

An Experimental Investigation on Geopolymer Concrete with Partial Replacement of M-Sand Using Iron Ore Tailings

Dr. P Senthamilselvi, Associate Professor, Dept of Civil Engineering, Government College of Engineering, Salem.

G. Harishmitha, PG Student, Structural Engineering, Government College of Engineering, Salem.

Manuscript Received: Jan 30, 2026; Revised: Feb 09, 2026; Published: Feb 10, 2026

Abstract: This research work aims to study further sustainability to the less geopolymer concrete cement by partially replacing fine aggregate by Iron ore tailings. Geopolymer concrete is one of the building materials that has become more popular in recent years because it is significantly more environmentally friendly than standard concrete. Geopolymer concrete usually includes fly ash, Ground Granulated Blast Furnace slag, fine aggregate and coarse aggregate activated by means of alkaline liquids like sodium silicate and sodium hydroxide. Further the Iron ore tailings which is a byproduct obtained from Steel manufacturing industry can be used as a replacement to fine aggregate. By using this for construction purposes, it reduces environmental pollution. Geopolymer concrete of grade M30 with Iron ore tailings as a partial replacement to fine aggregate was studied for its compressive, tensile and flexural behavior and compared with conventional Geopolymer concrete. The study derived that in all stages, the performance of the geopolymer concrete with Iron ore tailings was marginally better than the conventional Geopolymer concrete with fine aggregate. In this study, the Iron ore tailings are used in various percentages such as 0%, 20%, 40% and 60% and found 40% was effective in terms of strength.

Keywords: Geopolymer, Sodium hydroxide (NaOH), Sodium Silicate (Na₂SiO₃), Fine aggregate, Coarse aggregate, Compressive strength, Split tensile strength, Flexural strength, Optimum percentage.

1. Introduction

Environmental issues resulting from cement production have become a major concern. To develop a sustainable future, it is encouraged to limit the use of this construction material that can affect the environment. Cement replacement material was proposed to partially replace cement portion in concrete. Geopolymer is the best solution to reduce the use of cement in concrete. Geopolymer is a hardened cementitious paste made from fly ash, Ground Granulated Blast Furnace slag, alkaline solution and geological source material. This process produces less carbon dioxide emissions compared to traditional cement production. A number of studies have been conducted exploring the use of iron ore tailings as a substitute for fine aggregate. Iron ore tailings are obtained from the steel manufacturing waste.

2. Literature Review

Manjunatha M Katti et.al (2018): The study investigates the feasibility of using iron ore tailings (IOT) as a partial replacement in geopolymer concrete mixes. Experimental blends were prepared replacing fine aggregate with IOT at various levels and activated using alkaline solution. Results show that an optimum replacement percentage (around 30%) achieved maximum compressive strength, beyond which strength declined as IOT content increased. The use of IOT improved sustainability by reducing industrial waste and consumption of natural sand. Microstructural analysis indicated that higher IOT content increased porosity and negatively affected bonding within the geopolymer matrix. The paper concludes that IOT can be an effective substitute in geopolymer concrete if used within optimal limits under controlled mix design.

Saravanan S et.al (2024): The study investigates the Industrial residues such as fly ash (FA), Basic Oxygen Furnace (BOF) slag and iron ore tailings (IOT) are explored as sustainable building material components to reduce natural-resource consumption and carbon emissions. This study investigates the feasibility of using FA and BOF slag as primary precursors in steel-fiber reinforced engineered geopolymer composites (EGCs), while replacing fine aggregate with IOT. Extensive trial mixes (~600 mixes) were conducted to determine the influence of IOT content on compressive strength,

revealing that IOT significantly enhances strength, followed by steel fiber and BOF slag levels. The research further aims to improve geopolymer properties through fiber reinforcement and to understand how fiber type/quantity affects final composite behavior. Key mechanical properties including compressive, tensile and flexural strengths, as well as bond-slip behavior, are evaluated and optimized using response surface methodology. Finally, the optimized mix is compared to conventional geopolymer concrete to highlight performance improvements and sustainability potential.

Raghunandan Kumar et.al (2020): This study addresses the large volumes of industrial by-products such as ground granular blast furnace slag (GGBS), fly ash and iron ore tailings, and proposes their use in the manufacture of stabilized geopolymer bricks as a sustainable alternative to fired clay bricks. Alkali-activated geopolymer binders (sodium silicate and sodium hydroxide solutions) are used in combination with fly ash and GGBS, replacing clay or natural sand with iron ore tailings and slag sand. Various mix proportions including different tailings replacement levels and alkali molarity are evaluated for brick manufacture under ambient curing. Mechanical performance (compressive strength) and durability-related properties (e.g., water absorption, density) are examined at 7, 14 and 28 days. Results indicate that higher alkali molarity and higher percentage of slag sand improve strength, while higher iron ore tailings content tend to reduce strength. The bricks meet dimensionality, soundness and hardness tests, showing potential for use in sustainable construction.

B. Sethaswi et.al (2024): The author investigates the cement industry emits large amounts of CO₂, contributing to environmental degradation, making sustainable alternatives essential. Geopolymer concrete (GPC) replaces Portland cement by using aluminosilicate-rich industrial by-products like fly ash (FA) and GGBS activated with alkaline solutions. This study investigates the use of iron ore tailings (IOT) as fine aggregate replacement (20–50%) in 12M GPC, showing good strength and durability performance. After identifying the optimum IOT level, high-magnesium nickel slag (HMNS) was further incorporated at 5–12.5% replacement. Sodium hydroxide and sodium silicate were used as activators in a 2.5 ratio. Mechanical properties, including compressive, split tensile, and flexural strengths, were evaluated to assess the effect of combined IOT and HMNS replacement. Findings confirm that sustainable GPC mixes incorporating IOT and HMNS can yield strong and durable concrete.

R. Harini et.al (2024): The author investigates the Geopolymer concrete was composed of low-calcium (Class F) fly ash as the main source material, combined with fine and coarse aggregates, alkaline activators (sodium hydroxide and sodium silicate), water, and a superplasticizer admixture for workability improvement. The optimum strength and workability were achieved at a solution-to-fly ash (SF) ratio of 0.35 with an activator ratio of 2.0, yielding a 28-day compressive strength of 42.81 MPa, which was higher than conventional concrete. Specimens were heat-cured at 80°C for 24 hours to promote polymerization, followed by ambient curing at 23–24°C until testing at 7, 14, 21, and 28 days, resulting in superior strength development compared to normal water curing.

Gayana B. C et.al: The author investigates the Iron ore tailings (IOT), generated in large quantities from beneficiation processes, pose environmental challenges when disposed in landfills and tailings dams. This study examines the combined use of IOT as fine aggregate and alccofine as a cement replacement in concrete. Results show that workability decreases with increasing IOT-alccofine content, while mechanical performance improves. Maximum compressive strengths of 70.00, 68.67, and 65 MPa were achieved at 40%, 30%, and 20% IOT-alccofine replacement for w/c ratios of 0.35, 0.40, and 0.45, respectively. Flexural and splitting tensile strengths also increased with higher IOT-alccofine dosages. Multiple regression models demonstrated high accuracy in predicting mechanical properties, confirming the potential of IOT-alccofine concrete as a sustainable building material.

Sikiru Folahan Oritola, et al (2019): The author investigates the feasibility of using iron ore tailings (IOTs) as a partial replacement for sand in reinforced concrete beams. The study involved producing a control beam with conventional aggregates and four other beams where sand was partially replaced with varying percentages of IOTs. These beams were subjected to flexural performance tests using a Magnus frame testing setup. The research focused on evaluating parameters such as load-concrete strain, load-steel strain, load-deflection relationships, cracking behavior, and the ultimate load at failure. Among the samples, the beam with 30% IOT replacement (BCZT30) demonstrated the highest ultimate load at failure and exhibited lower strain compared to the control beam. The findings indicate that incorporating IOTs into concrete can enhance the flexural performance of reinforced concrete beams, suggesting a viable approach to sustainable construction by recycling industrial waste materials.

3. Material Properties

A. Fly Ash

Low calcium fly ash (Class F) is one of the deposits produced in the burning of coal. In this work, Class F fly ash is to be used which was collected from Mettur Thermal Power Station, Salem. Generally, Class F fly ash provides good pozzolanic activity and it contains less than 10% of lime (CaO).

Table. 1 Properties of fly ash

Description	Value
Fineness	8%
Specific Gravity	2.27

B. Ground Granulated Blast Furnace Slag

GGBFS which is a byproduct of iron manufacturing industry is an accepted mineral admixture for use in concrete. This granulated material when further ground to less than 45micron is called Ground Granulated Blast Furnace Slag (GGBS).

Table.2 Properties of GGBS

Description	Value
Fineness	4%
Specific Gravity	2.9

C. Iron Ore Tailings

Iron ore tailings which is a byproduct obtained from Steel manufacturing industry

Table.3 Properties of Iron ore tailings

Description	Value
Fineness Modulus	2.35
Specific Gravity	2.73

D.Fine Aggregate:

The fine aggregates used are manufactured aggregates (M- Sand) with a uniform grade. The fine aggregates with particle sizes less than 4.75 mm are generally employed.

Table.4 Properties of Fine aggregate

Description	Value
Fineness Modulus	2.84
Specific Gravity	2.53

The size of the aggregates used is 20mm,12.5 mm.

Table.5 Properties of Coarse aggregate

Description	Value
Size	20 Mm
Impact Value	19.44%
Specific Gravity	2.78
Crushing Value	33.45%
Fineness Modulus	6.9

F. Alkaline Liquid:

Alkaline Activated solution used here was a mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) with the molarity of 12M.

G. Water: The pH level of water is 7.

Iv. Mix Design of Geopolymer Concrete

REFERENCE: An Experimental Investigation on Properties of Geopolymer Concrete

AUTHOR: V. Bhikshma et.al

Fly ash : 286.23 kg/m³

GGBFS : 122.67 kg/m³

Fine aggregate : 554.4 kg/m³

Coarse aggregate : 1293.6 kg/m³

Alkalinity Solution : 143.11 kg/m³

5.Experimental Investigation

The cube and cylinder specimens were casted with different Iron ore tailings percentage such 0%, 20%, 40% and 60%. The specimens casted was tested under compression load, tensile load, single point load under flexural test. The specimens were demolded and allowed for ambient curing. The cubes (100 x 100 x 100 mm), cylinders (150 x 300 mm) and prisms (100 x 100 x 500 mm) were tested on 7,14,28 days under compression, tensile load, single point load under flexural test. The compression strength, tensile strength and flexural strength were analyzed.

6.Results

The results section presents the outcomes of strength tests conducted on the cast specimens, including cubes, cylinders, and prisms. Compressive strength tests were performed on cube specimens, split tensile strength tests on cylindrical specimens, and flexural strength tests on prism specimens to evaluate the mechanical behavior of the Geopolymer concrete.

Table 6: Compressive Strength Results

Percentage of replacement of Iron ore tailings (%)	Compressive Strength (N/mm ²)		
	7 days	14 days	28 days
0	35.9	40	49.5
20	31.9	36	45
40	39	42	53
60	30	33	41

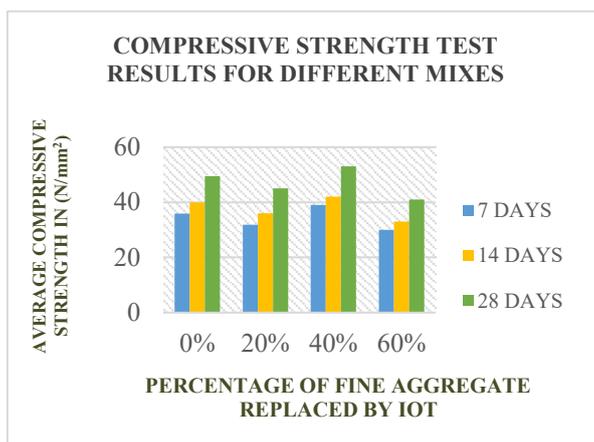


Fig 1: Graph for Compressive Strength Results

In the above results, it is seen that 40 % replacement of M-Sand using Iron ore tailings in Geopolymer concrete gives more Compressive strength compared with Conventional Geopolymer Concrete.

Table 7: Split Tensile Strength Results

Percentage of replacement of Iron ore tailings (%)	Split Tensile Strength (N/mm ²)		
	7 days	14 days	28 days
0	2.87	3.2	3.96
20	2.55	2.88	3.6
40	3.12	3.36	4.24
60	2.4	2.64	3.28

In the figure-2 result, it is seen that 40 % replacement of M-Sand using Iron ore tailings in Geopolymer concrete gives more Split tensile strength compared with Conventional Geopolymer Concrete.

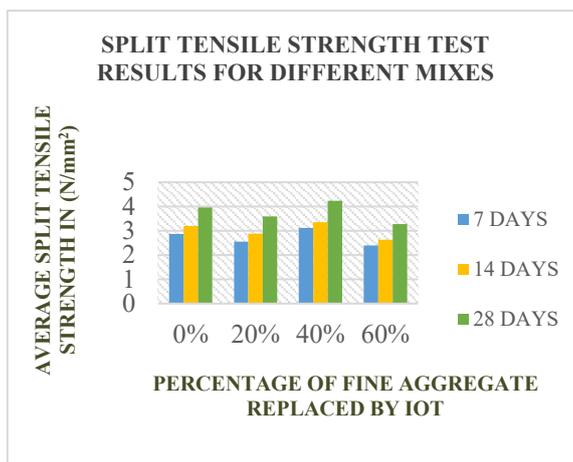


Fig 2: Graph for Split Tensile Strength Results

Table 8: Flexural Strength Results

Percentage of replacement of Iron ore tailings (%)	Flexural Strength (N/mm ²)		
	7 days	14 days	28 days
0	3.10	3.73	4.74
10	3.11	3.94	4.76
20	3.27	4.01	5.02
30	2.78	3.26	4.25

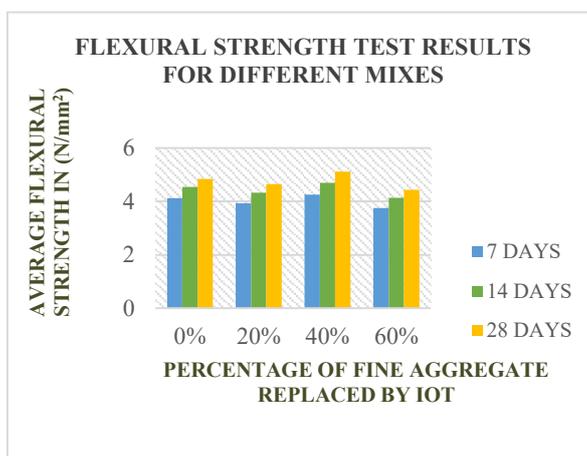


Fig 3: Graph for Flexural Strength Result

In the above results, it is seen that 40 % replacement of M-Sand using Iron ore tailings in Geopolymer concrete gives more Flexural strength compared with Conventional Geopolymer Concrete.

7. Conclusion

1. Geopolymer concrete properties can be enhanced by considering the replacement of fine aggregate with Iron ore tailings.
2. From the various percentage of addition of Iron ore tailings by the volume of fine aggregate, 40% addition of Iron ore tailings by the volume of fine aggregate was found to be optimum value.
3. The compressive strength, split tensile strength, flexural strength test results of 40% addition of Iron ore tailings are more than the control Geopolymer specimen.
4. This gives the scope that the Geopolymer concrete with fine aggregate in proportion with Iron ore tailings be employed in construction for better achievement of strength and durability characteristics.

8. References

- [1] Utilization of Iron Ore Tailings in Geopolymer Concrete [Manjunatha M Katti et.al, International Research Journal of Engineering and Technology (IRJET), April 2018, Volume: 05 Issue: 04]
- [2] Sustainable engineered geopolymer composites: A study on the potential of fly ash, BOF slag, and iron ore tailings [Saravanan Subramanian et.al, Environmental Engineering Research, February 2024, Volume 29(5);2024, <https://doi.org/10.4491/eer.2023.540>]
- [3] Geopolymer Bricks Using Iron Ore Tailings, Slag Sand, Ground Granular Blast Furnace Slag and Fly Ash [Raghunandan Kumar et.al, Intech open, February 2020, DOI: 10.5772/intechopen.81748]
- [4] Effect of Iron Ore Tailings and High Magnesium Nickel Slag on Fly ash-GGBS Based Geopolymer Concrete (GPC)[M. Srinivasula Reddy et.al, International Journal for Research in Applied Science & Engineering Technology (IJRASET), February 2024, Volume 12 Issue II, <https://doi.org/10.22214/ijraset.2024.58519>]
- [5] Experimental Investigation on Geopolymer Concrete with Partial Replacement of M-Sand using Iron Ore Tailing [R. Harini et.al, International Advanced Research Journal in Science, Engineering and Technology (IARJSET), (August 2021)]
- [6] Bhikshma, V, Koti Reddy, M & Srinivas Rao, T 2012, "An experimental investigation on properties of geopolymer concrete (no cement concrete) ", Asian Journal of Civil Engineering (Building and Housing), vol. 13, no. 6, pp. 841-853.
- [7] Flexural Behavior of Concrete Beams Incorporating Iron Ore Tailings [Adesina, Mojeed Adewumi, Federal University of Technology, Minna, August 2021, *Nigerian Journal of Technological Research*, 14(2), 1-9. <https://doi.org/10.4314/njtr.v14i2.1>]
- [8] Experimental and Statistical Evaluations of Strength Properties of Concrete with Iron Ore Tailings as Fine Aggregate [Gayana B. C, Journal of Hazardous, Toxic, and Radioactive Waste, November 2019, Volume 24, Issue 1, [https://doi.org/10.1061/\(ASCE\)HZ.2153-5515.0000480](https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000480)]
- [9] An Experimental Investigation on Strength Parameters of Fly ash Based Geopolymer Concrete with GGBS [K. Vivek et.al, International Research Journal of Engineering and Technology (IRJET), May 2015, Volume: 02 Issue: 02]
- [10] BIS, 456 2000 Code of practice for plain and reinforced concrete
- [11] Shetty MS. Concrete technology: theory and practice. 6th revised. New Delhi: S. Chand; 2012.
- [12] IS 1727: Methods of test for pozzolanic materials
- [13] ASTM C311/C311M: Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- [14] IS 383:1970 Specification for Coarse and Fine aggregates from Natural Sources for Concrete, Bureau of Indian Standard