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An Experimental Study on Strength Characteristics of M40 Grade Concrete by Partial Replacement of OPC by Red Mud and Hydrated Lime

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A B S T R A C T
Rapid industrialization results in a high volume of waste disposal, which in turn creates environmental risks. When used in the optimal way, these wastes can replace conventional materials. The disposal of red mud, a waste product produced by the aluminium industry's Bayer's process that produces an average of 4 million tonnes of waste annually, is a significant issue for these industries because the waste products' complex physio-chemical characteristics make them highly caustic and cause ground water contamination, which poses health risks. Utilizing the waste materials and by-products produced by industry in cement production and concrete building is crucial for solving this issue.

Massive efforts have been made globally to manage red mud in usage, storage and disposal based on related challenges. As a partial replacement for cement in concrete, aluminium red mud strength qualities are being evaluated as a part of the study. Here, an experiment was conducted to partially replace the Portland cement with red mud in concrete at varying percentages and also examine the impacts on the strength of the concrete by taking the cementitious behaviour of industrial wastes into consideration. Studying the impact of red dirt on the characteristics of M40 grade concrete is one of this work's key goals. Red mud is substituted for cement in quantities ranging from 0% to 50% while maintaining an internal consistency of 10% to create samples. A 5% addition of hydrated lime improves the mixtures binding abilities.

KEYWORDS
Fineness Modulus
Specific Gravity
Initial Setting Time
Final Setting Time
Red Mud
Hydrated Lime
Fine Aggregate
Coarse Aggregate
Water Absorption
Gradation Zone
Compressive Strength
Split Tensile Strength
Flexural Strength
Crushing Value
Water Cement Ratio

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I. INTRODUCTION

1.1General

India is said to be one of the richest country in mineral deposits. India ranks among the top ten countries in terms of mineral production. The mineral industries play a vital role in the Indian economy, as many industrial activities depends on minerals as raw materials. Red mud may be produced in large quantities during the mining and extraction of resources.

As the population of India continues to grow, so does the amount of solid dry waste that is generated from industries and agriculture. This poses a major problem for the country, as there is a shortage of land to deposit the waste and recycling methods are costly. Utilizing industrial waste to make concrete is one creative solution to this issue. This would provide a sustainable and cost-effective solution for disposing of solid waste while also creating a useful product.Utilizing solid waste in concrete has two benefits: it is may be cost effective and will aid in reducing environmental pollution.

Red mud is an industrial waste product produced during the aluminum manufacturing process. Bauxite ore is mined and processed to create aluminum, which is then used in a variety of industries such as food packaging, construction, electronics, defense and transportation. Aluminum is preferred over other metals due to its light weight, high strength, and recyclability.

The sinter process, Bayer process and combined process are only a few of the methods used to extract aluminium from bauxite. The Bayer process is the one that produces aluminium the most frequently out of all these techniques. Before being milled at high pressure and temperature, bauxite is first wet washed and ground into a powder. The bauxite ore is subsequently treated with caustic soda, resulting in the formation of a sodium aluminate solution and an undissolved residue.Red mud, also known as bauxite residue, is a byproduct of the aluminium manufacturing process. It is often discharged into residual ponds and is quite caustic. However, this waste product contains valuable minerals like silicon, iron and titanium, which can be recovered and reused.

1.2Objective of the Study

- Using cementation materials instead of CO-emitting cement manufacturing processes can help reduce emissions. Additionally, the utilization of industrial waste products can provide a sustainable solution for waste management.
- The goal of this investigation was to find out how red mud affected the characteristics of fresh and cured concrete. In addition, the study looked at the effect of adding lime to red mud, as well as using red mud without lime.
- The production of concrete is a vital process that has a significant impact on the environment. There is a need for more durable and sustainable concrete.
- Finding out weather industrial solid waste can be utilized as a raw material, blending material or additive is the goal of this study.
- It is vital to evaluate compatibility before deciding if industrial solid waste is appropriate as a source material, blending ingredient or additive.
- To encourage the use of industrial waste, recommendations are made to support its utilization.

II. LITERATURE REVIEW

2.1 General

[1] Tejaswini. C [2019]

The strength characteristics of concrete are reduced when red mud content rises. Red mud might however be used in concrete as a component of sustainable development. As the content of red mud increases, the carbonation rate falls. Red mud is hence more corrosion resistant. A great way to lessen environmental pollution and the carbon footprint of the building sector is to utilize red mud in concrete. Iron oxide is abundant in red mud a byproduct of the aluminium manufacturing process. Red mud can increase the concrete resistance to sulphate attack when used in place of some cement. Red mud replacement should be 20% at its ideal content.

[2] Akarsh .N .K [2017]

The study found that substituting Portland cement with red mud is a viable option to help mitigate environmental waste issues. Red mud, a waste product from aluminum production, can be used in up to 40% of the weight of cement without compromising the strength or quality of the final product. By lowering the annual garbage produced this change might have a substantial positive influence on the environment. Compressive, tensile and flexural strength are just a few of the qualities that make concrete a suitable building material. Red mud is a waste product that can be used to enhance these properties.

2.2. Summary of the Literature Review

From the literature studies, it is observed that partial replacement of cement by red mud has shown satisfactory results on compressive strength of concrete. Hence other strength properties like split, flexural are to be experimented for further extensive use of red mud for replacement in cement. However the use of red mud for partial replacement in cement is of very less in the studies conducted by authors, therefore efforts must be made to exploit use of red mud for replacement of cement in concrete for higher replacement.

III. MATERIALS

3.1 Cement

A substance called cement is used in building to bond other materials together after setting and hardening. It is made from a mixture of limestone, clay, and sand, with a small amount of water added to create a paste. This paste is then combined with gravel or sand, and water, which forms a slurry that can be poured or pumped into moulds. The material was procured by locally of OPC 43 grade. The properties of cement are calculated as per IS8112:1989.

3.2 Fine Aggregate

Fine aggregates are the one which occupies 40-50% of volume of concrete, which fills the voids present in concrete especially in coarse aggregate, thus minimizes the permeability by improving the cohesiveness of mix. Manufactured sand (M-sand) was procured from surrounding local market which was easily available and is being used. In accordance with IS 383: 2016, fine aggregate complied with zone II. The tests were conducted as per IS 2386: 1963.

3.3 Coarse Aggregate

This study used angular, coarse aggregate that was crushed and naturally sourced. The aggregate size was restricted to 20 mm or less. Tests were conducted in accordance with IS 2386:1963.

3.4 Red Mud

Red mud, commonly referred to as bauxite residue, is a byproduct of the Bayer process used to convert bauxite into alumina. Its red hue is a result of iron oxides, one of several oxide compounds that make up its makeup. Red mud is a hazardous waste material with the potential to cause environmental damage if not properly managed. An unwanted byproduct of the aluminiummanufacturing process is red mud. It is typically dumped in landfills, but can also be used in various applications, such as cement production. In this research, red mud was partially replaced with conventional cement at different percentages (10%, 30%, and 50%). The specific gravity of the product is 3.15 and its density is 2.70g/cm^3.

3.5 Hydrated Lime

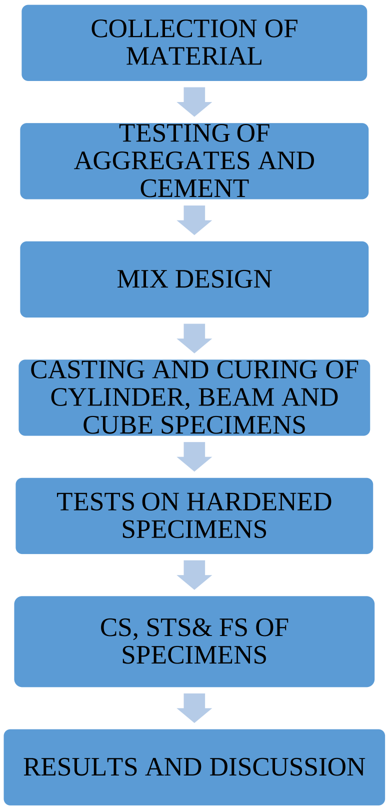
Calcium hydroxide, a kind of lime produced by combining water with calcium oxide (quicklime). This process is known as "slaking." Hydrated lime is used in many different industries, such as construction, painting, and leather tanning. It can also be used in the production of cement, mortar, plaster, and rubber. In this research, the cement is partially replaced with hydrated lime at a dosage of 5%. The specific gravity of the material is 2.25 and its density is 1.5g/cm^3.

3.6 Water

Water is essential to the creation of concrete because it facilitates the chemical interaction between cement and water. Portable water is best. The water used to mix concrete must be clear and devoid of salts, acids, alkalis, and other dangerous substances. Curing of blocks should also be done with clean water to prevent any damage or deterioration. The pH value of the water is 6.

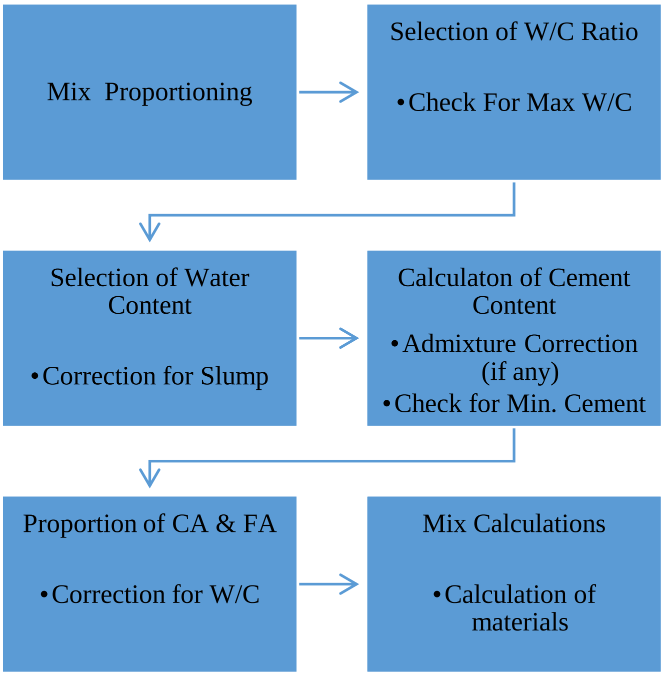
IV. EXPERIMENTAL METHODOLOGY AND INVESTIGATION

4.1 Methodology



- Developing different grade of concrete mixes by IS 10262:2019.
- Number of trial mixes were conducted.
- Then assess the fresh properties of concrete as per code provision.
- Next, the 100x100x100mm cubes were cast to be tested for compressive strength after seven and twenty-eight days, respectively.
- The 100x200mm cylinders were then cast, and their split tensile strength was evaluated after 7 and 28 days, respectively.
- After that, 100x100x500mm beams were cast to test their flexural strength after seven and twenty-eight days, respectively.

4.2 Mix Design – IS 10262:2019



4.3 Typical Mix Design:

Step 01 Proportioning
Concrete Grade = M40
Cement Grade = OPC 43 Grade
Nominal size of aggregate = 20mm
Type of mineral admixture = Red mud and Lime
"Minimum cement content and maximum water cement ratio = Sever
Workability = 100mm (slump)
Method of concrete placing = Pumping
Degree of supervision = Good

Step 02 Test Data
Cement used = OPC 43 Grade
SG of cement = 3.15
SG of RM = 3.14
SG of HL = 2.25
SG of CA = 2.7
SG of FA = 2.63
WA of CA = 0.60
WA of FA = 2.32

Step 03 Target Strength
F'ck = fck + 1.5 x SOrF'ck = fck + X
From table – 2 (IS 10262:2019) S = 5N/mm^2
From table – 2 (IS 10262:2019) X = 6.5
Therefore
F'ck = fck + 1.5 x 5
= 48.25N/mm^2.
F'ck = fck + 6.5
= 46.5N/mm^2.

Step 04 Approximate air content
From Table – 3 (IS 10262:2019) approximate amount of entrapped is 1.0 percent for 20mm nominal size aggregate.

Step 05 Selection of water cement ratio
From Fig – 1 (IS10262:2019) free W/C required for 48.25N/mm^2 is 0.36 for OPC 43 Grade. This is lower than 0.45 from table – 5 of (IS456)
0.36 < 0.45, hence OK.

Step 06 Selection of water content
From Table – 4 (IS10262:2019) water content = 186kg (for 50mm slump) of 20mm aggregate.
Estimate water content for 100mm slump. Increasing at the rate of 3% for every 25mm raise in slump.
= 186 + $\frac{6}{100}$ x 186
= 197.16kg

Step 07 Calculation of cement content
W/C = 0.36
Cement content = $\frac{197}{0.36}$= 547.22 kg/m^3
Cementitious material content = 547 x 1.10 = 601.942kg/m^3
W/C = $\frac{197}{602}$ = 0.327
RM @ 10% of total cementious materials = 602 x $\frac{10}{100}$ = 60kg/m^3.
HL @ 5% of total cementitious material = 602 x $\frac{5}{100}$ = 30kg/m^3.
Cement = 602 – (60 + 30) = 512kg/m^3.
From table – 5 of (IS456) minimum cement content = 320kg/m^3.
512 > 320, hence OK.

Step 08 Proportion of volume of coarse aggregate
From table – 5 of (IS10262:2019) volume of coarse aggregate to 20mm size aggregate and fine aggregate (Zone II) for water cement ratio of 0.50 = 0.60.
In the present case water cement ratio is 0.327. The water cement ratio is less than 0.173 the proportion of volume of coarse is increased by 0.0347
(At ± 0.01 for using ± 0.05 change in water cement ratio)
0.327 = 0.60 + 0.0347
0.327 = 0.6347
For pump able concrete coarse aggregate is reduced by 10%
Volume of coarse aggregate = 0.6347 x 0.9 = 0.57^3.
Volume of fine aggregate = 1 – 0.57 = 0.43m^3.

Step 09 Mix calculation
a. Total volume = 1m^3.
b. Volume of air in concrete = 0.01m^3.
c. Volume of cement = $\frac{512}{3.15}$ x $\frac{1}{100}$= 0.163m^3.
d. Volume of red mud = $\frac{60}{3.14}$ x $\frac{1}{100}$ = 0.0193m^3.
e. Volume of lime = $\frac{30}{2.25}$ x $\frac{1}{100}$ = 0.013m^3.
f. Volume of water = $\frac{197}{1}$ x $\frac{1}{1000}$ = 0.197m^3.
g. Volume of all in aggregate = (1 – 0.01) – (0.163 + 0.013 + 0.019 + 0.197)
= 0.598m^3.
h. Mass of coarse aggregate = 0.598 x 0.57 x 2.7 x 1000
= 920kg/m^3.
i. Mass of fine aggregate = 0.598 x 0.43 x 2.63 x 1000
= 676kg/m^3.

Step 10 Mix calculation
- Cement = 512 kg/m^3.
- Red mud = 60 kg/m^3.

- Lime = 30 kg/m^3.
- Water = 197 kg/m^3.
- Fine aggregate = 676 kg/m^3.
- Coarse aggregate = 920 kg/m^3.

Step 11 Adjustment on water for fine and coarse aggregate

- Fine aggregate = $\frac{676}{1+\frac{2.32}{100}}$ = 661kg/m^3.
- Coarse aggregate = $\frac{920}{1+\frac{0.6}{100}}$ = 915kg/m^3.
- The extra water to be added
- For fine aggregate = 676 – 661 = 15kg.
- For coarse aggregate = 920 – 915 = 5kg.
- The estimated water to be added = 197 + 5 + 15 = 217kg/m^3.

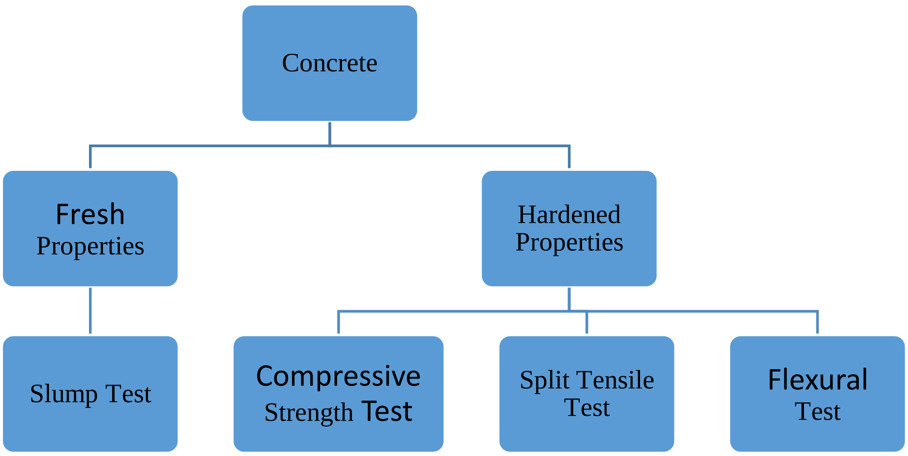
Step 12 Mix proportion after adjustment for wet aggregates

- Cement = 512 kg/m^3.
- Red mud = 60 kg/m^3.
- Lime = 30 kg/m^3.
- Water = 217 kg/m^3.
- Fine aggregate = 676 kg/m^3.
- Coarse aggregate = 920 kg/m^3.

4.4 Preparation of concrete

4.5 Testing the Fresh Properties and Hardened Properties of Concrete

It was decided that the concrete complied with all criteria after testing its fresh and hardened qualities in accordance with codal provision.



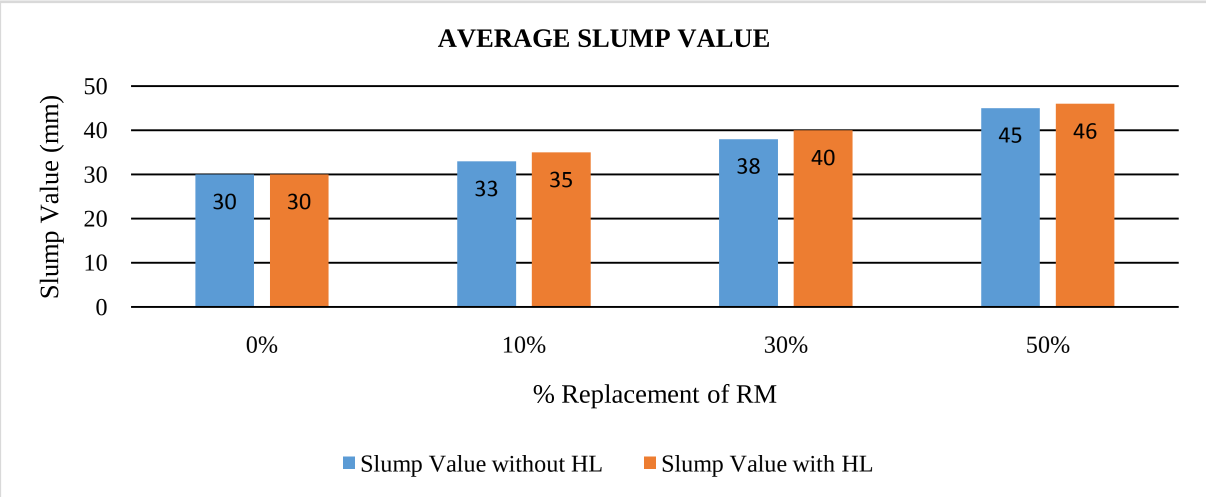
V. RESULTS AND CONCLUSION

5.1 General

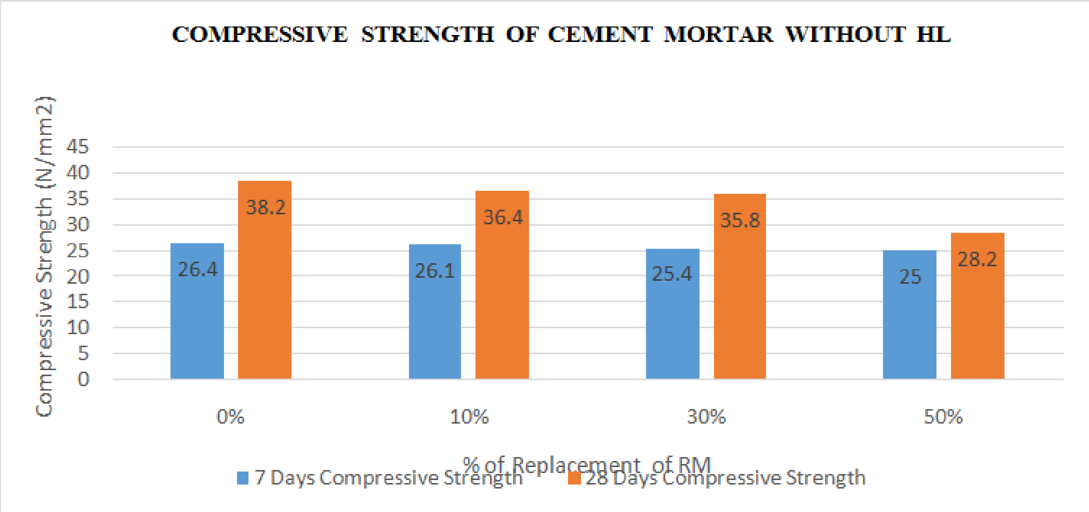
This section consists of test conducted on the specimens, discussions, includes achieving workability of the mixes and includes the comparison of the results so obtained with respect to published literature method for achieving strength of the concrete.

5.2 Fresh Properties

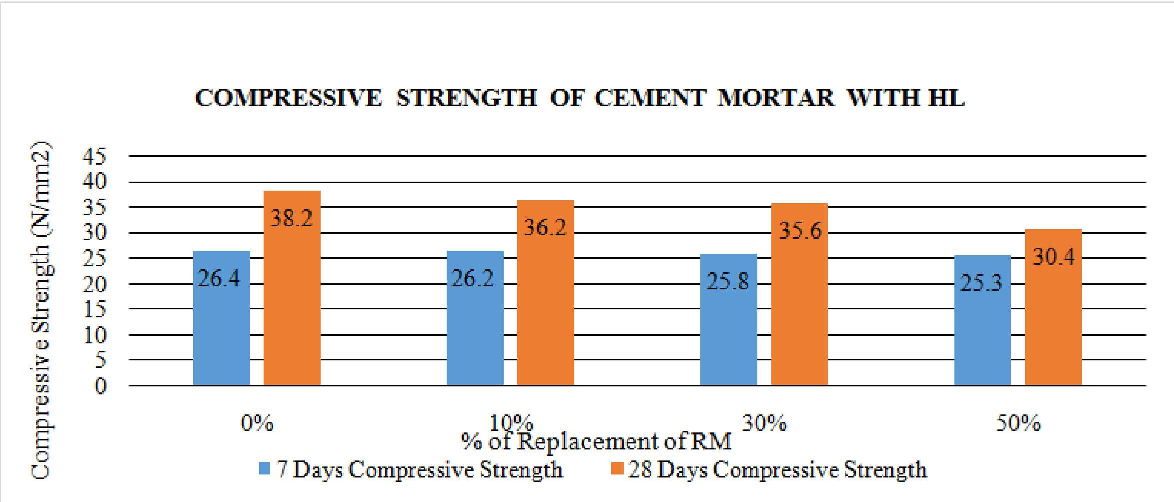
In accordance with IS 1199: 1959, fresh properties tests were conducted to evaluate the concrete mixtures workability in terms of slump. In Tables 4.1 and 4.2, the findings of the concrete mix's fresh characteristics are reported.

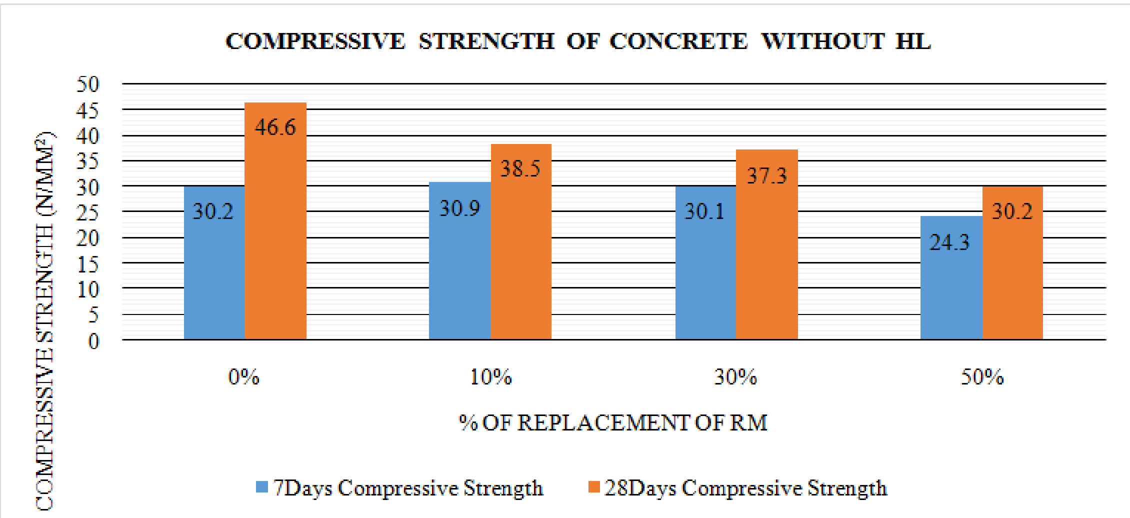


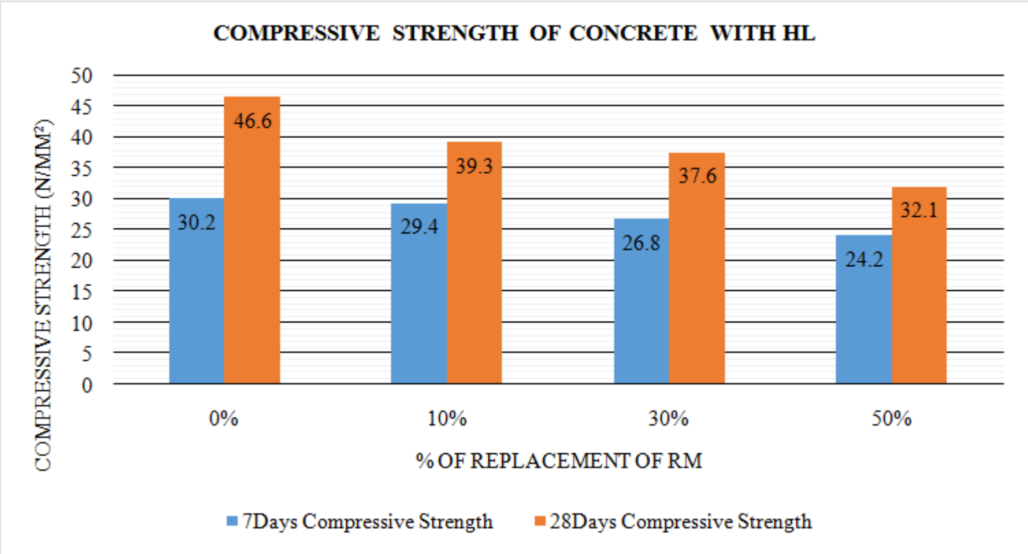
5.3 Compressive Strength Test



Cement cube and concrete cube specimens measuring 70.6x70.6x70.6mm and 100x100x100mm were subjected to a compression test, and six samples were evaluated to determine the average value at 7 and 28 days. According to IS 516-1959, a compressive strength test on a cube is conducted.

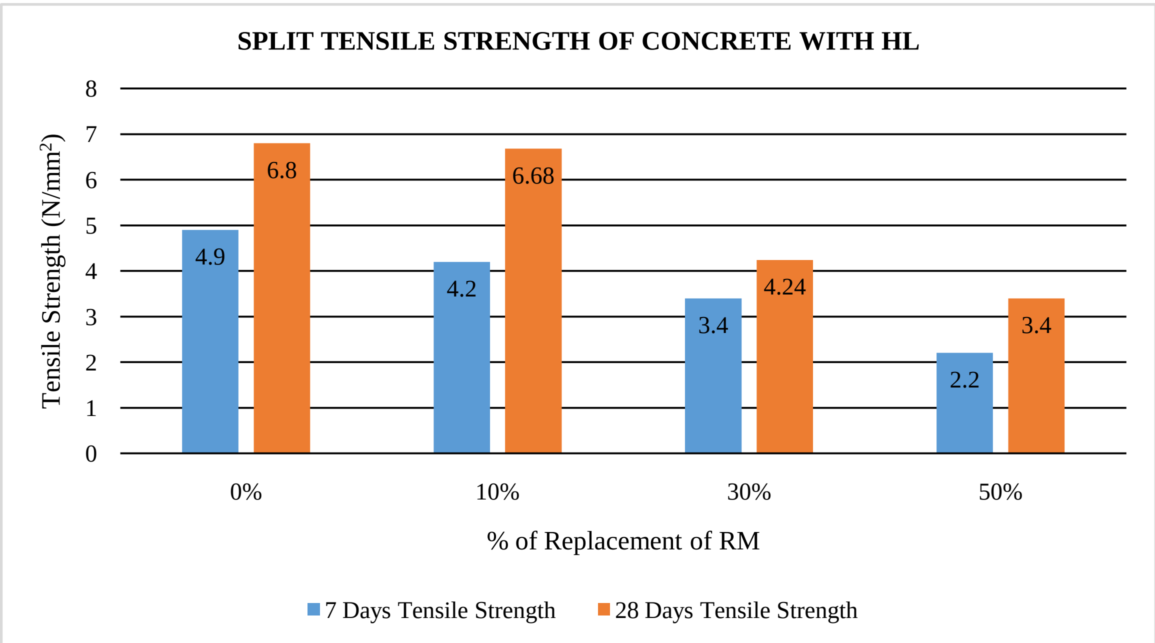


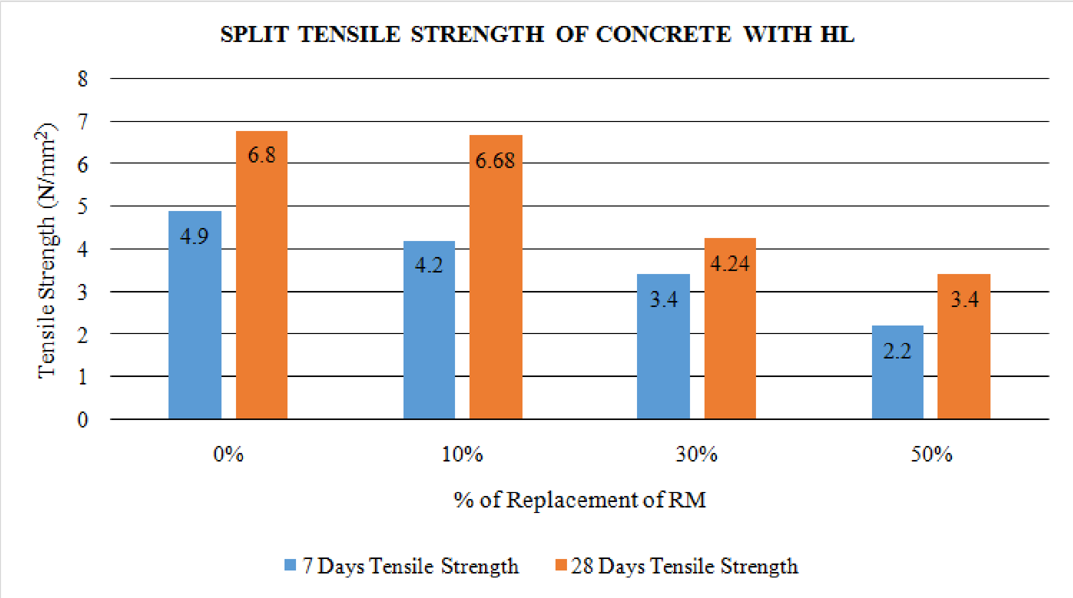




5.4 Split Tensile Strength Test

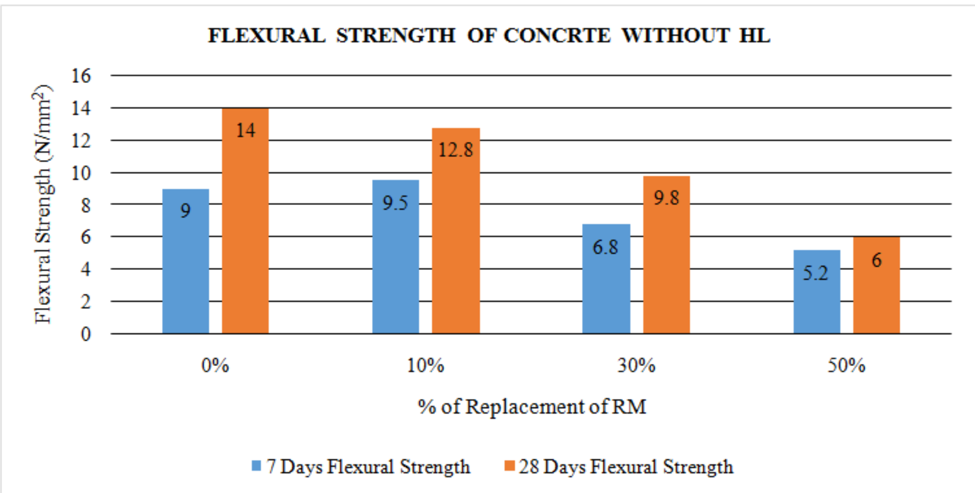
Six samples were evaluated for the tensile strength test on concrete cylinder specimens measuring 100x200mm in order to determine the average value at 7 and 28 days. The test is run with the IS 516-1959 code.

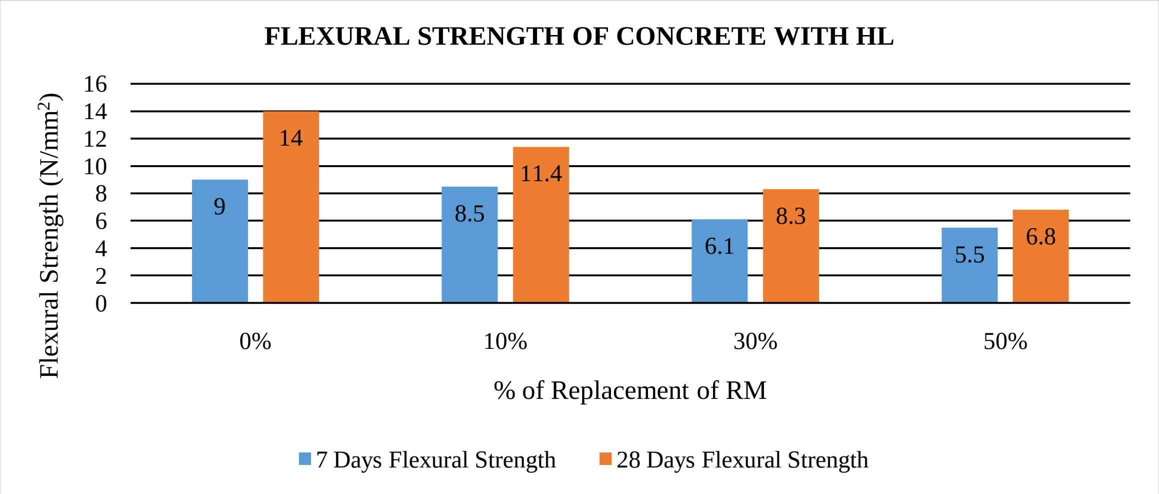




5.5 Flexural Strength Test

The test is carried out on concrete beam specimens of size 100x100x500mm, six number of samples were tested to get the average value at 7 and 28 days. The test is run with the IS 516-1959 code.





5.6 Concluding Remarks

From the above experiment with and without slacked lime along with red mud and cement mix of 1, 2, and 6 as shown better results compared to all mixes due to which use of red mud for replacement in cement may be recommended in the field of construction. Red mud strength qualities are decreased when its content is increased in concrete, yet red mud may still be used in concrete for sustainable development. 10% is the ideal red mud replacement amount. The best method to decrease environmental pollution and the building industry carbon footprint may be to utilize red mud in concrete.

For each percentage replacement up to 50%, the red mud percentage causes a fall in the red mud concrete's compressive strength values. The results of the experimental examination showed that as red mud concentration rises, so does the compressive strength of concrete. The ideal replacement rate for cement in terms of weight is discovered to be 10%. The results obtained through this replacement are almost as those of ordinary concrete.

For non-structural construction red mud and cement are used. From a structural standpoint, red mud concrete use offers possibilities in the future. Red mud may be used to create concrete that is ideal for decorative work and has a pleasing look.

5.7 Future Scope of Work

- In this test, red mud that hasn't been treated is employed. By introducing neutralised red mud, the resea rch may be continued and the qualities can be verified.
- Additional materials for investigation, Red mud may be combined with other materials, like fly ash or GGBS, to explore its properties.

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