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Fabrication and Performance Evaluation of Magneto Conductive Concrete for Improved Durability and Conductivity

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ABSTRACT

The modern world infrastructure is built on concrete which is valued due to mechanical power and flexibility. Nevertheless, its comparative lack of longevity and the lack of multifunctional capabilities are constant constraints. To deal with these problems, the current research examines the production and testing of Magneto-Conductive Concrete (MCC) that employs carbon fibers as well as manufactured sand (M-sand) as the sustainable alternative to river sand. Both the geopolymer based and Ordinary Portland Cement (OPC) concretes were prepared and experimented to establish their mechanical and durability behavior. The program included Compressive Strength (CS), Split Tensile Strength (SPS), Flexural Strength (FS) and Water Absorption tests in the experiment. Findings revealed that geopolymer concretes consistently delivered superior performance over OPC mixes, with compressive strengths ranging between 40–135 MPa, compared to 35–90 MPa achieved by OPC. Optimum performance was achieved at 50% M-sand replacement, though full substitution remained feasible with only minor reductions. Durability assessment showed slightly higher water absorption in geopolymer concretes than OPC, yet within acceptable limits, confirming the suitability of M-sand as an eco-friendly fine aggregate. The findings highlight the potential of MCC as a multifunctional material for sustainable and smart infrastructure.

KEYWORDS: *Magneto-conductive concrete, Geopolymer concrete, Carbon fibers, Mechanical properties, Durability performance.*

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1. INTRODUCTION

The construction industry relies heavily on concrete, valued for its durability, economic advantages, and superior structural properties [1]. Nevertheless, concrete made of regular cement is not without issues including massive dead weight and tendency to crack that will result in the reduction of structural performance and even severe safety risks [2]. In order to address these shortcomings, nanomaterials have been infiltrated in cementitious composites. The Nanoparticles (NPs) can be broadly divided as inorganic, organic, and carbon-based nanoparticles as presented in Figure 1, with carbon-based nanoparticles like graphene, carbon nanotubes, and carbon fibers demonstrating tremendous potential in improving conductivity and durability of concrete. Hence, concrete structural health monitoring has become a major area of study to support the safety of the concrete building as a whole on the basis of piezoresistive effect, structural faults signals can be measured using camera image analysis, optical fiber and acoustic emission sensors. However, the majority of monitoring techniques are indirect and involve inserting sensors into concrete, which might harm the integrity and mechanical characteristics of concrete structures [4,5]. Conductive concrete thus can be employed for smart health monitoring of concrete structures through its intrinsic characteristics and adequate interaction with cement phases. Compared with conventional sensors, conductive concrete exhibits high durability, simplicity of manufacture, and satisfactory compatibility with cement matrix [6]. Moreover, its electrical conductivity functions as self-heating when energized, rendering conductive concrete applicable to pavement deicing, construction of radiant heating, indoor dehumidification, electromagnetic shielding [7, 8], etc.

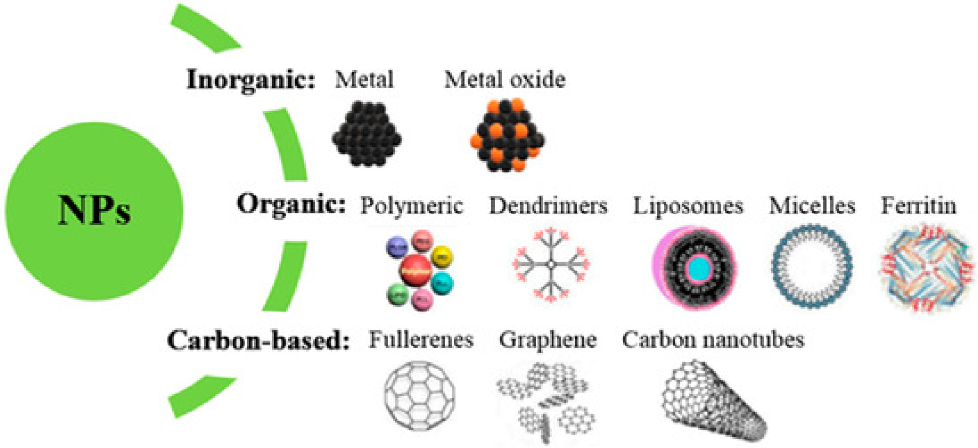

Figure 1: Chemical composition-based classifications of NPs [9].

Magneto conductive concrete is manufactured by selectively selecting and proportioning magnetic and conductive materials such as steel fibers, ferrites, carbon-based nanomaterials or metallic powders [10]. Redistribution and interaction of these additives in the base cement are the most important in achieving homogenous conductivity, best and improved mechanical actions and durability [11]. The conventional problems like nanoparticle flocculation, weak interfacial bonding, and unacceptable workability should be solved by innovative mix design, chemical admixtures and improved curing process. Moreover, the optimization of electrical and magnetic performance and mechanical integrity is also a central concern where too much conductive additive may reduce the mechanical integrity of the matrix and too little may not yield the desired conductivity [12,13].

The MCC should also be subjected to performance testing to determine whether it can be applied in the real-world applications [14]. Standard mechanical tests like CS, flexural strength, and fracture toughness should be conducted in order to determine durability besides structural integrity. Besides it, electrical resistivity, thermal conductivity, electromagnetic shielding effectiveness, and piezoresistive properties must be systematically studied [15]. The durability feature entails cracking, freeze-thaw, chloride ion ingress, and chemical resistance, which must exist to be subjected to a long service in severe conditions [16]. The sum of all these analysis gives a complete picture of why magneto conductive concrete is better than the normal concrete as a building and as a performance.

This study focuses fabrication and assessment of MCC which fills the gap between the conventional civil engineering materials and the high-functional composites. The research will help to develop MCC as a viable construction material of the next generation by systematically examining its mechanical strength, electrical performance and longevity. The results go beyond the functional scope of concrete, but also help in the creation of resilient, intelligent and sustainable construction systems. The work also focuses on the use of manufactured sand (M-sand) as a sustainable alternative to river sand and outlines the mechanical and durability properties of MCC which prove that it can be used in smart and environmentally conscious construction. The research is as given below:

- To fabricate magneto-conductive concrete by incorporating carbon fibers and replacing river sand with manufactured sand (M-sand).
- To evaluate the mechanical properties, including compressive, split tensile, and flexural strengths, of geopolymer and OPC concretes.
- To investigate the durability performance through water absorption and related tests to ensure long-term stability.
- To analyse the influence of different M-sand replacement levels and identify the optimum mix for strength, durability, and sustainability.

2. Review of Literature

In this section, the authors give a literature survey based on fabrication and performance evaluation of magneto conductive concrete for improved durability and conductivity

Javahershenas F.et al., (2025) [17] investigated the impact of applying immediately 0.5, 0.8 and 1 Tesla (T) magnetic flux densities to newly mixed concrete specimens of 5 and 10% Silica Fume (SF). The results indicated that the best results were obtained with MF (T=1 T) and an SF replacement of 10%). Thus, 24, 15, and

18 percent improvement in the CS, FS, and electrical strength of concrete specimens with 10% SF was observed under 1 T of MF. The level of penetration of chloride ions was decreased by one-fifth after treatment.

Rahman L. et al., (2024) [18] established that electrode-concrete interface zone is the primary heat source of ECON HPS. Results showed that the particular ECON slab system under investigation required a threshold value of 16 VAC and a power density of 425 W/m². These remarkable results provide important information for the development and deployment of ECON slabs in the future, which will benefit transportation agencies and the general public through effective and environmentally friendly snow removal.

Ji X. et al., (2023) [19] examined the effects of electromagnetic heating on electrical conductivity in carbon fibre conductive concrete with varying amounts and temperatures of carbon fiber. CS drops 19% and 55% at 0.38% and 1.5% carbon fiber content, respectively, according to the results. The use of carbon fiber increases the number of bubbles and agglomerates in the concrete, which facilitates the creation of stress concentration upon compression. In general, the optimal answer is 0.75 % fiber. The numerical simulation approach also provides an accurate representation of the heating process. The heating rate reduces as the energizing time increases until the heat equilibrium condition is reached, as shown by both the experimental and computational data.

Santillan N. et al., (2022) [20] developed multifunctional concretes that can alter their electrical properties and had improved mechanical performance. This study compared reference mixes with concretes that used various types of steel slag aggregates obtained from Spanish industries in place of natural aggregates. The use of slag and metallic fibers in concrete has shown promising results, with a 14% improvement in mechanical performance and an over 70% improvement in electrically conductive capacity.

Gordina A. et al., (2022) [21] looked at how electrically conductive sand concrete's electrical characteristics were affected by sulfate corrosion over time. Researchers analyzed how the samples' mineral makeup changed over time in an aggressive solution. A 29% reduction in electrically conductive composition sulfate ion absorption relative to total volume of absorbed sulfates and a 26% drop for the control composition were seen during the 28–224-day exposure period of the samples, as shown by the results. Under sulfate corrosion, both compositional samples increased in density by 6% and exhibited cyclic fluctuation in mechanical strength of up to 15%.

Gamal H. et al., (2021) [22] discovered more about the technical and long-term effects of hybrid nanomaterials in concrete. Variations in CNT percentages (0.01%, 0.02%, and 0.04% by weight) were introduced into the cement mixture, with NC remaining at a constant 5%. In order to analyze the microstructural properties of the materials, a SEM became necessary. It was determined how well the steel bar inserted in the concrete withstood corrosion. The SEM analysis revealed that the nano-clay-based concrete significantly attained a denser structure at all tested contents when CNT was added.

Verma A. et al., (2021) [23] discussed the electromagnetism of the concrete mix that is used to create ECC. Electrical current may flow through graphite and steel fiber. Maintaining a constant rate of strength increase up to 3% yields a maximal strength that is 9.77% greater than the controlled samples. Although the control sample only reached 26.60 MPa, the concrete's strength increased to 29.40 MPa after adding 1% steel fibers, and it reached a maximum of 30.50 MPa after increasing the steel fiber concentration to 2%. Incorporating 3% steel fibers allowed for a peak CS of 31.50MPa.

Dehghanpour H. et al., (2020) [24] assessed the potential of pyrolyzed nano carbon black derived from used tires and cutting debris for incorporation into electrically conductive concrete for anti-icing purposes on airport runways. There were ten distinct varieties of concrete slabs that were manufactured once the general qualities were determined. Conductive concrete slabs underwent electrothermal testing in a controlled environment maintained at 10 C. The authors used an optimization approach and providing a heat power ranging from 180 to 1315 W/m^2 for heating electrically conductive concrete slabs made from various combinations.

3. Material and Methods

Figure 1 illustrates the sequential approach used in the manufacture and testing of magneto-conductive concrete. The procedure is initiated with the selection of materials, wherein Ordinary Portland Cement, coarse aggregates, fine aggregates, 10 mm length carbon fibers, and an alkaline activator solution ($NaOH + Na_2SiO_3$) are selected in order to realize the targeted strength as compared to electrical conductivity. The proportion for mixing is then formulated with an M30 grade reference mix as per IS 10262, incorporating fine aggregate (660 kg/m³), coarse aggregate (1189 kg/m³), and water (171 kg/m³). For examining the effect of manufactured sand (M-sand), natural river sand is replaced by different percentages (0%, 25%, 50%, 75%, and 100%). Upon mix preparation, the test samples are subjected to mechanical testing, such as compressive strength, split tensile strength, and flexural strength, to analyze structural performance. The samples are also tested for durability to analyze resistance to environmental conditions like moisture and penetration of ions so that the incorporation of carbon fibers does not affect long-term performance. The framework ends with result analysis, contrasting the impact of fiber addition and sand replacement on mechanical and durability properties.

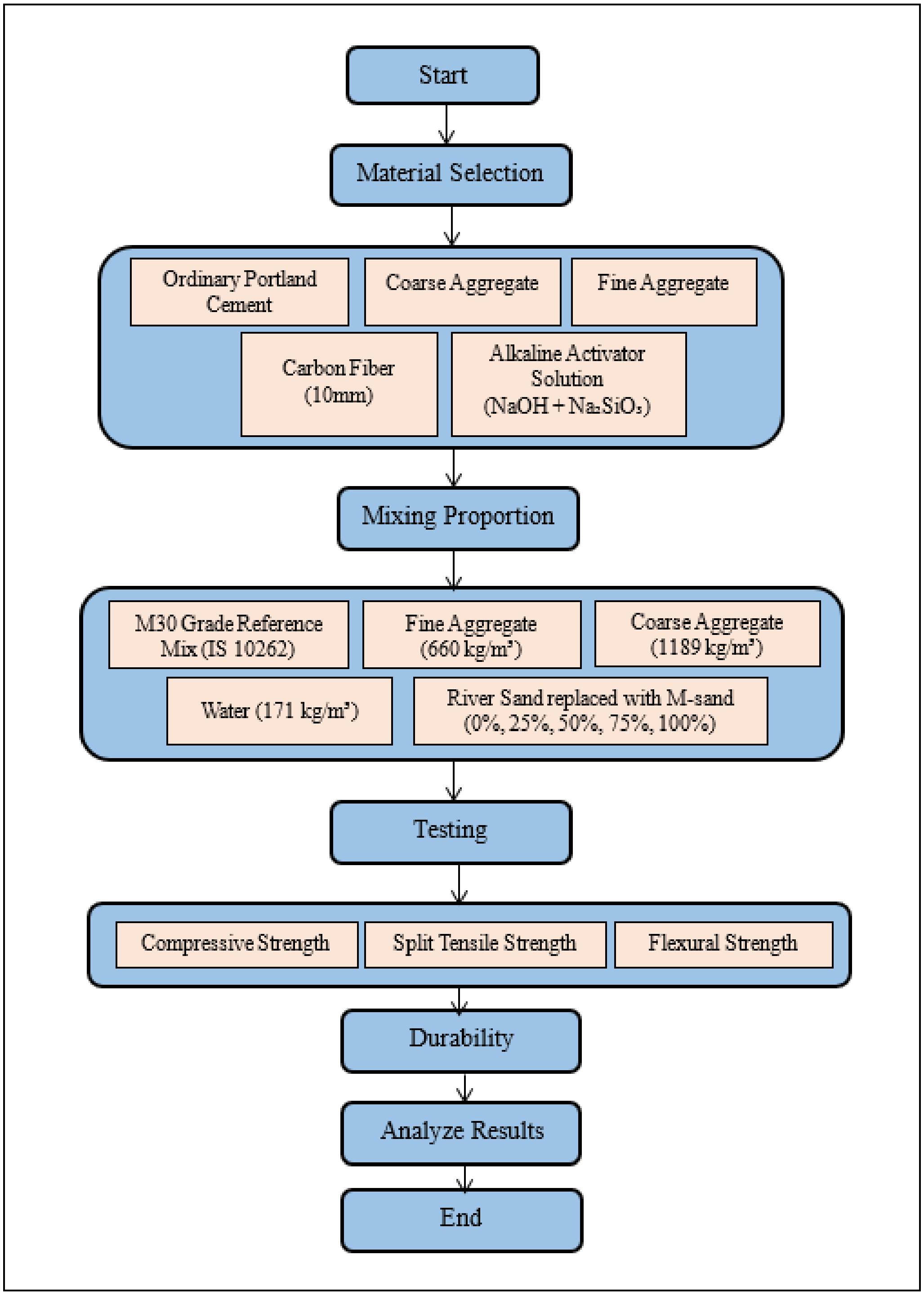

Figure 2: Proposed Methodology

3.1. Cement Used

In this study, used standard Portland cement (P.O. 42.5 grade) of Hubei Yadong Cement Co., LTD as the binder. The fume of silica produced in Sichuan was introduced to enhance the strength and easy dispersal of carbon fibres. Coarse aggregate (crushed gravel, 5 -15 mm (12 mm on average)) was used, as well as fine aggregate (natural river sand, less than 5 mm). As the conductive component, carbon fibers were used, and the length of the fibers was 10 mm since this length provides a good balance between the workability and the mechanical performance. These are their main characteristics, which are outlined in Table 1.

Table 1. Characteristics of 10 mm Carbon Fiber

Tensile Elastic Modulus (GPa)	Density (g cm^3)	Carbon Content (%)	Strength of Extension (GPa)	Ductility (%)	Monofilament diameter (µm)	Volume Resistivity (Ωm)
231	1.6	≥96.0	3.9	1.48	7	1.4

3.2. Mix Proportion

The conventional M30 grade concrete (IS 10262) was made with a cement 380 kg/m 3, fine 660 kg/m^3, coarse 1189 kg/m^3 and water 171kg/m^3 with mix ratio of 1: 1.74:3.13:0.45. In case of geopolymer concrete, Fly Ash (FA) was used as the main aluminosilicate binder which was substituted by GGBS to an extent of 0%, 10, 20 and 30. The alkaline activator solution (AAS) was made up with NaOH (8M) and Na_2SiO_3 in 1:4 proportions and the ratio of AAS to binder (0.45) remained constant. To maintain workability a superplasticizer (Conplast SP 430, 1%) was used. Fine aggregate alterations were incorporated with river sand and also M-sand that were indicated in the replacement levels.

3.3. Production Procedure

The geopolymer concrete production involved:

Dry Mixing: Coarse and fine aggregates were first mixed in SSD condition, followed by the addition of FA and GGBS.

Activator Addition: NaOH and Na_2SiO_3 solutions were combined and added to the dry mix. The mixture was blended thoroughly, with superplasticizer ensuring workability.

Casting & Curing: Fresh concrete was cast into molds, compacted properly, demoulded after 24 hours, and cured at ambient temperature for 28 days.

3.4. Tests on Hardened concrete

The mechanical properties were evaluated after 28 days:

- **Compressive Strength (CS)**

CS of concrete was found at 28 days in accordance with IS 516-1959 with a 150x 150x 150mm cube specimen. In case of geopolymer mortar, CS was tested in accordance with IS 10080-1982 using 70.6 mm of cube molds. Every mix proportion was tested on 3 samples and the average CS was determined using Equation (1). Figure 3 shows the CS test on cube sample.

$$Comp.Str.of\ cube\ sample\ N/mm^2 = \frac{\text{Ultimate compressive load}}{\text{Area of a cross-section of the sample}} \quad (1)$$

Figure 3: CS test on cube sample

- **Split Tensile Strength Test (STS)**

STS was the value calculated at 28 days per IS 516-1959 and done on cylindrical specimens of 200 mm length and 100 mm diameter. Each mix was tested on three samples and the mean STS determined by using Equation (2). Figure 4 depicts the CS test on cube sample.

$$Split\ tensile\ str.of\ sample\ (N/mm^2)\frac{2P}{\pi LD} \quad (2)$$

where, P = Ultimate load at failure (N),
D=Diameter of cylindrical sample (mm).
L =Length of cylindrical sample (mm),

Figure 4: CS test on cube sample

➢ Flexural Strength (FS) Test

In 28-day-old FS was assessed (IS 516-1959) in prism specimens, 500 x 100 x 100 mm thick, and the actual test was conducted over a 400 mm range with the point of central loading in a 1000 kN frame. Each mix was tested in three samples and the mean FS was obtained by use of Equation (3). Figure 5 shows the FS test on prism sample.

$$\text{FS of the sample } (N/mm^2) = \frac{PL}{bd^2} \quad (3)$$

where, P = Ultimate load at failure (N),
d =Depth of prism sample (mm),
b =Length of prism sample (mm).

Figure 5: FS test on prism sample

➢ Durability

Durability refers to concrete's ability to withstand deterioration under aggressive conditions such as chloride attack, sulphate exposure, freeze–thaw cycles, and carbonation. For magneto-conductive concrete, it is essential to confirm that the addition of carbon fibers does not affect long-term performance. Durability was assessed through standard tests including water absorption, sorptivity, and rapid chloride penetration to evaluate resistance to moisture and ion ingress, ensuring suitability in harsh environments.

4. Results and Discussion

This section presents the experimental results of geopolymer and control concretes, covering Compressive Strength, split tensile, flexural strength, and durability tests. The influence of varying M-sand replacement levels was analysed, showing that geopolymer mixes consistently outperformed OPC in strength and durability. The findings confirm M-sand as a viable and eco-friendly substitute for river sand in concrete.

4.1. Compressive Strength

Figure 6 shows the variation of CS with different M-sand replacement levels. Results indicate that CS improves with increasing M-sand content, reaching a peak at about 50% replacement before slightly decreasing. Geopolymer concrete consistently achieved higher CS than OPC mixes across all levels, with values ranging from 40–135 MPa compared to 35–90 MPa for OPC. The optimum performance was recorded at 50% M-sand replacement, though even 100% substitution showed only a marginal reduction, confirming M-sand as a feasible and sustainable alternative to river sand in both geopolymer and OPC concretes.

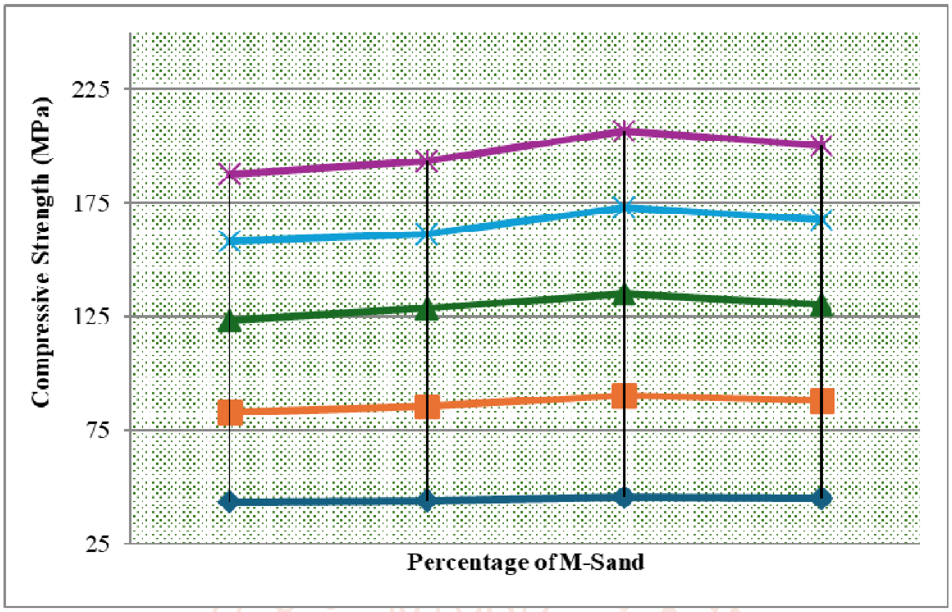

Figure 6: CS of geopolymer and control concrete

4.2. Split Tensile Strength (STS)

Figure 7 shows the STS of geopolymer and control concretes with different M-sand replacements. STS values remain fairly consistent across all levels, with geopolymer mixes (3.5–17.5 MPa) outperforming OPC. The best performance is observed at 50% M-sand, though even 100% replacement shows only a slight reduction, confirming its suitability as a full substitute. The use of GGBS further enhances the STS of geopolymer mixes.

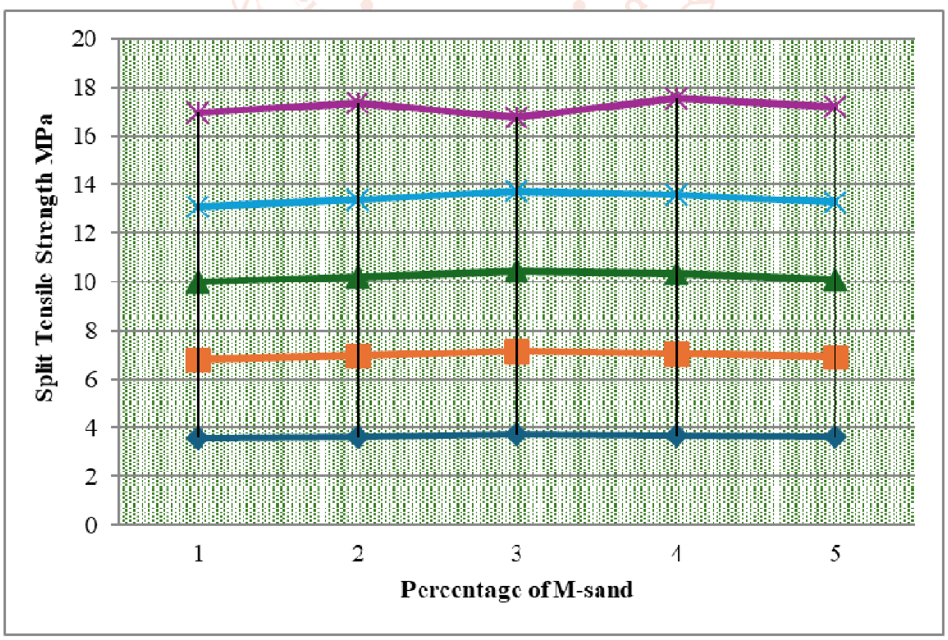

Figure 7: Spilt tensile strength of geopolymer and control concrete

4.3. Flexural Strength (FS)

Figure 8 presents the FS of control and geopolymer concretes with varying M-sand replacements at 28 days. Geopolymer mixes consistently show higher FS (4.5–25 MPa), nearly 3–4 times greater than OPC. Unlike CS and STS trends, FS decreases slightly as M-sand content increases, with the highest values at lower replacement levels. However, the difference between 0% and 100% replacement remains small, confirming that M-sand can substitute river sand without major performance loss.

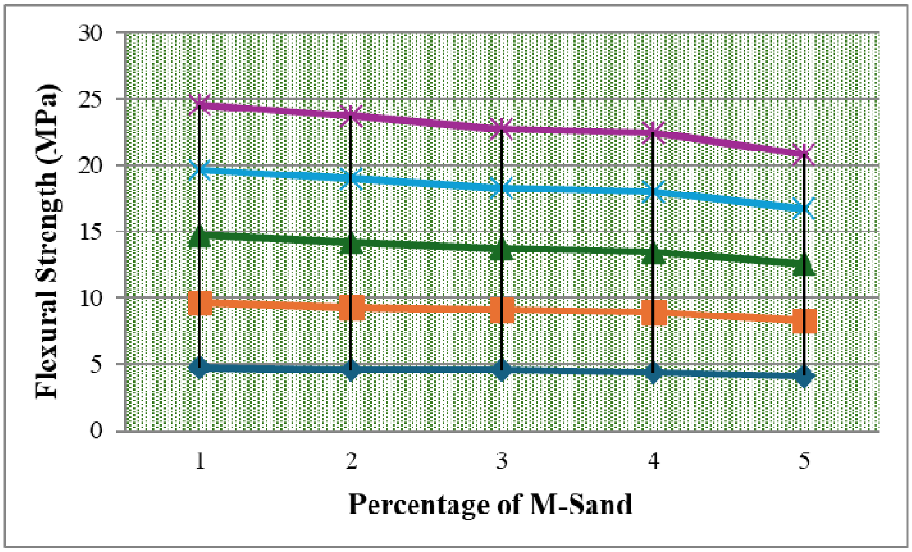

Figure 8: FS of geopolymer and control concrete

4.4. Water Absorption Test

Figure 9 shows the water absorption of OPC, GC1, GC2, and GC3 mixes at 28, 56, and 90 days. Water absorption increased with immersion time across all mixes. OPC consistently exhibited slightly lower absorption than geopolymer concretes, with differences becoming more evident at 56 and 90 days, where GC3 recorded the highest values. While GC mixes showed comparable behavior, OPC demonstrated marginally better resistance to water penetration under prolonged exposure.

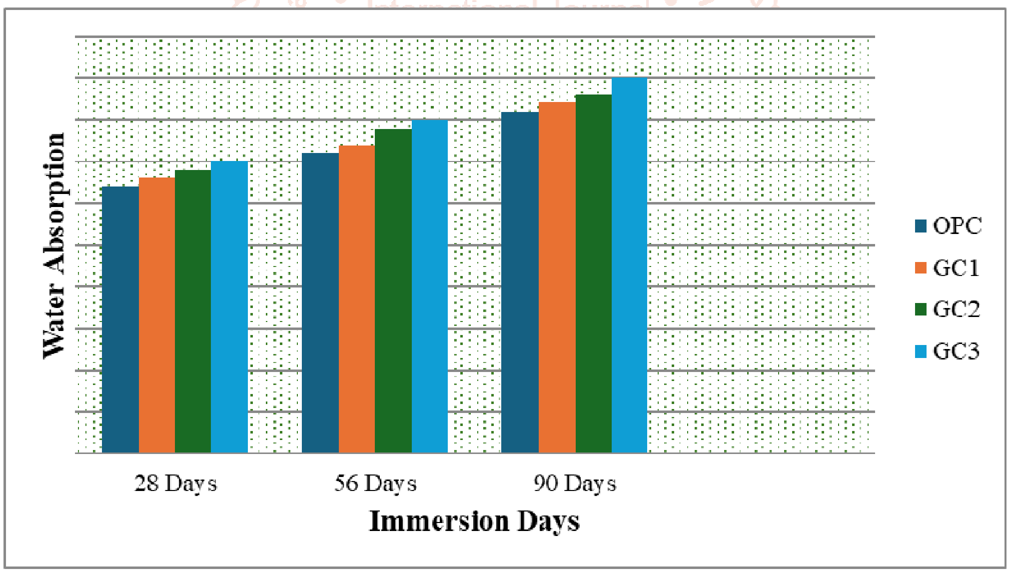

Figure 9: Water absorption percentage for different mixes

5. Conclusion and Future Scope

Concrete remains the most widely used construction material, yet its limitations in durability and functionality have prompted the development of advanced alternatives such as magneto-conductive concrete. In this study, evaluated on fabrication and performance evaluation of magneto conductive concrete for improved durability and conductivity. The results confirm that magneto-conductive geopolymer concretes exhibit superior mechanical performance over conventional OPC concretes across all M-sand replacement levels. While CS, STS, and FS peaked at 50% replacement, even 100% substitution of river sand with M-sand did not significantly compromise strength or durability. Water absorption results showed only marginal differences between geopolymer and OPC mixes, establishing the viability of geopolymer concretes with conductive fibers as durable and high-performance alternatives. The study demonstrates that incorporating M-sand and carbon fibers can enhance sustainability while maintaining required structural and functional properties.

Future studies should focus on long-term durability, microstructural analysis, optimization of conductive additives, and large-scale field validation to advance magneto-conductive concrete for smart and sustainable infrastructure applications.

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