iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.69996

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Enhancing Mechanical Performance of Geopolymer Concrete with Manufactured Sand: An Experimental Study

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Abstract: Concrete remains one of the most widely used and dependable construction materials globally. However, the rising demand for Ordinary Portland Cement (OPC) and natural river sand in the construction sector has led to significant environmental concerns. The production of OPC contributes heavily to CO_2 emissions—approximately one ton of CO_2 is released for every ton of OPC produced—due to limestone calcination and fossil fuel combustion. Additionally, the overexploitation of river sand has caused environmental degradation and supply shortages.

This study explores a sustainable alternative by investigating the mechanical performance of geopolymer concrete (GPC) incorporating manufactured sand (M-sand) as a substitute for natural river sand. Geopolymer concrete, composed of Class F fly ash, ground granulated blast furnace slag (GGBS), and activated with alkaline solutions such as sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH), offers a viable replacement for OPC-based concrete. The mixes were prepared with NaOH molarities of 12M and 16M for G30 grade concrete. A sodium silicate to sodium hydroxide ratio of 2.5 and a SiO_2 to Na_2O ratio of 2 were maintained. Oven curing was conducted at 60°C. Manufactured sand was used as a partial and full replacement for natural sand at 0%, 50%, and 100%.

The primary objective of this experimental investigation was to assess and compare the compressive strength, split tensile strength, and flexural strength of geopolymer concrete (G30) with conventional M30 grade concrete. The results revealed:

1) ***Compressive strength of G30 increased by 2.47% compared to M30 concrete.***
2) ***Split tensile strength of G30 improved by 2.45% over M30.***
3) ***Flexural strength of G30 showed a 2.5% increase relative to M30.***

These findings underscore the potential of geopolymer concrete with manufactured sand as a sustainable and high-performance construction material, reducing environmental impact while maintaining structural integrity.

Keywords: **Ordinary Portland Cement, CO_2 emissions, geopolymer concrete, Compressive strength, Split tensile strength**

I. INTRODUCTION

Concrete plays a crucial role in modern infrastructure development, serving as the backbone for various structures that enhance the built environment. It is the second most consumed material on Earth after water, with billions of tons produced annually to meet the demands of rapidly growing construction activities worldwide. On average, each person is estimated to consume approximately three tons of concrete per year. This immense demand is driven by its versatility, durability, and wide range of applications—from buildings and roads to bridges, runways, and dams.

The construction industry, particularly in countries like India, China, and the United States, accounts for nearly half of the global concrete demand. The increasing usage of concrete has simultaneously escalated the consumption of its primary components, especially Ordinary Portland Cement (OPC) and natural river sand. Globally, the annual production of OPC exceeds 4.1 billion metric tons, a figure projected to grow by over 25% within the next decade. OPC serves as the primary binder in conventional concrete.

However, two major environmental issues are associated with the production of OPC. Firstly, its primary raw material—limestone—is a non-renewable resource that may be exhausted within the next 40 years if current consumption trends persist. Secondly, the manufacturing process involves the calcination of limestone and the combustion of fossil fuels, leading to significant carbon dioxide (CO_2) emissions. It is estimated that for every ton of OPC produced, approximately one ton of CO_2 is released into the atmosphere. This makes the cement industry responsible for nearly 7% of global CO_2 emissions, contributing significantly to climate change and global warming.

Another critical component of concrete is river sand, used as a fine aggregate. In recent years, the availability of river sand has decreased due to unsustainable and illegal mining practices, making it both scarce and expensive. As a result, there is an urgent need to find reliable and eco-friendly alternatives. Manufactured sand (M-sand), produced by crushing hard stones, has emerged as a viable replacement due to its consistency, availability, and environmental benefits.

Simultaneously, the large-scale generation of industrial by-products such as fly ash (FA), ground granulated blast furnace slag (GGBS), red mud, and rice husk ash (RHA) offers opportunities for sustainable material substitution in concrete production. Utilizing these waste materials not only helps in mitigating CO_2 emissions but also addresses the challenge of industrial waste disposal.

In this context, geopolymer concrete presents a promising solution. Unlike OPC-based concrete, geopolymer concrete does not require any cement. First conceptualized by Joseph Davidovits in 1972, geopolymers are aluminosilicate materials formed through the geo polymerization of silica and alumina-rich industrial by-products in an alkaline medium. The resulting material exhibits a three-dimensional amorphous network that delivers superior performance characteristics.

Geopolymer concrete has several advantages over conventional concrete, including higher compressive strength, better durability, lower shrinkage, excellent resistance to acids and high temperatures, and significantly lower thermal conductivity. Moreover, it does not emit toxic fumes and requires less energy for production, making it an environmentally responsible alternative for construction and engineering applications. Its growing use in areas such as fire-resistant structures, biomaterials, and waste containment underscores its potential.

As the construction industry continues to seek sustainable and high-performance alternatives, geopolymer concrete, especially when combined with manufactured sand, offers a viable pathway to reducing the environmental footprint of concrete production without compromising structural quality.

TABLE 1 Milestones in alumina-silicate chemistry

Year	Zeolite Molecular Sieve	Alkali-Activation (Slag)	Hydrosodalite (Kaolin)	Geopolymer
1930			1934: Olsen (Netherlands)	
1940	1945: Barrer (UK)	1940: Purdon (Belgium)	1945: US Bureau of Standard 1949: Borchert, Keidel (Germany)	
1950	1953: Barrer, White (UK) 1956: Milton (USA)	1953: Trief Cement (USA) 1957: Glukovsky (Ukraine) Soli-silicate concrete		
1960			1963: Howell (USA) 1964: Berg et al. (USSR) 1969: Besson et al. (France)	
1970				1976: Davidovits (IUPAC terminology) 1979: Davidovit s (France) Geopolymer

II. OBJECTIVE

A. Problem Statement of Research

The production of Ordinary Portland Cement (OPC) relies heavily on the extraction and processing of natural materials such as limestone, clay, and other mineral resources. This manufacturing process is energy-intensive and significantly contributes to environmental degradation by releasing a large amount of carbon dioxide (CO_2) into the atmosphere. For every ton of OPC produced, nearly one ton of CO_2 is emitted, which accelerates global warming and threatens ecological balance. Additionally, the excessive use of river sand in conventional concrete has led to its scarcity, increased cost, and environmental issues such as illegal mining. These challenges highlight the urgent need for a sustainable, eco-friendly alternative to OPC-based concrete.

B. Objectives of the Study

The primary goals of this study are as follows:

- To explore geopolymer concrete as a sustainable alternative to OPC-based concrete, reducing dependence on non-renewable resources.
- To minimize environmental impact by lowering carbon dioxide emissions by up to 80% through the use of industrial by-products.
- To evaluate the mechanical properties of geopolymer concrete incorporating fly ash and Ground Granulated Blast Furnace Slag (GGBS).
- To assess the effect of replacing natural river sand with manufactured sand (M-sand) in varying proportions.
- To investigate the potential of geopolymer concrete in reducing creep, drying shrinkage, and enhancing overall durability.

C. Scope of the Study

This research aims to promote the utilization of geopolymer concrete as an eco-conscious and cost-effective construction material. The adoption of geopolymer technology can significantly reduce environmental pollution and lower the carbon footprint associated with traditional cement production.

Although geopolymer concrete is still an emerging technology in India, it has already found application in notable projects such as the Delhi Metro. Internationally, it is gaining momentum in countries like the USA, Australia, and those across Europe. The ongoing global research is focused on enhancing the properties of geopolymer binders to match or surpass those of OPC.

Given its promising performance and sustainability, geopolymer concrete presents a viable and scalable alternative for widespread use in the Indian construction industry.

III.MATERIALS AND METHODS

A comprehensive overview of the materials used and the mix design methodology adopted for the experimental investigation of geopolymer concrete incorporating manufactured sand. It outlines the physical and chemical characteristics of constituent materials and the rationale behind their selection.

A. Materials Used

The materials selected for this research were carefully chosen based on their availability, performance characteristics, and sustainability factors. The primary ingredients for both geopolymer and conventional concrete mixes included the following:

- Ordinary Portland Cement (OPC), 53 Grade (used for control concrete)
- Class-F Fly Ash (low-calcium)
- Ground Granulated Blast Furnace Slag (GGBS)
- Coarse Aggregate (angular, crushed stone)
- River Sand (natural fine aggregate)
- Manufactured Sand (M-sand) (alternative to natural river sand)
- Sodium Silicate Solution (Na_2SiO_3)
- Sodium Hydroxide Pellets (NaOH)
- Water
- Superplasticizer (Gelenium B233)

These materials were used to develop different mix proportions of geopolymer concrete with varying levels of manufactured sand as a replacement for river sand. The controlled concrete mix was designed with OPC to compare mechanical performance parameters.

1) Fly Ash

Class-F fly ash, a low-calcium variety, was sourced from the Vijayawada Thermal Power Station. It served as the primary alumino-silicate binder in the geopolymer mix. This type of fly ash is preferred in geopolymer concrete for its pozzolanic behavior and compatibility with alkaline activators, which facilitates effective geopolymerization.

The typical chemical composition of Class-F fly ash includes high amounts of silica (SiO_2) and alumina (Al_2O_3), along with minor contents of iron oxide (Fe_2O_3), calcium oxide (CaO), and other trace elements. The specific composition used in this study is presented in Table 2.

TABLE 2 Composition of fly ash as determined by XRF (mass %)

Silicon Dioxide (SiO_2)	Aluminum Oxide (Al_2O_3)	Calcium Oxide (CaO)	Chromium (Cr)	Ferric Oxide (Fe_2O_3)	Potassium Oxide (K_2O)	Magnesium Oxide (MgO)	Sodium Oxide (Na_2O)	Phosphorus Pentoxide (P_2O_5)	Sulfur Trioxide (SO_3)	Titanium Dioxide (TiO_2)	Manganese Oxide (MnO)	Loss on Ignition (LOI*)
47.8	24.4	2.42	0.01	17.4	0.55	1.19	0.31	2.0	0.29	1.328	0.12	1.1

LOI (Loss on Ignition) indicates the amount of mass lost when the fly ash sample is heated to a high temperature, typically representing volatile substances or moisture content.

2) Ordinary Portland Cement (OPC)

In traditional concrete production, Ordinary Portland Cement (OPC) serves as the principal binding agent. For the purposes of comparison in this experimental study, OPC of 53 grade was sourced from a reliable local supplier. This grade is widely recognized for its superior strength characteristics, making it suitable for high-performance construction applications. Although OPC remains a fundamental component in conventional concrete, its production involves significant consumption of natural resources such as limestone and releases a substantial amount of CO_2. This environmental impact is a key motivation for exploring sustainable alternatives like geopolymer concrete in this research.

TABLE 3 Physical properties of Ordinary Portland Cement

S. No	Property	Test Method	Test Results	IS Standard
1.	Normal Consistency	Vicat Apparatus (IS: 4031 Part - 4)	31%	
2.	Specific gravity	Sp. Gr bottle (IS: 4031 Part - 4)	3.15	
3.	Initial setting time Final setting time	Vicat Apparatus (IS: 4031 Part - 4)	45 minutes 182 Minutes	Not less than 30 min Not less than 10 hours
4.	Fineness	Sieve test on sieve no.9 (IS: 4031 Part – 1)	1.3%	10%
5.	Soundness	Le-Chatlier method (IS: 4031 Part – 3)	2 mm	Not more than 10 mm
6.	Compressive Strength		55.3 N/mm^2	

3) Coarse Aggregate

20 mm aggregates of uniform size are used which are produced from locally available crusher Physical properties are tabulated below in Table 4

TABLE 4 Physical Properties of Coarse Aggregate 20mm

S. No	Property	Method	20mm Aggregate
1	Specific gravity	Pycnometer IS:2386-part 3-1986	2.672
2	Water absorption		1.116
3	Flakiness Index	IS:2386-part 2-1986	4.18
4	Elongation Index	IS:2386-part 2-1986	5.85
5	Bulk density(compact)	IS:2386-part 3-1986	1574 Kg/cum
6	Bulk density(loose)	IS:2386-part 3-1986	1424Kg/cum
7	Fineness modulus	Sieve Analysis (IS:2386 Part 2 1963)	7.01

4) Fine Aggregate

- *River Sand*

The fine aggregate utilized in this study was natural river sand, procured from local suppliers. It conforms to the grading requirements specified in IS: 383 – 1970 for fine aggregates used in concrete. The physical properties of the sand, including specific gravity, fineness modulus (FM), and bulk density, were determined in accordance with IS: 2386 – 1963 (Methods of Test for Aggregates for Concrete). The results of these tests are presented in Table 5 below.

TABLE 5 Physical Properties of River Sand

SR.NO	Property	Method	Fine Aggregate
1	Specific gravity	Pycnometer IS:2386-part 3-1986	2.70
2	Flakiness Index	IS:2386-part 2-1986	-
3	Elongation Index	IS:2386-part 2-1986	-
4	Bulk density(compact)	IS:2386-part 3-1986	1711Kg/cum
5	Bulk density(loose)	IS:2386-part 3-1986	1631Kg/cum
6	Fineness modulus	Sieve Analysis (IS:2386 Part 2-1963)	2.64
7	Bulking	IS:2386 Part 3-1986	4% wc
8	Grading		Zone -II

TABLE 6 Sieve Analysis of Natural Sand

SR. No	IS Sieve Size	Weight retained gm.	Cumulative e Weight retained gm	Cumulative %Weight retained	Cumulative % Passing	Limits of Grading (IS 383-1970) Zone II
1	10 mm	0	0	0	100	100
2	4.75mm	9	9	0.9	99.1	90-100
3	2.36mm	25	34	3.4	96.6	75-100
4	1.18mm	163	197	19.7	80.3	55-90
5	600 microns	408	605	60.5	39.5	35-59
6	300 microns	210	815	81.5	18.5	8-30
7	150 microns	165	980	98.0	02.0	0-10
8	<150 microns	20	--	--	--	--
9	Total	1000		264		

Fineness Modulus = Cumulative Percentage weight retained / 100
= 267/100
= 2.67

Fine aggregate belongs to Zone II

- *Manufacturing Sand (M-Sand)*

Manufactured sand (M-Sand) is produced by mechanically crushing hard rock stones into fine aggregates that resemble the texture and size of natural river sand. In this study, M-Sand was sourced from local suppliers and found to meet the requirements outlined in IS: 383 – 1970 for fine aggregates.

The physical characteristics of M-Sand—such as specific gravity, fineness modulus (FM), and bulk density—were evaluated in accordance with IS: 2386 – 1963 (Methods of Test for Aggregates for Concrete). The test results are summarized in Table 3.6 below.

TABLE 7 Physical Properties of Manufactured Sand

S.NO	Property	Method	Fine Aggregate
1	Specific gravity	Pycnometer IS:2386-part 3-1986	2.71
2	Flakiness Index	IS:2386-part 2-1986	--
3	Elongation Index	IS:2386-part 2-1986	--
4	Bulk density(compact)	IS:2386-part 3-1986	1720Kg/cum
5	Bulk density(loose)	IS:2386-part 3-1986	1663.27Kg/cum
6	Fineness modulus	Sieve Analysis (IS:2386 Part 2-1963)	2.67
7	Bulking	IS:2386 Part 3-1986	4% wc
8	Grading		Zone –II

TABLE 8 Sieve Analysis of Manufactured Sand

SR. No	IS Sieve Size	Weight retained gm.	Cumulative Weight retained gm	Cumulative %Weight retained	Cumulative % Passing	Limits of Grading (IS 383-1970) Zone II
1	10 mm	0	0	0	100	100
2	4.75mm	12	12	1.2	98.8	90-100
3	2.36mm	28	40	4.0	96	75-100
4	1.18mm	165	205	20.5	79.5	55-90
5	600 Microns	410	615	61.5	39.5	35-59
6	300 microns	205	820	82.0	18	8-30
7	150 microns	160	980	98.0	02.0	0-10
8	<150 Microns	20	--	--	--	--
9	Total	1000		267		

Fineness Modulus = Cumulative Percentage weight retained / 100
= 267/100
= 2.67

Fine aggregate belongs to Zone II

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Volume 13 Issue V May 2025- Available at www.ijraset.com

5) Sodium Hydroxide (NaOH)

Sodium Hydroxide is a key alkaline activator used in the production of geopolymer concrete. In this study, sodium hydroxide was obtained in pellet form from certified chemical suppliers based in Hyderabad. The material was sourced from local laboratory chemical vendors and complied with the required purity standards for use in construction applications. The detailed specifications of the sodium hydroxide pellets used are presented in Table 9.

TABLE 9 The Physical properties of NaOH

Appearance	White solid
Molar mass	40 gm/mol
Density	2.1 gr/cc
Melting point	318^{o}C
Boiling point	1390^{o}C
Amount of heat liberated when dissolved in water	266 cal/gr

TABLE 10 The Chemical properties of NaOH Pellets

Purity	97%(Assay)
Na_2Co_3	2%
CI	0.01%
SO_4	-0.01%
SiO_2	0.02%
Zinc	-0.02%
PO_4	0.00%
Aluminium(Al)	0.00%

6) Sodium Silicate Solution (Na_2SiO_3)

Sodium Silicate (Na_2SiO_3) solution is a vital alkaline activator in geopolymer concrete, significantly contributing to the polymerization process. In this study, the sodium silicate solution was sourced from reputable laboratory chemical vendors located in Hyderabad. The specifications of the sodium silicate solution, as provided by the suppliers, are presented in Table 11.

TABLE 11 Properties of Na2SiO3 Solution

Specific gravity	1.57
Molar mass	122.06 gm/mol
Na_2O (by mass)	14.35%
SiO_2 (by mass)	30.00%
Water (by mass)	55.00%
Weight ratio (SiO_2 to Na_2O)	2.09
Molarity ratio	*0.97*

7) Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is an industrial by-product obtained from the steel manufacturing process. It is formed when molten iron slag is rapidly cooled at a temperature of approximately 1500°C. In this study, GGBS was procured from local suppliers for use in the preparation of geopolymer concrete. GGBS plays a crucial role in enhancing the performance of geopolymer concrete by reducing the setting time and promoting early strength development. Additionally, its use contributes to sustainable construction practices by reducing the environmental impact associated with conventional cement-based materials.

TABLE 12 Chemical Properties of GGBS

SiO_2	32.78
Al_2O_3	22.4
Fe_2O_3	1.1
MgO	0.08
CaO	34.86
Na_2O	-
LOI	*0.62*

8) Water

Water is a critical component in both conventional and geopolymer concrete, as it facilitates the chemical reactions necessary for the hydration of cement and the polymerization process. According to IS 456:2000, the water used for mixing and curing must be clean and free from harmful impurities that could adversely affect the strength and durability of concrete or cause corrosion in reinforcement steel. The water should have a pH value not less than 6. In this study, potable water was used for both mixing and curing processes to ensure the quality and integrity of the concrete.

9) Superplasticizer

To enhance the workability of the concrete mix without increasing water content, a superplasticizer was used. In this study, GLENIUM B233, a high-performance superplasticizer from Fosroc Chemicals India Ltd., was employed as a water-reducing admixture. The technical specifications of the superplasticizer are provided in Table 13.

TABLE 13 Details of Super Plasticizer

Parameters	Specifications	Results
Physical state	Reddish brown liquid	Reddish brown liquid
Chemical name of active ingredient	Polycarboxylate polymers	Polycarboxylate polymers
Relative density @25 C	1.08 +/- 0.1	1.08
Ph	Min 6	7.1
Chloride ion content %	Max 0.2	0.073
Dry material content	34 +/- 5%	34.09

10) Advantages of Superplasticizer

- Enhances Workability: Significantly improves the flowability of the concrete mix without the need for additional water.
- Accelerates Early Strength Development: Especially beneficial for precast concrete elements, enabling faster demolding and handling.
- Improves Concrete Quality and Durability: Reduces permeability, which enhances the long-term durability and resistance of concrete to aggressive environmental conditions.
- Reduces Segregation and Bleeding: Ensures a uniform mix and facilitates smoother pumping and placement of concrete, particularly in complex formworks.

B. Mix Design

The mix proportions were selected based on established literature and experimental requirements. Various mix ratios were evaluated to determine their influence on the strength characteristics of the concrete.

1) Mix Design for Conventional Concrete (M30 Grade)

The mix design for M30 grade conventional concrete was developed in accordance with the guidelines provided in IS 10262:2009 and IS 456:2000. These standards ensure a reliable and systematic approach to achieving the desired strength, workability, and durability of the concrete mix.

TABLE 14 Test data of materials of M30 Concrete

Test Data of Materials		
1	Cement Used	OPC of 53 grade
2	Specific gravity of cement	3.15
3	Specific gravity of coarse aggregate	2.672
4	Specific gravity of fine aggregate	2.84
5	Specific gravity of water	1
6	Water absorption of the coarse aggregate	1.12%
7	Water absorption of the fine aggregate	1%
8	Free (surface) moisture content of coarse aggregate	NIL
9	Free (surface) moisture content of fine aggregate	NIL
10	Sieve Analysis of Fine Aggregate	Separate Analysis Done

TABLE 15 Stipulations for Proportioning M30 Concrete Mix Design

M30 CONCRETE MIX DSIGN		
AS per IS 10262-2009		
Stipulations for Proportioning		
1	Grade Designation	M30
2	Type of cement	OPC of 53 grade
3	Maximum Nominal Aggregate Size	20 mm
4	Minimum Cement Content	320 kg/m^3
5	Maximum Water Cement Ratio	0.45
6	Workability	50-75mm(slump)
7	Exposure Condition	Normal
8	Degree of Supervision	Good
9	Type of Aggregate	Crushed Angular Aggregate
10	Maximum Cement Content	540 kg/m^3

a) Target mean Strength of Concrete

f'ck = fck + 1.65 S

i.e., f'ck = 30 + 1.65 x 5 = 38.25 N/mm^2

f'ck = target avg compressive strength at 28 days curing time,

fck = characteristic compressive strength at 28 days curing time, and s = standard deviation.

b) Selection of Water to Cement (w/c) Ratio

From Table 8 of IS 456,

The water to cement ratio required for the target mean strength of 38.25 N/mm^2 is 0.45.

Adopt W/C ratio of 0.45

c) Selection of Water Content

From Table 3 (IS 10262: 2009), maximum water content =186 liter (for 50 to 75 mm slump range) for 20 mm aggregate.

d) Calculation of Cement Content

Water-cement ratio = 0.45

Cement content = 186/0.45

= 413.33 kg/m^3

Cement content 320 kg/m^3 < 413.33 kg/m^3 > 540 kg/m^3

As per clause 8.2.4.2 of IS 456:2000 (Cement content not including fly ash and GGBS more than 450 kg/m^3 should not be used)
Estimated water content = 162.10 liters
Cement Content = (162.10/0.45)
= 362.64 Kg/m^3

e) Proportion of vol. of Course Aggregate and fine Aggregate Content

From Table 4 (IS 10262: 2009), volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone II) for water-cement ratio of 0.50 =0.62.
Here water-cement ratio is 0.45.
Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water to cement ratio is lower by 0.10, the proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in water to cement ratio).
Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.45 = 0.62.
Therefore, Volume of coarse aggregate = 0.62
Volume of coarse aggregate = 1- 0.62
Volume of fine aggregate = 0.38

f) Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

- Volume of concrete = 1m^3
- Volume of cement = mass of cement/ (specific gravity of cement x1000)
  = 362.64 / (3.15*1000)
  = 0.115 m^3
- Volume of water = mass of water / (specific gravity of water x1000)
  = 162.10 / (1*1000)
  = 0.162 m^3
- Volume of all in aggregates = 1 – (Volume of cement + Volume of water)
  = 1 – (0.115+0.162)
  = 0.72 m^3
- Mass of coarse aggregate = Volume of all in aggregate x1000x Volume of coarse aggregate x specific gravity of coarse aggregate x1000
  = 0.72*0.62*2.672*1000
  = 1184.18 kgs
- Mass of fine aggregate = Volume of all in aggregate x I 000 x Volume of fine aggregate x specific gravity of fine aggregate x 1000
  = 0.72*0.38*2.84*1000
  = 681kgs

TABLE 16 Mix Proportions of M30 Concrete

Mix Proportion		
1	Cement	1
2	Fine Aggregate	1.88
3	Coarse Aggregate	3.26

2) Mix Design for Geopolymer Concrete (G30)

Unit weight of concrete =2400Kg/m^3 Mass of combined aggregate
= 78.14% of unit weight of concrete
= ((78.14/100) *2400)
=1875.36Kg/m^3

Mass of flyash (class F) and alkaline liquid = Unit weight of concrete – Mass of combined aggregate
= 2400 – 1875.36
= 524.64 Kg/m^3

Considering Alkaline liquid to flyash ratio= 0.45

Calculation for mass of flyash = ((Mass of flyash and alkaline liquid)/ (1+Alkaline liquid to Fly ash ratio))
= ((524.64)/ (1+0.45)) = 361.82 Kg/m^3

Calculation for Mass of Alkaline liquid = Mass of flyash and alkaline liquid – Mass of flyash
= 524.64 – 361.82 = 162.81 Kg/m^3

Considering Na2SiO_3 to NaOH ratio = 2.5

Calculation for Mass of NaOH = Mass of alkaline liquid/ (1+ratio of Na2SiO_3 to NaOH))
= (162.81/ (1+2.5))
= 46.51 Kg/m^3

Calculation for Mass of NaOH for 12M (NaOH Solids) = (36.1/100) * Mass of NaOH
Where 36.1 = Number of moles for 12M
= ((36.1/100) * 46.51
= 16.79 Kg/m^3

Calculation for Mass of Na2SiO3 = Mass of Alkaline liquid -Mass of NaOH
= 162.81 – 46.51
= 116.299 Kg/m^3

Calculation for Mass of water = Mass of NaOH – Mass of NaOH solids for 12M
= 46.51 – 16.79
= 29.72 Kg/m^3

Table 17 Details of G30 GPC Mix Design

Geopolymer Concrete (G30)		
1	Unit weight of concrete	2400 Kg/m^3
2	Mass of combined aggregate 78.14% of 2400	1875.36 Kg/m^3
3	Mass of flyash and alkaline liquid	524.64 Kg/m^3
4	Considering Alkaline liquid to flyash as	0.45
4(a)	Mass of flyash	361.82 Kg/m^3
4(b)	Mass of Alkaline liquid	162.819 Kg/m^3
5	Considering Na2SiO_3 to NaOH ratio	2.5
5(a)	Mass of NaOH	46.51 Kg/m^3
	For 12 Molarity(NaOH solids)	16.79 Kg/m^3
5(b)	Mass of Na2SiO_3	116.3 Kg/m^3
6	Mass of water	29.72 Kg/m^3
7	From Na2SiO_3	162.81 Kg/m^3

TABLE 18 Mix proportions of G30 Concrete

Mix Proportion		
1	Flyash	1
2	GGBS	0.17
3	Fine Aggregate	2.21
4	Coarse Aggregate	3.85

IV. TESTING INVESTIGATIONS

Low calcium (class F) dry fly ash collected from Vijayawada thermal power station was used as the source material to make Geopolymer Concrete in the laboratory. For the alkaline activator, a combination of sodium silicate (Na2SiO3) to sodium hydroxide (NaOH) solution was used. The NaOH solution of required molarity is prepared by dissolving the sodium hydroxide solids, either in the shape of pellets or flakes, in water. In order to improve workability of fresh fly ash and slag based Geopolymer Concrete we have added master gelenium sky B233 -based superplasticizer and some extra water as per the mix design. The sodium silicate solution used contained Na2O=14.35%, SiO2=30.00%, and 55% of water, by mass. All the liquids are mixed jointly before adding to the solids.

The Parameters Considered are as follows:

- The molarity of NaOH used 12M for G30 grade of concrete.
- The Silicon Dioxide (SiO2) to Sodium Oxide (Na2O) ratio as 2
- Alkaline liquid to fly ash ratio
- One day rest period
- The ratio of Na2SiO3 to Sodium hydroxide (NaOH) as 2.5.
- Oven Curing temperature of 60oC for 24 hours
- Effect of super plasticizer on compressive strength
- Effect of replacement of fine aggregate on mechanical properties of Geopolymer Concrete. In the present study river sand is replaced with manufactured sand in different proportions viz. 0%, 50% up to 100%.

Fig.1 Solution of Sodium hydroxide and Sodium Silicate ($Na2SiO_3$)

Fig.2 Materials ready to mix

A. Preparation of Specimens

In the preparation of specimens primarily alkaline activator solution was prepared by together mixing the sodium hydroxide (NaOH) pellets and Sodium silicate (Na2SiO3) solution according to the mix proportions. The NaOH and Na2SiO3 solution is prepared before 2 hours. In this experimental work, G30 grade of Geopolymer Concrete was prepared with different molarities of NaOH solutions i.e. 12 M. The mass of NaOH varied depending on the concentration of solution. The ratio 2.5 of sodium hydroxide to sodium silicate is used in experimental study. The fly ash, GGBS, fine aggregates, coarse aggregates and alkaline activator.

A Tilting drum type concrete mixer used for obtaining uniform mixture of concrete with less effort. The fresh Geopolymer Concrete was used to cast cubes of size 100mm X 100mm X 100mm to determine its compressive strength, 150mm X 300mmsize cylinders to determine its split tensile strength, 100mm X 100mm X 500mm size prism to determine Flexural strength. Each specimen was casted and compacted by using table vibrator. This is the most commonly used vibrator for concrete. The period of vibration is 30 sec to 2min.

Fig. 3 Cubes and Cylinders after casted

B. Curing

After a resting period of one day, the specimens were placed in an oven and cured at a temperature of 60°C for 24 hours. Following this thermal curing process, the samples were exposed to ambient atmospheric conditions until the time of testing. In contrast, the control concrete specimens were subjected to conventional water curing.


Fig. 4. Oven curing of cubes


Fig. 5 Cubes after oven cured


Fig. 6. Cylinders after Oven Curin

C. Tests on Geopolymer and Conventional Concrete

1) *Compressive Strength Test:* Concrete is known for its high strength in compression. In this study, cube specimens of size 100 mm × 100 mm × 100 mm were tested as per IS: 516–1969 standards. A 200-ton capacity Compression Testing Machine (CTM) was used, which was properly calibrated. The plates were cleaned and checked before use. Specimens were tested after 3, 7, and 28 days of curing. The smooth sides of the cubes were placed on the CTM bearing plates, and the test was conducted on three samples at each interval. The average of the results was taken as the compressive strength.


Fig. 7 Testing of cubes on Compression testing machine

2) Split Tensile Test: Tensile strength helps assess a concrete's resistance to cracking and bonding with steel. Since direct tension testing is difficult, the split tensile method is commonly used. Cylindrical specimens of 150 mm diameter and 300 mm height were loaded along their sides, inducing tension across the vertical diameter. The splitting tensile strength is calculated using the formula:

$\sigma = 2P / (\pi DL)$

Where: σ = tensile strength (MPa), P = applied load at failure (kN), D = diameter (mm), L = length (mm)

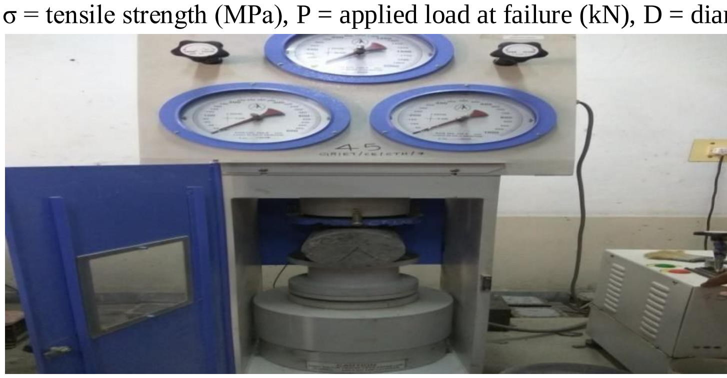
Fig. 8 Testing of cylinders on Compressive testing machine

3) Flexural Strength Test: Flexural strength measures a concrete beam's ability to resist bending. Concrete prisms (150 mm × 150 mm cross-section) were tested over a span at least three times the depth, using the three-point loading method (ASTM C78). The flexural strength (modulus of rupture) is calculated by:

$\sigma = 3FL / 2bd^2$ Where: F = load at failure (N), L = span length (mm), b = width (mm)d = depth (mm)

Fig. 9 Testing Beam on Flexural strength machine

V. CONCLUSION

Based on the experimental investigations carried out, the following conclusions have been drawn:

1) Geopolymer concrete (G30) exhibited a maximum compressive strength of 42.37 N/mm² at 28 days when cured with 12M NaOH solution, surpassing the performance of conventional M30 concrete.
2) The compressive strength of conventional M30 concrete was recorded at 41.37 N/mm² after 28 days of curing.
3) The improved strength in geopolymer concrete is primarily attributed to the rapid polymerization reaction facilitated by oven curing and the aging of alkaline activators.
4) An oven curing temperature of 60°C for 24 hours was found to be optimal for achieving enhanced mechanical properties.
5) The compressive strength of G30 showed a 2.47% improvement compared to M30 conventional concrete.
6) The split tensile strength of geopolymer concrete increased by 2.45% compared to its conventional counterpart.
7) A 2.5% enhancement in flexural strength was also observed in G30 compared to M30 concrete.
8) Geopolymer concrete achieved higher early-age strength under oven curing conditions compared to conventional water-cured concrete.
9) The compressive strength of geopolymer concrete increased with NaOH molarity up to 16M, indicating the importance of activator concentration in strength development.
10) Economically, G30 geopolymer concrete was found to be 7.52% more cost-effective than traditional M30 concrete, making it a viable alternative for sustainable construction.

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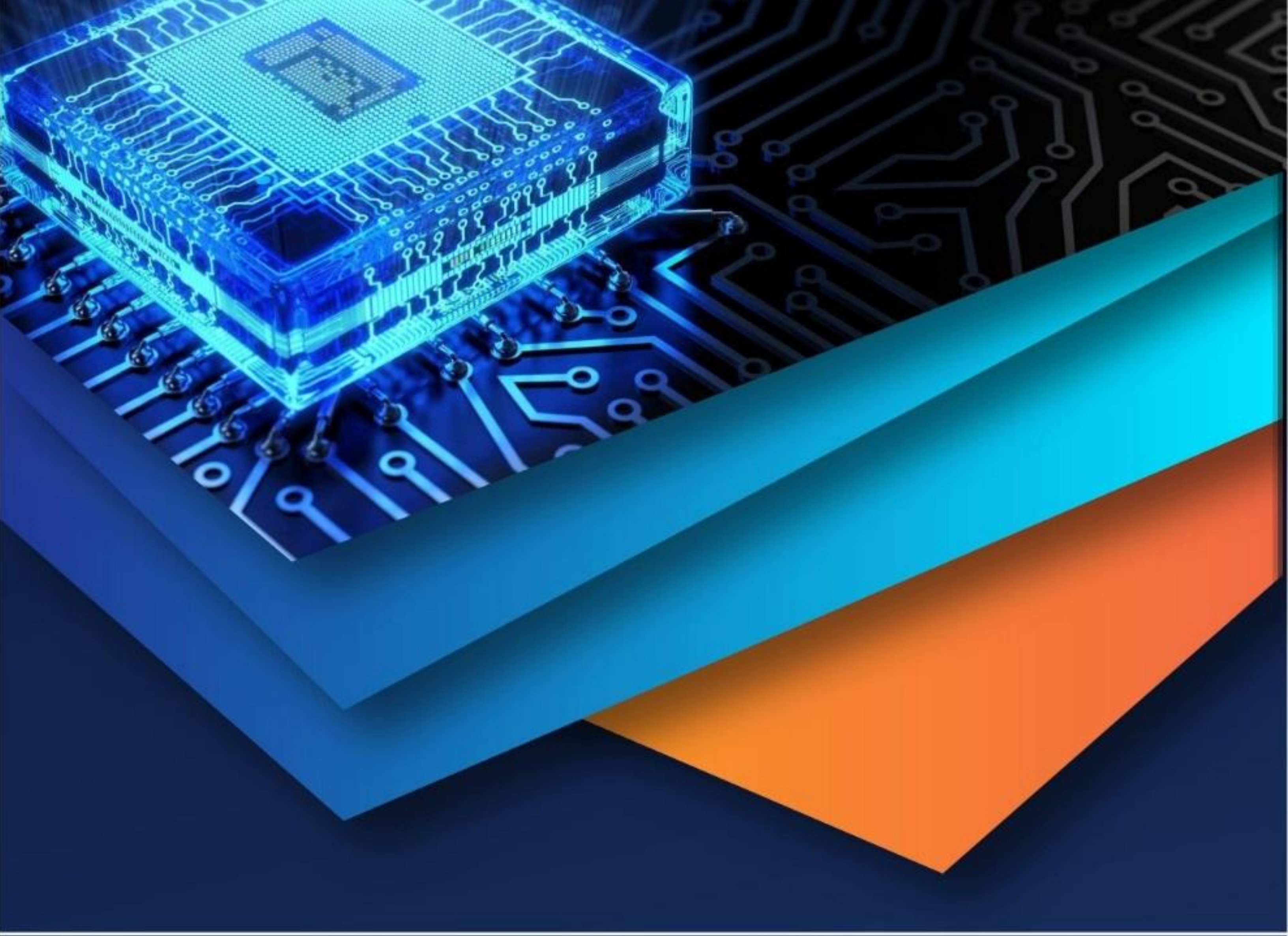

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