



# A COMPARATIVE ANALYSIS OF MECHANICAL, PERFORMANCE OF GEOPOLYMER CONCRETE AND OPC CONCRETE

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## Abstract

This paper presents a comprehensive comparative study between Ordinary Portland Cement (OPC) concrete and Geopolymer Concrete (GPC) incorporating Ground Granulated Blast Furnace Slag (GGBS), Fly Ash (FA), and Metakaolin (MK). The investigation includes mechanical performance and resistance to sulfuric acid exposure. Results demonstrate that GPC, particularly the GGBS–Metakaolin blend, exhibits enhanced chemical durability, highlighting its viability as a sustainable alternative to OPC in aggressive environments.

## INTRODUCTION

Concrete is the most widely utilized construction material globally due to its versatility, durability, and structural performance. However, the primary binding material in conventional concrete—Ordinary Portland Cement (OPC)—is associated with considerable environmental concerns. OPC manufacturing accounts for nearly 8% of global carbon dioxide emissions, largely due to the calcination of limestone and high thermal energy requirements. With increasing emphasis on sustainable construction practices, researchers have explored various methods to reduce the carbon footprint of cement production.

Geopolymer Concrete (GPC) represents a promising alternative, leveraging industrial by-products rich in aluminosilicate compounds. These materials undergo alkaline activation to form polymeric Si–O–Al frameworks, producing binders with lower environmental impact. Among geopolymer precursors, Fly Ash

and GGBS have been widely studied, while Metakaolin has gained attention due to its high reactivity.

The performance characteristics of GPC differ fundamentally from OPC, especially under elevated temperatures and aggressive chemical environments. Traditional OPC experiences structural deterioration when subjected to high temperatures due to dehydration and decomposition of calcium-based hydrates. Conversely, GPC often displays enhanced thermal performance owing to its ceramic-like microstructure. Additionally, the low-calcium makeup of geopolymers makes them inherently more resistant to acid attack, whereas OPC rapidly deteriorates in acidic exposures.

This study aims to compare OPC with two GPC formulations—GGBS + Fly Ash (GPC1) and GGBS + Metakaolin (GPC2)—in terms of strength, thermal behavior, UPV response, and acid resistance. The objective is to determine whether GPC, particularly the MK-blended version, can outperform conventional OPC in durability and structural integrity.

## LITERATURE REVIEW

Several researchers have investigated the development, performance, and environmental benefits of geopolymer concrete. The geopolymerization process is influenced significantly by precursor type, alkaline activator concentration, curing regime, and binder composition. Past studies indicate that the inclusion of GGBS enhances early-age strength due to its calcium content, promoting C–A–S–H gel formation in addition to N–A–S–H gel. This dual-gel system contributes to a

denser microstructure and improved mechanical properties.

Fly Ash-based GPC often exhibits slower strength gain compared to GGBS-based systems; however, it provides long-term stability and improved workability. Meanwhile, Metakaolin, obtained by calcining kaolin clay, is recognized for its high pozzolanic reactivity and fine particle size. Its inclusion in geopolymer binders has been shown to accelerate geopolymerization, refine pore structure, and increase final strength. Studies on thermal performance reveal that GPC generally outperforms OPC at elevated temperatures. OPC undergoes decomposition of calcium hydroxide and C-S-H gel above 300°C, causing irreversible damage and strength loss. In contrast, the geopolymer matrix experiences structural densification up to moderate temperatures, sometimes resulting in increased strength. Beyond certain temperature thresholds, microcracking may occur; however, degradation remains lower than in OPC. Acid resistance is another domain where GPC significantly outperforms OPC. The calcium-rich hydrates in OPC readily react with sulfate and hydrogen ions, forming expansive by-products such as gypsum and ettringite, leading to spalling and strength loss. GPC, having minimal calcium content, exhibits relatively stable performance in sulfuric acid environments. Despite extensive research, comparative studies analyzing GGBS-FA and GGBS-MK blends under both thermal stress and acidic environments remain limited. This study aims to address these gaps.

#### **MATERIALS AND METHODS**

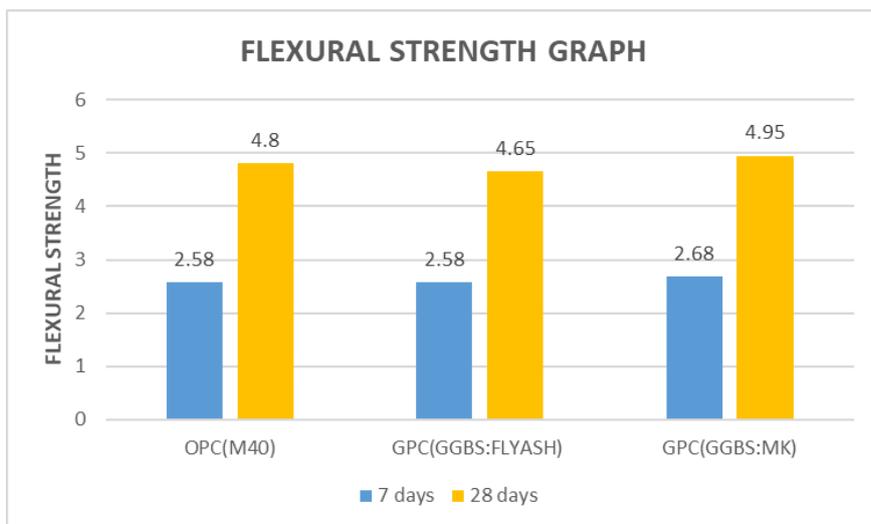
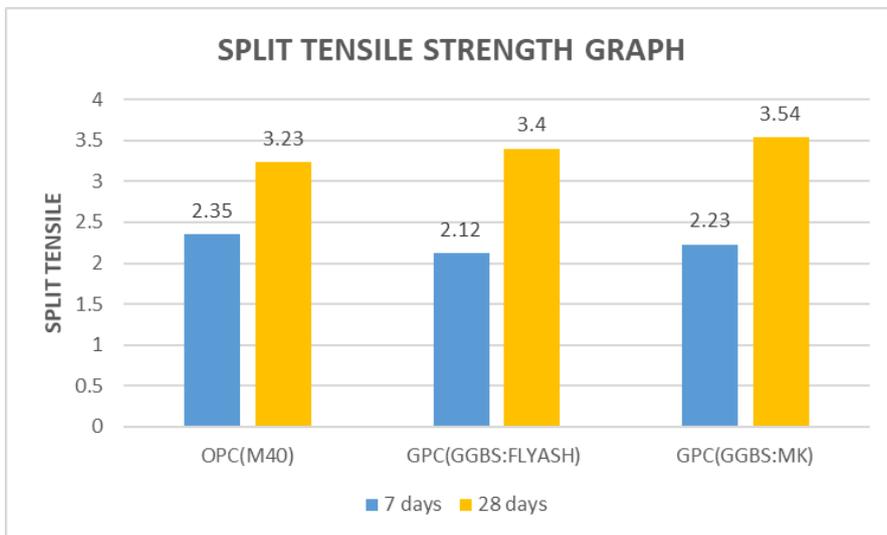
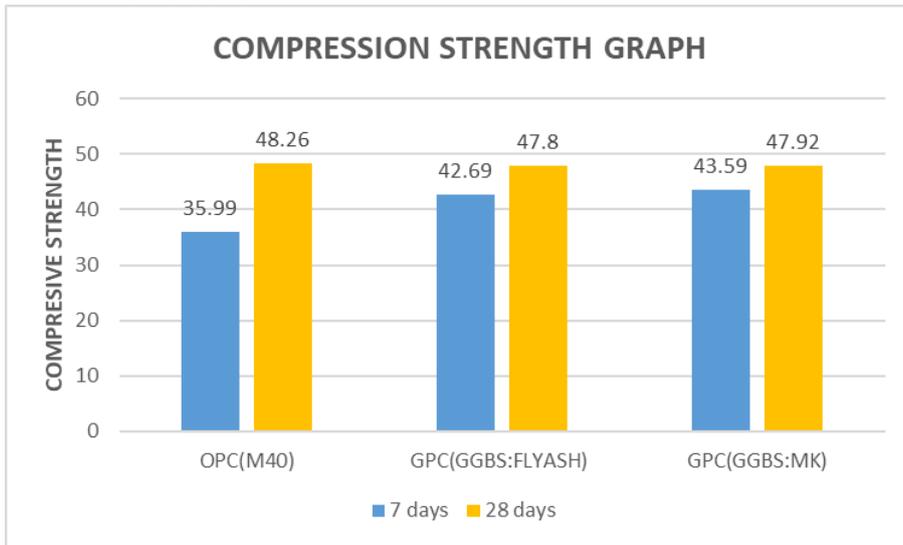
The materials used in this study included 53-grade Ordinary Portland Cement (OPC), river sand conforming to IS 383 as fine aggregate, and well-graded crushed granite as coarse

aggregate. For geopolymer concrete (GPC), the binder system comprised Class F Fly Ash, Ground Granulated Blast Furnace Slag (GGBS) with high calcium oxide content, and highly reactive Metakaolin rich in silica and alumina. The alkaline activator solution was prepared using Sodium Hydroxide (NaOH) at 12M concentration and Sodium Silicate ( $\text{Na}_2\text{SiO}_3$ ), with potable water used for both OPC and activator preparation. Two geopolymer mixes were developed: GPC1, containing GGBS and Fly Ash in a 75:25 ratio, and GPC2, containing GGBS and Metakaolin in the same 75:25 proportion. In both GPC mixes, the Sodium Silicate to Sodium Hydroxide ratio was maintained at 2.5:1, while the OPC mix was designed for M40 grade as per conventional guidelines. Standard specimen sizes were adopted for testing, including 100 × 100 × 100 mm cubes for compressive strength and temperature exposure, 150 × 300 mm cylinders for split tensile strength, and 100 × 100 × 500 mm beams for flexural strength. OPC specimens were cured under conventional water-curing conditions, whereas GPC specimens were ambient-cured to facilitate the geopolymerization process.

#### **IV. EXPERIMENTAL PROGRAM**

Mechanical property evaluation included measuring compressive strength at 7 and 28 days using a calibrated compression testing machine, while split tensile strength was assessed according to IS 5816 and flexural strength was determined using a two-point loading system. Durability performance was further examined through an acid resistance test, in which the specimens were immersed in a 5% sulfuric acid solution for a period of 28 days, and subsequent measurements of mass loss and residual strength were used to evaluate the extent of acid-induced deterioration

V. RESULTS AND DISCUSSION



Material	Weight of specimen before immersion in acid (gms)	Weight of specimen after immersion in acid (gms)	Difference in weight of specimen (gms)	Compressive strength before immersion in acid (MPa)	Compressive strength after immersion in acid (MPa)
OPC	2622	2101	521	48.26	28.57
GGBS+ FLYASH	2594	2336	258	47.80	31.56
GGBS+ METAKAOLIN	2610	2450	160	47.92	36.23

#### Acid test reaction of Specimens

GPC demonstrated competitive and often superior mechanical and durability properties compared to OPC. The GGBS–Metakaolin mix (GPC2) achieved the highest strength retention at elevated temperatures, showing a 15.10% increase at 200°C, whereas OPC strength decreased by 24.38% at the same temperature. GPC also exhibited significantly lower weight loss during thermal exposure and superior UPV values, indicating denser internal microstructure. In acid resistance testing, OPC showed a 43.44% reduction in compressive strength, whereas GPC1 and GPC2 showed only 37.22% and 24.95% reduction, respectively.

#### CONCLUSIONS

The results obtained from various tests conducted on the specimens of conventional concrete, geopolymer concrete made with GGBS & FLY-ASH and GGBS & METAKAOLIN concludes the following:

- GPC1 showed 5.26% and GPC2 showed 9.59% split value more than OPC: GPC1 showed 3.22% and GPC2 showed 6.45% flexural value more than OPC.
- In Temperature analysis the percentage changes in compressive strength were as follows; OPC's strength at 100°C decreased by 7.55%, at 200°C decreased by 24.38%, at 300°C decreased by 31.80%, GPC1 strength at 100°C increased by 9.35%, at 200°C

decreased by 14.50%, at 300°C decreased by 24.2%, GPC2 strength at 100°C increased by 9.50%, at 200°C increased by 15.10%, at 300°C decreased by 17.3%.

- From acid test the percentage decrease in compressive strength of OPC is 43.44%, GPC1 is 37.22%, GPC2 is 24.95%.
- From all the results compared the best type of specimen type was found out to be GPC2 i.e., GGBS:Metakaolin

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