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RED MUD AS A CEMENT PARTIAL REPLACEMENT IN CONCRETE ADMIXTURE WITH HYDRATED LIME

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ABSTRACT
Red mud is a solid waste formed in the alumina sector that provides a substantial environmental risk as well as a storage issue. In this study, an attempt is made to partially replace cement in concrete with red mud in various percentages to reduce the harmful effects of red mud and cement on the environment. Hydrated lime is also added to assist the red mud in achieving pozzolanic properties. The suitability of red mud with hydrated lime as a partial replacement for cement in concrete admixture was investigated. The mechanical properties of concrete admixture with the addition of red mud and hydrated lime as a partial replacement for cement were analyzed. Efforts were also made to determine the optimum percentage of red mud and hydrated lime in a concrete mixture. The results showed that adding red mud with hydrated lime as a partial replacement to concrete mixtures boosted the workability, strength, durability, and general performance of concrete in all varying percentages, with the exception of those where the red mud replacement was equal to 5% and a percentage of either 5% or 7% hydrated lime. The results also revealed that the highest compressive strength value obtained was 30.24 MPa with a 10% red mud and hydrated lime replacement at 7% and 28 days of curing age. The study concluded that the properties of the concrete were enhanced by using varying red mud percentages of 5%, 10% and 15%; and a fixed rate of hydrated lime at 7% and 5%. This will lower the cost of producing concrete by utilizing a waste product, thereby promoting recycling efforts as the main strategy for mitigating the overwhelming impact of massive waste volumes on the environment.

Keywords:
Red mud, Hydrated lime, compressive strength, concrete mixture, optimum percentage

INTRODUCTION

Concrete is one of the most commonly utilized materials in the construction industry and a variety of civil engineering works. Concrete is mainly composed of aggregates, water, and cement. A chemical reaction occurs when cement mixes with water to produce a gel or paste covering the aggregates and binds them together. This process causes the concrete to harden. Hardening in concrete typically occurs in a few hours; although it takes weeks for concrete to fully harden and sometimes, even longer to reach its full-strength potential. Due to the concrete's impressive sturdiness, moldability, versatility, ease of access in every locale in the world, and its relatively cheap production cost, it has been historically the most popular option for construction all over the globe. Concrete also possesses high fire resistance, high water resistance, and high wind resistance. It is excellent for sound and vibration isolation, and it has unmatched longevity. It is a construction material that never rots, burns, or rust. However, due to the rapid global industrialization of today's market, concrete has been in demand more than ever in recent history. This massive surge in demand causes a few problems in the environment due to the cement's tendency to generate carbon dioxide, a potent greenhouse gas (K. Viyasun, 2020). Furthermore, due to inflation in today's market and other factors, cement is more expensive to produce than ever.

Concrete's global usage has led researchers to explore and experiment with its properties by adding different materials such as waste and recycled materials as admixtures. One such material is red mud. (Mr. P. Ajay Kumar, 2017) Red mud is a waste material generated in the aluminum industry during the extraction of alumina from bauxite through the Bayer process. Due to red mud's sheer abundance, toxic nature, and difficulty to dispose of or recycle effectively, it has been declared that red mud is causing significant harm to the environment (W.C. Tang & Z. Wang, 2018). Despite that, red mud provides many advantages as a partial replacement for cement in concrete (Bavani, 2018). In most cases, red mud is reported to help increase concrete's compressive and tensile strength, especially when paired with hydrated lime. It is also reported that the red mud improves the workability of the concrete. In addition, using red mud helps reduce the production cost of concrete as well as improves the impact absorption ability of the concrete. Red mud also helps prevent the corrosion of reinforcement and acts as an excellent binding material. Red mud is a good waste material that can benefit the construction industry.

In this research study, an attempt was made to solve both cement and red mud problems by reducing cement demand and recycling red mud by utilizing it as a partial replacement for cement in concrete, with hydrated lime to assist red mud in achieving Pozzolanic properties. The study thus also focuses on the addition of the lime as an additive that will improve the strengthening outcomes.

METHODOLOGY

In this section, the processes and methods needed to successfully carry out the objective of this research study are explained: processes such as examining the effects of red mud (Figure 1) with hydrated lime (Figure 2) as a partial replacement for cement in concrete, explaining the materials needed and the methods involved, laboratory activities required, sampling and replacement percentages details, and experiments that were performed. The experiments conducted were the slump test and the compressive strength test. All the experiments were conducted in the Infrastructure University Kuala Lumpur's civil engineering laboratory. The replacement percentages for red mud as a partial replacement for cement in concrete were 0%, 5%, 10%, 15%, with a fixed rate of hydrated lime at 7% and 5%. The cube sample size was 100mm x 100mm x 100mm, which was used for the compressive strength test.

Figure 1: Sintering Red Mud

Figure 2: Hydrated lime

Slump Test

As stated by Pateliya (2017), it is crucial for concrete to have sufficient workability to assist in removing entrapped air by acquiring minimum compaction. The slump test is by far the simplest and most widely used test to test the workability of fresh concrete. The concrete slump test is conducted from batch to batch to check the concrete's uniform consistency during construction

Curing Process

Concrete curing is the method of securing sufficient moisture in concrete within an acceptable temperature range in order to help cement hydration at early ages. Hydration is the chemical reaction between water and cement that ends in the formation of various chemicals contributing to setting and hardening. The hydration process is influenced by the initial concrete temperature, the ambient air temperature, the dimensions of the concrete, and the mix design

Compressive Strength Test

The compressive strength test is regarded as one of the most common tests conducted on concrete in the construction industry. It gives a comprehensive idea of all the properties of the concrete sample. This test is the deciding factor on whether the concrete sample will get accepted or rejected. Compressive strength as a concrete trait relies on various constituents associated with the quality of the adopted materials, mix design, and quality control through concrete manufacturing. The compressive strength of concrete is fundamentally the ability of the concrete to resist axial force. The more compressive strength the concrete poses, the more axial load it can bear before fracturing. The compressive strength test is designed to examine the compressive strength of a concrete sample by gradually applying load on the sample until it fails, and the reading of compressive strength is taken at the point of failure using a compressive testing machine. For this research study, 42 cubes were cast with a size of 100mm x 100mm x 100mm for a curing period of 7 and 28 days. To conduct the compressive strength test, concrete was poured into a mold and appropriately compacted to reduce the number of voids in the mix. After 24 hours, molds were removed, and test specimens were then stored in water for curing. After the specified curing period, specimens were tested by the compressive testing machine. Load was applied gradually until specimen failure. The load of failure was divided by the cross-sectional area of the sample to get the compressive strength of the concrete. The test was carried out in accordance with BS EN 12390-3 (2009). Figure 3 depicts the flow of the processes

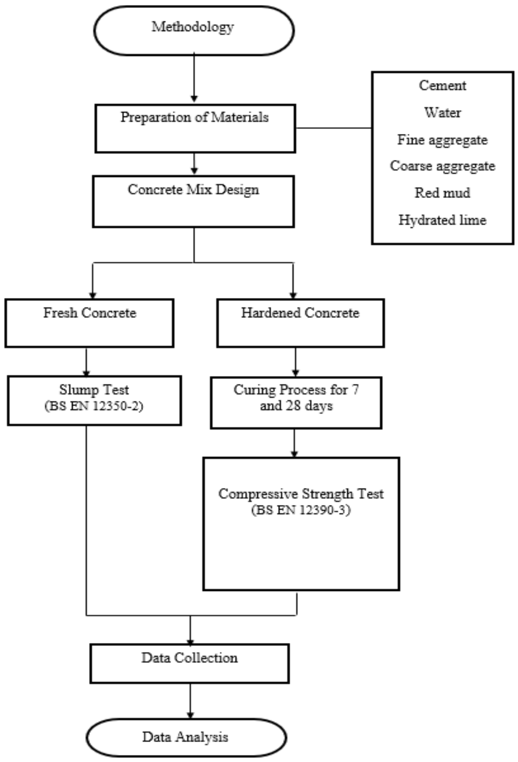

Figure 3: Research Flow Chart

RESULT AND DISCUSSION

The data analysis and results are covered in this section to demonstrate a thorough comprehension of the study. In this study, two different types of concrete were made. The first was a standard mix, and the second was a combination of red mud and hydrated lime in varying proportions. The purpose of this study is to present, analyze, and contrast the conventional concrete's test findings with those of concrete created from red mud and hydrated lime. The concrete cubes with varying red mud percentages (0%, 5%, 10%, 15%) and a fixed rate of hydrated lime at 7% and 5% produced the results shown below. The experiments were conducted along with slump tests to determine whether the addition of red mud and hydrated lime concrete was workable. The cubes, which measure 100 x 100 x 100 mm, were put to the test at the ages of 7 and 28 days. All of the tests that were run followed the procedures outlined in the preceding section. Table 1 contains the details of the experiments.

Table 1: Total Concrete Cubes for Compressive Strength Test

No of Samples.	Cement percentage	Red mud %	Hydrated Lime %	Number of cubes	
				7 days	28 days
CS	100%	0%	0%	3	3
S1	88%	5%	7%	3	3
S2	83%	10%	7%	3	3
S3	78%	15%	7%	3	3
S4	90%	5%	5%	3	3
S5	85%	10%	5%	3	3
S6	80%	15%	5%	3	3
	Total no.			42	

Sieve Analysis for Coarse and Fine Aggregate

The sieve analysis was carried out in accordance with the British Standard (BS) for fine aggregates (sand) and coarse aggregates (stones with a maximum size of 20mm). The goal of this test was to create well-graded fine and coarse aggregates with maximum packing, which increased the toughened characteristics. Tables 2 and 3 indicate the aggregate mix proportion from various sieve sizes

Table 2**:** Coarse Aggregate (Stone Chips)

Sieve size(mm)	Weight retained (gm)	% of weight retained	Cumulative % wt. retained
20	581	14.53%	14.53%
16	1338	33.45%	47.98%
12.5	994	24.85%	72.83%
10	670	16.75%	89.58%
4.75	387	9.68%	99.25%
Pan	30	0.75%	100.00%
Sum	4000	100.00%	424.15%

Table 3**:** Fine Aggregate (Coarse Sand)

Sieve size(mm)	**Weight retained (gm)**	**% of weight retained**	**Cumulative % wt. retained**
4.75	245	8.17%	8.17%
2.36	176	5.87%	14.03%
1.18	389	12.97%	27.00%
0.6	1056	35.20%	62.20%
0.3	123	4.10%	66.30%
0.15	979	32.63%	98.93%
Pan	32	1.07%	100.00%
Sum	3000	100.00%	376.63%

Following data computation, it was discovered that aggregate's fineness modulus (FM) was 8.00, indicating that the test concluded that stone chips would be suitable for construction.

FM (Fineness modulus) = $\frac{\sum \% \text{ Cumulative Wt. retained}}{100}$

$=\frac{(424.15+376.63)}{100}$

$= 8.00$

Slump Test

When red mud replacement percentage was increased, the slump value rose in S1, S2, and S3 with red mud percentages of (5%, 10%, and 15%) and a fixed rate of hydrated lime at 7% (See Table 1 for the details of combinations). With red mud replacement percentages of (5%, 10%, and 15%) and a fixed rate of hydrated lime at 5%, a similar observation was made in S4, S5, and S6; as red mud replacement percentage rises, slump value rises. Additionally, it can be inferred that S3, which contained 15% red mud and 7% hydrated lime, had the largest slump value and hence the highest workability of fresh concrete. Due to its finer particles, larger volume, and slightly lower weight, red mud actually has a lower flow property since it requires more water to be absorbed (Chavan et al., 2021). The slump value for the control sample was 22 mm, while the slump values for the samples with replacements of red mud at 5%, 10%, and 15% and a fixed rate of hydrated lime at 7% were 18 mm, 29 mm, and 39 mm respectively. Additionally, the slump values obtained are 16 mm, 26 mm, and 36 mm, respectively, when replacing red mud with percentages of 5%, 10%, and 15% with a fixed rate of hydrated lime at 5%. Figure 4 depicts the results in a graphical format. The results lead to the conclusion that fresh concert is more workable the more the combination of red mud and hydrated lime is added.

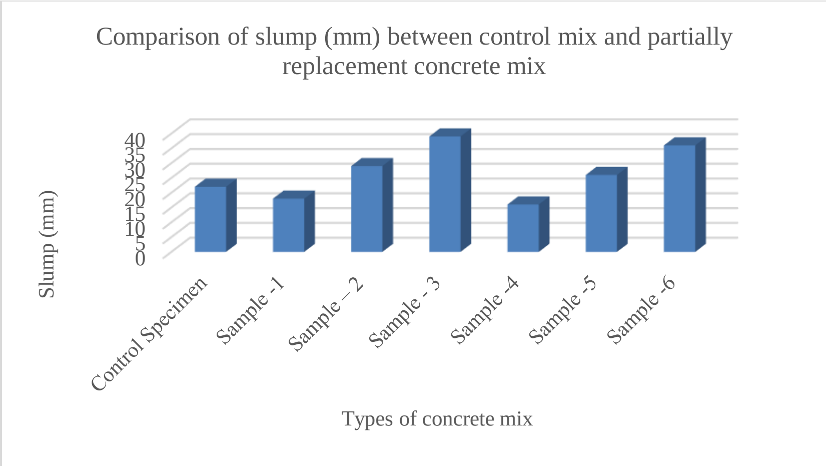

Figure 4: Slump Test Results

Compressive Strength Test

The primary goal of this study is to investigate the compressive strength of concrete having varying amounts of red mud (0%, 5%, 10%, and 15%) and a fixed amount of hydrated lime (7% and 5%), and to compare it to the compressive strength of the control sample. Before being taken out of the curing tank for testing on compressive strength, the concrete samples were cured for periods of 7 and 28 days. In this study, a total of 42 100mm x 100mm x 100mm concrete cubes were evaluated (21 cubes for both 7 and 28 days).

7-Day Curing Age

Since concrete obtains 65% of the desired strength after 7 days of casting, concrete specimens were evaluated at 7 days after curing. Testing the concrete on day 7 is crucial because the results of the compressive strength test may be used to anticipate the final strength and ascertain whether the cube reaches the desired strength by displaying the trend of the concrete's strength. Table 4 contains the findings from the compressive strength test for the 7th day curing age while Figure 5 is the graphical depiction.

Table 4: Compressive Strength Test Result (7 days)

7 Days Curing						
Sample Name	**Replacement Percent**		**Specimens**			**Average of the Specimens**
	Red Mud	**Hydrate lime**	**S – 1**	**S – 2**	**S – 3**	
Control Specimen	0	0	18.41	16.47	18.31	17.73
Sample -1	5	7	20.81	20.60	19.69	20.37
Sample – 2	10	7	20.83	23.33	22.67	22.28
Sample - 3	15	7	19.47	19.35	19.53	19.45
Sample -4	5	5	20.49	20.38	19.97	20.28
Sample -5	10	5	21.37	21.61	21.40	21.46
Sample -6	15	5	18.19	18.84	19.45	18.83

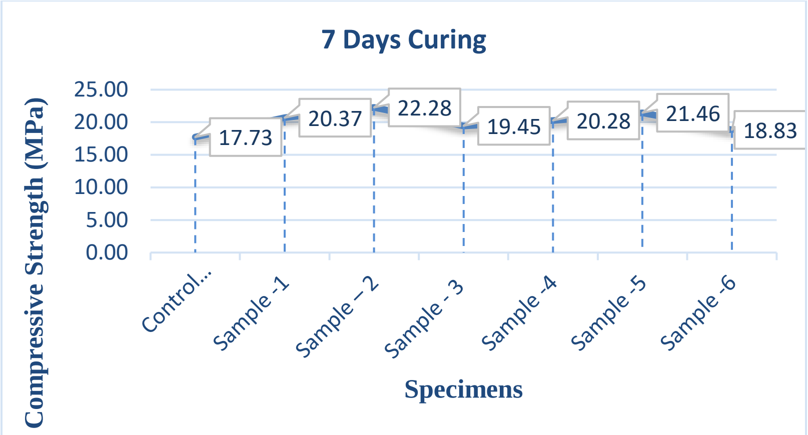

Figure 5: Average compressive strength of concrete at 7 days of curing age

The control sample that contains 0% of red mud and hydrated lime gave a compressive strength of 17.73 MPa. On the other hand, Samples 1, 2 and 3, containing a mix of red mud of 5%, 10%, and 15%, and a fixed rate of hydrated lime at 7%, achieved a compressive strength of 20.37 MPa, 22.28 MPa and 19.45 MPa respectively. As a result, red mud at 10% and a fixed rate of hydrated lime at 7% yields concrete with the maximum compressive strength, 22.28 MPa, which is within the range of what has been calculated. According to Bhardwaj and Gupta (2019), the seven-day compressive strength should vary between 19 and 22.35 MPa. In addition, the compressive strength test results for 4, 5 and 6 which contained red mud of 5%, 10%, and 15%, and a fixed rate of hydrated lime at 5% gave 20.28 MPa, 21.46 MPa and 18.83 MPa respectively. This shows that with 10% of red mud and 5% of hydrated lime, the maximum compressive strength was obtained at 21.46 MPa. These findings are consistent with the compressive strength data obtained by Bhardwaj and Gupta (2019) for 5%, 10%, and 15% red mud, which were 22.5, 21.3, and 19.7 MPa respectively, after 7 days of curing. Furthermore, the specimen containing 10% of red mud and 7% of hydrated lime achieved the highest compressive strength out of all 6 average compressive strength at 7 days of curing age giving 22.28 MPa.

28-Day Curing Age

In addition to being tested after 7 days of curing, specimens of concrete were also tested after 28 days, when 99% of its strength had been attained. Testing the concrete on Day 28 is crucial to determining whether the concrete cube reaches the desired strength. Table 6 contains the findings of the compressive strength test for 28-day curing age while Figure 5 is the graphical depiction.

Table 5: Compressive Strength Test Result (28 days)

28 Days Curing						
Sample Name	**Replacement %**		**Specimens**			**Average of the Specimens**
	Red Mud	**Hydrated lime**	**S – 1**	**S – 2**	**S – 3**	
Control Specimen	0	0	25.08	25.53	24.42	25.01
Sample -1	5	7	26.81	26.73	26.24	26.59
Sample – 2	10	7	29.66	30.51	30.54	30.24
Sample - 3	15	7	24.87	24.84	25.64	25.12
Sample -4	5	5	26.67	27.81	24.31	26.26
Sample -5	10	5	29.08	29.13	27.90	28.70
Sample -6	15	5	24.38	24.59	25.25	24.74

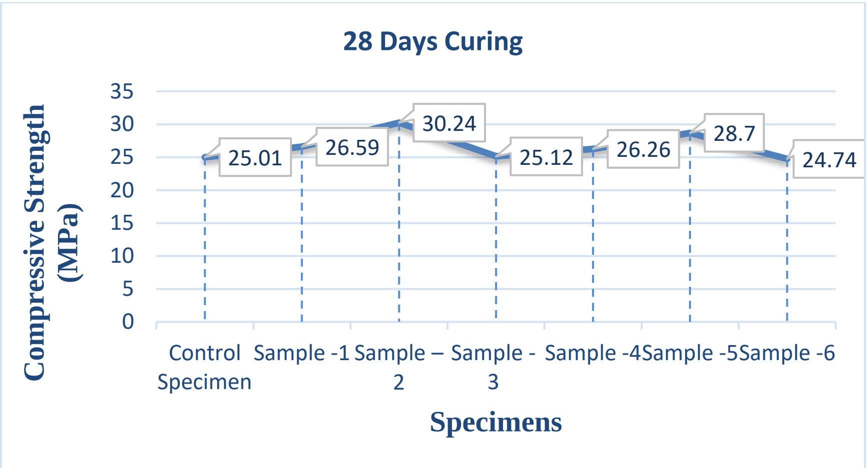

Figure 6: Average compressive strength of concrete at 28 days of curing age

The control sample which contains 0% of red mud and hydrated lime gave a compressive strength of 25.01 MPa. On the other hand, Specimens 1, 2 and 3 containing a mix of red mud of 5%, 10%, and 15%); and a fixed rate of hydrated lime at 7% achieved a compressive strength of 26.59 MPa, 30.24 MPa and 25.12 MPa respectively. As a result, red mud at 10% and a fixed rate of hydrated lime at 7% yields concrete with the maximum compressive strength of 30.24 MPa. In addition, the compressive strength test results for specimens 4, 5 and 6 which contained red mud of 5%, 10%, and 15% and a fixed rate of hydrated lime at 5% gave 26.26 MPa, 28.70 MPa and 24.74 MPa respectively. This corresponds to the range calculated by Cholkar et al. (2021) where the twenty-eight-day compressive strength varied from 27 to 31.8 MPa, and that with 10% of red mud and 5% of hydrated lime, the maximum compressive strength was obtained at 28.70 MPa. Furthermore, the specimen containing 10% red mud and 7% hydrated lime achieved the highest compressive strength out of all 7 average compressive strengths at 28 days of curing age giving 30.24 MPa. Lastly, the highest compressive strength of concrete achieved at 7 days and 28 days of curing age for cubes with varying red mud percentages at 0%, 5%, 10%, 15% and a fixed rate of hydrated lime at 7% and 5% was 30.24 MPa with 10% red mud and hydrated lime at 7%, whereas the lowest was achieved with 0% of red mud and hydrated lime and 7 days of curing age, giving only 17.73 MPa.

The Effect of Red Mud on the Compressive Strength of Concrete

Based on an analysis of the results, utilizing red mud with cement paste has increased and decreased their compressive strengths. The main ingredients in red mud that contribute to its pozzolanic activity are alumina and reactive silica (Kang et al., 2020). These reactive substances have the ability to react chemically with calcium hydroxide to produce products of secondary hydration. The concrete microstructure's voids are filled in part by the pozzolanic process. The concrete's mechanical qualities are enhanced by this filling action, which creates a denser and more compact matrix. The red mud concrete's compressive strength values were higher than those of the control sample for both the 5 and 10 percent replacement percentages. This is because the red mud accelerates the pozzolanic reaction between cementitious materials (cement and red mud), which increases the compressive strength values. It also strengthens the bond between the cement and aggregate through a slight pozzolanic reaction and the matrix-filling effect of fine red mud particles. Nevertheless, a strength reduction was noted when the replacement reached 15%; this reduction was not, however, smaller than in the control sample. The reason for this reduction is that the higher replacement content of red mud led to insufficient cement hydration through the filler and internal curing effects of red mud. Between the red mud and the other minerals in the concrete, there was not enough pozzolanic reaction. The result was a decrease in the development of calcium silicate hydrate (C-S-H) gel. This explains why, following the 10% mix, all mechanical qualities were drastically reduced.

CONCLUSION

This investigation was methodically carried out to assess the viability and possible advantages of utilizing red mud and hydrated lime as partial substitutes for cement in concrete admixtures. Based on thorough analyses, it was concluded that this combination has promising features that could make it useful in concrete applications. Furthermore, the experiments in adding red mud and hydrated lime provided important information about the workability, strength, durability, and general performance of the material. These results greatly advance knowledge of how the added elements affect the mechanical properties of the concrete. Previous experiments demonstrated that adding red mud with hydrated lime as a partial replacement to concrete mixtures boosted the workability of concrete in all varying percentages, with the exception of those where red mud replacement was equal to 5% and a percentage of either 5% or 7% hydrated lime. Additionally, the results showed greater values compared to the control sample when varied red mud percentages of 5%, 10%, and 15% and a set rate of hydrated lime at 7% and 5% were used as a partial replacement for cement in concrete admixture. The results also revealed that the highest compressive strength value obtained was 30.24 MPa with a 10% red mud and hydrated lime replacement at 7% and 28 days of curing age, confirming the hypothesis of improving concrete mechanical properties such as compressive strength and workability. The study concluded that the properties of the concrete were enhanced by using varying red mud percentages 5%, 10%, and 15% and a fixed rate of hydrated lime at 7% and 5%.

AUTHORS BIOGRAPHY

Mohamed Emierul graduated at Universiti Sains Malaysia with Master Degree of Science in Structural Engineering in 2017. His expertise is in Structural Analysis, Reinforced concrete, Project management and Construction Materials.

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