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Investigating Physical and Durability Properties of Pervious Concrete with Fly Ash-Based GP, PPC, and FaL-G Binders

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Abstract

Pervious concrete is gaining prominence as a sustainable pavement material due to its enhanced permeability, reduced runoff, and environmental benefits. This study evaluates the physical and durability properties of pervious concrete incorporating different binders, including Ordinary Portland Cement (OPC), Fly Ash-based Geopolymer (GP), Portland Pozzolana Cement (PPC), and Fly Ash-Lime-Gypsum (FaL-G). The key parameters assessed include permeability, porosity, dry density, salt resistance, sulfate resistance, acid resistance, water absorption, and thermal expansion. Permeability results indicate that FaL-G mixes exhibit the highest permeability (2.70 cm/sec for Fg12.5), whereas GP mixes demonstrate lower permeability, signifying a denser microstructure. Porosity analysis reveals that GP mixes have the lowest porosity (GP6.3 at 11.67%), whereas FaL-G mixes show the highest porosity (Fg12.5 at 20.97%). Dry density results confirm that GP mixes achieve the highest density (GP6.3 at 2468 kg/m³), while FaL-G mixes exhibit the lowest density (Fg12.5 at 1927 kg/m³), highlighting the influence of binder type on material compactness. Durability tests indicate that GP mixes perform best under aggressive environmental conditions, demonstrating superior salt, sulfate, and acid resistance, with the highest weight retention of 94.00% (salt resistance) and 93.71% (acid resistance). Water absorption tests show that GP mixes absorb less water, enhancing strength and longevity, whereas FaL-G mixes have higher absorption, increasing susceptibility to deterioration. Thermal expansion results indicate that FaL-G mixes undergo the highest expansion (Fg12.5 at 0.43 mm), whereas GP mixes exhibit the lowest expansion, ensuring better dimensional stability. Overall, the study confirms that geopolymer-based pervious concrete offers superior durability and reduced environmental impact, making it an ideal sustainable alternative for pavement applications.

Keywords: Ceramic tiles waste, waste fiber metal, sustainable concrete, low-cost road construction, waste material utilization

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INTRODUCTION

Pervious concrete is a sustainable construction material characterized by high porosity, allowing water to pass through its structure, thereby reducing surface runoff and promoting groundwater recharge. The incorporation of alternative binders, such as Fly Ash-based Geopolymer (GP), Portland Pozzolana Cement (PPC), and Fly Ash-Lime-Gypsum (FaL-G) in pervious concrete presents an opportunity to enhance its mechanical and durability properties while reducing its environmental impact. This study aims to evaluate the physical properties and durability aspects of pervious concrete made with these binders in comparison to conventional Ordinary Portland

Cement (OPC). Key properties assessed include permeability, porosity, dry density, salt resistance, sulfate resistance, acid resistance, water absorption, and thermal expansion [1–4].

OBJECTIVES

This study aims to evaluate the performance of pervious concrete incorporating alternative binders, such as Fly Ash-based Geopolymer (GP), Portland Pozzolana Cement (PPC), and Fly Ash-Lime-Gypsum (FaL-G) compared to conventional Ordinary Portland Cement (OPC). Key parameters analyzed include permeability, porosity, and dry density to assess structural efficiency. Additionally, durability aspects, such as resistance to salt, sulfate, and acid attacks, along with water absorption and thermal expansion, are examined. The findings aim to identify the most effective binder for enhancing the strength, durability, and sustainability of pervious concrete in pavement applications [5–7].

Material

- *Binders:* OPC, Fly Ash-based Geopolymer (GP), PPC, FaL-G.
- *Aggregates:* Coarse aggregates with varying sizes (6.3 mm, 8 mm, 10 mm, and 12.5 mm).
- *Alkaline Activators:* Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) for geopolymer concrete.
- *Water:* Potable water for mixing and curing

RESULTS AND DISCUSSION

Permeability

PPC and FaL-G-based pervious concrete exhibited the highest permeability values, whereas GP-based mixes showed relatively lower permeability due to denser matrix formation (Figure 1) [8–15].

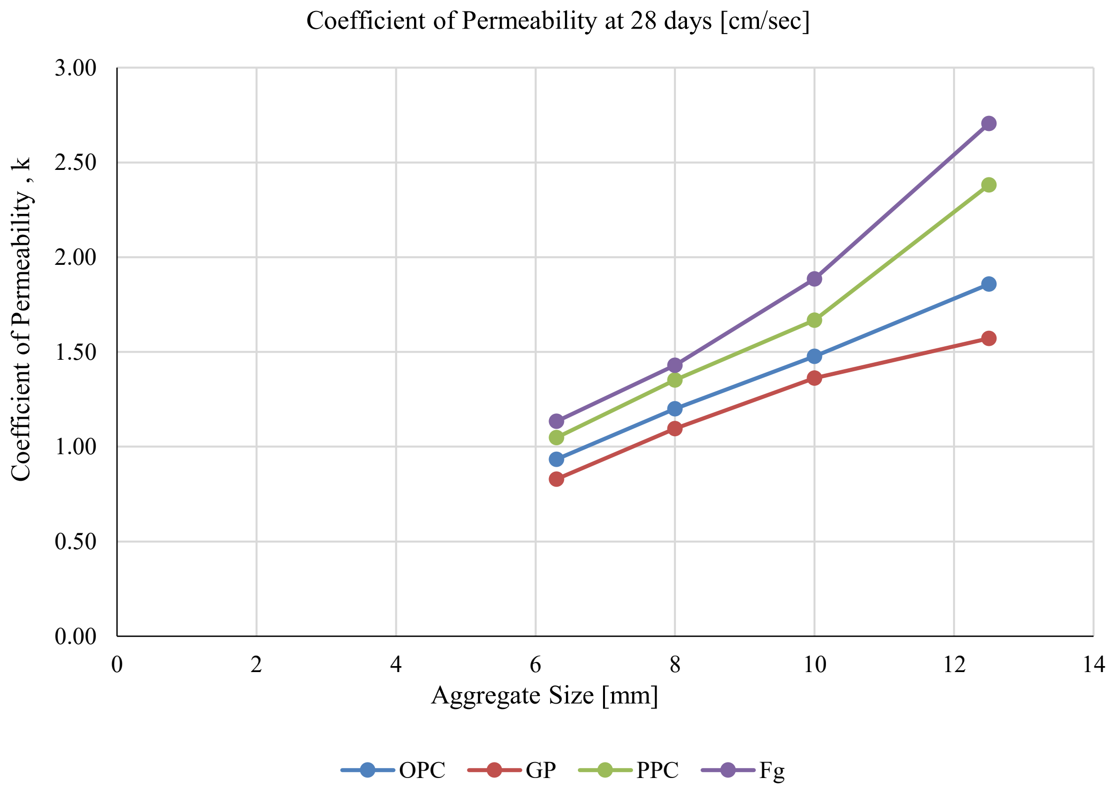

Figure 1. Permeability characteristics of pervious concrete with various binders porosity.

Porosity was highest in FaL-G-based mixes, while GP-based concrete demonstrated reduced porosity, indicating improved densification and lower void content (Figure 2).

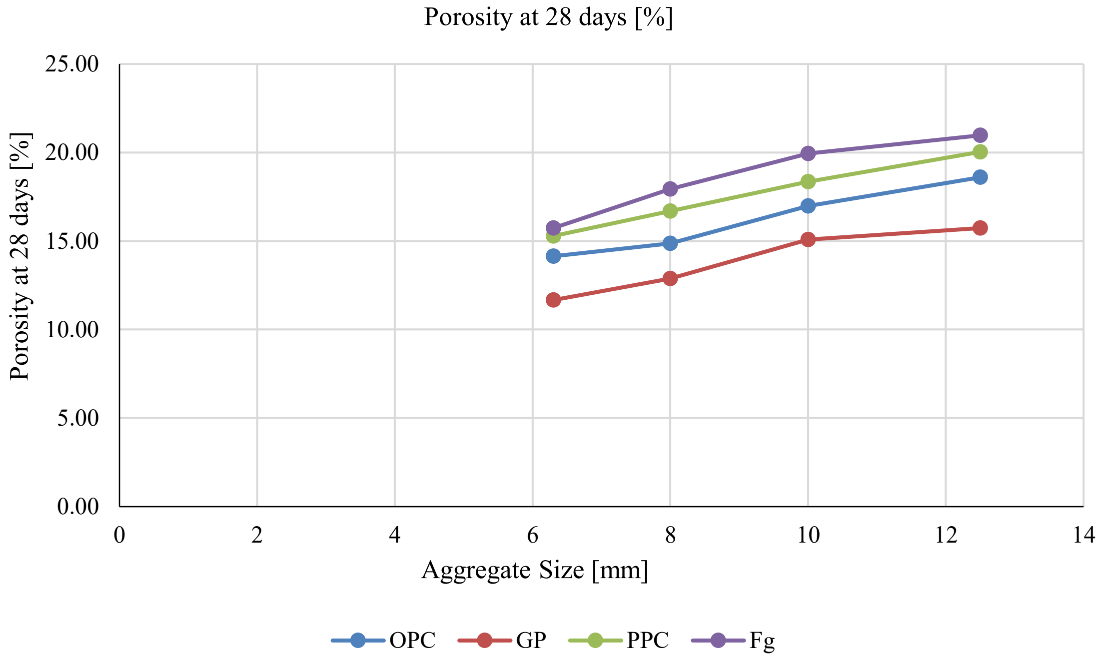

Figure 2. Porosity comparison of pervious concrete across binder types dry density.

Geopolymer concrete exhibited the highest dry density, followed by OPC, PPC, and FaL-G, confirming the impact of binder composition on concrete compactness (Figure 3).

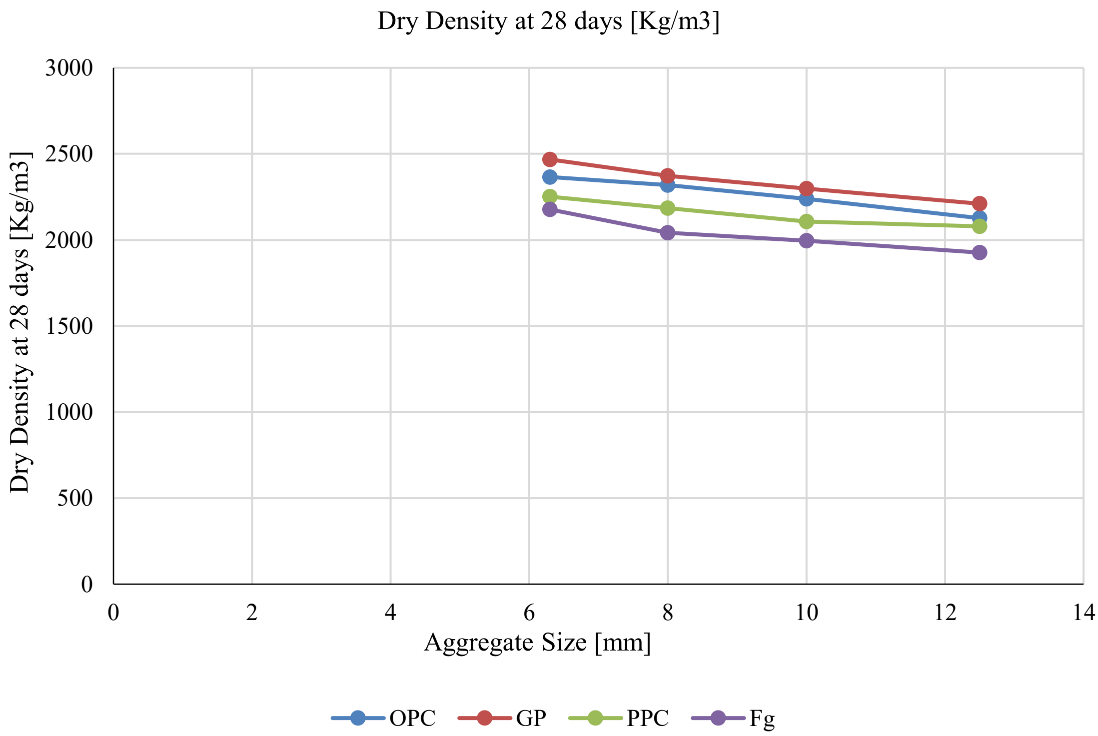

Figure 3. Variation in dry density of pervious concrete with different binders salt resistance.

All binder types showed weight retention above 91%, with GP-based mixes demonstrating the highest resistance due to enhanced microstructure stability (Figure 4) [16].

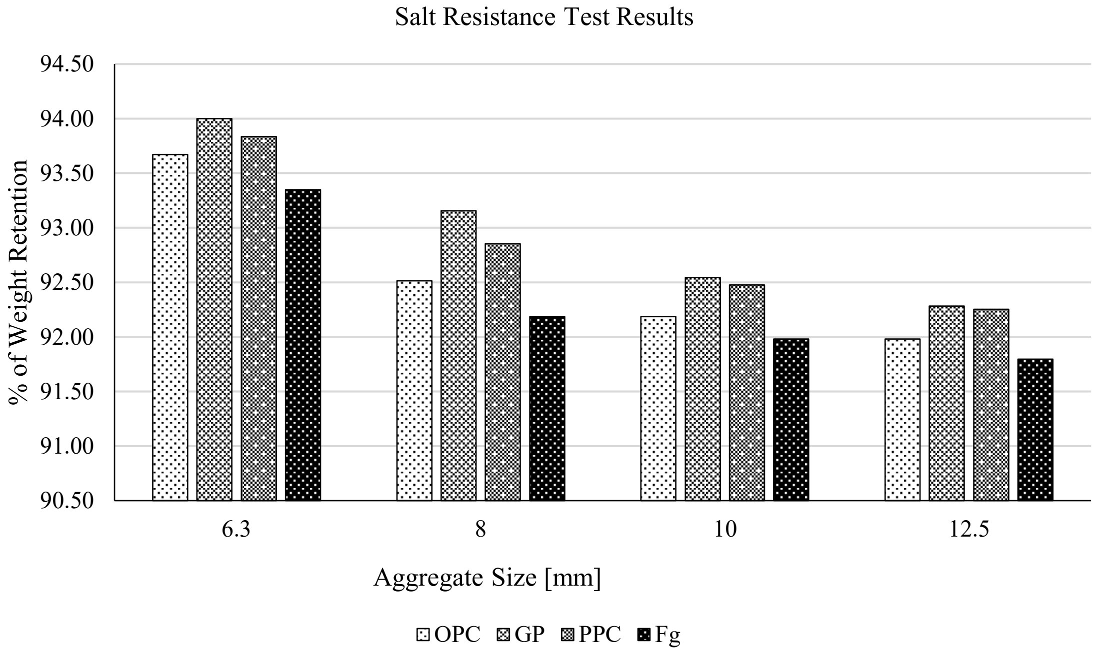

Figure 4. Weight retention percentage after 180 days of chloride exposure sulphate resistance.

PPC and GP-based mixes exhibited better sulfate resistance, attributed to their pozzolanic reactions reducing sulfate attack vulnerability (Figure 5) [17].

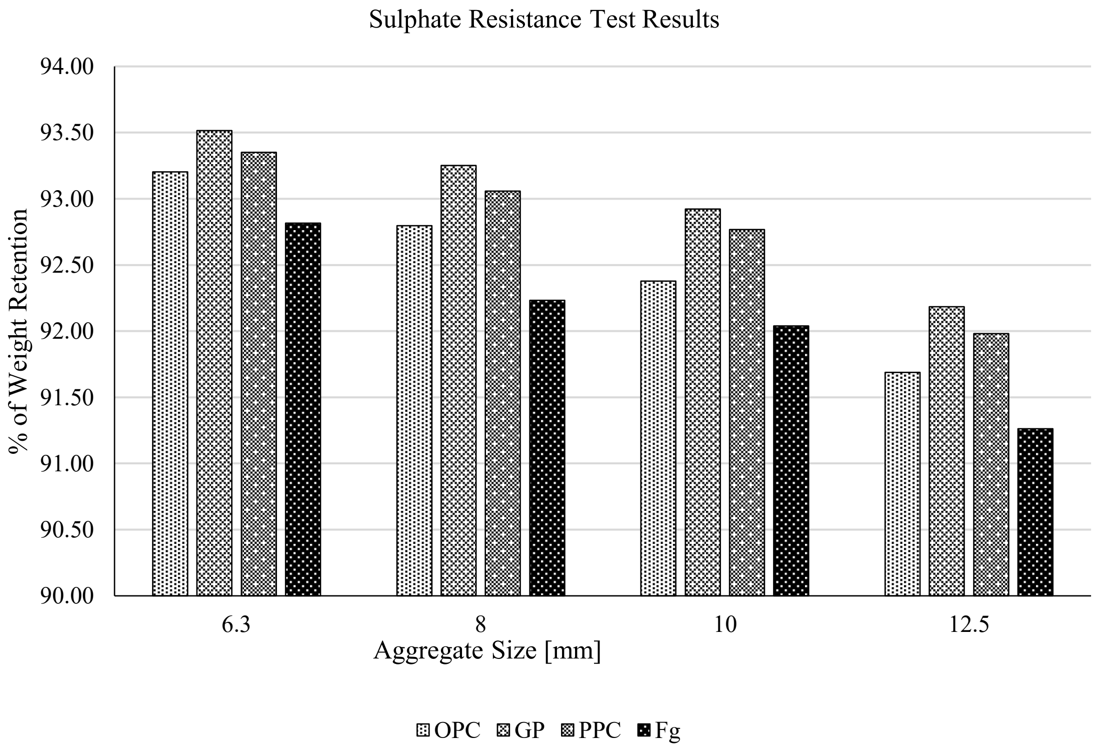

Figure 5. Weight retention percentage after 180 days of sulfate exposure acid resistance.

GP and PPC-based pervious concrete exhibited higher acid resistance than OPC and FaL-G, highlighting their durability in aggressive environments (Figure 6) [18].

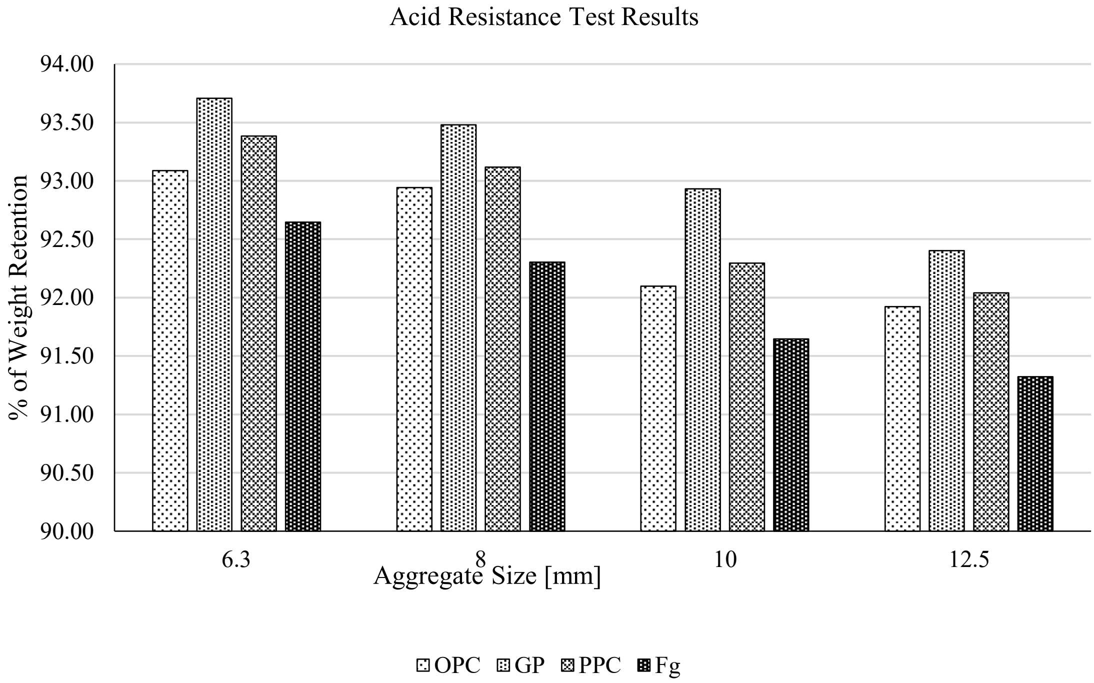

Figure 6. Weight retention percentage after 180 days of acid exposure water absorption.

GP-based mixes showed the least water absorption, indicating improved pore refinement, whereas FaL-G exhibited higher absorption due to its porous nature [19–25].

Thermal Expansion

FaL-G-based pervious concrete recorded the highest thermal expansion, whereas GP and PPC demonstrated better thermal stability, making them more suitable for varying temperature conditions (Figure 7) [26–31].

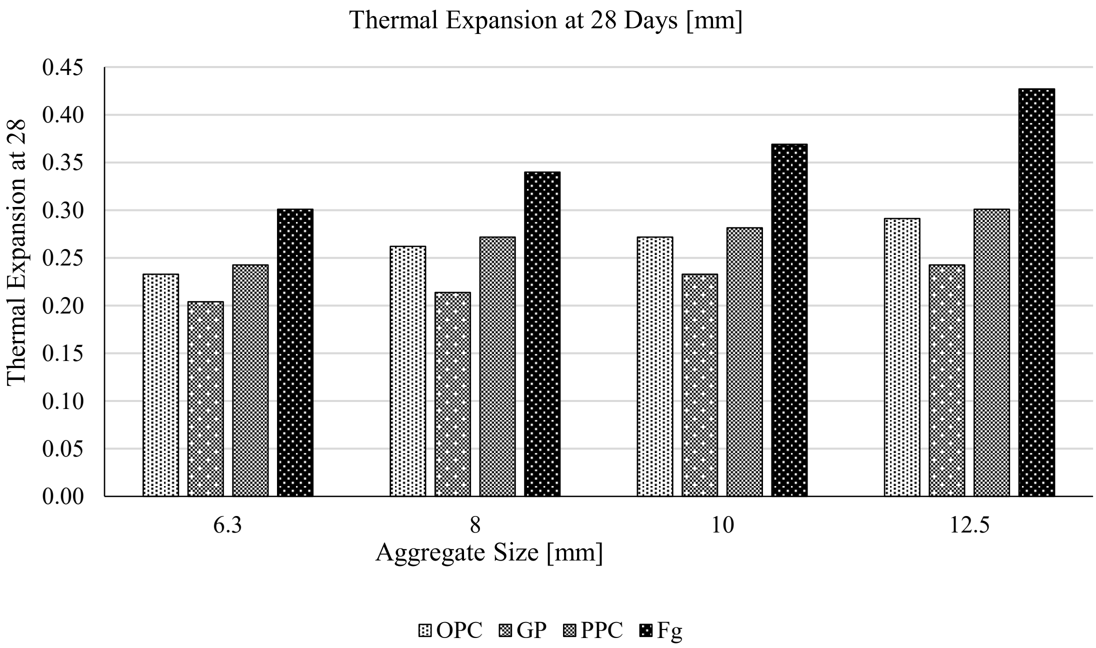

Figure 7. Thermal expansion behavior of pervious concrete with different mixes conclusions.

CONCLUSIONS

- *Permeability:* Among all binders, FaL-G (Fg) mixes exhibited the highest permeability, with Fg12.5 recording 2.70 cm/sec, followed by PPC and OPC mixes. GP mixes demonstrated the lowest permeability, indicating denser matrix formation due to geopolymerization.
- *Porosity:* GP mixes showed the lowest porosity values, with GP6.3 at 11.67%, confirming a denser structure. Fg mixes exhibited the highest porosity, with Fg12.5 reaching 20.97%, indicating a more porous nature due to the use of waste materials.
- *Dry Density:* GP mixes had the highest dry density, with GP6.3 recording 2468 kg/m³, suggesting superior packing and lower void content. Fg mixes had the lowest dry density, with Fg12.5 at 1927 kg/m³, signifying a lightweight but porous structure.
- *Salt Resistance:* GP mixes showed the highest weight retention, with GP6.3 at 94.00%, indicating superior durability in saline environments. Fg mixes had the lowest retention, with Fg12.5 at 91.80%, making them more vulnerable to salt exposure.
- *Sulfate Resistance:* GP and PPC mixes exhibited better sulfate resistance, with higher weight retention values, while Fg mixes showed lower retention, highlighting increased deterioration under sulfate attack.
- *Acid Resistance:* GP and PPC mixes retained higher weight percentages, with GP6.3 at 93.71%, demonstrating enhanced resistance. Fg mixes had the lowest weight retention, with Fg12.5 at 91.32%, making them more susceptible to acid-induced degradation.
- *Water Absorption:* GP mixes had the lowest water absorption, with GP10 absorbing 19.5% less water than OPC10, due to the denser microstructure. Fg mixes had the highest water absorption, increasing susceptibility to strength reduction and durability issues.
- *Thermal Expansion:* Fg mixes exhibited the highest thermal expansion, with Fg12.5 reaching 0.43 mm, indicating greater dimensional changes under temperature variations. GP mixes had the lowest expansion values, confirming better thermal stability.

Overall, GP mixes demonstrated superior durability, density, and resistance to environmental exposures, making them the most suitable for durable pervious concrete applications. Fg mixes, while lightweight, had higher porosity, permeability, and lower chemical resistance, limiting their performance in aggressive conditions.

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