Experimental Investigation on a Concrete Sample using Red Mud as a Partial Replacement of Portland Cement

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Abstract:- *At global level, red mud (RM) production is rising as a result of the expansion of the aluminum industry. In overall, 0.8 to 1.5 tons of RM can be produced for every ton of alumina produced. Globally, 1.7 billion tons of RM are produced each year due to the aluminum industry's quick development. Due to the hydroxide (NaOH) injected throughout the production of aluminum, RM typically has a pH between 10.5 to 12.5. The argument for red mud reuse is not without difficulty; the mud's toxicity has acted as a deterrent to reuse. The goal of this study is to conduct an experimental investigation on a concrete sample using red mud as a partial replacement of Portland cement at a rate of 5, 10, 15, and 20% RM by weight of cement.*

Keywords: *Red mud, Compressive strength test, Split tensile test, Non-destructive test, concrete, physical properties.*

I. Introduction

Red mud, produced by the Bayer cycle, is a mechanical waste procured throughout the production of aluminum. It is estimated that more than 66 million tons of this waste are produced annually worldwide. For every large load of alumina produced, approximately 1.6 large tons of red mud are delivered. The red mud is typically spread on land or released into the ocean, contaminating the water, air, and soil nearby, especially in areas where this industry is present. In light of this, actions should be taken to reuse this loss in an environmentally friendly manner. Significant efforts are made worldwide to address the executives red mud in use, stockpiling, and removal with knowledge of both financial implications as well as issues related to the natural environment.

Red mud is currently produced in roughly the same mass proportion as metallurgical alumina and is placed in either locked or fixed fake impoundments similar to landfills, causing serious environmental problems. An effort is made inside the task to evaluate the aluminum red mud's strength characteristics as a partial trade for concrete inside concrete. replacing concrete with red mud as a substitute in percentages ranging from 0% to 40% at a contained rate of 10%.

This study is specifically focused on the compressive strength, split lastingness, and flexural strength properties of concrete, that are the crucial criteria to research in concrete production of the diversified proportions of raw materials. This is done to upgrade, the limiting characteristics of hydrated lime contains alongside everything else.

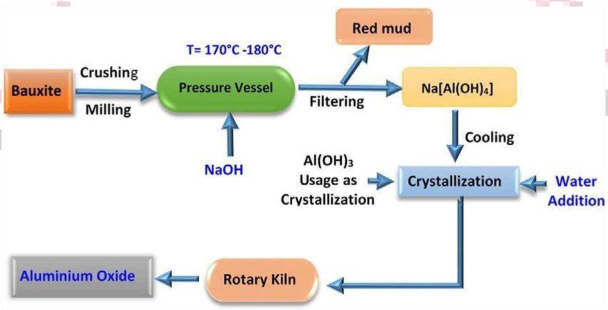

Figure 1 Bayer process of red mud and alumina production.

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. The optimum firing temperature and firing time for the production of this cement was 13000C and 1.5 hour respectively.

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.

The reuse of red mud in construction materials would be a multi-faceted advantage; not only would it mitigate the risks associated with storing red mud, but it would also reduce the construction industry‘s dependence on mined raw materials. As mining is an energy-intensive endeavour, the benefits would be further compounded by the savings in energy. 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.

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. The study, found that when red mud was used as an alternative filler to limestone powder, the resulting porous asphalt exhibited improved resistance to wear such as rutting and raveling.

II. Literature review

Kim Hyeok-Jung et al (2018)[1] research paper investigated efflorescence characteristics in pavement containing red mud which can be affected by strong alkaline through various tests such as compressive strength, porosity, absorption, efflorescence area, alkali leaching content, and properties of the efflorescence compound. The compressive strength of pavement was evaluated to be higher over 15.0 MPa in all cases regardless of replacement ratio of red-mud and binder type, which can provide a reasonable strength for walking and bike lanes. The pavement with red mud was applicable to parking lots only when the replacement ratio of red mud is within 10%. The efflorescence area increased with a higher replacement ratio of red mud and its propagation appeared though the efflorescence was removed through evaporation of moisture. The result further stated that the area of efflorescence gradually decreased with the repetition of the test.

Ramesh R. Rathod et al (2013) [2] the aim of the research work was to investigate the possibility of replacing the Portland cement by red mud. Because of storing issues, the waste negatively affects the environment. To solve this problem, Portland cement was replaced up to 40 % RM by wt of cement. And evaluating its compressive and splitting tensile strength of red mud concrete. This study examines the effects of red mud on the properties of hardened concrete. Results stated that with increase in red mud content their decreases the compressive as well as tensile strength of concrete. Optimum percentage of the replacement of cement by weight is found to be 25%.

Kedar S. Shinge et al (2015) [3] parent objective of the research was to suggest possible percentage of use of red mud and rice husk ash along with cement which will help to reduce the cement consumption in construction industry. Red mud and rice husk ash was used in partial quantities with the cement in mortar. 10% replacement of the red mud for cement was possible from compressive, tensile and flexural strength point of view with a little compromising in compressive strength. However, from compressive strength point of view, rice husk ash was best alternative materials for replacement of cement in mortar and can be used upto 10% to 15 %. Moreover, tensile and flexural strength reduced to some extent even for 5% rice husk quantity.

P.Ashok and M.P. Suresh kumar (2019)[4] the objective of the research paper was to identify various industrial wastes suitable for utilization in cement manufacture and investigate it Physico-chemical and mineralogical characterization. Such industrial solid waste can be compatible as raw material/blending material/ admixture. Therefore, red mud was investigated for its suitability in construction industry.Five test groups were constituted with the replacement percentages 0%, 5%, 10%, 15%, 20% of red mud and 5% of hydrated lime with cement in each series. To achieve Pozzolanic property of red mud, hydrated lime was added.

Results after testing of 5 blended cement samples (5% to 25 % replacement of Cement by NRM) with an increment of 5 %, stated that the optimum use of NRM is 15% as a partial replacement of cement by NRM. The cost of M 30 grade NRM Concrete (i.e. 15 % Replacement) was around 7.48 % less than the Conventional Concrete, with an increase upto 21.712 % in the 28 days Compressive strength. The percentage economy increased with the increase in the grade of concrete but at the same time there was a reduction in the percentage increase in the Compressive Strength. The optimum utilization of Neutralized Red Mud in concrete was 15 % as a partial replacement of cement by NRM. Red mud can be effectively used as replacement material for cement and replacement enables the large utilization of waste product. Red mud did not effect of the cement properties, rather improved the cement quality by way reducing the setting time & improved compressive strength.

Mahin Sha O B et al (2016)[5] The physical characteristics of blended cement (Portland cement substituted by 0%, 5%, 10%, 15%, 20%, and 25%) red mud with constant water ratio concrete design mix of grade M25 were made and design mix was investigated for compressive strength in the research article.The results obtained through this replacements are almost on par with those of ordinary concrete. The best percentage of Red mud to use in concrete by replacing for cement, according to the study's conclusions, was 20 percent.

N.K. Mhaisgawl et al (2021)[6] The purpose of the article was to examine the possibility of using red mud in place of Portland cement in concrete, as well as to assess the strength of a material in compression and cracking tensile tests. Results showed that Red Mud, when used as a replacement for concrete in the range of 0%, 5%, 10%, 15%, and 20%, may easily mimic the properties of concrete. Red mud and cement should be combined for non-structural construction. From a structural perspective, red mud concrete has potential use in the future.

Supriya Kulkarni (2018)[7] The goal of this study is to investigate the use of geo-polymerization of industrial effluents to create a green substitute for concrete mixture. In this work, the physico - mechanical characteristics of geopolymer concrete made from red mud, fly ash, and ground granule blast furnace slag (GGBFS) were investigated. Moisture content, compressive strength, flexural strength, and tensile splitting strength are among the characteristics that have been tested. Geopolymer concrete is shown to absorb more water than traditional concrete. According to the findings, geo-polymerization of industrial effluents can be a good and environmentally friendly substitute for traditional concrete.

Gowsalya. R and Bhagyalakshmi. A (2015)[8] In the research project, it was evaluated whether red mud might partially substitute cement in concrete at various percentage (0, 5, 10, 15, 20, and 25%). Compressive strength and strength and flexural strength for cement concrete of M30 grade were used to study its impacts on the strength as well as other parameters of the concrete. The findings demonstrated that concrete's compression and tension strength are both decreased when more red soil is added. It has been determined that 20% is the appropriate replacement rate for cement in terms of weight. The outcomes of these substitutions are fairly comparable to those of controlled concrete.

Nevin Koshy et al (2019) The research report investigated the manufacture of geopolymer paste material using two untreated inorganic compounds, Class-F fly ash and red mud. The red mud's high level of alkalinity was used to dissolve the silica inside the fly ash and red mud. Results revealed an inverse exponential distribution between the end products' unconfined compressive strength and the L/S ratio, which is comparable to the porous character traits. The minimum L/S ratio of 0.35 was discovered to be ideal for producing higher-strength fly ash-red mud-based alumino - silicate materials with less porosity.

Tejaswini. C and Anupama Natesh (2019) The goal of the study was to evaluate the aluminum red mud's strength properties in order to replace some of the cement in concrete. Red mud was substituted for cement in percentages ranging from 0% to 60%, with an internal of 10%, to create the specimens.Red mud is added to concrete to make it resistant to sulphate assault. The red mud replacement's ideal content was 20 percent. The best method to reduce environmental damage and the constructions industry's carbon footprint may be to utilize red dye in concrete.

III. METHODOLOGY

Throughout the experiment, ordinary Portland cement (53 Grade) according to IS: 269-1976 was employed. To make sure the cement met the requirements of the IS guidelines, various tests were run on it. According to IS: 4031-1968, the cement's physical characteristics were ascertained. The current work uses locally accessible coarse aggregate that conforms to Table 2 of IS 383 and has a minimum size of 20 mm down size. It is discovered that coarse aggregate has a specific gravity of 2.64. The results of the determination of moisture content on cementitious material were 0.4 percent. River sand that can be found locally and passes thru a 4.75mm screen in accordance with IS 383 provisions is the sands used in the experimental investigation. It is discovered that fine aggregate has a specific gravity of 2.62. The fine aggregate tested positive for moisture absorption at 1.0 percent.

For castings and cures of specimens, fresh and clean water is utilized. According to Indian standards, the water is largely devoid of organic materials, silt, oil, sugars, chloride, and acidic substances. A cement paste is created when liquid and a

cementitious substance are combined during the hydration process. A cement paste fills up any gaps and produces a floor by gluing the aggregates together.
Red mud, which is one of the biggest disposing issues for the aluminum sector, is made up of a mixture of solids and metals oxide-bearing contaminants. The iron that is present, which can account for up to 60% of the red mud's mass, is what gives it its red color. The other predominant particulates, in additional to iron, are silica, unleached residual aluminum, and titanium oxide. Red mud is difficult to get rid of. The mud, which is a byproduct of the Bayer process, has a Ph between 10 and 13, making it a very basic substance. The

The type of bauxite ore utilized affects the features of red mud. It has been neutralized by lowering the pH from 10.6 to 8.6 with commercially available HCl. Furthermore, mud was sieved, and homogeneous powder that passed thru a 1.18 mm hole was employed. Red mud has a 2.93 specific gravity, according to research.

Figure 2: Cement, Coarse Aggregate, Fine Aggregate, Red Mud

The replacement level of concrete is simply a measurement about how much water has been added to the mixture and how much of it is in a working condition based on gravity flow of the concrete cone's surface.

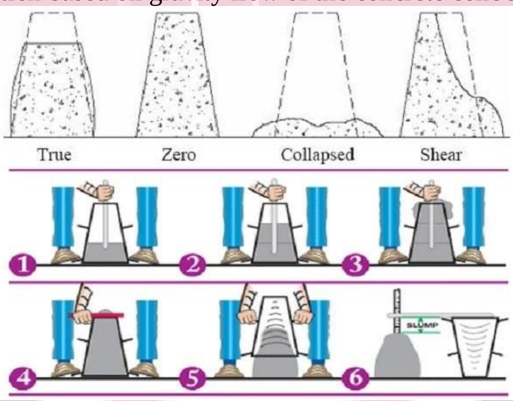

Figure 3: Slump Cone Test

For extremely drying concrete, this testing doesn't really produce favorable findings. It is not sensitive at all for stiff-mix. The table below compares different slump values to concrete workability.

Table 1 Value of Slump at different degree of Workability

Degree of workability	Placing Conditions	Slump(mm)
Very Low	Binding concrete (member of concrete by spreading, shallow sections, Pavements using pavers (mixer with spreading arrangements)	0.75 – 0.8
Low	Mass concrete, lightly reinforced slab, beam, wall,	25 – 75

	column sections, canal lining, strip footing (ling wall with smaller width)	
Medium	Heavily reinforced sections in slab, beams, walls, columns. Slip formwork (slope concrete), pumped concrete	50-100
High	Trench fill, in-situ piling	100-150
Very high	Tremie concrete (concreting in water by using water tight pipe to pour concrete.)	

The flow test is more appropriate for measuring workability in the extremely high category. The ability to support loads on the surface of the material or structural without cracking or deforming is known as compressive strength. An object's size will decrease when it is compressed, but it will lengthen when it is under tensions.

Compressive Strength = Load / Cross-sectional Area

Sand, cement, and aggregates are the main components of concrete. The compressive strength of each of the concrete's constituent parts (cement, sand, and aggregates), as well as the materials' quantity, cures techniques, water-to-cement ratio, air-entrainment mixed ratio, and a number of other variables, all affect the concrete's strengths. temperature has an effect.

We can learn more about strength and the aforementioned parameters by using the compressive strength test. This test makes it simple to determine the concrete's psi strength and the level of quality being produced. For domestic cement, the compressive strength ranges from 15 MPa (2200 psi) to 30 MPa (4400 psi), and it is higher in commercial constructions. In some situations, forces up to 10,000 psi are used (70 MPa).

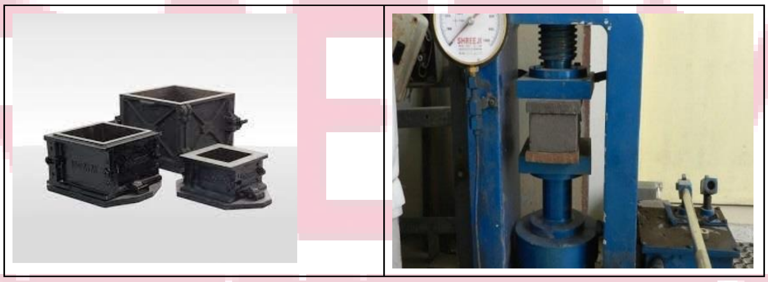

Figure 4 Apparatus for Compressive Strength Test

Split Tensile Strength

Tensile strength is one of the key characteristics of concrete because structural components make it susceptible to tensile cracks. Steel is utilized to carry the tensile stresses since the tensile strength of concrete is much lower than just its compressive strength. According to estimates, the tensile strength of concrete is equivalent to around 10% of its compressive strength. Due to the complexity of the direct approach, indirect methods are used to calculate the tensile strength. It should be noted that the results of these procedures are better than the results of the uniaxial tension. The split cylinders testing and the test method are two examples of these indirectly approaches.

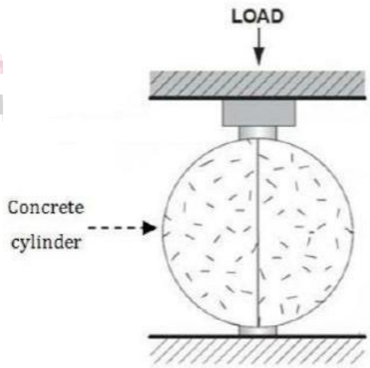

Figure 5 Splitting Tensile Strength Test

Non-destructive Testing

Concrete testing is done for a number of reasons, including to determine the strength, toughness, and projected longevity of the structure. These test findings could be used to decide if a structure needs to be repaired or if its integrity is good enough as is.

Rebound Hammer Testing

Rebound Hammer tests is a non-destructive method of determining the compressive strength of concrete that offers an easy-to-use and quick indicator. The rebound hammer, which is also known as a Schmidt hammer, is made out of a mass controlled by a spring that travels along a plunge inside of a tubular housing. Figure 6 depicts the ballistic pendulum in action. A spring-controlled mass with consistent energy is made to hit the concrete surface whenever the plunger of the load applied is pressed against it. On a graded scale, the amount of rebounding, which measures hardness value, is evaluated. Rebound Number is the name given to this measured number (rebound index).

Low strength and stiffness cement will absorbs more energy, resulting in a lower rebound value. A tool known as a Schmidt Hammer is used for this test, which gauges the concrete's surface roughness. The hammers has a spring-operated hammers head that slides on a plunging mechanism. During testing, the spring mechanism drives the hammers heads into the concrete; once it makes contact with the concrete surface, it springs back. To estimate the hardness of the hard floor, this rebounding is measured. Once more, this procedure is repeated numerous times to establish an average that will serve as a measure of the hardness value of the concrete pavement evaluated.

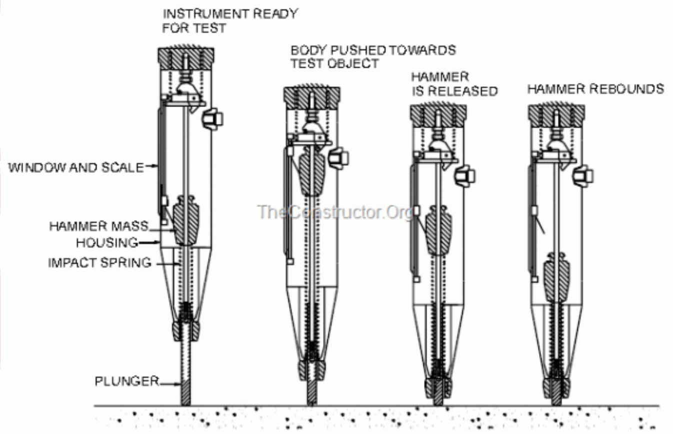

Figure 6 Rebound Hammer Test

The premise behind the rebound hammer testing method is whether an elasticity mass' ability to rebound is dependent on how hard the concrete structure it strikes is. The spring-controlled mass in the rebound hammer bounces back when the plunge is pressed against by the surface of the concrete. The hardness of the concrete surface affects how much the mass bounces back. As a result, the compressive strength of concrete can be connected to the rebound hammer readings and hardness of cement. The rebounding value, also known as the rebound number or rebounding index, is read off along a graded scale. Direct reading of the compressive is possible from the graphs located on the hammer's body.
The calibrating of the rebound hammer is the first step in the process for the rebound hammer test on concrete buildings. For this, a steel test anvil with a Brinell hardness of roughly 5000 N/mm2 is used to test the rebound hammer. The rebound hammer is held at a correct angle to the surface of concrete construction for taking readings after being checked for accuracy on the testing anvil. Thus, the testing can be conducted vertically or upwards down on horizontal surfaces and horizontal on vertical surfaces, as shown in the figure below. The rebounding number for the same cement will differ if the rebound hammer is held at an intermediate angle.

For various purposes, the rebounding hammers requires a variable amount of impact strength. The table below lists approximated Impact energy values for various uses.

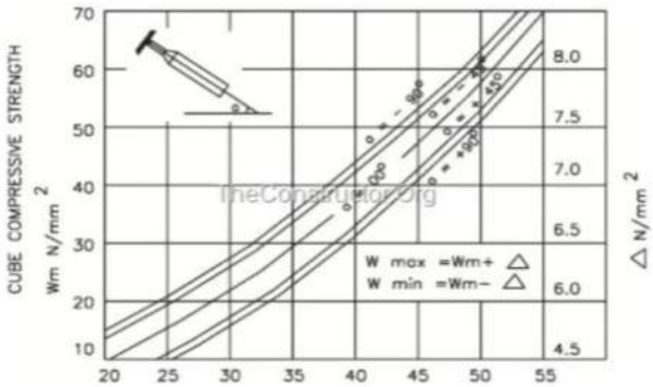

Figure 7 Relationship Between Cube Strength and the Rebound Number

Penetration Testing

Using a Windsor Probe testing machine, liquid penetrant tests are performed on concrete buildings. In this test procedure, a rapid explosion fires a steel probing onto the concrete surface. The strength of the concrete has an inverse relationship with penetrating. The aggregate strengths and characteristics of the concrete's produced surfaces have an impact on the test's outcome. Even while it's not strictly destructive testing, testing does include firing a small probing at the cement with a loaded charges. The depth to which the probe penetrates the concrete after being fired into it is measured, and this value is used to calculate the building's compressive. To get an accurate average of depths and to determine the final compressive strength test value, care shall be exercised to verify that the equipment is correctly calibrated.

The penetrating resistant test is used to assess the in-place strength of the concrete, identify areas of low quality or damaged cement, and measure the homogeneity of concrete.

concrete. For early form removal or to look into the concrete strength already in place due to weak cylinder test results, it is occasionally required to evaluate the strength of the concrete on-site.

Because of the equipment's limitations, absolute strength measurements cannot and shouldn't be expected. The Standard Test Method for Penetration Resistance of Hardened Concrete (ASTM C 803/ 803M- 97) or British Standard can be used to conduct the penetration resistance test on concrete structure (BS 1881 Part 207).

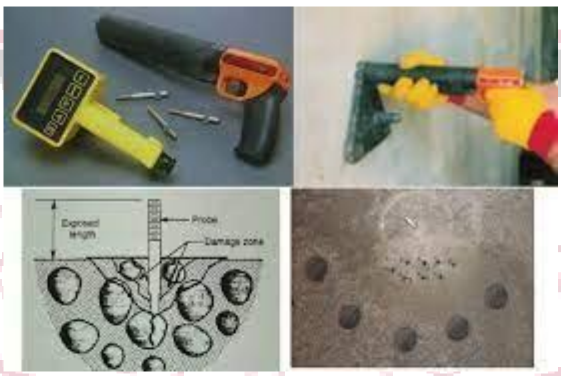

Figure 8 Penetration Testing of Concrete

Ultrasonic Pulse Velocity

A pulse generator and a pulse receiver are needed for ultrasonic pulse velocities analysis. Ultrasonic pulses are fired through a concrete patch to conduct the test, and the time it takes for the pulse to be received is then recorded. These tests can determine any anomalies in the concrete, such as sections that have not yet hardened, fractured, or disintegrating, as well as any other elements that may be present inside and interfere with the signal. This is a qualitative test to assess whether a cement section is "TRUE" and solid or whether repairs are required right away. It should be emphasized that in order to get correct findings from such readings, temperatures must be taken into account as a factor.

An electro-acoustical transducers kept in touch with one surface of concrete member being tested generates an ultrasonic wave of 50 to 54 kHz, and an identical transducers in contact with a surface at the other end measures the transit time, T. The pulse velocity (V=L/T) is determined using the path length L (i.e., the distance between the two probes) and time of traveling T. The pulses velocity increases with concrete's elastic modulus, density, and integrity. The densities and elasticity characteristics of the material being examined influence the ultrasound beam velocity. Despite the fact that pulse velocity and cement crushed strength are related, no statistical association can be drawn.

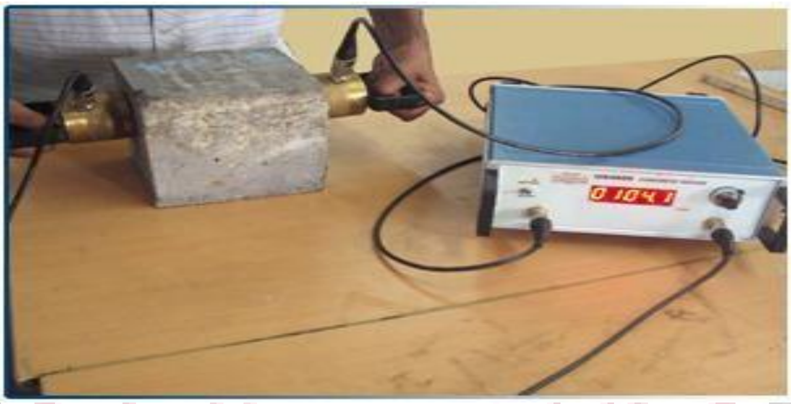

Figure 9 Ultrasonic Pulse Velocity

IV. RESULT AND DISCUSSION

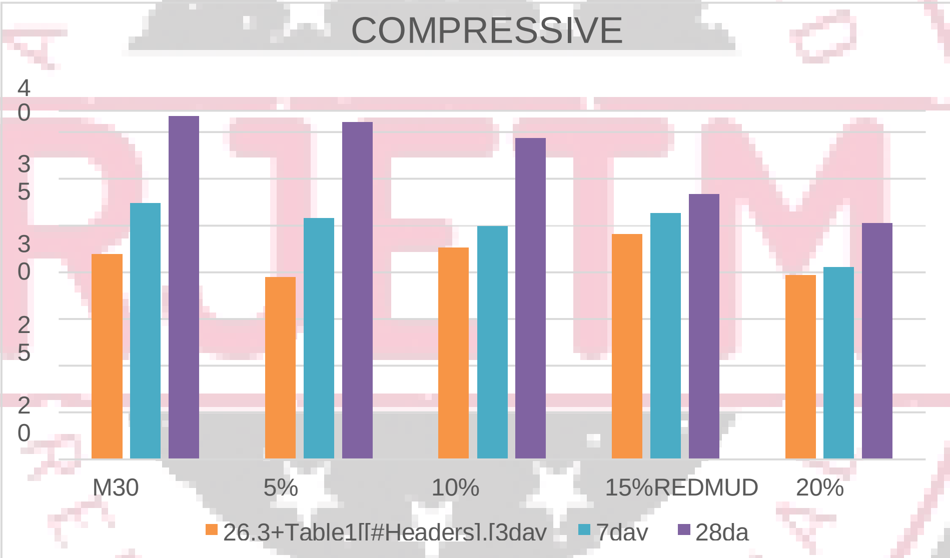

Figure 10 Compressive Strength

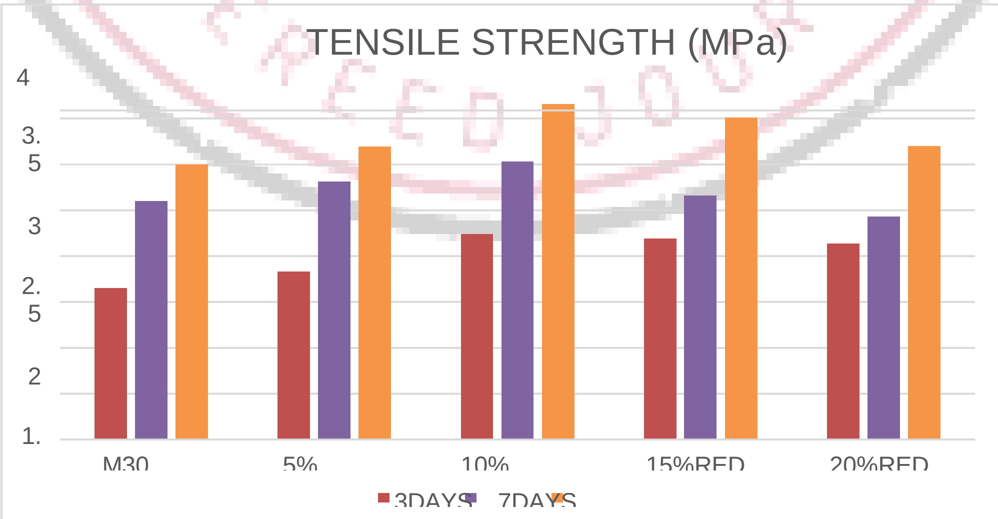

Figure 11 Tensile Strength

Table 2 Split Tensile Strength calculation

Grade	Age of specimen	Specimen	Dimension of sample	Load (KN)	Tensile Strength	Average strength
M30	28 days	Sample 1	150 x 300 mm	100	1.415428167	1.420146261
	28 days	Sample 2	150 x 300 mm	102	1.44373673	
	28 days	Sample 3	150 x 300 mm	99	1.401273885	

V. Conclusion

The purpose of the current experiment experiments is to determine whether using red mud in cement concrete is practical. From the perspective of compression, tensile, and flexing strength, it has been found that substituting 5 to 10 percent of the red mud for cement is feasible without sacrificing concrete strength. From the perspective of compressive, tensile and flexural strength are, however, somewhat diminished even for 5 percent, with satisfactory results being seen at 10 percent, but after this progressive loss is noticed. The compression strength of the red mud concrete are equal to those of concrete mixture with each percentage of replacement up to 20 percent.

The experiment investigation revealed that both the mechanical properties and the tensile strength of concrete diminish when red mud content was increased (higher than 10%). The ideal replacements rate for cement in terms of weight is discovered to be 10%. Results from this substitution are almost on par with those of ordinary concrete. For non-structural operations, red mud and cement are mixed together.

Red mud concrete can be used for building structures with a mix of 5%, where compressive strength is good. However, with additional mixes, we saw a decline in the sample's overall ability, demonstrating that mixes higher than 5% can be used for non-structural work like infill masonry, blocks, etc.

From a structural perspective, red mud concrete has potential in the future. Red mud can be used to create concrete that is ideal for ornamental work and has a nice appearance. An embankment landfill used for road building is a desirable choice with a high potential for large volumes reuse.

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