An experimental analysis of the utilization of red mud in concrete by Ansys as a primary research method

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ABSTRACT

An increasing amount of red mud (RM) is being generated globally due to the growth in aluminum production. In general, 0.8 to 1.5 tons of RM can be generated per ton of produced alumina. With the rapid development of the aluminum industry, approximately 1.7 billion tons of RM is generated per year globally. The pH of RM is typically 10.5–12.5 owing to the hydroxide (NaOH) added during aluminum production. The case for reusing red mud is not without challenge – the toxic nature of the mud has served as a barrier to reuse. And while more research is needed, recent studies have brought to light the promising potential for red mud to be reused in a variety of applications within the construction industry. In addition to providing an outlet for mass quantity utilization of red mud, studies have found that in many cases, red mud can even offer improvements to the end product.

The purpose of this study is to perform an experimental study on concrete M30 samples considering red mud as a partial replacement of Portland cement by 5%, 10%, 15%, 20%, 25% and 30% RM by wt of cement.

Keywords: Red mud, Compressive strength test, Split tensile test, waste material, concrete, physical properties.

INTRODUCTION

Red Mud, created by the Bayer cycle, is a mechanical waste acquired during the creation of aluminium for every huge load of alumina created, roughly 1.6 huge a lot of red mud are delivered, and it is assessed that in more than 66 million plenty of this waste is yearly produced round the world. The red mud is usually released into marine or arranged on land dirtying the encircling water, air, and soil, particularly within the spaces where this industry is found. Along these lines, steps should be taken to reuse this loss in an eco-accommodating way. By supplanting the red mud as a substitution for concrete in rates from 0% to 40% at an enclosed of 10%.

Red Mud Production

The production of aluminium in China is more than 50% whereas India covers about 5% of the world‘s smelter production. Now days, more and more aluminium industries are being set up resulting in more production of alumina which in turn increases the production of red mud. As it is pertinent from Pie chart, China share in total world‘s production of Aluminium is more than 50% whereas our country‘s share is about 5% from the total world‘s production.

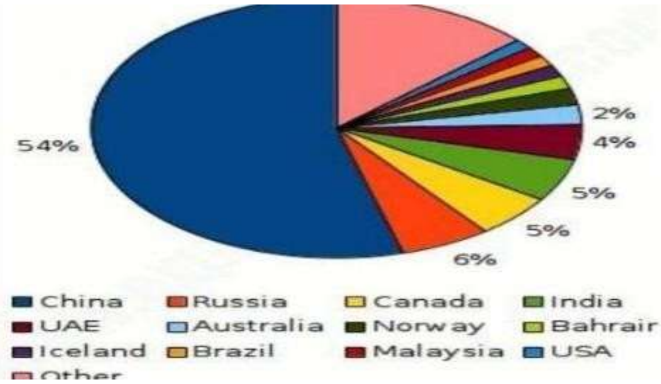


Fig 1: Pie chart indicating the scenario of the percentage of production of Aluminium in the world.

Use of Red Mud in Cement Production

The practicality of red mud in cement production has been studied by different researchers all around the world. In India around two million tonne of red mud is used in cement production. In Japan, red mud is used as raw material with other raw material such as clay and lime stone during the production of cement. The cement developed using red mud also meets with the specification of Standards. It was found that the compressive strength of these cements was comparable to Ordinary Portland Cement. The 28-day compressive strength of cement made with 50% lime, 30% red mud and 20% bauxite was around 10 MPa.

Application of Red Mud in Construction Industry

Red mud, also referred to as bauxite residue, is an industrial by-product of aluminum production. The highly caustic nature of red mud, combined with the vast quantities in which it is produced make it a constant challenge to effectively and safely manage. Historically, the method of managing red mud has been to store it in containment ponds, but this approach is far from perfect; the waste is responsible for devastating a number of areas after containment pond failures. This method of waste management also takes up large sections of land and can pose a variety of additional environmental risks as well.

General Construction Application

- Cement Production (including clinkers, composite cement, and alkali activated cement).
- Pigment in Concrete and Brick.
- Base of Road
- Embankment material.
- Backfill material

Use in Porous Asphalt

A recent study looked at the replacement of limestone powder with red mud in porous asphalt. Porous asphalt is a special type of asphalt employed for the many benefits it can provide. And while the porosity offers many advantages, it can also make the structure more susceptible to wear.

Use in Interlocking Blocks

Researchers in India, where there is a substantial aluminum industry, studied red mud for its use in interlocking blocks – an important material in Indian construction. Using 20-40% red mud as part of the brick‘s makeup, researchers anticipate that bricks composed in part by red mud would reduce the weight of structures, ultimately reducing building and foundation costs.

Challenges in utilization of Red Mud

The reuse of red mud presents a number of challenges that must be overcome while still allowing the intended process to be economical.

The composition of red mud can vary significantly and often contain trace heavy metals, but perhaps the most challenging aspect standing in the way of red mud reuse is its high alkalinity. Depending on the application, this often requires that the material be neutralized first, by one of many methods. Unfortunately, a neutralization method that does not present additional environmental risks and is cost-effective has largely eluded the industry. However, a recent study has found a potential alternative to previously employed neutralization techniques.

REVIEW OF LITERATURE

Lili Kan et.al (2022) research paper focused on studying the properties of Engineered Cementitious Composites with RM as a replacement for FA (i.e. RM-ECCs). A series of experiments were performed to investigate the influences of RM on the mechanical and microscopic properties of the studied system. A DIC technology was employed to allow effective real time observation of the cracking processes under loading.

The results revealed that excellent tensile strain capacities can be achieved by all the studied mixes with different RM ratios and the maximum strain is up to 7.43%. Instead of negatively affecting mechanical properties, RM replacement with the ratios below 10% could improve both tensile and compressive strengths of the mixes. A Digital Image Correlation (DIC) technology was employed to allow effective real time observation of the whole cracking processes under loading. Analysis of the three-point bending and single crack tensile test results indicated that the high tensile ductility of the studied mixes can be explained by the determined meso-scale parameters. The results from SEM-EDS and FT-IR demonstrated that the reaction products are mainly silicate and aluminosilicate gels, and the inclusion of RM modifies the microstructure.

Risabh Vishwakarma et.al (2022) research paper aimed to check the suitability and utilization of neutralized red mud and hydrated lime as a partial replacement of Portland cement in concrete. To develop concrete mix design with industrial waste red mud and hydrated lime, workability of the concrete, compressive strength, Split tensile strength of the concrete and flexural strength of the concrete is determined and comparative study was done.

Testing of concrete degradation capacity increases with a percentage of red mud from 0% to 60% in both liquid and non-aqueous. The amount of compaction factor increases with an increase in the percentage of red mud from 0% to 60% in both wet or non-liquid lime. The highest quality compression was obtained in 10% red mud for 7 days and 28 days for healing. Total total separation and flexibility was observed in 10% red mud for 7 days and 28 days for healing and beyond 10% the divided strength of the divided concrete decreased.

Objectives Behind the Research

The large amount of red mud produced by the alumina industry creates disposal problems, as red mud pollutes the surrounding environment and leads to ecological imbalance.

To develop suitable uses for red mud, concrete in which some of the cement was replaced with red mud may lead to settlement of red mud waste and may enhance the physical and mechanical properties of concrete. In this study, 5%, 10%, 15%, 20%, 25% and 30% of the cement was replaced by red mud. This study has the following objectives as follows:

1. To determine the improvement in compressive strength, durability and tensile strength of concrete using red mud and compare the results with different proportions.
2. To determine the compressive and tensile strength of concrete samples prepared as cubes.
3. To determine split tensile test on concrete sample.
4. To determine the enhancement in concrete and carbon emission using carbonation test.
5. Modelling of red mud soil using analytical application ANSYS and computing results with physical cubes.

MATERIAL AND PROPERTIES

- **Cement**

Ordinary Portland Cement (53 Grade) confirming to IS: 269-1976 was used throughout the investigation. Different tests were performed on the cement to ensure that it confirms to the requirements of the IS specifications.

Fig 2: Cement

- **Coarse Aggregate**

Locally available coarse aggregate having the maximum size of 20 mm down size and confirming to Table 2 of IS 383 are used in the present work. The specific gravity of coarse aggregate is found to be 2.64.

Fig 3: Coarse Aggregate

- **Fine Aggregate**

The sand used for the experimental program is locally available river sand and passing through 4.75mm sieve as per IS 383 provision. The specific gravity of fine aggregate is found to be 2.62. The water absorption test on fine aggregate is found to be 1.0% .

Fig 4: Fine Aggregate

- **Water**

Fresh and clean water is used for casting and curing of specimens. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per requirements of Indian standard. Combining water with a cementitious material forms a cement paste by the process of hydration. A cement paste glues the aggregate together fills voids within it, and makes floor freely.

- **Red Mud**

Red mud is composed of a mixture of solid and metallic oxide-bearing impurities, and presents one of the aluminium industry's most important disposal problems. The red colour is caused by the oxidized iron present, which can make up to 60% of the mass of the red mud. In addition to iron, the other dominant particles include silica, unleached residual aluminium, and titanium oxide. Red mud cannot be disposed of easily.

Red Mud used in Building Material

Building materials (bricks, cement, lime and their subsidiaries) are becoming increasingly uneconomical because of obsol escence, exhaustion of raw materials, low plant efficiencies and increasing costs. The use of red mud as a replacement for cement in the production of cementitious materials with mechanical, microstructure, and hygroscopic properties which is suitable to use in the civil construction sector has been demonstrated. The incorporation of industrial by-products in building materials may lead to concern regarding the presence of natural radionuclides in the component materials. However, bauxite and red mud contents in special cement appear to be viable from radiological aspect. Naturally occurring radioactive materials (NORM) such as 40K, 232Th, and 226Ra in the construction materials should be evaluated.

Fig 5: Red Mud

Mix Design

Mix design M30 Grade designed as per IS 10262:2009 & IS 456:2000 Mix proportioning for a concrete of M30 grade is given in 1 & 2.

1. **STIPULATIONS FOR PROPORTIONING**

a) Grade designation: M30

b) Type of cement: OPC 53 Grade conforming IS 12269

c) Maximum nominal size of aggregate: 20mm

d) Minimum cement content: 320 kg/m (IS 456:2000)

e) Maximum water-cement ratio: 0.45 (Table 5 of IS 456:2000)

f) Workability: 100-120mm slump

g) Exposure condition: Moderate (For Reinforced Concrete)

h) Degree of supervision: Good

i) Type of aggregate: Crushed Angular Aggregates.

2. **TEST DATA FOR MATERIALS**

a) Cement used: OPC 53 Grade conforming IS 12269

b) Specific gravity of cement: 3.15

c) Specific gravity of

1) Coarse aggregate: 2.734

2) Fine aggregate: 2.53

d) Aggregate

1) Coarse aggregate: Conforming to all in aggregates of Table 2 of IS 383

2) Fine aggregate: Conforming to Grading Zone II of Table 4 of IS

3. **STEP I. TARGET STRENGTH FOR MIX PROPORTIONING** f'ck =fck + 1.65 s

Where

f'ck = target average compressive strength at 28 days, fck = characteristics compressive strength at 28 days, and s = standard deviation.

From Table I of IS 10262:2009, Standard Deviation, s = 4 N/mm. Therefore, target Strength = 30+ 1.65 x 5 = 38.25 N/mm^2.

STEP II. SELECTION OF WATER CEMENTS RATIO:-

Adopted maximum water-cement ratio = 0.50 Based on experience adopt w/c ratio as = 0.45

.045<0.50, hence ok

STEP III. SELECTION OF WATER CONTENT:-

Estimated water content

Cement content x w/c ratio = 157.5

STEP IV. CALCULATION OF CEMENT CONTENT

Adopted w/c Ratio = 0.45

Cement Content = 157.5/0.45 = 350 kg/m

From Table 5 of IS 456, Minimum cement content for 'Very severe' exposure conditions 300kg/m

350 kg/m > 300 kg/m hence ok.

STEP V. PROPORTION OF VOLUME OF COURSE AGGREGATE AND FINE AGGREGATE

From Table 3 of (IS 10262:2009) volume of coarse aggregate and fine aggregate

Volume of fine aggregate content = 1-0.62= 0.38

STEP VI. MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m

b) Volume of cement = (Mass of cement / Specific Gravity of Cement) x (1/1000)

   = (350/3.15) x (1/1000)

   = 0.111 m3

c) Volume of water = (Mass of water/Specific Gravity of water) x(1/1000)

   = (157.5/1) x(1/ 1000)

   = 0.158 m3

d) Volume of all in aggregate = [a-(b+c)]

   = [1-(0.111+0.158]

   = 0.731 m

e) Mass of coarse aggregate= d x Volume of Coarse Aggregate x Specific Gravity of coarse Aggregate x 1000

   = 0.731x 0.62 x 2.734 x 1000

= 1239.1 kg/m

f) Mass of fine aggregate= d x Volume of Fine Aggregate x Specific Gravity of Fine Aggregate Aggregate x 1000

= 0.731 x 0.38 x 2.53 x 1000

= 702.78kg/m

STEP VII.-MIX PROPORTIONS

Cement = 350kg/m3

Water = 157.5 kg/m3 Coarse aggregate= 1239.1

20mm (60%) = 743.46

10mm (40%) = 495.64

Fine aggregate = 702.78 Water-cement ratio = 0.45

Table 4.7 M30 grade of concrete for materials required 1m^3

Cement	Sand	Aggregate	water
350 kg/m^3	702.78 kg/m^3	1239.1 kg/m^3	157.5 L/m^3

Methodology Adopted in ANSYS

Step:1 Geometry of concrete Cube in Ansys

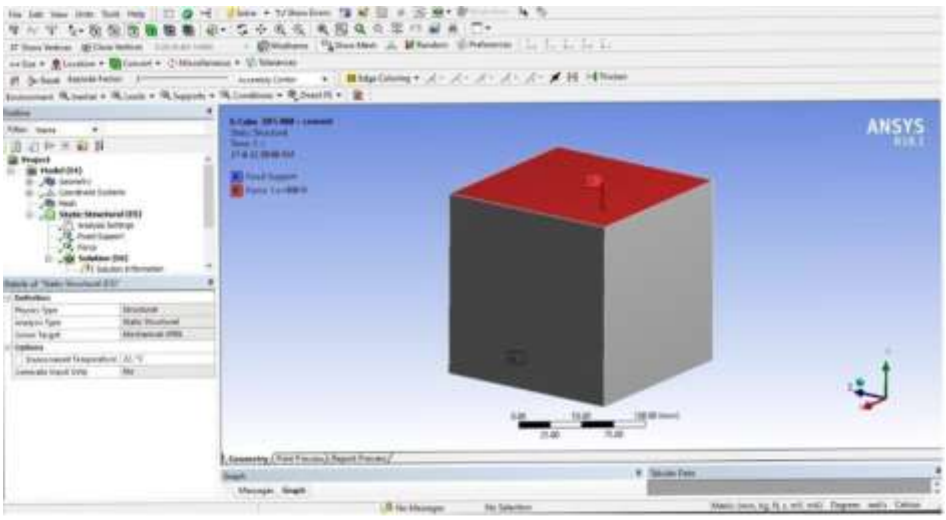
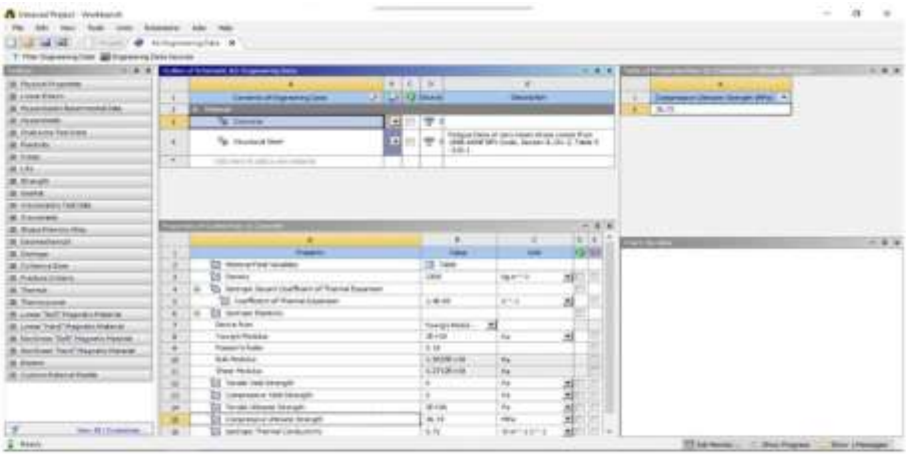
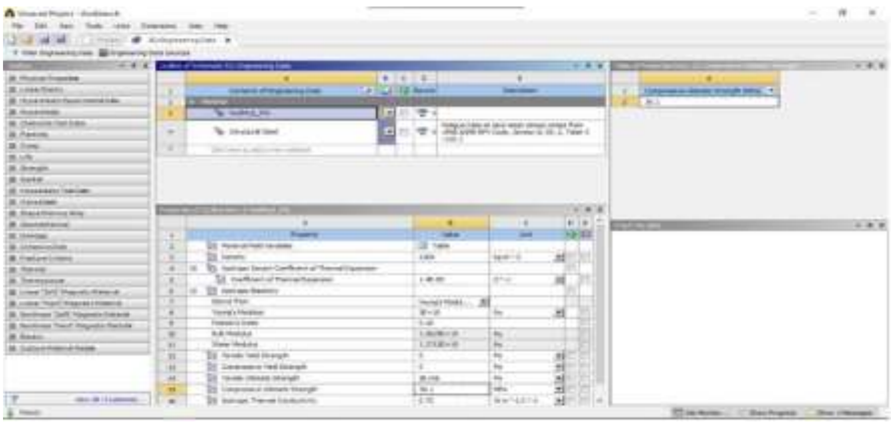


Fig 6: Modelling in ANSYS

Step 2: Creating Material in Ansys:



(A) concrete



(B) Red mud

Fig 7 Designing Material Properties for Concrete and Red Mud

step 3: Assigning loading condition

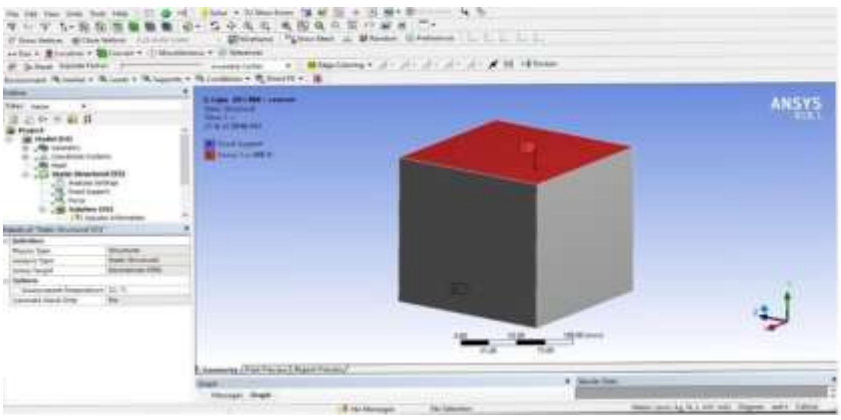


Fig 8: Loading Condition

Step 4: Analysis Output

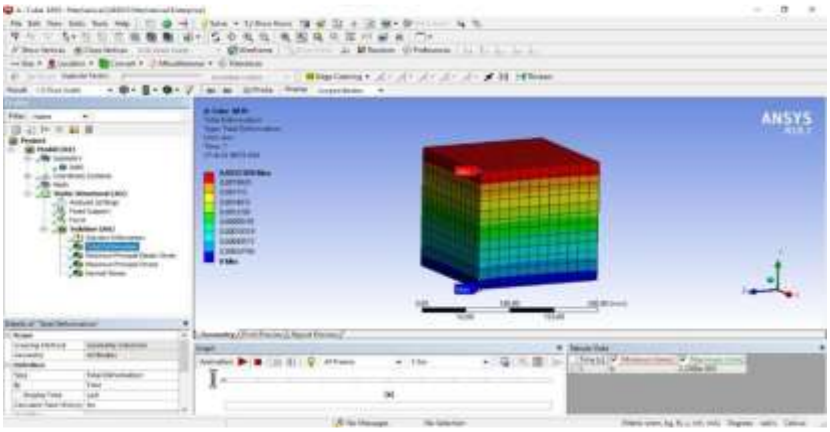


Fig 9: Deformation

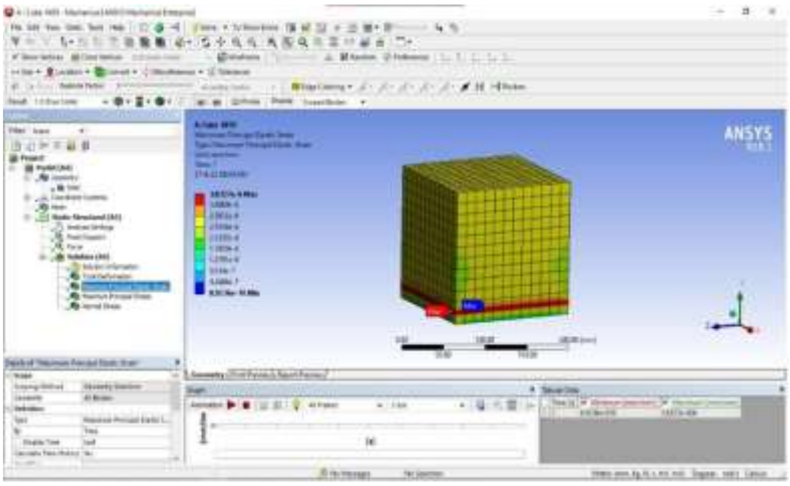


Fig 10: Strain

Results and Discussion

- **Compressive Strength**

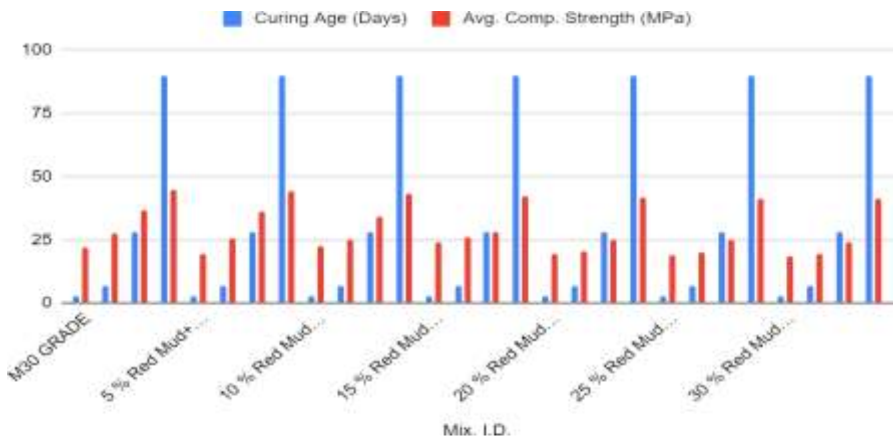


Fig 11: Compressive Strength of Concrete Cube

- **Tensile Strength**

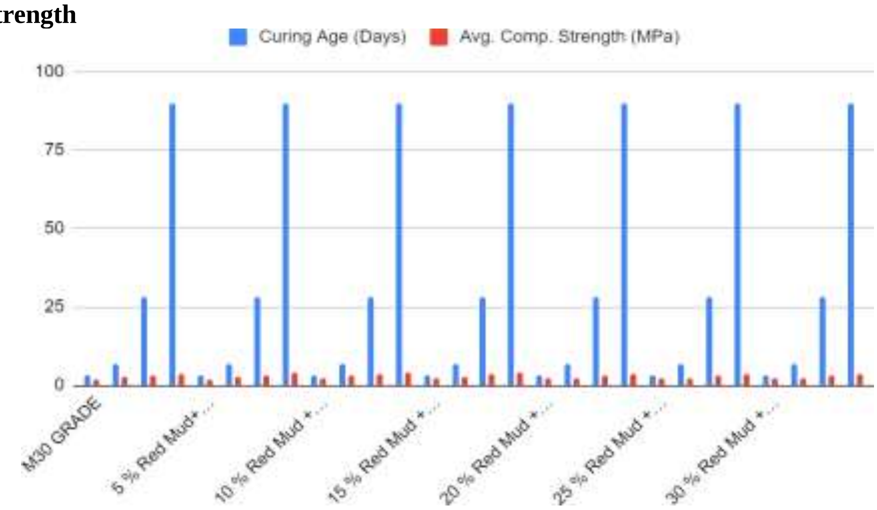


Fig 12: Tensile Strength (Mpa)

- **Flexural Strength**

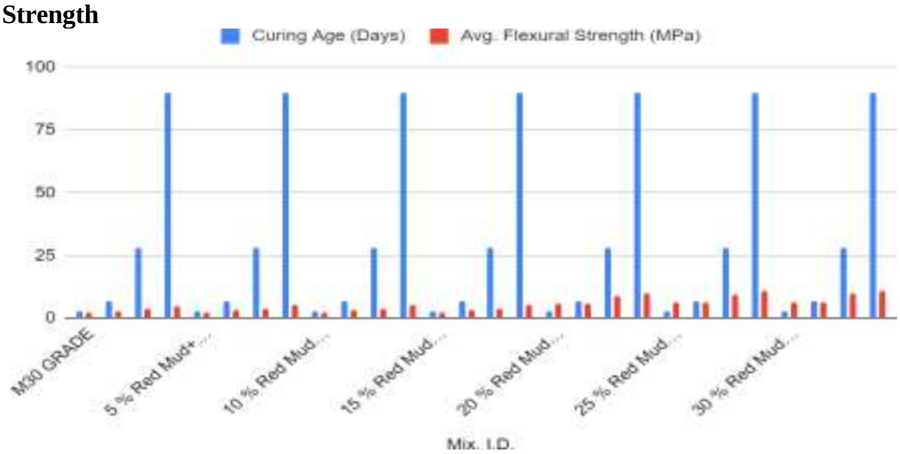


Fig 13: Flexural Strength (N/mm2)

- **Slump Cone Test**

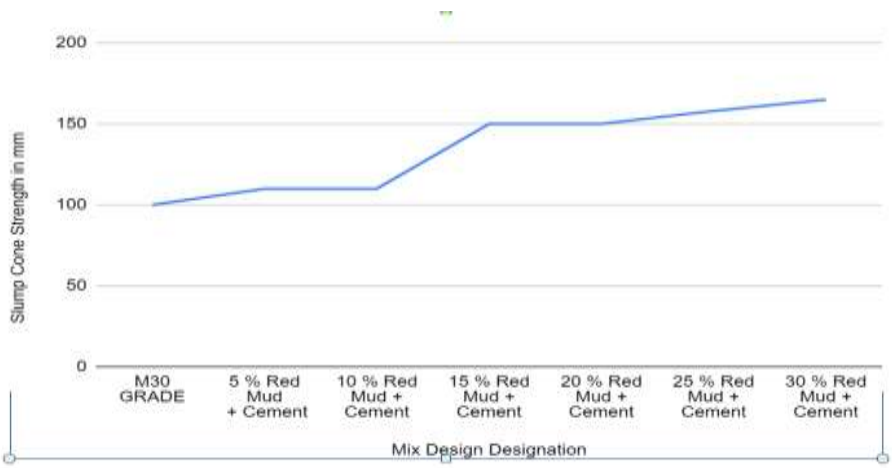


Fig 14: Slump Cone Test

- **Compaction Factor Test**

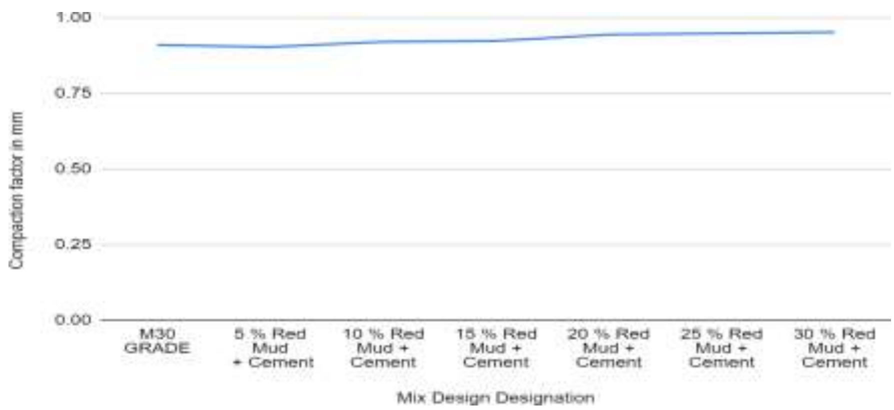


Fig 15: Compaction Factor Test

- **Durability Test (Acid Attack Test)**

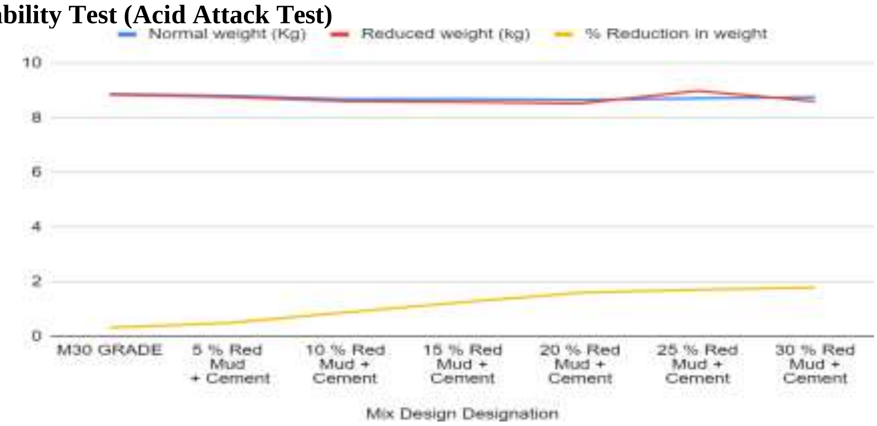


Fig 16: Weight Reduction Results for M30

Carbonation Testing

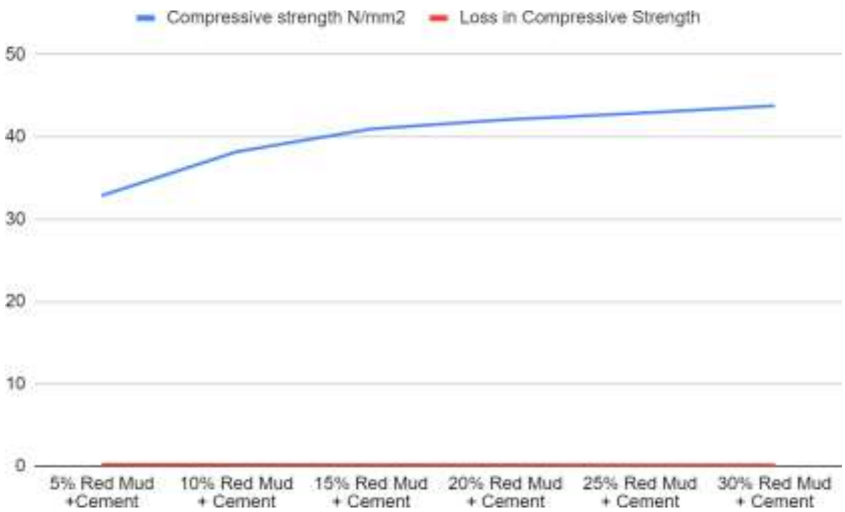


Fig 17: Carbonation Test

Ultrasonic pulse velocity

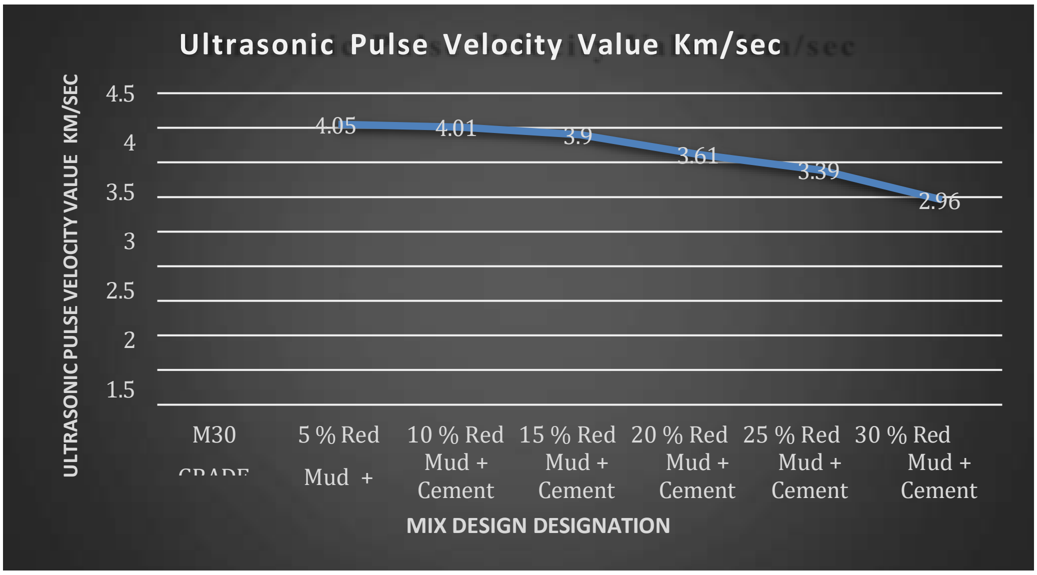


Fig 18: Ultrasonic pulse velocity

Rebound Hammer test

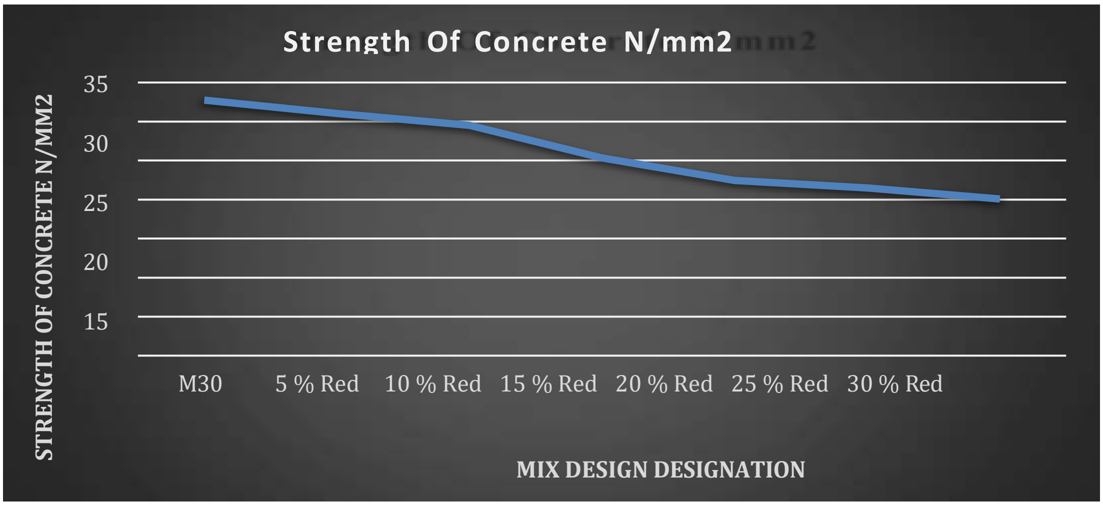


Fig 19 Rebound Hammer test

Penetration Test

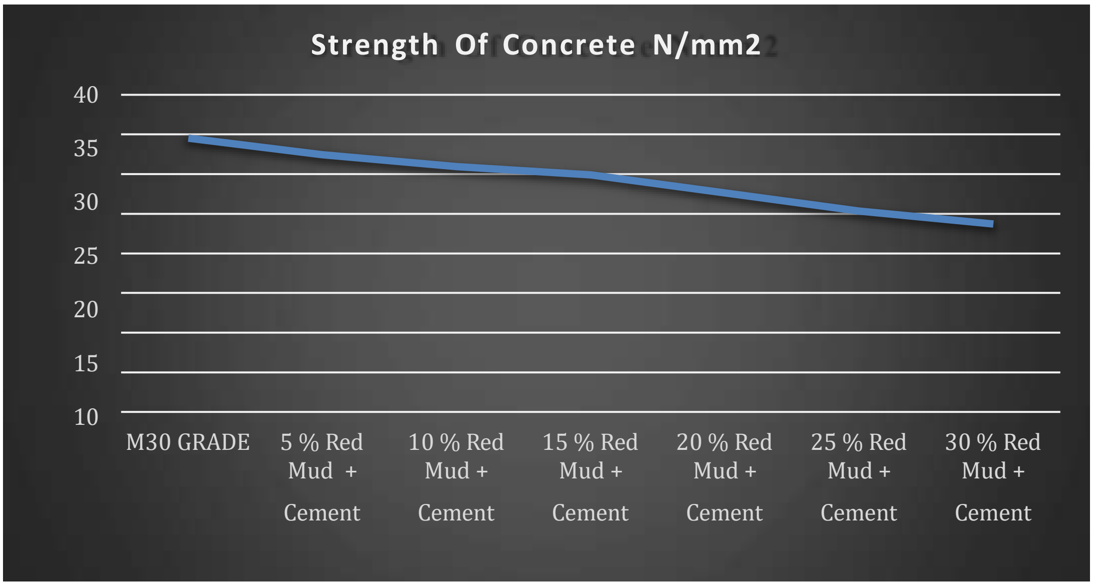


Fig 20: Penetration Test

CONCLUSION

Compressive Strength Test

The samples with red mud show comparable result as the control mix at 28 days of curing for 10% of replacement of red mud. Curign age was considered for 3, 7, 28 and 90 days where 5%,10%, 15%, 20%, 25% and 30% replacement of cement with red mud was done. Maximum compressive strength of 44.3 N/mm2 was visible with 5% replacement in 90 days curing period. The strength reduction is around 27% as compared to the control mix.

Tensile Strength Test

As the percentage of red mud increase the split tensile strength reduces. The results are comparable with red mud replacement up to 30%, thereafter the values are drastically reducing. So, the optimum dosage of red mud can be 20-30%.

Flexural Strength Test

As the percentage of the red mud is increases the flexural strength reduces. For the control mix the flexural resistance is 7.2 N/mm2 and for the Mix with10 % replace of red mud is 5.62 N/mm2. If the red mud is added more than 20% the flexural strength is drastically reduces. So that optimum dosage of the red mud is 20% gives the better strength as compared to other mixes.

Slump Cone Test

It can be seen that the slump value of the concrete made with red as replacement to the cement is more than that of the Control Mix. It can be seen that as the replacement level of red mud increases the slump value also increase.

Compaction Factor Test

The compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It shall normally be stated to the nearest second decimal place. Nearest factor to zero was visible for the mixture 5 % Red Mud + Cement as 0.904 in comparison the mixture with 30% red mud +cement stood at 0.953.

Durability Test

The test is carried out for 56 days. The specimens are immersed in a solution of 5% H2SO4 by weight. The durability is determined in terms of reduction in weight as well as in compressive strength.

Carbonation Test

It can be seen that depth of carbonation was only can be seen for just for mixes with lower red mud content. The mix with higher red mud content does not appear any event of carbonation. As the substance of red mud expanded in concrete, depth of carbonation reduced.

Ultrasonic pulse velocity (UPV)

An ultrasonic pulse velocity (UPV) test is an in-situ, nondestructive test to check the quality of concrete This test is conducted by passing a pulse of ultrasonic through concrete to be tested and measuring the time taken by pulse to get through the structure.

Rebound hammer

It is extremely important to note that the hammer must not be regarded as a substitute for standard compression tests but rather as a method for determining the uniformity of concrete in the structures, comparing one concrete against another, and reducing the number of core samples we found strength 32.74 N/mm^2 for normal concrete and 30 % Red Mud + Cement we found 20.06 N/mm^2.

Penetration resistance

Concrete materials and mixture proportions as in the structure 34.52 N/mm^2 for normal concrete and 30 % Red Mud + Cement we found 23.69 N/mm^2.

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