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Red mud as a Sustainable Partial Substitute for Cement in Concrete

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Abstract — The Indian cement industry is facing significant challenges, including scarcity of raw materials, environmental concerns, and increasing demand for sustainable construction materials. This study investigates the feasibility of using Red Mud, a bauxite residue, as a partial replacement for cement in concrete. The research aims to reduce cement consumption, mitigate environmental impacts, and utilize industrial waste. The study involves replacing cement with Red Mud at varying percentages and evaluating the mechanical properties of concrete, including compressive strength, flexural strength, and water absorption capacity. The results show that Red Mud can be used as a viable alternative to cement, improving the sustainability of concrete without compromising its quality. The findings of this research can contribute to the development of sustainable construction materials and utilization of industrial waste, supporting the growth of the construction industry in India.

Keywords — Red Mud, replacement, sustainable.

I. Introduction

The building industry is essential for the advancement in worldwide infrastructure, which is significantly contributing towards economic growth. However, the traditional building techniques, especially the widespread use of Portland cement, have raised environmental concerns due to its large carbon footprint and energy-intensive manufacturing process. Researchers as well as manufacturing experts have been looking for alternative materials that can reduce the environmental effect of cement which resulted in the increased focus on sustainable construction approaches in recent years [1-3].

A feasible approach to achieve sustainability is to replace a portion of the cement with alternative substances. The aim of this research was to investigate the effect of partially replacing cement with red mud in concrete. Significant amount of dust-like, highly alkaline bauxite leftovers known as red mud are produced during the production of alumina from bauxite ore [4-6]. Nowadays, red mud is created in nearly the same mass ratio as metallurgical alumina and dumped in either sealed or unsealed artificial impoundments, or landfills, which poses serious environmental problems [7-9].

Red mud was used as material for partial replacement of cement in the project. The percentage of red mud replaced with cement was 0%, 5%, 7.5%, 10%, 12.5%, 15%, and 17.5%. Tests such as test on hardened concrete was done to determine compressive, flexural and water absorption test were conducted to determine effect of red mud in concrete.

II. Material Properties and Mix Design

A. *The Determination of material properties*

The first stage was choosing the necessary materials required, such as red mud, cement, fine and coarse aggregates, and an appropriate superplasticizer.

1) *Cement:* Ultratech OPC cement 53 grade confirming to IS 12269:2013 had been used for the study. OPC 53 grade was chosen because high strength concrete mix, M40 in this case, demand higher grade cement. Properties such as specific gravity and fineness of cement were found out.

   a) *Specific gravity of Cement:* The specific gravity of cement was determined by Le Chatelier flask test by using Kerosene, which does not react with cement, as the medium as per IS 4031:1988 Part-2.

   b) *Fineness of cement*: Fineness is a measure of total surface area of cement. For finer cements, surface area will be more and fineness influences the rate of hydration, rate of strength development, shrinkage and rate of evolution of heat. The test was conducted using a 90micron sieve as per IS 4031-1996 Part-1.

2) *Fine aggregate:* Particle size less than 4.75mm is considered as fine aggregates. Addition of fine aggregate in concrete increases its compressive strength and also increases its density as fine aggregate would fill in the voids created between the coarse aggregate. Manufactured sand (M Sand) procured locally was used as fine aggregates. Specific gravity of fine aggregate was determined using pycnometer test as per IS 2386:1963 Part 3.

3) *Coarse aggregate:* Coarse aggregates of 20 mm size were procured locally. Specific gravity of fine aggregate was determined using wire basket apparatus as per IS 2386:1963 Part 3. The properties of the materials used in concrete are given in the table I.

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TABLE I: SPECIFIC GRAVITY AND FINENESS OF CONSTITUENT MATERIALS

Sl. No.	Material	Property	Testing apparatus	Result	Specified range as per IS code
1.	Cement	Specific gravity	Le Chatelier flask test	3.05	3.0 to 3.16
2.	Cement	Fineness	90micron sieve	8%	less than 10%
3.	Fine aggregate	Specific gravity	Pycnometer test	2.69	2.6 to 2.8
4.	Coarse aggregate	Specific gravity	Wire basket test	2.76	2.6 to 2.8

4)Red mud: Red mud was procured from HINDALCO Aluminium company, Belgaum, Karnataka. The red mud was oven dried and sieved through 90-micron sieve in order to match the fineness of cement [10].

It was sieved through 90 microns because replacement can be only possible if two materials are of same fineness. The specific gravity of red mud was determined using Le Chatelier’s flask and the specific gravity was found to be 3.15. The chemical composition of red mud collected is given in the table II.

TABLE II: CHEMICAL COMPOSITION OF RED MUD

Composition	Constituent percentage
Ferric oxide (Fe_2O_3)	51.8
Aluminium oxide (Al_2O_3)	17.5
Silicon dioxide (SiO_2)	6.7
Sodium oxide (Na_2O)	3.35
Calcium oxide (CaO)	2.84

5) Admixture: Fosroc Auramix 500 was used, which is a high-performance superplasticizer that complies with IS: 9103-1999 (2007).

B. Mix Design

The mix proportioning consisted of determining the optimal ratios of ingredients like cement, aggregates, water, and sometimes admixtures to achieve desired properties in concrete. The proportion for the M40 project was determined from the workability test performed.

The slump test yielded a 100mm slump at a 10% water reduction and 0.2% admixture in the concrete, maintaining a water-cement ratio of 0.42.

According to IS 10262:2019, the mix proportion obtained was:

- Water = 177.3 kg/m^3
- Cement = 422.142 kg/m^3
- Fine aggregate = 706.76 kg/m^3
- Coarse aggregate = 1163.264 kg/m^3

The mix proportion for the M40 mix, with a water-cement ratio of 0.42, was obtained as 1:1.67:2.75.

III. TEST ON HARDENED CONCRETE

Concrete has mechanical properties such as compressive strength, flexural strength and tensile strength. To evaluate these parameters, test for hardened concrete was used.

The control mix and samples of varying percentages of red mud for all the tests to find out the optimum percentage of red mud which can be replaced with cement were casted. 5%, 7.5%, 10%, 12.5%, 15%, 17.5% of cement were taken as the quantity to be replaced by red mud.

A. Compressive strength

Compressive strength testing is a fundamental aspect for assessing the performance and quality of concrete. It can be defined as the capacity of concrete to withstand loads before failure. This property is crucial in determining the structural integrity and durability of concrete structures. In this study, the compressive strength test of all the concrete mixes was performed on cubes of 15 cm×15 cm×15 cm. The specimens were tested using a compression testing machine with a loading rate of 5.2 kN/s as per Indian Standards (IS 516–1959).

B. Flexural strength

Flexural strength refers to a material's ability to withstand bending or being flexed without breaking or permanently deforming. It measures how much stress or force a material can handle before it fails under a bending load. Flexural strength test was carried out on samples of 50 cm x 10 cm x 10 cm (length x breadth x depth) using concrete beam test apparatus as per the Indian Standard guidelines (IS 516–1959).

C. Water absorption

Water absorption is an indirect measurement of concrete durability. Mostly harmful chemicals are present in water. These chemicals react with concrete ingredients, which changes the properties of concrete. Extra water present in the pores of concrete results in freezing and thawing cycles effect because of the change in temperature, which results in a concrete crack. Therefore, a water absorption test has to be carried out to understand it’s durability nature.

Water absorption test was carried out to find the permeability of the concrete which also exhibits the presence of pores present inside the concrete. For the test, cubes of size 100mm X 100mm X 100mm cured for 28 days as per ASTM C 642**.** After curing, concrete specimens were taken out and kept for oven drying at a temperature of 105°C for 24 h. After oven dry the weights of the specimens are measured (A). After that the specimens were immersed in water for not less than 48 h and the weight of the specimens were measured (B).

The water absorption values are calculated using the formula:

$$\text{Water absorption in \%} = [(B - A)/A] \times 100\%$$

Where, A=oven dry weight and B=surface dry weight

IV. Results of Hardened Concrete Test

A. Compressive strength

TABLE III: COMPRESSIVE STRENGTH OBTAINED ON 7TH AND 28TH DAY OF CURING

Sample	Compressive strength ($\frac{N}{mm}^2$) of 7th day	Compressive strength ($\frac{N}{mm}^2$) of 28th day
RM0	30.97	40.13
RM5	28.1	39.68
RM7.5	34.28	40.22
RM 10	27.99	32.93
RM12.5	22.69	32.73
RM15	21.8	31.69
RM17.5	20.82	28.25

From analyzing the above results in table III, it was observed that at lower replacement levels, the pozzolanic activity of red mud might not have been fully utilized to contribute to the strength development. The 7.5% red mud concrete yielded the highest compressive strength because it enhanced the internal microstructure of concrete, resulting in a dense and optimal morphology which eventually results in required pozzolanic activity [11]. The solid particle filler and ideal size distribution were responsible for increasing all strengths [12]. However, after replacing 7.5% of cement with red mud, an optimal size distribution was not observed, leading to reduced strength and a disturbed microstructure.

B. Flexural strength

TABLE IV: FLEXURAL STRENGTH OBTAINED ON 7TH AND 28TH DAY OF CURING

Sample	Flexural strength ($\frac{N}{mm}^2$) of 7th day	Flexural strength ($\frac{N}{mm}^2$) of 28th day
RM 0	1.57	3.6
RM 5	1.5	5.3
RM7.5	4.5	7.58
RM10	4.25	5.8
RM12.5	4	5.1
RM15	2.75	4.3
RM17.5	3.9	2.3

From the above results in table IV, 7.5% red mud concrete showed higher flexural strength than the other percentage of red mud concrete samples [13]. Here all the specimens were cracked more than 13 cm from the support which makes it true flexural strength. If the distance from the end point of the beam specimen to the support is less than 13 cm, it can lead to inaccurate test results and may not represent the true flexural strength of the concrete. When the distance is too short, the bending moment applied to the beam is concentrated within a limited section, resulting in localized stress concentrations. This can lead to premature failure or even collapse of the beam at a lower load. The stress concentration near the support may not truly reflect the overall behaviour of the beam.

C. Water absorption

From the results of the test in table V, the percentage of water absorption was observed to be decreasing with increase in red mud replacement. The absorption of water by the concrete samples were reduced from 6.13% to 5.36% compared to the normal concrete. The water absorption of RM 7.5 samples (optimum percentage samples) were 0.38% less than the control mix. Red mud additions even above the optimum replacement percentage have a beneficial effect on the concrete samples' ability to absorb water. It can be concluded that increasing the amount of red mud replacement reduces the percentage of water absorption [14].

TABLE V: WATER ABSORPTION ON 28TH DAY OF CURING

Sample	Percentage of water absorption
RM 0	6.13
RM 5	5.82
RM 7.5	5.75
RM 10	5.63
RM 12.5	5.57
RM 15	5.41
RM 17.5	5.36

V. Conclusion

From the experiments conducted, it can be concluded that cement can be partially replaced by red mud in concrete. The compressive and flexural strength of concrete in RM0 and RM7.5 is almost equivalent so there is no compromise in strength of concrete. Comparing values of water absorption, a drop in values is observed which indicate a dense structure and pore filling property [15]. The red mud when added to concrete enhances its properties as well as promotes sustainability.

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