosilicate-rich industrial by-products like fly ash or slag. These binders, activated by alkaline solutions, form durable gels that can fully replace cement clinker, offering a low-carbon, sustainable alternative for concrete production.

AACs provide superior early strength, chemical resistance, and excellent fire performance compared to OPC. Unlike conventional concrete, which loses strength above 600 °C, AACs maintain structural integrity at elevated temperatures, showing minimal shrinkage and dimensional change even up to 800 °C.

Fly ash-based AACs activated with sodium hydroxide and sodium silicate-common activators in geopolymer systems-exhibit remarkable thermal stability, retaining strength beyond 600 °C. This contrasts with OPC concrete, which rapidly deteriorates under similar conditions.

The present study evaluates the thermal performance of alkaline-activated concretes made from Colombian fly ash combined with ground granulated blast furnace slag (GBFS) or OPC. The mixtures were tested across temperatures up to 1100 °C and compared with traditional OPC concretes to assess strength and stability under high thermal exposure.

A. Objectives

The important goals of this experimental study are,

1. Develop optimal mix proportions for geopolymer- based wall panels.
2. Analyse the mechanical performance of wall panels for compression and Diagonal Test.
3. To compare the result of Optimum mix wall panels with control wall panels

II. LITERATURE REVIEW

As mentioned earlier, masonry structures are among the oldest and most commonly used systems for load-bearing applications in low- and medium-rise buildings. To address these challenges and enhance the resilience of masonry construction, researchers have explored the use of alternative materials such as geopolymer concrete. Geopolymer-based masonry units, produced from industrial by-products like fly ash and activated using alkaline solutions, offer superior mechanical strength, improved bonding characteristics, and enhanced energy absorption capacity. These properties contribute to better performance under seismic loading, reducing the likelihood of sudden brittle failure.

Meng Zhao et al. (2024) investigated the axial performance of precast geopolymer concrete sandwich panels (PGCSP) reinforced with GFRP hexagonal tube connectors. The study examined six panel specimens to evaluate the influence of panel height, concrete thickness, and connector spacing on structural behavior, including failure mechanisms, load–deflection response, and axial load capacity. The experimental findings indicated that panels primarily failed due to eccentric compression, with concrete crushing and horizontal cracking amplified by second-order effects. Reduced connector spacing decreased lateral deformation but expanded the crushing zone, whereas shorter panels and thicker concrete wythes enhanced axial capacity. Complementary 2D finite element modeling and a modified GB50010-2010 formula successfully predicted panel behavior, highlighting the critical role of design parameters in optimizing PGCSP performance.

Syafiadi Rizki Abdila et al. (2024) highlighted the potential of geopolymers, or alkali-activated binders, as sustainable alternatives to conventional cement in paving block production. Utilizing silica- and alumina-rich materials such as fly ash and ground granulated blast furnace slag (GGBS), geopolymers minimize waste and reduce CO_2 emissions. The polymerization process, activated by alkaline solutions like Na_2SiO_3 and NaOH, enhances the mechanical and physical properties of paving blocks. Both ambient and oven curing methods were effective, and tests on water absorption and unconfined compressive strength confirmed the viability of fly ash– and GGBS-based geopolymers as binder materials.

Saloma et al. (2023) examined the performance of reinforced geopolymer concrete (GC) wall panels under cyclic lateral loading, addressing the limited research on GC walls compared to beams, columns, and slabs. Using numerical analysis validated against aerated concrete wall models, three configurations were studied: a fully solid wall and two with horizontal and vertical square openings. Results showed that the fully solid GC wall achieved the highest lateral load capacity and superior ductility. The study demonstrates that geopolymer concrete can provide structurally reliable, environmentally sustainable wall panels with enhanced resistance to cyclic lateral forces.

Adrian-Victor Lazarescu et al. (2023) emphasized the role of circular economy and sustainable development in promoting resource efficiency through recycling and the use of industrial by-products in construction. Rapid urbanization has increased solid waste, highlighting the need for low-carbon, resilient building materials. The study focused on fly ash–based geopolymer paving blocks produced with locally available Romanian raw materials. Key factors affecting mechanical performance were evaluated, demonstrating that alkali-activated geopolymers can serve as sustainable substitutes for conventional cement while supporting environmental conservation and compliance with relevant construction standards.

Ming Feng et.al (2022) This work investigates the influence of the silica-to-sodium (SS) modulus and

Na_2O concentration on the fresh behavior and microstructural development of high-uranyl geopolymer (HUGG) paste made from ultrafine desulfurized slag (UDS) and ground granulated blast-furnace slag (GGBS). To mitigate drying shrinkage, basalt fibers (BF) and polypropylene fibers (PPF) were added to the most optimized mixture. The study also emphasizes the practical difficulties of utilizing UDS in geopolymer systems, as its extremely fine size, smooth surface texture, and strong shrinkage tendency create challenges in terms of workability and processing.

III. MATERIALS & EXPERIMENTAL METHODS

A. Materials

The following sections present the materials utilized in this project.

1) Cement

Cement is a fine powder often made from heated limestone and clay. This fine powder serves as a binding agent in constructions. The cement used is Ordinary Portland Cement (OPC 53).

2) Fine Aggregate

Fine aggregates are small particles, usually sand or crushed stone. They have a particle size less than 4.75mm. The fine aggregates used is M-sand, produced by crushing hard rocks like granite. It is a sustainable alternative to river sand, offering consistent quality and better workability when used in concrete.

3) Fly Ash

In this study, approximately 50% of the cement was replaced with fly ash, an industrial by- product obtained from thermal power plants. The fly ash used was collected directly from the plant, which typically generates three types of ash: fly ash, bottom ash, and pond ash. Fly ash is captured from flue gases using mechanical or electrostatic precipitators, making it a readily available and sustainable material for partial cement replacement in concrete. Incorporating fly ash not only reduces the consumption of conventional cement but also contributes to waste valorization and environmental sustainability in construction.

4) Coarse Aggregate

Coarse aggregate is a primary granular component in concrete, typically constituting 60– 80% of its total volume. It is commonly sourced from recycled concrete, crushed stone, or gravel. The quality and durability of coarse aggregate play a crucial role in determining the mechanical performance and workability of concrete. According to standard sieve analysis, particles larger than 4.75 mm are classified as coarse aggregates. Ensuring proper selection and grading of coarse aggregate is essential for achieving the desired strength, stability, and durability in concrete structures.

Experimental methods

The standard tests done on each material and test specimens are detailed in the subsequent sections,

1) *Specific Gravity*

Specific gravity refers to the ratio of weight of a material to the weight of an equivalent volume of water. It is a dimensionless quantity. It helps in assessing the quality of materials.

2) *Sieve Analysis of Fine aggregate*

Sieve analysis of fine aggregate, also known as gradation testing, determines the particle size distribution within a sample by passing it through a series of sieves with progressively smaller openings and measuring the weight of the aggregate that remains on each sieve.

3) *Consistency test for Cement*

Consistency refers to the degree of fluidity or stiffness of the cement paste, which is the combination of cement and water. The standard consistency test helps to find out the quantity of water needed to achieve a paste of a specific consistency, which is essential for consistent and predictable results in subsequent tests on cement.

4) *Fineness test of Cement*

Cement fineness is a measure of how fine the cement particles are, essentially the particle size and the specific surface area, which significantly impacts hydration rate, strength development, and heat generation.

5) *Setting time of Cement*

The setting time of cement is the interval needed for a cement paste to harden once water is added. It is categorized into two stages: initial and final setting. The initial setting time indicates when the paste begins to lose its plastic nature, while the final setting time represents the stage at which the paste has fully lost plasticity and attained sufficient hardness.

6) *Compressive strength of Blocks*

Compressive strength, also known as crushing strength, is the property of a brick that represents the amount of load it can resist per unit area before breaking or deforming.

7) Water absorption test on Blocks

Water absorption capacity of bricks refers to the quantity of water a brick can absorb when soaked in water for 24 hours. It is a vital property of bricks, indicating their porosity and ability to withstand moisture.

8) Compressive strength test of cement mortar cube Compressive strength in cement refers to its ability to withstand pressure or compressive loads without fracturing.

9) Compressive strength test of masonry prisms A masonry prism is a small representative assembly of brick units bonded with cement mortar, used to measure the compressive strength of masonry. The prism is constructed to show the behaviour of actual masonry construction, assuring that the test results are reflective of in- situ conditions.

10) Prism Test on Blocks

Prism test on blocks refers to a method for evaluating the shear strength of masonry bed joints, particularly when strong units are combined with weak mortar joints, using a constraint system to create a shear box. The test is necessary to understand the structural integrity of masonry walls under shear loading, which is crucial for seismic design and overall durability assessments.

B. Preparation of test specimens

In this section, preparation of test specimens required for conducting the experiment are detailed,

1) Masonry prism

The masonry prisms are constructed by placing the masonry units in a stretcher bond pattern ensuring the mortar joints are of uniform thickness. The masonry prisms constructed are of size 215mm X 102.5mm X 415mm as shown in Fig.1.

As per IS specifications, the aspect ratio must be between 2 and 5. For brickwork prisms with an aspect ratio below 5, the compressive strength obtained from tests should be corrected by applying the appropriate correction factors.

Here the aspect ratio is 4.05, hence the correction factor is given by 0.9525. These specimens are kept for curing for a period of 28 days before the test is conducted.

2) Triplet specimen

The triplet specimens are constructed using three units of bricks bonded together with two mortar joints as shown in Fig.2. And the capping is provided with rich cement mortar on bottom of the outer bricks and on top of the middle brick. Then the specimens are tested after 28 days of curing period.

3) Masonry wallets

In this project, For assessing the structural performance of masonry panels, wallet specimens were prepared using geopolymer blocks. The wallets were constructed in stack-bond fashion, with the blocks laid one over the other and bonded using cement–sand mortar in the ratio of 1:3. A uniform mortar thickness of 10 mm was maintained between successive courses. Each wallet consisted of four courses of blocks, resulting in an overall panel size of 1000 mm × 1000 mm × 1000 mm. After casting, the specimens were cured for a period of 28 days to ensure adequate strength development. Upon completion of curing, the wallets were subjected to testing to evaluate their compressive strength and overall load-bearing behavior.

IV. EXPERIMENTAL RESULTS

The experimental results obtained after testing the materials used and the test specimens required for the experiment are presented in the subsequent sections,

A. Tests on cement

The basic test results obtained on carrying out the tests on Ordinary Portland Cement of grade OPC 53 are tabulated in Table 1.

B. Tests on cement mortar

The compressive strength of cement mortar cube of size 70.6mm having 1:6 cement to sand ratio is performed using compression testing machine. The mean strength of cement mortar cube after 28 days of curing period obtained is 15.42N/mm^2.

The other test conducted on cement mortar is flow table test, to identify the appropriate water content. The appropriate water content is determined by knowing the percentage of flow of cement mortar which should be between 110 to 115, as specified in the code IS: 2250-1981 to accomplish the necessary consistency and workability of cement mortar. From the test results it is found that, the water to cement ratio of 1.0 is required to achieve the consistency and workability of cement mortar and the same is used for the construction of masonry wallets.

C. Tests on fine aggregate

The tests done on fine aggregate are specific gravity and gradation test. From the gradation analysis, the fine aggregate used for the experiment falls within the Grading Zone II and the fineness modulus obtained for fine aggregate is 2.64. From the fineness modulus result of the M-Sand it is categorized as medium sand. The Specific gravity of M-Sand used in the cement mortar is obtained as 2.51

D. Tests on blocks

The mean value of compressive strength measured for the bricks is 5.194 N/mm^2.

The water absorption capacity of bricks obtained after soaking it for 24 hours in cold water is 11.314%. The measured water absorption percentage is below 20% which is as specified in the standard code for this class of bricks.

The other test done on brick units is the flexural strength test. In this test, the flexural strength of brick unit placed both in flat-wise orientation (taking depth as 75 mm) and side-wise orientation (taking depth as 102.5 mm) is

determined. From the results it is observed that, the bricks loaded flat-wise (0.884 N/mm^2) shown greater flexural strength than the bricks loaded side-wise (0.466 N/mm^2).

E. Compressive strength test on masonry prisms Prism compressive strength is a combined effect of masonry unit and mortar.

The mean compressive strength obtained on applying the correction factor is 1.88 N/mm^2. The failed specimens are shown in Fig.7.

Fig.7 Crushing & Splitting mode of failure of masonry prism specimens

F. Triplet shear test

The shear bond strength obtained from the triplet shear test is 0.195 N/mm^2. These specimens failed in shear in the unit/mortar bond area on one face as shown in Fig.8.

Fig.8 Failure mode of triplet specimen

g) Test on masonry wallets

This study investigates the structural performance of both geopolymer concrete walls and conventional (Portland cement-based) concrete walls under two loading conditions: axial compression and diagonal (shear) compression. Axial-compression tests were conducted to evaluate the vertical load-bearing capacity and stiffness of the wall specimens. Diagonal compression tests, commonly known as shear strength tests, were performed following ASTM E519 to assess the in-plane shear behaviour and failure patterns. The experimental results, including ultimate load capacity, deformation characteristics, and failure modes, were analysed and compared between the two types of concrete walls.

- *Compression Test on Masonry Wall*

The test specimen includes a geopolymer concrete block masonry wall and conventional (normal) concrete wall of dimension 910 mm (length), 810 mm (height), and 150 mm (width), and the steel plate which is provided where the load is applied. The wall is constructed on the 75 mm thick concrete base. The wall is constructed in such a way that it is resting vertically without any eccentricity, thereby ensuring uniform axial load transfer. At the loading face of the wall, a steel plate equal in area to the cross-section of the wall is fitted to ensure uniform load distribution.

For both geopolymer concrete block wall (GCBW) and normal concrete block wall (NCBW), axial load applied on the top surface using a screw jack of 350 kN capacity. Prior to loading, specimens were properly centred and aligned to avoid eccentricity and tilting. A typical setup is shown in Ch. 4. The Ultimate Load (Pu) at failure was directly recorded during testing. The compressive stress (σc) was determined as:

Fig.9 Failure pattern of Compression Test

- *Diagonal Compression Test on Masonry Wall*

The diagonal compression test is performed to evaluate the shear strength and diagonal tensile resistance of masonry wall panels, as recommended by ASTM E519. In this test, a square masonry panel specimen is subjected to a compressive load applied along one of its diagonals, which induces a state of uniform shear stress within the specimen.

For both geopolymer concrete block wall (GCBW) and normal concrete block wall (NCBW), diagonal compression tests were conducted on square wall panels placed with one diagonal in the vertical position. The axial load was applied along this diagonal using a 350 kN screw jack, and the ultimate load at failure (P) was directly recorded. Steel plates were provided at the loaded corners to ensure uniform load transfer, and specimens were properly aligned to avoid eccentricity and tilting.

Fig.10 Failure pattern of Diagonal Compression Test

V. CONCLUSIONS

1. The average compressive strength of Geopolymer blocks which is 10.76 MPa is found better than the compressive strength of conventional blocks which is 6.65 MPa.
2. The average water absorption of geopolymer blocks is found to be 7.79% and that of the conventional block is 10.91%. Geopolymer blocks absorb less amount of water compared to conventional blocks.
3. The dimensional test is conducted on geopolymer blocks and conventional blocks. The dimensional errors are found to be relatively small in geopolymer blocks.
4. The flexural test shows that the blocks can withstand moderate bending forces, with flexural strengths ranging from 3.663 MPa to 4.385 MPa**,** the highest being for the block loaded at 150 kN**.**
5. The compressive-strength of the geopolymer block masonry prisms is found to be 2.43 MPa and that of the conventional block masonry prisms is found to be 2.46 MPa. Here the results of both geopolymer blocks and conventional blocks are more or less the same.
6. The axial compression test shows that geopolymer concrete block walls exhibit slightly higher average ultimate load (284.66 kN) compared to normal concrete block walls (281.33 kN**).** This indicates that geopolymer blocks provide comparable or marginally improved compressive performance, making them a viable alternative to conventional blocks for structural applications.
7. The diagonal compression test indicates that geopolymer concrete block walls have a higher average ultimate load (89.33 kN) compared to normal block walls (80.66 kN). This demonstrates that geopolymer blocks offer better resistance to shear stresses and improved overall stability over conventional blocks.

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