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Performance Evaluation Of Geopolymer Concrete Slabs: A Comparative Study With Opc Concrete

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Abstract— This study presents a comprehensive investigation into geopolymer concrete (GPC), an innovative and sustainable alternative to conventional Portland cement concrete. Driven by the need to reduce carbon emissions and utilize industrial by-products, geopolymer concrete offers a promising solution by employing aluminosilicate-rich materials such as fly ash, ground granulated blast furnace slag (GGBS), and metakaolin, activated with alkaline solutions. This research critically reviews the material composition, chemical reactions, mechanical properties, durability, and environmental benefits of geopolymer concrete in comparison to traditional concrete. Experimental results and literature findings highlight GPC's superior resistance to chemical attack, high early strength, and excellent thermal stability. Additionally, its significantly lower carbon footprint underscores its potential role in sustainable construction practices. The study also explores challenges related to mix design standardization, curing methods, and large-scale implementation. Overall, this work provides a solid foundation for understanding the current advancements, limitations, and future prospects of geopolymer concrete, aiming to guide researchers, engineers, and policymakers in adopting greener construction technologies. The performance of the geopolymer slab is compared with that of traditional ordinary Portland cement (OPC) concrete, highlighting its potential for reduced environmental impact and improved long-term performance. The findings emphasize the viability of geopolymer concrete as a sustainable alternative for structural elements such as slabs and offer guidance for further development and application in the construction industry.

Index terms - Geopolymer concrete, Fly ash, GGBS, Alkaline activators, Concrete slab, Mix design, Heat curing, Mechanical properties, Durability, Microstructural analysis, Sustainable construction.

I. INTRODUCTION

This study presents a comprehensive investigation into geopolymer concrete (GPC), an innovative and sustainable alternative to conventional Portland cement concrete. Driven by the need to reduce carbon emissions and utilize industrial by-products, geopolymer concrete offers a promising solution by employing aluminosilicate-rich materials such as fly ash, ground granulated blast furnace slag (GGBS), and metakaolin, activated with alkaline solutions. This research critically reviews the material composition, chemical reactions, mechanical properties, durability, and environmental benefits of geopolymer concrete in comparison to traditional concrete. Experimental results and literature findings highlight GPC's superior resistance to chemical attack, high early strength, and excellent thermal stability. Additionally, its significantly lower carbon footprint underscores its potential role in sustainable construction practices. The study also explores challenges related to mix design standardization, curing methods, and large-scale implementation. Overall, this work provides a solid foundation for understanding the current advancements, limitations, and future prospects of geopolymer concrete, aiming to guide researchers, engineers, and policymakers in adopting greener construction technologies.

While numerous studies have investigated the properties of GPC in general, most focus on small-scale specimens or standard cubes and cylinders. However, for practical applications and field implementations, it is essential to understand how geopolymer concrete performs in real-world structural elements such as slabs, beams, and columns. Slabs, in particular, are fundamental components in both residential and commercial buildings and are frequently subjected to bending, impact, and environmental exposure. Therefore, assessing the structural behavior, mechanical performance, and durability of geopolymer slabs is critical for advancing its adoption in the construction industry.

This review focuses on a geopolymer concrete slab, analyzing its material composition, mechanical behaviour under flexural and compressive loading, durability, and sustainability credentials. The paper also discusses the practical aspects of mix design, casting, and curing, along with potential challenges in large-scale deployment. The overall aim is to bridge the knowledge gap between laboratory-scale research and field-level application of GPC slabs, thereby contributing to the broader goal of environmentally responsible and high- performance construction.

II. LITERATURE REVIEW

Over the past two decades, extensive research has been conducted on the development and performance of geopolymer concrete (GPC), especially in terms of its low-carbon construction materials has accelerated interest in geopolymer technology due to its ability to utilize industrial waste products and significantly reduce CO_2 emissions compared to Ordinary Portland Cement (OPC) concrete.

Hardjito and Rangan [6] laid the foundation for fly ash- based geopolymer concrete development by evaluating its mechanical performance under various curing regimes. Their work emphasized the significance of curing temperature and duration on strength gain, concluding that elevated temperature curing (60–90°C) for 24 hours substantially enhanced early compressive strength.

Davidovits [3], who originally coined the term “geopolymer,” highlighted the environmental advantages of alkali-activated binders, demonstrating that geopolymer production consumes 60–80% less energy than OPC and reduces greenhouse gas emissions by up to 90%. The environmental aspect is crucial for the construction industry, which is under pressure to meet global sustainability goals.

Nath and Sarker [10] investigated the ambient curing feasibility of fly ash and GGBS-based geopolymer concrete. Their results showed that partial replacement of fly ash with GGBS improved early strength development and eliminated the need for thermal curing—an essential step for field applications. This finding is especially relevant for slab construction where on-site curing constraints exist.

In terms of mechanical properties, Sarker et al. [10] conducted flexural strength tests on reinforced GPC beams and reported comparable, if not superior, performance to OPC concrete. This suggests potential for structural members such as slabs, especially in terms of load-bearing capacity and ductility under flexural stresses.

Several researchers have examined the mix design of GPC. Rangan [13] proposed a mix design procedure considering factors such as molarity of NaOH, activator-to-binder ratio, and the water-to-solids ratio, which significantly influence workability and strength development. However, there is no universally accepted standard for geopolymer mix design, leading to inconsistencies in performance across studies.

Despite promising results in lab-scale specimens, limited research focuses specifically on geopolymer slabs with practical dimensions. Studies on slab elements often highlight challenges in casting, uniform curing, shrinkage behaviour, and scale-up of laboratory formulations for structural applications.

Overall, the literature reveals that while GPC has proven to be a sustainable and technically sound alternative to OPC concrete, further research is needed on its application in real- size structural elements. Understanding the structural response of geopolymer slabs under realistic loading and environmental conditions remains a key area for future investigation.

III. BINDER CHEMISTRY AND MATERIAL SOURCES

The chemical reaction in GPC is markedly different from the hydration reaction in OPC. In OPC, calcium silicates hydrate to form calcium silicate hydrate (C- S-H) gel and calcium hydroxide. In contrast, GPC formation involves polymerization of aluminosilicate precursors into three-dimensional frameworks comprising Si–O–Al bonds [7].

a. Hardjito and Rangan [6] showed that class F fly ash with low calcium content is particularly effective in producing GPC with high mechanical strength. GGBS can also be used, providing calcium that may aid in ambient curing. Metakaolin, while more expensive, offers better reactivity and is suitable for high-performance applications.

b. Palomo et al. [12] examined various precursor- activator combinations and concluded that factors such as molarity of NaOH, Na_2SiO_3/NaOH ratio, and curing temperature significantly influence geopolymerization efficiency. GPC offers flexibility in material selection, promoting industrial waste reuse and reducing reliance on virgin resources.

IV. MECHANICAL PROPERTIES: STRENGTH AND STIFFNESS

i. Compressive strength is the primary parameter for evaluating concrete. Bakharev [1] demonstrated that GPC specimens achieved compressive strengths exceeding 60 MPa after thermal curing at 70°C. Chindaprasirt et al. [2] also found that the fineness of fly ash significantly affects early strength development in GPC.

ii. Tensile strength, modulus of elasticity, and flexural behavior are also critical for structural applications. Sofi et al. [18] and Ryu et al. [14] reported that GPC typically exhibits slightly lower tensile strain capacity but higher stiffness compared to OPC. Nonetheless, its mechanical reliability remains sufficient for beams, slabs, and other load-bearing elements.

iii. A significant advantage is the fast strength gain under heat curing, making GPC suitable for precast applications. However, this can also pose limitations for cast-in-place concrete, especially in colder climates where ambient temperature curing is less effective.

V. DURABILITY AND MICROSTRUCTURAL STABILITY

Durability is often more crucial than strength when evaluating long-term structural performance. Rangan [13] highlighted that GPC has excellent resistance to sulfate attack, due to the absence of calcium hydroxide, which in OPC reacts with sulfates to form expansive ettringite.

Van Jaarsveld et al. [20] found that GPC exhibits very low permeability and minimal chloride diffusion, crucial for reinforced concrete durability. Wallah and Rangan [22] observed that GPC shows significantly lower drying shrinkage and creep than OPC, contributing to dimensional stability.

GPC also shows resistance to thermal degradation and fire exposure, retaining strength up to 600°C. These features make GPC attractive for marine structures, industrial floors, and chemical containment areas.

VI. ENIVRONMENTAL IMPACT AND CARBON FOOTPRINT

The primary motivation for adopting GPC is its low carbon footprint. McLellan et al. [9] estimated that GPC can reduce greenhouse gas emissions by up to 80% compared to OPC concrete. This is primarily because fly ash and GGBS are industrial by-products that require minimal additional processing.

Habert et al. [5] and others emphasize that the actual environmental benefit depends on transportation logistics and energy source for activator production. Sodium silicate, for instance, has a notable environmental cost.

Nevertheless, if industrial waste sources are located near construction sites, GPC can be a highly sustainable alternative, helping to meet green building certification requirements like LEED and BREEAM.

VII. WORKABILITY, CURING AND FIELD APPLICATIONS

Practical application of GPC presents both advantages and challenges. While GPC does not require water curing, it often requires elevated curing temperatures for optimum performance. Ryu et al. [14] reported that 24-hour curing at 60°C resulted in early compressive strengths over 50 MPa.
Workability can be an issue due to the high viscosity of the activator solution. Zhang et al. [23] suggested that the use of superplasticizers compatible with alkali systems can mitigate these issues.
Sofi et al. [18] conducted field trials using GPC for pavement and precast panels, finding good performance but also noting the lack of established standards and on-site expertise. Ambient curing formulations using slag and admixtures offer a path toward broader application, especially in developing regions where heating may not be feasible.

VIII. CONCLUSION:

The findings are consistent with a broad body of literature demonstrating that Geopolymer Concrete (GPC) outperforms Ordinary Portland Cement (OPC) in several key areas, including strength and durability. These results underscore the potential of GPC as a more sustainable and high-performance material for structural applications, particularly where load-bearing capacity and fatigue resistance are critical. For more comprehensive research, consider further exploring reinforcement types and long-term durability under variable environmental conditions. Key research gaps include ambient- curing solutions for all climates, standardization of mix designs, and long-term performance data in varied environmental conditions. Collaboration between academia, industry, and government agencies will be crucial in transitioning GPC from a promising research material to a widely adopted solution.

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