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Experimental Studies on Strength and Permeability Characteristics of Fiber Reinforced Pervious Concrete Incorporating GGBS

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Abstract: ***Pervious concrete is increasingly recognized as a sustainable construction material for mitigating urban flooding, enhancing stormwater management, and promoting groundwater recharge. This study investigates the performance of fiber-reinforced pervious concrete (FRPC) incorporating Ground Granulated Blast Furnace Slag (GGBS) as partial cement replacement, with polypropylene fibers (0.2%) to improve mechanical properties. Experimental evaluation was conducted on mixes with varying GGBS percentages (20%, 40%, 60%) and aggregate sizes (20 mm, 13.2 mm, 10 mm). Tests included fresh properties, compressive strength, split tensile strength, flexural strength, and permeability using codal provisions (IS 516:1959; IS 5816:1999; IS 3085:1965). Results indicate that 20% GGBS replacement with 0.2% polypropylene fibers provides the optimum balance between strength and permeability, achieving compressive strength of 18.1 MPa and split tensile strength of 4.5 MPa at 28 days, while maintaining adequate permeability (5.3×10^{-3} m/s). Beyond 20% replacement, strength declined due to reduced cement content and slower hydration, while permeability decreased with higher GGBS levels owing to finer particle packing. The findings highlight the potential of FRPC with controlled GGBS incorporation to reduce cement consumption, lower embodied carbon, and support sustainable pavement applications.***

Keywords: Pervious concrete, GGBS, polypropylene fibers, permeability, sustainable construction

1. Introduction

Pervious concrete has emerged as a vital sustainable construction material due to its dual role in **stormwater management** and **groundwater recharge**, addressing pressing urban challenges such as flooding, waterlogging, and aquifer depletion (Saha & Guntakal, 2018; Wu et al., 2024). Unlike conventional concrete, which is impermeable and contributes to runoff accumulation, pervious concrete is characterized by interconnected voids (15–30%) that enable water infiltration and reduce surface discharge (Chougale et al., 2020; Bharanidharan et al., 2019).

Despite these environmental benefits, pervious concrete typically exhibits lower mechanical strength (8–20 MPa) compared to conventional concrete (20–40 MPa), limiting its application in heavy-load pavements. To overcome this limitation, researchers have explored **supplementary cementitious materials (SCMs)** such as ground granulated blast furnace slag (GGBS), which not only enhances strength but also reduces cement consumption and associated **CO_2 emissions** (Baskar & Theenathayalan, 2019; Mukesh et al., 2021; Alomayri et al., 2023). Fiber reinforcement, particularly polypropylene fibers, has further been shown to improve crack resistance and durability, thereby extending service life.

This study focuses on the experimental evaluation of **fiber-reinforced pervious concrete (FRPC)** incorporating GGBS as partial cement replacement. By systematically varying GGBS content (20%, 40%, 60%) and maintaining a constant fiber dosage (0.2%), the research aims to identify optimum mix proportions that achieve improved mechanical strength while preserving adequate permeability. The outcomes are expected to contribute to **sustainable pavement design**, reduce reliance on cement, and support cleaner production practices in the construction industry.

2. Materials and Methods

The experimental program was carried out using **Portland Pozzolana Cement (PPC)**, Ground Granulated Blast Furnace Slag (GGBS) with replacement levels of **20%, 40%, and 60%**, coarse aggregates of sizes **20 mm, 13.2 mm, and 10 mm**, polypropylene fibers at a constant dosage of **0.2%**, and potable water. The concrete mixes were designed for **M20 grade** with a water-to-cement ratio of **0.35**. A small proportion of fines (~6%) was incorporated to improve bonding between particles while maintaining permeability.

Figure 1: Polypropylene fibers

Figure 2: Aggregates of sizes 10mm, 13mm & 30mm

Test specimens including **cubes, cylinders, and beams** were cast and cured for **14 and 28 days** under controlled laboratory conditions. Fresh properties were evaluated using the **slump test, compaction factor test, and density measurements**, while mechanical properties were assessed through **compressive strength (IS 516:1959; BIS, 1959)**, **split tensile strength (IS 5816:1999; BIS, 1999)**, and **flexural strength (IS 516:1959; BIS, 1959)**. Permeability characteristics were determined using the **falling head method (IS 3085:1965; BIS, 1965)** to measure infiltration capacity.

The methodology was aligned with **Indian Standard (IS) codes** and validated against prior studies on pervious concrete incorporating GGBS and fibers, which reported similar improvements in strength and permeability performance (Mukesh et al., 2021; Saha & Guntakal, 2018).

2.1 Mix Design for M20 Grade Pervious Concrete

The mix design for M20 grade pervious concrete was developed in accordance with codal provisions such as **IS 10262 (mix design guidelines)** and **IS 456:2000 (general concrete requirements)**, with necessary modifications to account for the unique characteristics of pervious concrete. Since Indian codes do not fully cover pervious concrete, adjustments were made based on experimental studies and international guidelines, particularly **ACI 522R (American Concrete Institute recommendations)**. The design emphasized achieving the required strength, durability, and permeability while ensuring proper compaction.

The **target mean strength** was calculated as **26.6 MPa**, considering a standard deviation of 4 MPa. **Void content** was determined to be **15%**, corresponding to a percolation value of **50 mm/min**, as per **IRC 44:2017** tables. The **paste volume** was fixed at **16.8%**, accounting for the inclusion of 6% fine aggregates. Cement and water quantities were derived from the paste volume, resulting in **314.84 kg/m³ of cement** and **110.19 litres of water**. Aggregate volumes were distributed as **96.16 kg/m³ of fine aggregates** and **1461.48 kg/m³ of coarse aggregates**.

The final mix proportion for M20 grade pervious concrete was established as:
1: 0.27: 4.23 (Cement: Fine Aggregate: Coarse Aggregate) with a **water-cement ratio of 0.35**.

2.2 Slump Test Results for M20 Grade Pervious Concrete

The slump test was conducted to assess the workability of M20 grade pervious concrete mixes with varying GGBS replacement levels and a constant polypropylene fiber dosage of 0.2%.

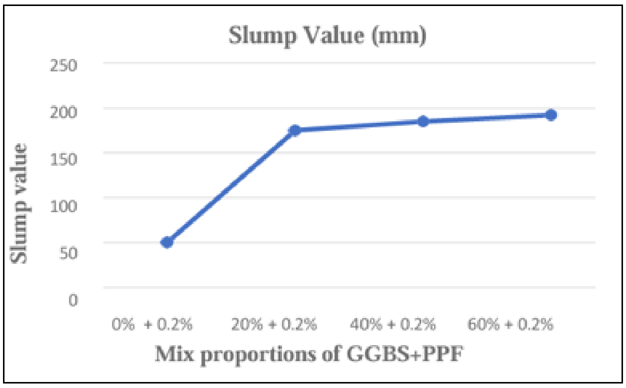

Figure 3: Slump Test Results for M20 Grade Pervious Concrete

As shown in Figure 3, the slump value increased with higher GGBS content. The mix without GGBS recorded the lowest value (50 mm), while mixes with 20%, 40%, and 60% GGBS and 0.2% PPF showed higher values of 175 mm, 185 mm, and 192 mm, respectively.

This trend indicates that GGBS improves workability by enhancing paste volume and cohesion, while fibers maintain stability of the mix. The optimum balance was observed at 40% GGBS + 0.2% PPF.

Compaction Factor Test Results for M20 Grade Pervious Concrete

The compaction factor test was conducted to assess the workability of M20 grade pervious concrete mixes containing varying percentages of Ground Granulated Blast Furnace Slag (GGBS) and a constant PPF dosage of 0.2%.

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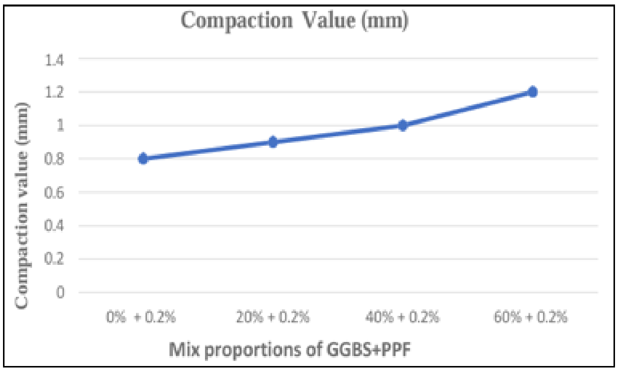

Figure 4: Compaction Factor Test Results for M20 Grade Pervious Concrete

As shown in Figure 4, the compaction factor increased with higher GGBS content. The mix without GGBS recorded the lowest value (0.8 mm), while mixes with 20%, 40%, and 60% GGBS showed values of 0.9 mm, 1.0 mm, and 1.2 mm, respectively. This trend indicates that GGBS enhances workability by improving paste cohesion and aggregate bonding, while fibers maintain mix uniformity. The optimum compaction factor was observed at 40% GGBS + 0.2% PPF, which provided adequate workability suitable for pervious concrete applications.

Compressive Strength Test

The compressive strength test was conducted to determine the load-carrying capacity of M20 grade pervious concrete. Cube specimens of size 150 mm × 150 mm × 150 mm were cast, demoulded after 24 hours, and cured in water for 14 and 28 days. Testing was performed using a Compression Testing Machine (CTM), with load applied gradually until failure, in accordance with IS 516:1959 – Methods of Tests for Strength of Concrete (BIS, 1959).

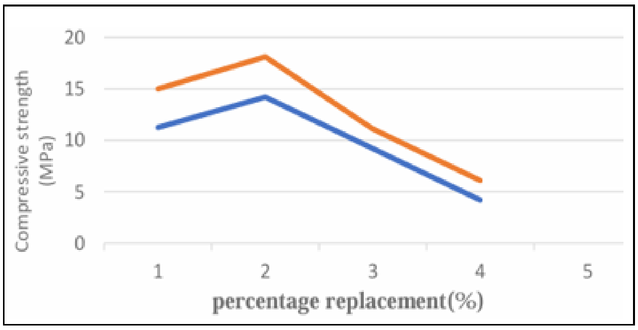

Figure 5: Compressive Strength of M20 Grade Pervious Concrete with Varying GGBS Replacement and Constant PPF (0.2%)

As shown in Figure 3, the compressive strength increased with GGBS replacement up to 20%, then decreased at higher levels. The control mix (0% GGBS + 0.2% PPF) achieved 11.25 MPa at 14 days and 15 MPa at 28 days. The mix with 20% GGBS + 0.2% PPF recorded the highest strength of 14.2 MPa (14 days) and 18.1 MPa (28 days). Beyond this, strength declined—40% GGBS yielded 9.2 MPa and 11.1 MPa, while 60% GGBS dropped to 4.2 MPa and 6.1 MPa at 14 and 28 days, respectively.

Flexural Strength Test

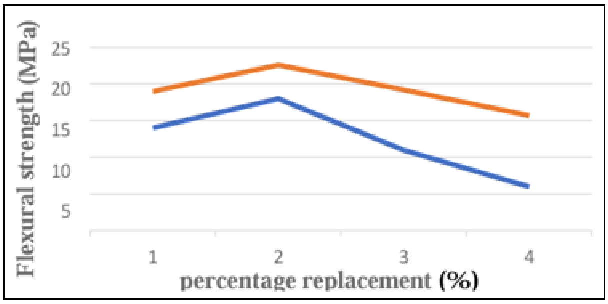

Figure 6: Flexural strength of M20 grade pervious concrete mixes with varying GGBS replacement and constant polypropylene fiber (0.2%) after 14 and 28 days curing

The flexural strength of M20 grade pervious concrete increased with GGBS replacement up to 20%, achieving 1.60 MPa at 14 days and 2.72 MPa at 28 days, which was higher than the control mix (1.65 MPa and 2.8 MPa). Beyond 20%, strength decreased, with 40% GGBS showing 0.82 MPa at 14 days and 0.95 MPa at 28 days, while 60% GGBS dropped further to 0.60 MPa and 0.72 MPa. These results confirm that 20% GGBS replacement with 0.2% polypropylene fibers provides the optimum balance of flexural strength and durability, consistent with earlier studies (Saha & Guntakal, 2018; Mukesh et al., 2021).

Split Tensile Strength Test

Cylindrical specimens of size 150 mm diameter × 300 mm height were cast, cured for 14 and 28 days, and tested in a Compression Testing Machine under split loading as per IS 5816:1999 – Splitting Tensile Strength of Concrete (BIS, 1999).

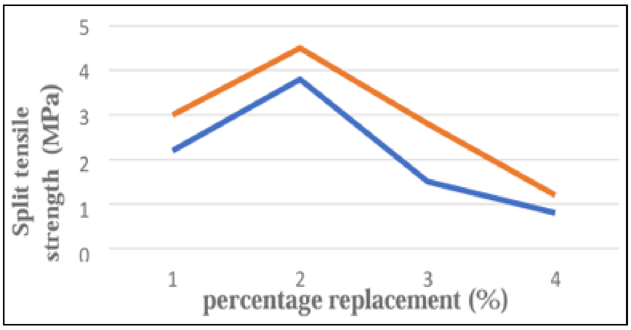

Figure 7: Split tensile strength of M20 grade pervious concrete mixes with varying GGBS replacement and constant polypropylene fiber (0.2%) after 14 and 28 days curing.

The control mix (0% GGBS + 0.2% PPF) achieved 2.2 MPa at 14 days and 3 MPa at 28 days. At 20% GGBS replacement, strength increased significantly to 3.8 MPa at 14 days and 4.5 MPa at 28 days, which was the highest among all mixes. Beyond this, strength declined: 40% GGBS showed 1.5 MPa at 14 days and 2.8 MPa at 28 days, while 60% GGBS dropped sharply to 0.8 MPa at 14 days and 1.2 MPa at 28 days.

These results confirm that 20% GGBS replacement with 0.2% polypropylene fibers provides the optimum tensile performance due to improved bonding and microstructure. At higher replacement levels, reduced cement content and slower hydration weaken tensile capacity. Similar observations have been reported in earlier studies (Saha & Guntakal, 2018; Mukesh et al., 2021).

Permeability Test (Falling Head Method)
The falling head permeability test was conducted to evaluate the drainage capacity of M20 grade pervious concrete, following **IS 3085:1965 – Method of Test for Permeability of Cement Mortar and Concrete** (BIS, 1965). The coefficient of permeability was calculated from the rate of water level drop in the standpipe.

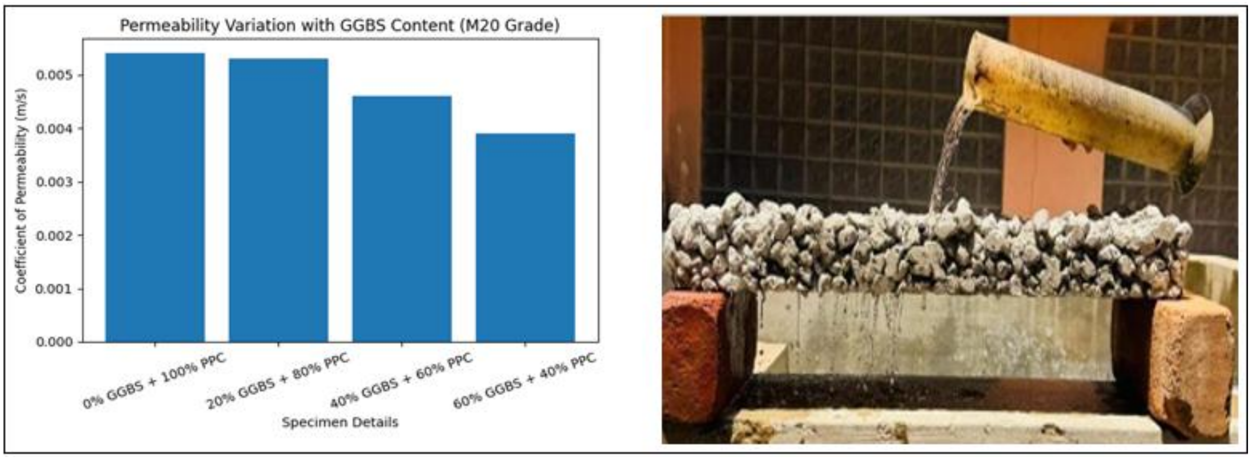

Figure 8: Permeability variation of M20 grade pervious concrete mixes with varying GGBS replacement using the falling head method

The control mix (**0% GGBS + 100% PPC**) exhibited the highest permeability of **5.4 × 10^{-3} m/s**, attributed to maximum void content. At **20% GGBS replacement**, permeability slightly decreased to **5.3 × 10^{-3} m/s**, showing minimal effect on pore structure. Further replacement reduced permeability: **40% GGBS** recorded **4.6 × 10^{-3} m/s**, while **60% GGBS** dropped to **3.9 × 10^{-3} m/s**, indicating reduced pore connectivity due to finer GGBS particles filling voids.

Overall, permeability decreased with increasing GGBS content, but all mixes maintained adequate values for drainage applications. The results suggest that **20% GGBS replacement** provides the best balance between permeability and strength in fiber-reinforced pervious concrete. This observation aligns with earlier studies that reported similar trends in pervious concrete behavior with supplementary cementitious materials (Saha & Guntakal, 2018; Mukesh et al., 2021).

3. Conclusion and Future Trends

The experimental investigation on M20 grade fiber-reinforced pervious concrete incorporating GGBS demonstrated that mechanical properties such as compressive, flexural, and split tensile strength improved up to **20% GGBS replacement**, after which strength declined due to reduced cement content and slower hydration. Permeability decreased gradually with increasing GGBS content, yet all mixes maintained adequate drainage capacity, confirming suitability for pervious concrete applications.

The identification of **20% GGBS replacement with 0.2% polypropylene fibers** as the optimum mix highlights a practical pathway for reducing cement consumption while maintaining functional performance. This directly supports cleaner production by lowering embodied carbon, conserving natural resources, and promoting sustainable pavement design. The integration of industrial by-products such as GGBS into pervious concrete aligns with circular economy principles, reducing waste while enhancing infrastructure resilience.

Future research should extend these findings through **microstructural characterization** (SEM, XRD, FTIR) to better understand hydration mechanisms, and **long-term durability studies** under aggressive environments to validate field performance (Tiwari et al., 2021; Patra & Mukherjee, 2021). In addition, **lifecycle assessments** are needed to quantify reductions in CO_2 emissions and energy consumption (Biswal & Dinakar, 2021; Mallikarjun Rao et al., 2020). Large-scale **pilot projects** will be essential to confirm scalability, while exploration of **hybrid binders** such as metakaolin or silica fume may further enhance mechanical and durability properties.

By bridging experimental performance with sustainability outcomes, this study contributes to the advancement of **low-carbon, resource-efficient construction practices**, reinforcing the role of pervious concrete as a cleaner production material for resilient urban infrastructure.

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