Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.1, August : 2024

CHARACTERISTIC EVALUATION OF GEOPOLYMER CONCRETE BY USING FIBERS AND INDUSTRIAL WASTES

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Abstract
This study investigates the characteristic evaluation of geopolymer concrete (GPC) enhanced with fibers and industrial wastes. Geopolymer concrete, a sustainable alternative to traditional Portland cement concrete, utilizes industrial by-products such as fly ash and slag, reducing carbon footprint and promoting waste utilization. This research explores the mechanical properties, durability, and microstructural behavior of GPC when reinforced with various fibers, including steel, glass, and polypropylene. The addition of fibers aims to improve tensile strength, ductility, and crack resistance. Comprehensive experimental procedures, including compressive strength tests, flexural strength tests, were conducted to assess the performance enhancements. The findings indicate significant improvements in mechanical properties and durability, positioning fiber-reinforced geopolymer concrete as a viable material for sustainable construction. This study underscores the potential of combining industrial wastes and fibers to create high-performance, eco-friendly construction materials.
Keywords: Compressive strength**,** Geopolymer concrete, Flexural strength, Steel fibers.

1. Introduction

To foster sustainable development in the construction sector, the research community is actively seeking low-carbon technologies and eco-friendly products. The production of ordinary Portland cement (OPC) is a significant source of CO2 emissions, which increases energy consumption and contributes to greenhouse gas emissions [1]. Approximately seven percent of global CO2 emissions are attributed to the clinker process in OPC production, a major factor in climate change [2]. To mitigate this impact, researchers are exploring alternative low-carbon cementing binders. A promising approach involves using alumina-silicate (pozzolanic) waste materials from various industries, such as fly ash [3], bottom ash, cement kiln dust, silica dust, and ground granulated blast furnace slag (Nath & Sarker, 2012). Fly ash, in particular, has become a leading candidate in the production of sustainable cement-based concrete. Researchers are investigating the partial or complete replacement of OPC with these pozzolanic by-products [4]. Furthermore, alumina-silicate materials can be activated with alkaline solutions to form a cementitious binder known as "geopolymer cement" or alkali-activated cement [5]. This innovative approach holds significant potential for reducing the environmental impact of cement production and promoting sustainability in construction. Numerous studies have investigated the impact of curing conditions on the properties of geopolymers. Initial research indicates that fly ash-based geopolymer cement exhibits slow strength development under ambient curing conditions [6]. Conversely, curing at elevated temperatures, such as in ovens, significantly enhances strength and mechanical properties [7]. Overcoming the limitations of heat curing, especially for precast components, is a key challenge. To address this, the aim is to produce ambient-cured geopolymers with adequate strength. Efforts to achieve this include strategies such as using finely ground raw materials, incorporating additional heat from various sources, or increasing the calcium content in geopolymer mixtures [8]. Developing ambient-cured geopolymer cement is crucial for enhancing commercial viability, facilitating on-site usage, and improving energy efficiency and economic sustainability [9-11]. The shift towards environmentally friendly concrete is crucial for reducing the consumption of natural resources, energy usage, and CO_2 emissions [12]. Geopolymer concrete (GPC) marks a significant leap in developing sustainable concrete alternatives [13]. This innovative material was pioneered by French scientist Professor Davidovits and consists of inorganic alumino-silicate compounds derived from geological materials or industrial by-products like fly ash, slag, and rice husk ash [14]. Using a geopolymer binder has the advantage of eliminating Ca $(OH)_2$, which can adversely affect concrete durability [15-16]. Incorporating pozzolanic materials such as fly ash, bottom ash, rice husk ash, and slag into geopolymer concrete also addresses environmental pollution concerns [17]. Extensive research has been conducted on the application of these pozzolanic materials in geopolymer mortar and concrete, focusing on the effects of various material combinations, curing conditions, alkali activators, and other factors on the performance of geopolymers. Despite this, there has been no prior assessment of the combined impact of bottom ash and metakaolin on concrete performance.

This research article emphasis on application of geopolymer concrete to enhance the strength of concrete. The paper illustrates the durability and strength characteristics of the created geo-polymer concrete.

II. Materials

Geopolymer concrete is an innovative and sustainable alternative to traditional Portland cement-based concrete. Its potential to reduce carbon emissions and enhance durability has garnered increasing attention in the construction industry. This introduction highlights the essential materials and methods used in a geopolymer concrete project, stressing the significance of proper material selection, mix design, and quality control to achieve optimal performance and environmental benefits. Cement (OPC), Fly-ash, Metakaolin, Steel Fiber, Basalt Fiber, Fine Aggregates, Coarse Aggregates, Potable water, Alkali Activators, Super-plasticizers were used to carry out the research work. For the research work Class F Fly-Ash are procured from the Dirk India Company, Nashik, Maharashtra, India.

Methodology:

Fine aggregates are essential in geopolymer concrete, just as they are in conventional Portland cement concrete. They contribute to workability, strength, durability, and cost-effectiveness. Proper selection, testing, and management of fine aggregates are crucial to achieving the desired performance and characteristics in geopolymer concrete mixtures.

To prepare a NaOH solution:

Determine the volume of the solution to be prepared.

Calculate the moles of NaOH needed using the formula: Moles (mol) = Molarity (M) x Volume (L).

Weigh the required amount of NaOH using a balance or scale. The molar mass of NaOH is 40.00 grams/mol. Place the weighed NaOH pellets or flakes into a glass or plastic container.

Add approximately 300 mL of distilled water to the container to help dissolve the NaOH more easily. Gently stir the mixture until all the NaOH has dissolved. Be cautious, as this process generates heat, causing the solution to become very hot. Ensure proper ventilation during this step.

Mix Design of M40 Concrete grade:

1.: Pre-Requisite Data:

a) concrete category: M40

b) maximum aggregate size: 20mm

c) minimum cement content: 360 kg/m^3 (IS 456:2000)

d) maximum water-cement ratio: 0.40 (Table 5 of IS 456:2000)

e) workability: 100mm slump

F) Exposure condition: Moderate (For Reinforced Concrete)

G) Maximum cement content: 420 kg/m^3

H) Type of Chemical admixture: Super Plasticizer ECMAS HP 890

2. Materials data:

a) Specific gravity of cement: 2.95

d) Specific gravity of

1) Coarse aggregate 20mm: 2.73
2) Fine aggregate: 2.57
e) Water absorption: Coarse aggregate: 0.5 % Fine aggregate: 2.5 %
g) Sieve analysis: Fine aggregate: Zone II
3. Mean target strength: f'ck =fck + 1.65 s
where, f'ck = target strength at 28 days, fck = characteristics strength at 28 days,
and s = standard deviation.
As per IS 10262:2009, Standard Deviation(s) = 5 N/mm^2.
Therefore,
Mean target strength = **40 + 1.65 x 5 = 48.25 N/mm^2**
4. Calculating water-cement ratio: Adopted maximum water-cement ratio = 0.40
5. Determining water content in design mix:
maximum water content for coarse aggregate = 186 litre (for 25 to 50 mm slump range) water requirement for 100 mm slump concrete = 186+ (6/186) = 197 L.
Hence the arrived water content = 197-[197 x (20/100)] = 157.6 L.
6. Calculation of cement content:
w/c ratio = 0.4 cement required by weight = 157.6/0.4 = 394 kg/m^3
minimum cement content for 'very severe' exposure conditions = 360kg/m^3
394 Kg/m^3 > 360 Kg/m^3
The mix calculations per unit volume of concrete shall be as follows:
a) Volume of concrete = 1 m^3
b) Volume of cement = [Mass of cement] / {[Specific Gravity of Cement] x 1000} = 394/ {2.95 x 1000} = 0.134 m3
c) Volume of water = [Mass of water] / {[Specific Gravity of water] x 1000} = 157.6/ {1 x 1000} = 0.158m^3
d) Volume of Plasticizer @ 2% of mass of cement = (0.02x394)/1.15 x (1/1000) kg/ m3 =0.007 m^3
f) Mass of coarse aggregate= 0.701x Volume of Coarse Aggregate x Specific Gravity of Fine Aggregate x 1000 = 0.701x 0.0.64 x 2.73 x 1000 = 1224.79 kg/m^3
g) Mass of fine aggregate= 0.701 x Volume of Fine Aggregate x Specific Gravity of Fine Aggregate x 1000 = 0.701 x 0.360 x 2.57 x 1000 = 648.57 kg/m^3
9. Mix Design content: Cement = 394 kg/m^3 Water = 157.6 kg/m^3 Fine aggregate = 648.57 kg/m^3 Coarse aggregate 20mm = 1224.79 kg/m^3 Chemical admixture by 2% weight of cement Water-cement ratio = 0.40 Mix Proportion By weight = **1: 1.65: 3.11**
e) volume of all in aggregate = [a-(b+c+d)] = [1-(0.134+ 0.158+ 0.007)] = 0.701 m^3
Results and Discussion:
Throughout the research, Ordinary Portland Cement (OPC) was cast with an M40 mix design and compared to its native geopolymer concrete (GPC) mix of the same grade. The comparison revealed that while the geopolymer mix provided strength, it exhibited reduced workability, becoming stiff quickly upon mixing the ingredients. To address both workability and strength, metakaolin was introduced, proving to be effective. The optimal combinations were identified, and test results were analyzed to determine the most efficient mix. The following descriptions outline the items considered:
OPC: M40 control mix
GPC40: Geopolymer control mix of 40 grades
GPC1: Geopolymer mix with 10M concentration
GPC2: Geopolymer mix with 12M concentration
GPC3: Geopolymer mix with 14M concentration
The study's findings were analyzed to identify the most effective and efficient combination.

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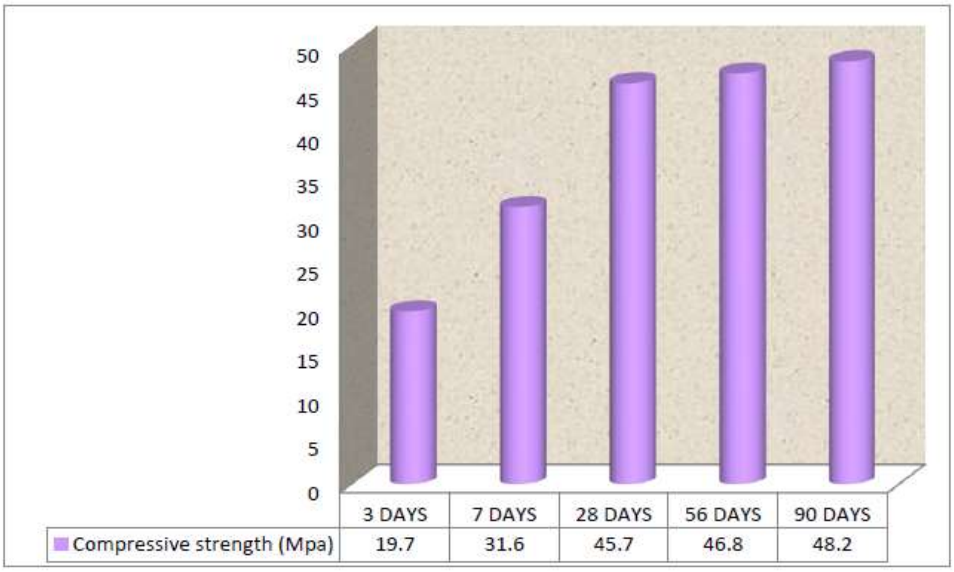

Fig. 1. Compressive strength of cube specimens for OPC: M40

Compressive strength measures how well a material, particularly concrete, can resist forces that compress it. It is quantified by the amount of force per unit area needed to crush a sample of the material. In the case of concrete, this strength is generally tested using cube specimens and is typically reported in megapascals (MPa). The compressive strength of cube specimens for Ordinary Portland Cement (OPC) in the M40 grade of concrete is typically measured at different curing times. For M40 concrete, which is a high-strength concrete mix, the target strength is 40 Mpa. Highest compressive strength achieved 48.2 Mpa after 90 days.

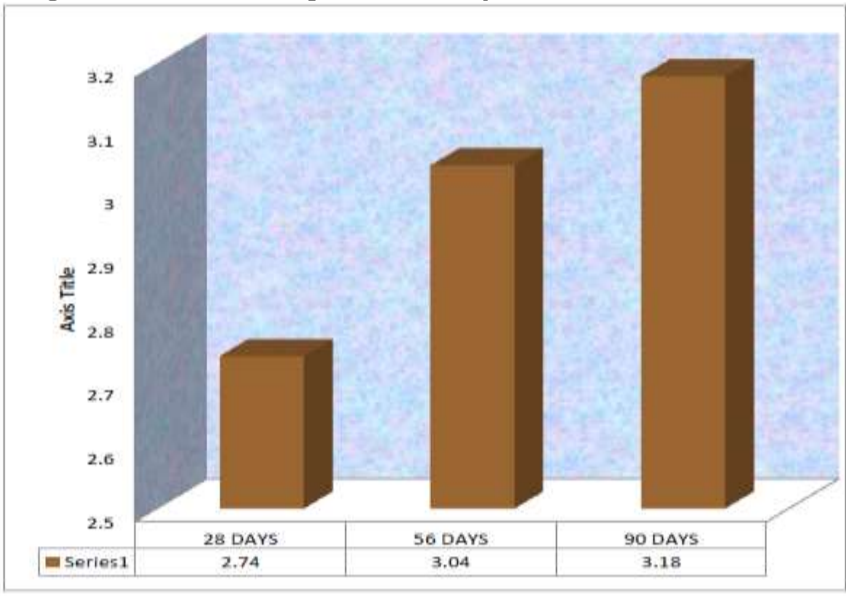

Fig. 2. Split tensile test: results for m40 grade of concrete

The split tensile test, or Brazilian test, is used to measure the tensile strength of concrete. In this method, a compressive load is applied to a cylindrical concrete specimen, creating tensile stress along its vertical diameter, which eventually causes the specimen to fail in tension. The split tensile strength of M40 grade concrete typically ranges from 2.5 MPa to 3.5 MPa. For 28th days split tensile value is 2.74 Mpa, for 56 days 3.04 MPa and for 90 days around 3.18 MPa.

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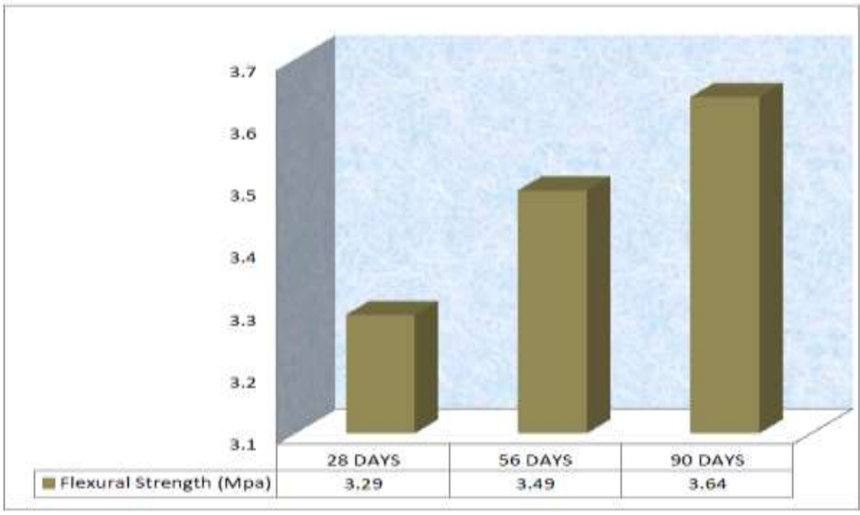

Fig. 3. Flexural strength: M40 grade of concrete

The flexural strength of M40 grade concrete typically ranges from 4 MPa to 5.5 MPa. Flexural strength is an important property that indicates the concrete's ability to resist bending or cracking under load. Maximum flexural strength achieved 3.64 Mpa in 90 days.

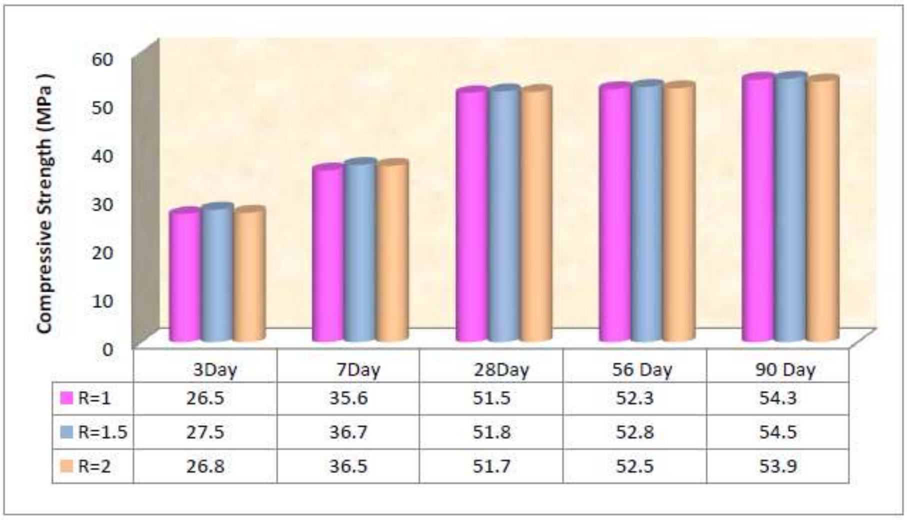

Fig. 4. Results for 10m GPC: GPC1-40 with final optimum mix, (GPC1+3MK+4BF+4SF)

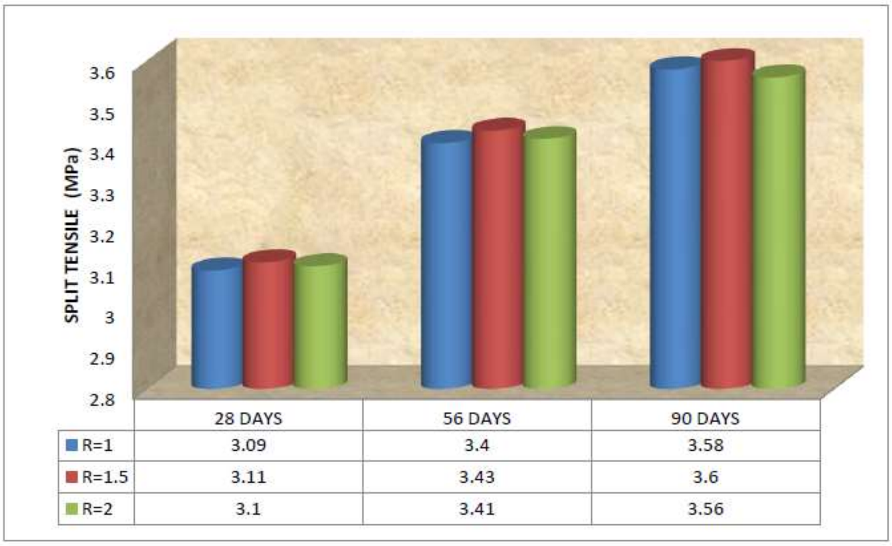

fig. 5. results for 10M GPC: GPC1-40 with final optimum mix

Conclusion:

- The study involved creating geopolymer concrete with a mix design of 40, using concentrations of 10M, 12M, and 14M. The binder ratios tested were 1.0, 1.5, and 2.0. Initial tests revealed that using only fly ash as a replacement for cement did not yield satisfactory results. To enhance strength, metakaolin (MK) was added. Additionally, fibers were incorporated to further improve the study's parameters. Concrete cubes of control mix M40 for 7days, 28 days and 56 days of curing tested under compression testing machine. This is compared with Geopolymer mix of grade 40N/mm^2. It was found that only fly-ash does not give that strength so MK was mix and its optimum percentage was found to be 3% by weight of cement and the strength was found to have improved from control mix. Following the introduction of steel fiber and basalt fiber, a significant improvement in the parameters was noted. The strength saw a nearly 35% increase during the initial stages, at maturity increment was up to 20% which again provides sufficient reason to find it more suitable and effective. The optimum fiber addition was found to be 4% in both steel and basalt cases.
- This study evaluated the strength properties of geopolymer concrete using a split tensile test. The results showed that the new GPC blend had better split tensile strength than both the M40 control mix and the GPC 40 mix. The optimal performance was achieved with a binder ratio of 1.5 in the 12M blend. The highest split tensile strength was observed with the addition of 4% basalt fiber by weight of cement, resulting in a 12% increase in strength.
- The flexural strength of concrete significantly influences its deformation properties, making it a crucial parameter. The newly developed GPC blend has notably increased flexural strength by approximately 15%, thereby enhancing its bending capacity.

Conflict of Interest

No conflict of interest

Acknowledgment

First author thanks to Dr. Manish Patkar for guidance and support for Ph.D. work.

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