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An Experimental Study on Strength Properties of Concrete Prepared by Partial Replacement of Cement with Red Mud and Fine Aggregate with GGBFS Along with Shredded Steel

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ABSTRACT

This study investigates the mechanical performance of fiber-reinforced concrete incorporating crimped steel fibers and Granulated Blast Furnace Slag (GBFS) manufactured sand (M-sand) as partial replacements for conventional materials. Conventional concrete is strong in compression but weak in tension, and it typically uses natural river sand as fine aggregate. However, excessive sand mining has created significant environmental concerns, necessitating sustainable alternatives.

In this experimental investigation, natural river sand is replaced with GBFS M-sand, a homogeneous fine aggregate produced from gravel crushing processes. Additionally, crimped steel fibers are incorporated to enhance the compressive and tensile strength of concrete. The study further explores the utilization of industrial waste materials such as copper slag, pond ash, red mud, and shredded steel as partial replacements in concrete production.

The primary objective is to identify suitable alternative materials that improve mechanical properties while reducing cement consumption and overall construction costs. The research also aims to evaluate the strength characteristics of modified concrete in comparison with conventional concrete. The use of these waste materials is expected to enhance workability, improve strength performance, and mitigate environmental issues associated with sand mining and industrial waste disposal.

KEYWORDS: *Concrete, fine aggregate, Red Mud, Strength parameter, sustainable construction, waste material.*

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INTRODUCTION

Concrete is one of the most widely used construction materials in the world, with nearly 12 billion tons produced annually according to global estimates. The rapid growth of infrastructure development has significantly increased the demand for cement and aggregates. Over the past two decades, global cement consumption has tripled, largely driven by economic expansion and urbanization. However, this rapid production has led to excessive exploitation of natural resources, environmental degradation, and increased greenhouse gas emissions, contributing to global warming and climate change.

The depletion of natural sand and coarse aggregates has become a major concern due to uncontrolled mining activities. At the same time, industrial and agricultural wastes are accumulating worldwide, creating disposal and environmental challenges. Sustainable construction practices therefore require the identification of alternative materials that can partially replace cement and aggregates without compromising strength and durability.

Concrete a composite material consisting of cement, fine aggregate, coarse aggregate, and water, exhibits different properties in its plastic, setting, and hardened states.

Its key characteristics include workability, strength, durability, cohesiveness, and impermeability. Improving these properties while reducing environmental impact is a major research focus in modern construction technology.

Industrial by-products such as red mud, ground granulated blast furnace slag, pond ash, and agricultural wastes like walnut shell have gained attention as potential replacement materials. Red mud, a residue from alumina production through the Bayer process, is generated in large quantities globally and poses disposal challenges due to its alkaline nature. Similarly, ground granulated blast furnace slag, a by-product of the steel industry, offers improved durability and long-term strength when used in concrete. Steel fibers are also widely used to enhance tensile strength, crack resistance, and impact performance.

This study focuses on the utilization of pond ash and walnut shell as partial replacements for cement and coarse aggregate, respectively, to improve sustainability, reduce construction cost, and enhance mechanical performance. The research aims to compare the strength characteristics of modified concrete with conventional concrete and promote eco-friendly alternatives in construction practices.

METHODOLOGY

A. Mix Design

Concrete mix design was carried out for M30 grade concrete in accordance with IS 10262: 2019 and IS 456: 2000. The exposure condition considered was severe, with a maximum water cement ratio of 0.45. Ordinary Portland Cement Grade 53, natural river sand (Zone II), crushed stone aggregate (10 mm and 20 mm), and super plasticizer were used.

1. Target Strength

Target mean strength was calculated using:
ft = fck + 1.65s

Where
fck = 30MPa
s = 5 MPa

Target strength = 38.25 MPa

2. Water Cement Ratio

Based on trial mixes and workability requirements, a water cement ratio of 0.42 was selected, which satisfies the IS 456 limit for severe exposure (0.45).

3. Water and Cement Content

Estimated water content for 20 mm aggregate = 186 kg per cubic meter.

After slump correction and 23 percent reduction using super plasticizer, final water content = 150 kg per cubic meter.

Cement content = 355 kg per cubic meter.

With 10 percent increase for cementitious material, final cementitious content = 390 kg per cubic meter.

Water cementitious ratio = 0.38

4. Aggregate Proportion

Based on IS guidelines and correction for pumpable concrete:

Coarse aggregate = 1156 kg per cubic meter

Fine aggregate = 786 kg per cubic meter

Final mix proportion (C : FA : CA) = 1 : 2 : 2.9

B. Replacement Strategy

Phase 1: Red Mud as Cement Replacement
Cement was partially replaced by red mud at 2.5 percent intervals up to 15 percent. Due to similar specific gravity to cement, no correction was required.

Phase 2: GGBFS as Fine Aggregate Replacement
Fine aggregate was replaced by GGBFS from 10 percent to 60 percent. Since specific gravity of GGBFS is lower than sand, replacement was done using absolute volume method.

Phase 3: Addition of Shredded Steel Fiber
After determining optimum red mud and GGBFS percentages, shredded steel fibers were added in proportions ranging from 0.25 percent to 1.5 percent by volume.

C. Specimen Preparation and Testing

Concrete specimens were cast and cured under standard conditions. Tests conducted include:
- Slump test for workability
- Compressive strength test
- Split tensile strength test
- Flexural strength test

Testing was carried out at 7, 14, and 28 days.

MATERIAL TESTING

A. Testing of Cement

Ordinary Portland Cement (OPC) 53 Grade of Ultra-Tech brand conforming to IS 8112: 2013 was used in this study. The physical properties and setting characteristics were determined.

1. Fineness Test

The fineness of cement was determined using a 90 micron sieve.

Trial	Weight of Cement (gm)	Weight Retained (gm)	% Fineness
1	200	16.20	8.10%
2	200	15.90	7.95%
3	200	15.80	7.90%

Average fineness = 8%
(Specification: Less than 10%)

2. Physical Properties of Cement

Property	Observed Value	Standard Requirement
Grade	OPC 53	OPC 33, 43, 53
Specific Gravity	3.15	3.15
Initial Setting Time	35 min	Minimum 30 min
Final Setting Time	245 min	Maximum 600 min
Normal Consistency	33%	26–33%

All values satisfy IS requirements.

B. Testing of Fine Aggregate

Fine aggregate used was natural river sand.

1. Silt Content Test

Conducted as per IS 2386 (Part II): 1963.

Trial	Silt Height (mm)	Sand Height (mm)	% Silt Content
1	9.5	300	3.17
2	7.5	270	2.78
3	8	280	2.86

Average silt content = 2.93%
(Permissible limit = 6%)

2. Sieve Analysis

Sample weight = 1000 g

The fineness modulus obtained = 2.80

The grading falls under Zone II as per IS 383: 1970, which is suitable for concrete production.

C. Testing of Coarse Aggregate

Sample weight = 5000 g

Sieve analysis was performed and fineness modulus obtained was 7.03. The aggregate grading was within permissible limits for 20 mm nominal size aggregate.

D. Sieve Analysis of GGBFS

Sieve analysis confirmed that GGBFS grading falls under Zone III as per IS 383: 1970. The particle size distribution makes it suitable for partial replacement of fine aggregate.

TESTING OF CONCRETE

A. Slump Cone Test

The slump cone test was conducted to determine the workability of fresh concrete. This test measures the consistency of concrete and its ability to flow and compact without segregation. The slump value obtained for the control mix was approximately 80 mm, indicating medium workability suitable for reinforced concrete works.

B. Compressive Strength Test

Compressive strength was determined using a Compression Testing Machine (CTM) as per IS 516 and IS 15658: 2006. Cube specimens were tested at 7, 14, and 28 days. The average of three specimens was taken as the compressive strength value.

C. Flexural Strength Test

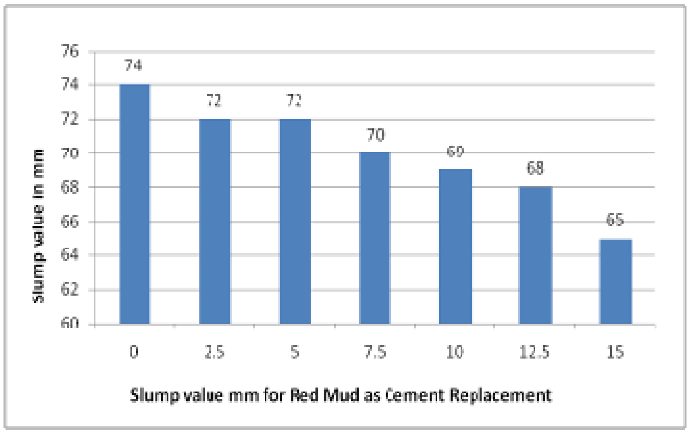
Flexural strength was determined as per IS 516: 1959 using prism specimens of size 700 mm × 150 mm × 150 mm. The load was applied at a constant rate until failure.

RESULTS

Workability of Concrete

Table No 1 ***Slump value on cement replacement***

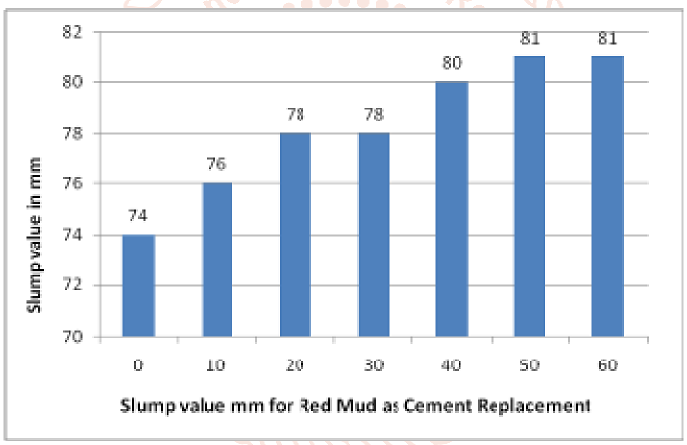
%replacement	0	2.5	5	7.5	10	12.5	15
Slump value, mm for Red mud as Cement replacement	74	72	72	70	69	68	65



Graph 1. ***Graphical Representation of variation of slump value on cement replacement***

Table No 2 ***Slump value on sand replacement***

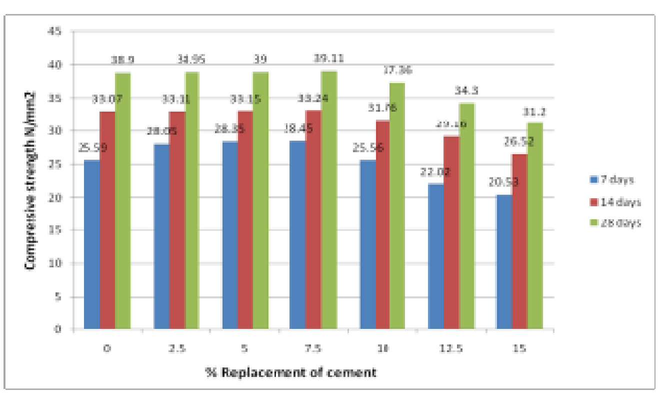
%replacement	0	10	20	30	40	50	60
Slump value, mm for GGBFS as sand replacement	74	76	78	78	80	81	81



Graph 2 Graphical Representation of variation of slump value on sand replacement

Table. 3 Compressive strength of sample containing Red mud as Cement Replacement

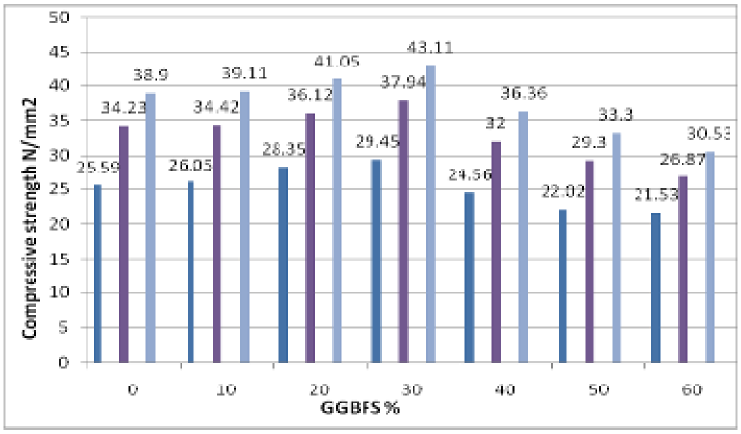
Compressive strength (N/mm²) on Cement replacement							
% replacement	0	2.5	5.0	7.5	10.0	12.5	15.0
Compressive strength MPa after7 days	25.59	28.05	28.35	28.45	25.56	22.02	20.53
Compressive strength MPa after 14 days	33.07	33.11	33.15	33.24	31.76	29.16	26.52
Compressive strength MPa after 28 days	38.90	38.95	39.0	39.11	37.36	34.30	31.20



Graph 3. ***Compressive strength contain of red mud***

Table No 4 ***Compressive strength of containing GGBS***

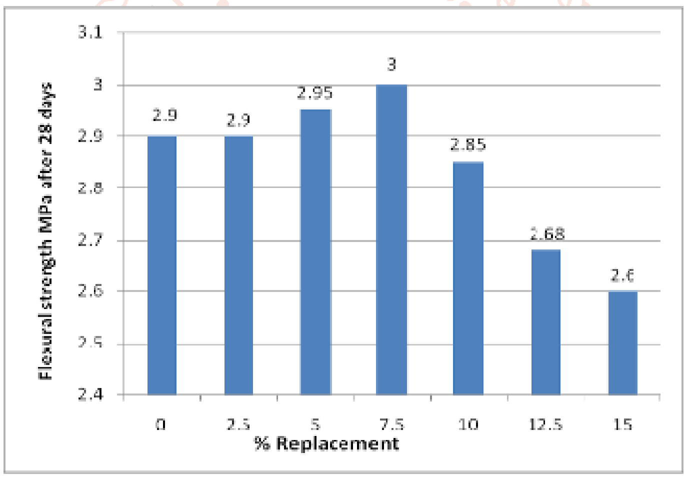
Compressive strength (N/mm2) on Sand replacement							
GGBFS%	0	10	20	30	40	50	60
Compressive Strength MPa after 7 days	25.59	26.05	28.35	29.45	24.56	22.02	21.53
Compressive Strength MPa after 14 days	34.23	34.42	36.12	37.94	32.00	29.30	26.87
Compressive Strength MPa after 28 days	38.90	39.11	41.05	43.11	36.36	33.30	30.53



Graph 4 ***Compressive strength of containing GGBS***

Table 5 Flexural Strength of M30 having cement replacements

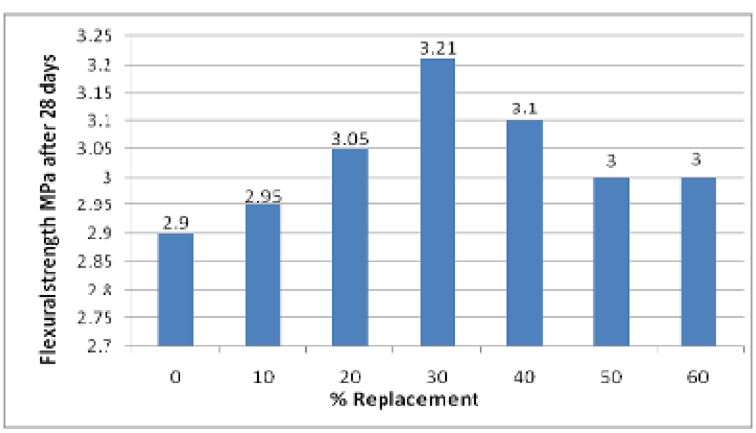
%replacement	0	2.5	5.0	7.5	10.0	12.5	15.0
Flexural strength MPa after 28 days for cement replacement	2.90	2.90	2.95	3.00	2.85	2.68	2.60



Graph 5 ***Flexural Strength of M30 having Cement replacement***

Table 6 Flexural Strength of M30 having sand replacements

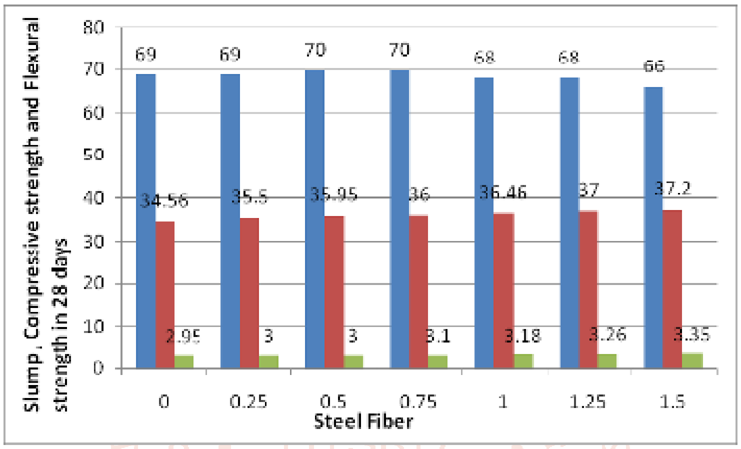
%replacement	0	10	20	30	40	50	60
Flexural strength MPa After 28 days For CS Replacement	2.90	2.95	3.05	3.21	3.10	3.00	3.00



Graph 6 ***Flexural Strength of M30 having sand replacement***

Table 7 Flexural Results for optimum replacements

Sample ID	Steel Fiber %	Observed Slump in mm	Observed 28 days Compressive strength in MPa	Observed 28days Flexural strength in MPa
CONCRM+GG	0	69	34.56	2.95
RM+GG+SF0.25	0.25	69	35.50	3.00
RM+GG+SF0.50	0.5	70	35.95	3.00
RM+GG+SF0.75	0.75	70	36.00	3.10
RM+GG+SF1.00	1.0	68	36.46	3.18
RM+GG+SF1.25	1.25	68	37.00	3.26
RM+GG+SF1.50	1.5	66	37.20	3.35



Graph 6 *Flexural* Results for optimum replacements

CONCLUSION

- The replacement of cement with Red Mud up to 12.5% resulted in a decrease in slump value, indicating reduced workability of concrete. However, the workability remained within satisfactory limits for construction purposes.
- Partial replacement of sand with GGBFS led to an increase in workability, as observed from the slump value results.
- In terms of compressive strength, the mix containing 30% GGBFS achieved the highest strength at 7, 14, and 28 days, exceeding that of the control mix.
- Similarly, the mix containing 7.5% Red Mud exhibited the maximum compressive strength at 7, 14, and 28 days compared to the control mix.
- The flexural strength of concrete with sand replacement increased with the addition of GGBFS up to 30%, and the GGBFS 30% mix showed the maximum flexural strength.
- The flexural strength of concrete with cement replacement increased with the addition of Red Mud up to 7.5%, and the RM 7.5% mix designation exhibited the maximum flexural strength.
- Based on the overall test results, the mixture containing 30% GGBFS as sand replacement and 7.5% Red Mud as cement replacement can be considered a suitable combination for use in severe environmental conditions without compromising strength.
- The addition of shredded steel fibers enhanced the flexural strength of concrete. Workability and compressive strength were not significantly affected when fibers were added up to 1.5% of cement content.

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