Study On Geopolymer Concrete with Partial Replacement of Scrap Steel Slag as Coarse Aggregate and Foundry Sand as Fine Aggregate

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***Abstract*—Generation of waste foundry sand and steel slag from the metal casting and steel industries causes significant environmental problems due to improper disposal. This research investigates the production of low cost, eco-friendly geopolymer concrete by utilizing these industrial by products. Experimental investigations were conducted on concrete containing waste foundry sand (WFS) as a partial replacement for fine aggregate (0%,20%, 40%) and steel slag as partial replacement for coarse aggregate (0%,20%, 40%) in M-40 grade concrete. The mechanical properties, including compressive and split tensile strength, were tested at 7, 14, 28 days. Results indicate that while replacement leads to a slight decrease in strength compared to conventional geopolymer concrete, the 20% steel slag and 25% foundry sand mix showed the most promising results for sustainable construction.**

Index Terms—Geopolymer concrete, waste Foundry Sand, Steel Slag, Compressive Strength.

I. INTRODUCTION

Geopolymer concrete is an emerging sustainable alternative to conventional cement-based concrete, offering reduced carbon emissions and improved durability. This study focuses on the use of industrial by-products—scrap steel slag as a partial replacement for coarse aggregate and foundry sand as a substitute for fine aggregate—in geopolymer concrete. By incorporating these waste materials, the research aims to enhance resource efficiency, minimize environmental impact, and evaluate the mechanical and durability properties of the resulting concrete. The study ultimately seeks to demonstrate a viable approach to sustainable construction through effective waste utilization.

Also focuses on the use of geopolymer concrete with partial replacement of natural aggregates using industrial waste materials. Scrap steel slag is utilized as a substitute for coarse aggregate, while foundry sand is used as a replacement for fine aggregate. These materials, often considered waste, pose environmental disposal challenges but possess suitable physical and mechanical properties for construction applications.

The primary objective of this research is to evaluate the performance of geopolymer concrete incorporating steel slag and foundry sand, particularly in terms of strength, durability, and workability. By integrating these waste materials, the study aims to promote sustainable construction practices, reduce environmental impact, and enhance resource efficiency in the construction industry.

II. OBJECTIVE

The objectives of this study include:

- To evaluate the behavior of geopolymer concrete with partial replacement of foundry sand and steel slag.
- To assess the cost-effectiveness of using these waste materials compared to conventional concrete.
- To develop an eco-friendly concrete solution by utilizing industrial waste.
- To study the performance of scrap steel slag as coarse aggregate and foundry sand as fine aggregate in geopolymer concrete.
- To formulate mix designs for various percentages of geopolymer concrete.

- To investigate the flexural strength, split tensile strength, compressive strength, and deflection of beams.

III. MATERIALS USED

CEMENT:

Ordinary Portland cement is composed of calcium silicate, calcium aluminate and alumina ferrite. It is obtained by blending predetermined proportions limestone clay and other minerals in small quantities which is pulverized and heated at high temperature around 1500 degree centigrade to produce clinker. The clinker is then ground with small quantities of gypsum to produce a fine powder called Ordinary Portland cement (OPC).

Table 1 Properties of Cement

Properties	Results
Specific Gravity	3.15
Fineness	7.2%
Initial Setting Time	40 min
Final Setting Time	10 hrs.

AGGREGATE:

Normally Sand is used as fine aggregate for preparing concrete. An individual particle in this range is termed as Sand grain. These sand grains are between coarse aggregate (2mm to 64mm) and silt (0.004mm to 0.0625mm). Aggregate most of which passes through 4.75mm sieve is used. The Coarse aggregate for the work should be river gravel or crushed stone. Angular Shape aggregates of size is 20mm and below. The aggregate which passes through 75mm sieve and retain on 4.75mm are known as coarse aggregate.

Table 2 Properties of Fine Aggregate

Properties	Results
Specific Gravity	2.40
Water Absorption	0.8%
Fineness	29.52%

Table 3 Properties of Coarse Aggregate

Properties	Results
Specific Gravity	2.36
Fineness	21.5%
Water Absorption	0.5%

Waste Foundry Sand (WFS)

Waste foundry sand (WFS) is a by-product generated from metal casting industries, where high-quality silica sand is used to create molds and cores for shaping molten metal. After repeated use, the sand loses its binding properties and is discarded as waste.

WFS typically contains fine silica particles along with residual binders such as clay, resins, and small amounts of metal impurities. Due to its fine texture and uniform grain size, it can be effectively used as a partial replacement for natural fine aggregate (sand) in concrete and other construction materials.

Fig. 1 Waste Foundry Sand

Utilizing waste foundry sand in construction helps reduce the demand for natural river sand, minimizes landfill disposal, and promotes sustainable waste management. However, its use must be carefully controlled, as excessive replacement may affect the strength and workability of concrete.

Table 4 Properties of Waste Foundry Sand

Properties	Results
Specific Gravity	2.13
Water Absorption	13%
Fineness	29.52%

Steel Slag:

Fig. 2 Steel Slag

Steel slag is a by-product obtained during the manufacturing of steel in industries, particularly from processes such as basic oxygen furnaces and electric arc furnaces. It is formed when impurities in molten steel react with fluxes like lime, resulting in a hard, stone-like material. Steel slag possesses high strength, good durability, and excellent resistance to abrasion, making it suitable for use as a construction material. It is commonly used as a partial or full replacement for coarse aggregate in concrete, road construction, and pavement layers. The use of steel slag in concrete helps conserve natural aggregates and reduces environmental pollution caused by industrial waste disposal. However, proper processing and aging of steel slag are necessary to avoid issues like expansion due to the presence of free lime and magnesium.

Table 5 Properties of Steel Slag

Properties	Results
Specific Gravity	3.10
Water Absorption	0.79%

IV. EXPERIMENTAL METHODS

1. Concrete Mix Design
The mix design is done by the various proportions of materials for M40 grade concrete which is used in the present study. Then the mix design is designed as per IS 10262-2009 standards.

Table 6 Mix Proportion

Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water kg/m^3
386.73	618.50	743.40	113
1	1.60	1.92	0.30

2. Casting of Specimen:
Cubes of Size 150mm x150mm x150 mm, Cylinder of size 200mm x 300 mm, Beam of size 700mm x 150mm x 150mm were casted. The materials which are mixed by coarse aggregate, fine aggregate, cement, with partial replacement of various percentages of steel slag as coarse aggregate, waste foundry sand as fine aggregate and water. After the molds were casted and compacted. Demoulding was done after 24 hours of casting and specimens were allowed to cured in a water tank.

V. CONCRETE TESTS AND RESULTS FRESH CONCRETE TESTS

SLUMP CONE TEST in M40 Grade Concrete

Table 7 Slump Cone Test

Sl. No.	% Replacement	Slump (mm)
1	0%SS + 0% WFS	33
2.	2.5%SS + 2.5% WFS	45
3.	5 %SS + 5% WFS	67
4.	7.5 %SS + 7.5% WFS	83

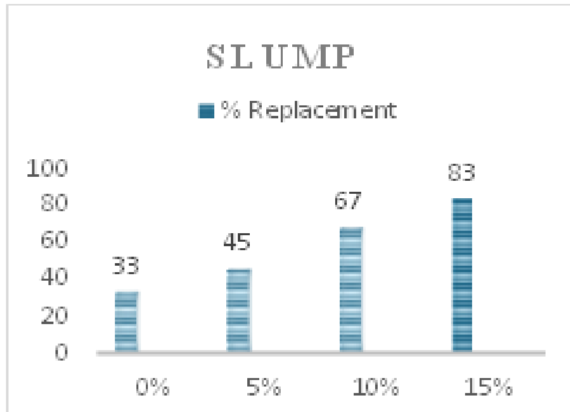

Fig.3 Slump Cone Test HARDENED CONCRETE TEST

The individual variations of specimen were not more than ± 15 percent of the average. The specimen stored in water was tested immediately on the removal from the tank. The specimen was wiped off and the dimensions of the specimen and their weight were recorded before testing. The bearing surface of the testing machine were wiped clean the other materials, which may come in contact with the compression plates. While placing in the cube in the machine, care was taken such that the load was applied to opposite side of the cube as casted and not to the top and the bottom. The maximum load applied to the specimen was recorded and any unusual appearance in the type of failure was noted.

COMPRESSIVE STRENGTH OF CONCRETE

Table 8 Compressive Strength Test

Sl. No.	% Replacement	Compressive Strength N/mm^2		
		7 days	14 days	28 days
1	0%SS + 0% WFS	29.05	34.60	37.80
2.	2.5%SS + 2.5% WFS	26.63	33.80	36.49
3.	5 %SS + 5% WFS	31.50	38.46	41.75
4.	7.5 %SS + 7.5% WFS	18.41	24.68	29.10

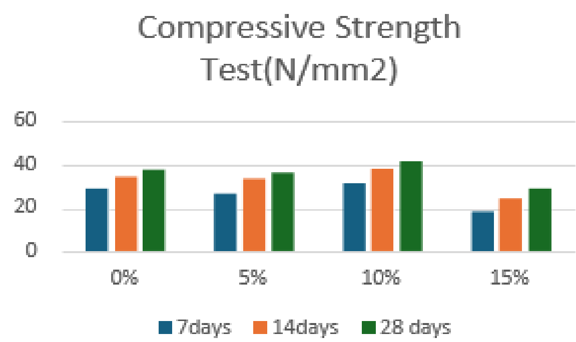

Fig.4 Compressive Strength Test

SPLIT TENSILE TEST

The test provides an indirect measure of tensile strength, commonly expressed as modulus of rupture, and is important for understanding the cracking behavior and flexural performance of concrete, including geopolymer concrete mixes.

Table 9 Split Tensile Test

Sl. No.	% Replacement	Compressive Strength N/mm^2		
		7 days	14 days	28 days
1	0%SS + 0% WFS	2.27	2.90	2.67
2.	2.5%SS + 2.5% WFS	2.48	2.65	2.44
3.	5 %SS + 5% WFS	2.68	2.90	2.86
4.	7.5 %SS + 7.5% WFS	2.24	2.48	2.68

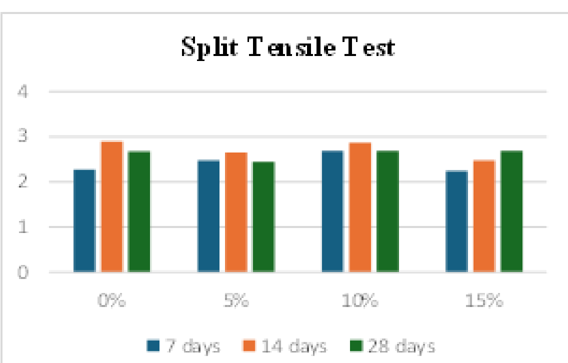

Fig. 5 Split Tensile Test

FLEXURAL STRENGTH TEST RESULT BY USING ANSYS SOFTWARE

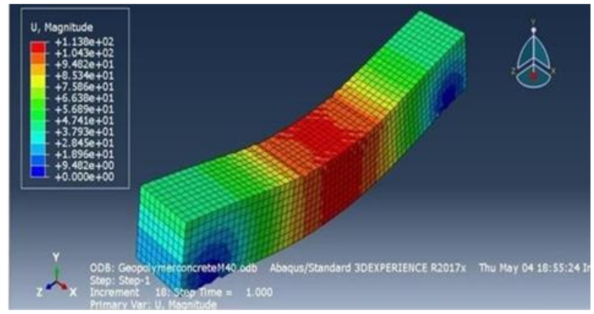

Fig. 6 Flexural Strength of Beam

VI. CONCLUSION

This study demonstrates that geopolymer concrete incorporating partial replacement of scrap steel slag as coarse aggregate and foundry sand as fine aggregate is a viable and sustainable alternative to conventional concrete. Based on the experimental results, it is observed that moderate replacement levels improve the performance of geopolymer concrete. In particular, the mix with 5%, 10%, 15% of steel slag and foundry sand exhibited better compressive strength and split tensile strength compared to other replacement levels. However, higher replacement percentages resulted in a reduction in strength, indicating the need for optimum proportioning.

Overall, the study confirms that the use of steel slag and foundry sand in geopolymer concrete is both technically feasible and environmentally beneficial. It can be recommended for sustainable construction practices, provided that proper mix design and material proportions are maintained.

Experimental results indicate that, at optimal replacement levels, the concrete exhibits comparable or improved compressive strength, durability, and resistance to chemical attack.

Additionally, the improved interlocking characteristics of steel slag contribute to better bonding within the matrix, while foundry sand enhances particle packing and workability to a certain extent. However, excessive replacement may lead to a reduction in performance, highlighting the need for proper mix optimization. Overall, this study supports the development of cost-effective, eco-friendly construction materials and encourages the broader adoption of geopolymer technology in sustainable infrastructure development.

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