

Experimental Study on Blend Cement Concrete by Partial Replacement of Cement with Lime Sludge and Fly Ash

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Abstract—Concrete is a basic material for the construction industry. To fulfil this construction demand, a large amount of concrete is required. Cement, Sand, and coarse aggregate are the basic materials required in construction. The growing demand for cement in concrete causes environmental damage and greenhouse gas emissions. For the production of 1 ton of ordinary Portland cement (OPC), nearly 1 ton of CO₂ is released, which accounts for 5-7% of carbon dioxide (CO₂) worldwide from manmade sources. This number is undoubtedly rising in the coming decades because developing nations are rapidly building infrastructure to match population expansion. Increasing infrastructural requirements increase the need to produce concrete using conventional materials, which increases the carbon footprint. This study explores the use of supplementary cementitious materials (SCM) from industrial waste materials like Lime sludge and Fly ash used in concrete to minimise CO₂ emissions.

Lime sludge is a residual substance that comes from the paper industry, while Fly ash (class F) is a waste material obtained in thermal power plants by the combustion of coal. The current study investigates the effects of adding lime sludge and fly ash to the M20 grade of conventional concrete (0%), as 10% (5% lime sludge + 5% fly ash), 20% (10% lime sludge + 10% fly ash), 30% (15% lime sludge + 15% fly ash) and 40% (20% lime sludge + 20% fly ash). Mechanical properties (compressive, split tensile, and flexural strength) were measured at 7 and 28 days. At 10% partial replacement of lime sludge and fly

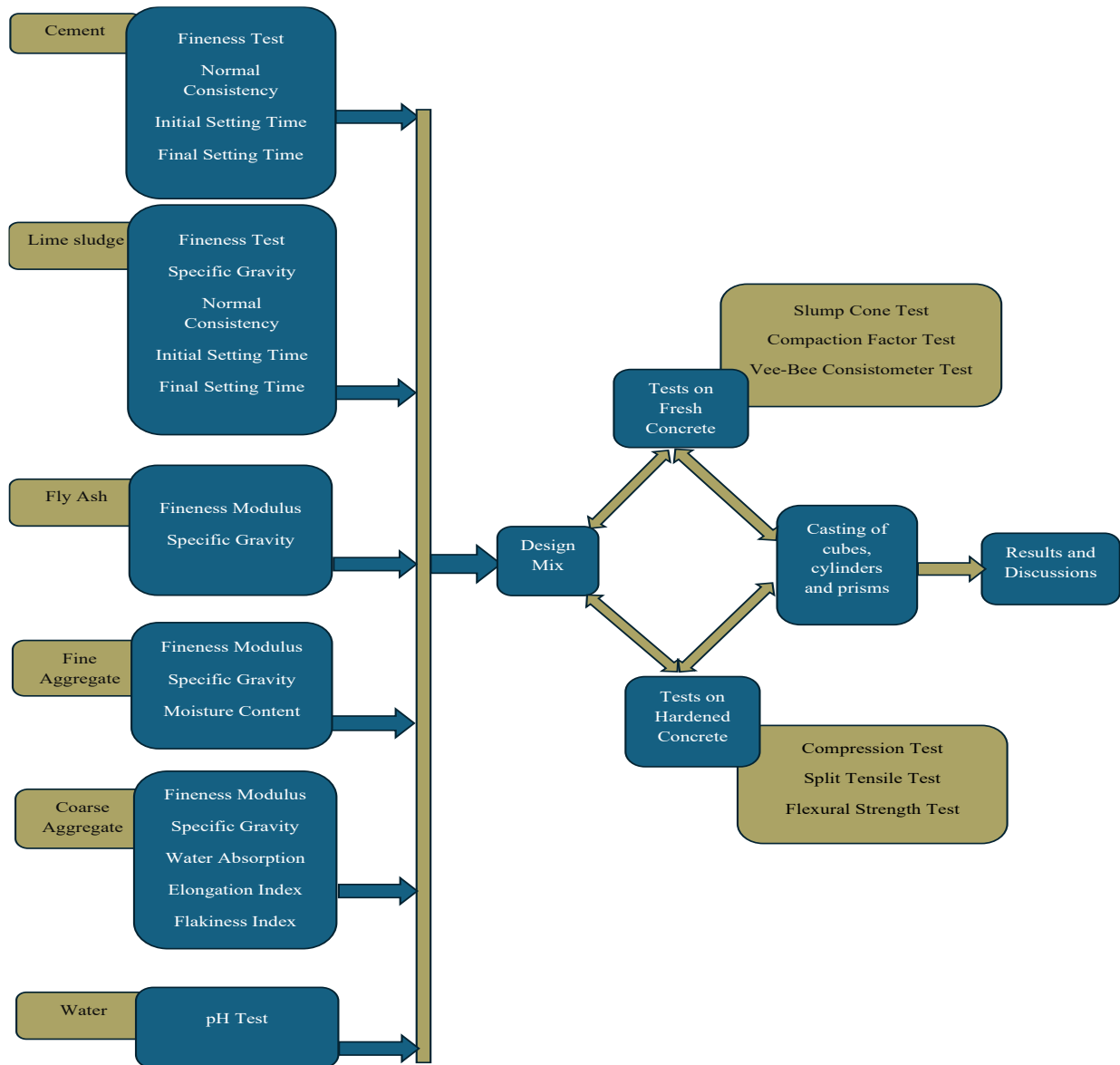
ash, the results performed better than conventional concrete.

Index Terms—Compressive strength, Lime sludge, split tensile strength, Fly ash, flexural strength and blend cement concrete.

1. INTRODUCTION

Cement production contributes significantly to global CO₂ emissions. Incorporating industrial by-products in concrete not only reduces environmental impact but also provides an effective waste disposal solution. Lime sludge has shown notable changes in the blended cement concrete mix with improvement in the workability. The inclusion of lime sludge in the mixture of blended cement concrete results in the generation of additional C-S-H gels, leading to an enhancement in the strength of the concrete. The usage of class F fly ash in conventional concrete helps to improve the workability of the mix, making it easier to place and finish. Fly ash reacts with calcium hydroxide to form additional cementitious compounds. This results in a denser and more compact concrete mix, reducing permeability and increasing resistance to chemical attack.

2. FLOW CHART FOR METHODOLOGY



3. MATERIALS USED

- 3.1 Cement: The entire test procedure adopted 53 grade-OPC as per IS: 12269-2013 [1]. The cement came from one consignment and source. The final setting, the initial setting, normal consistency, and specific gravity are 560 min, 42 min, 32%, and 3.15, respectively.
- 3.2 Fine aggregate: IS: 383-2016 Zone-2 fine aggregate was applied [2]. The fine aggregate came from a flowing stream reach point. The sand utilized had a 2.46 fineness modulus and 2.66 specific gravity.

3.3 Coarse aggregate: This study uses IS: 383-2016 coarse aggregate with a 90% at 20 mm maximum size [2]. The coarse aggregate utilized had a 3.76 fineness modulus and 2.74 specific gravity.

3.4 Fly ash: For the purpose of the project work, NTPC-Simhadri (Thermal power plant), Vishakhapatnam, India, through the proper channels with authorization from higher authorities, Fly ash (class F) is procured. The fly ash utilized had a 23.53% fineness modulus and a 2.2 specific gravity.

3.5 Lime sludge: Lime sludge is collected from the paper industry for the purpose of the study. The

collected Lime sludge was appropriately stored.

The final setting, initial setting times, normal

consistency, and specific gravity are 540 min, 43 min, 31%, and 2.3, respectively.

Table 1

Chemical composition of cement, Lime sludge, and Fly ash (%)

Constituent	Cement	Lime sludge	Flyash
Cao	62.24	48.20	2.35
SiO ₂	24.08	9.35	61.55
Fe ₂ O ₃	2.46	2.95	4.22
Al ₂ O ₃	4.72	3.15	28.15
MgO	1.95	2.58	1.02
LOI	3.82	33.77	0.3

Table 2 Notation of the specimens

Notation	Lime sludge (LS) %	Fly ash (FLS) %
Conventional Concrete (CC)	0%	0%
10%	5%	5%
20%	10%	10%
30%	15%	15%
40%	20%	20%



Figure 1: Partial replacement of cement with Class F Fly ash



Figure 2: Partial replacement of cement with Lime sludge

4. TESTS ON HARDENED CONCRETE

4.1 Compressive strength test: Compressive strength test was conducted as per IS: 516-1959[8]. Cement, fine aggregate and Coarse aggregate (up to 20mm) are brought to the room temperature (preferably 27°C), weighed in the ratio and mixed by hand mixing or machine mixing. The test specimens recommended are 150 × 150 × 150mm size cubes. The CTM is used to test whether the cubes are applied perpendicular to the route of casting the cube (see Fig.3). The axis of the cube is aligned to the middle of the loading frame. The rate of weight applied at 140 kg/cm²/min until the cube



Figure 3: Testing of the cube under direct compression

4.2 Split tensile strength test: The split tensile strength of concrete is determined by conducting tests on cylindrical specimens of 150 mm × 300 mm. The specimens underwent direct compression loading. The samples were positioned horizontally in the machine (see Fig.4). The weight is used in the longitudinal direction on a 300 mm diameter. The load borne by the specimen is recorded. The specimen was determined using the following formula:.



Figure 4: Testing of the cylinder for split tensile strength

breaks down and fails. Three cubes were tested for every percentage of replacement with the replacement mixture to establish the average compressive strength. The measured characteristic compressive strength (f) of the specimen is calculated using the following formula:

$$\text{COMPRESSIVE STRENGTH} = \frac{P}{A}$$

Where,

P = Maximum load in Newton's applied to the specimen

A = Area of specimen in mm²



$$\text{SPLIT TENSILE STRENGTH} = \frac{2P}{\pi DL}$$

Where,

P = Maximum load in Newton's applied to the specimen

L = Length of the specimen in mm

D = Cross-sectional dimension of the specimen in mm



4.3 Flexural strength test: Flexural strength of concrete is found by casting prisms of dimensions 500 mm × 100 mm × 100 mm, conducted as per IS: 516-1959[8]. The weight was used on the samples under three-point bending using a Universal Testing Machine capacity of 1000 KN. The weight was used at a constant rate and constantly till the prism failed. The mixed concrete is filled into the moulds in layers. The specimens are stored at a temperature of 27°C. After this period, the specimens are removed from the moulds and placed in water (curing) at the age of 28 days. The measured characteristic of flexural strength (f_r) of the specimen is calculated using the following

formula:

$$\text{Flexural strength } (F_r) = \frac{3Pa}{bd^2} \quad (\text{when } a < 13.3 \text{ cm})$$

Where,

a = the distance between the line of fracture and the nearest support, measured on the centre line of the tensile side of the specimen (cm)

P = Maximum Load taken by the specimen

b = width of specimen (cm)

d = failure point depth (cm)



Figure 5: Testing of the prism under flexure

5. RESULTS AND DISCUSSION

5.1.1 Workability test results of blended cement concrete (M20)

Table 3

Combination	Slump value in (mm)	Compaction Factor value	Vee-bee time in (sec)
Conventional concrete (0%)	100	0.95	4.5
10% (5% LS + 5% FLS)	120	0.97	3.2
20% (10% LS + 10% FLS)	125	0.92	5
30% (15% LS + 15% FLS)	120	0.94	3.8
40% (20% LS + 20% FLS)	135	0.90	6

5.1.2 Workability: Table 3 illustrates the workability results of the blend cement concrete (M20).

5.1.3 Influence of mixture of fly ash along lime sludge in workability of concrete:

Fly ash (FLS) produced a pozzolanic material with

high silica and alumina concentration. One finds more calcium in the Lime sludge (LS) when the mineral oxide in mixed concretes reacts with lime in spite of water, C-S-H gel resembling those of the components present in hydrated cement from Portland cement results. The weakest and most important feature of

concrete is the interfacial alteration zone in the cement paste and aggregates, which forms based on the particle dimension distribution of these components. The particle dimensions of LS and FLS influence filling micro-voids, thereby strengthening ternary blended cement concrete. This essential quality fills in small empty areas and generates tiny fractures through the fine texture of concrete, therefore improving its strength. While cement and LS comprise more calcium, class F fly ash comprises more silica. This disparity in composition results in the generation of a greater concentration of C-S-H gels, leading to an enhancement in the strength of the concrete. Up to 40% of partial replacement of LS and FLS in conventional concrete improves more workability of

blended cement concrete.

- The percentage of partial replacement of Lime sludge and Fly ash, and the slump of concrete at 10% to 40% showed that it has a high workability of blended cement concrete.
- With a further increase in the percentage of partial replacement of Lime sludge and Fly ash, the compaction factor of concrete is found to be increased at 0%, 10%, and 30% shows that it has a high workability.
- The Vee-Bee values of concrete are increased at 0%, 20%, and 40% also shows that it has a high workability.

5.2 Hardened strength results of blended cement concrete (M20)

5.2.1 Mechanical characteristics of M20 Grade of concrete

Table 4

Combination	Compressive strength (Mpa)		Split tensile strength (Mpa)		Flexural strength (Mpa)
	7 Days	28 Days	7 Days	28 Days	28 Days
Conventional concrete (0%)	20.44	28.51	2.26	2.51	3.61
10% (5% LS + 5% FLS)	22.00	31.55	1.78	2.54	3.92
20% (10% LS + 10% FLS)	21.62	30.73	1.86	2.42	3.86
30% (15% LS + 15% FLS)	20.10	29.03	1.84	2.33	3.84
40% (20% LS + 20% FLS)	18.29	26.44	1.76	2.05	3.76

5.2.2 Compressive strength results

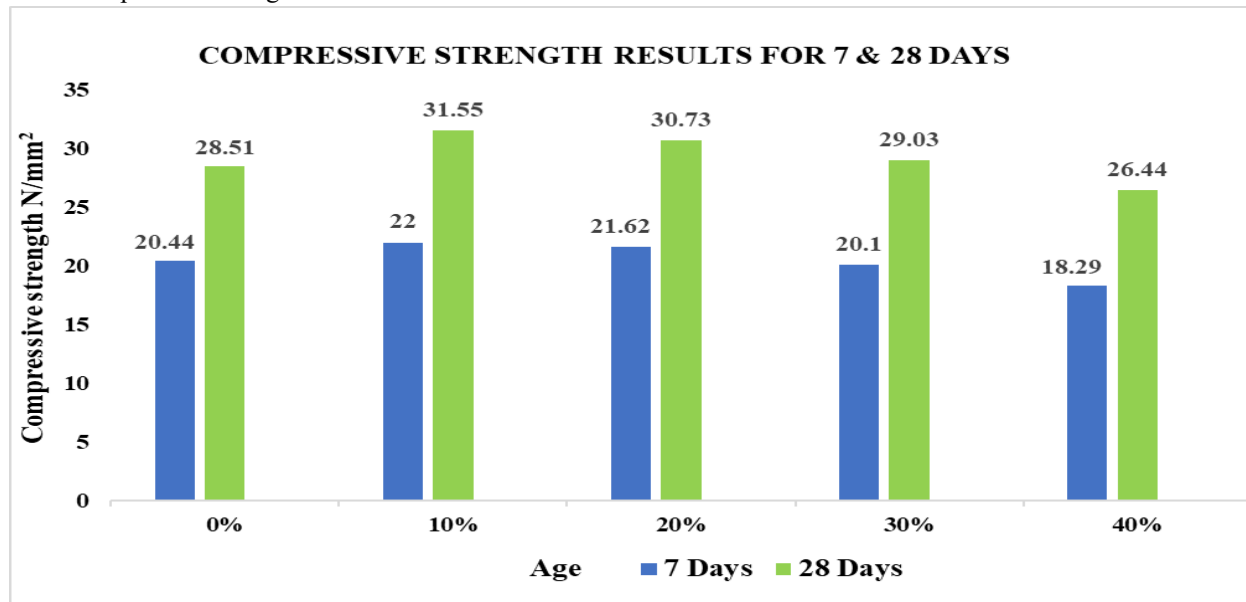


Figure 6: Changes in compressive strength of M20 grade concrete at 7 and 28 days

5.2.3 Split tensile strength results

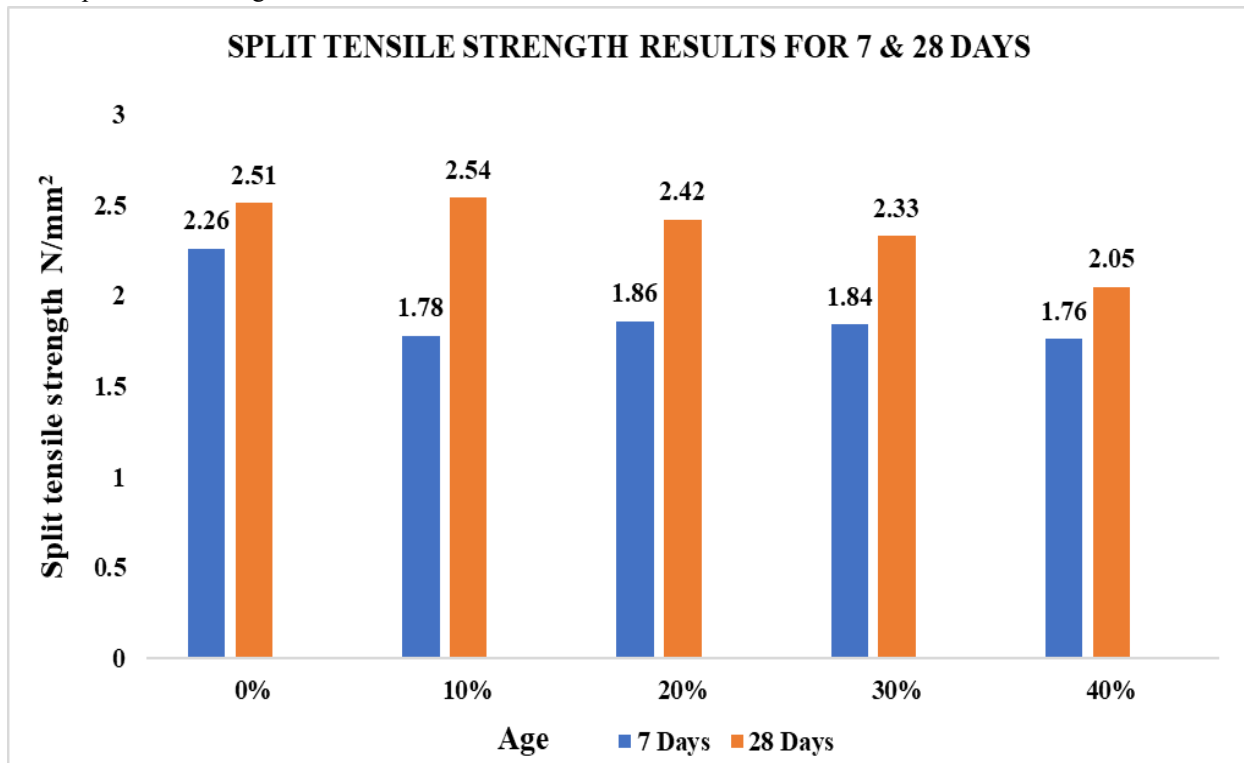


Figure 7: Changes in split strength of M20 grade concrete at 7 and 28 days

5.2.4 Flexural strength results

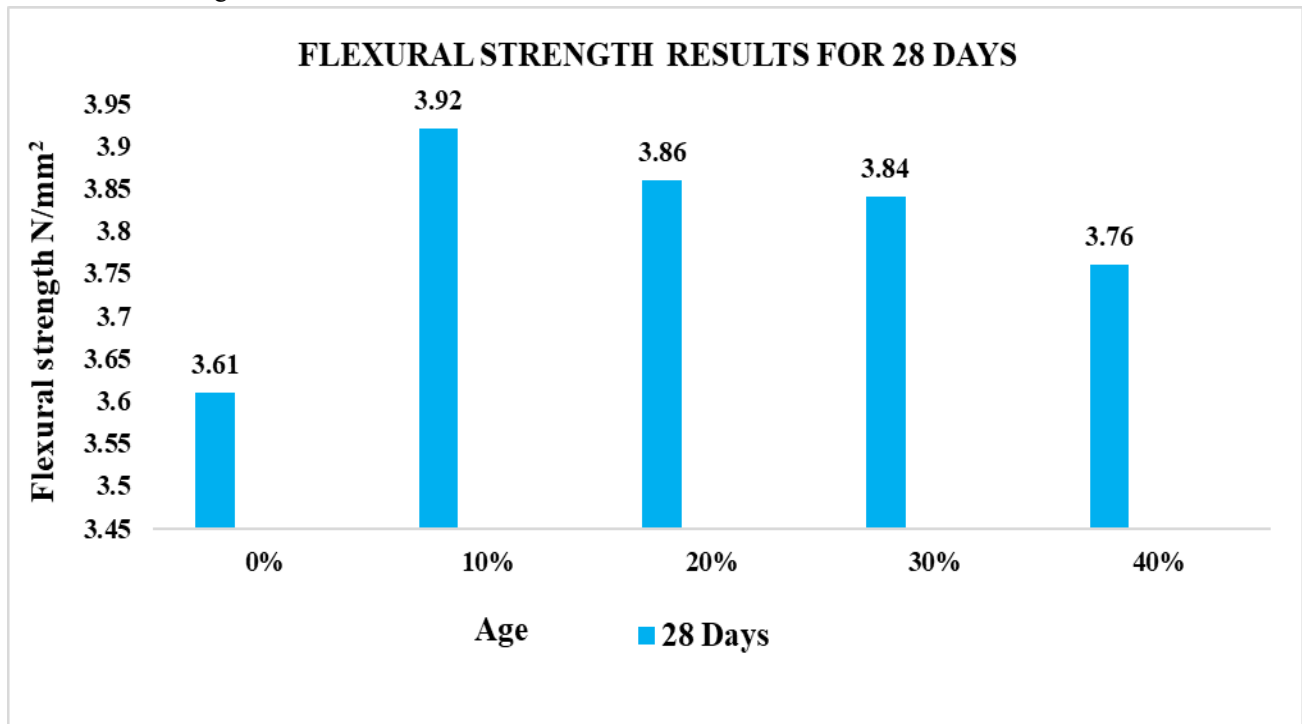


Figure 8: Changes in Flexural strength of M20 grade concrete for 28 days

6. CONCLUSIONS

Based on an experimental study on blended cement concrete by partial replacement of cement with Lime Sludge and Fly Ash, the following conclusions are drawn:

1. It is observed that when cement is partially replaced with Lime sludge and Fly ash, the workability (slump, compaction factor, and vee-bee consistometer) of the concrete is increased.
2. The partial replacement of cement with Lime sludge and Fly ash at 10%, 20%, 30%, and 40% for 7 and 28 days has been tested. Optimum percentage of replacement was obtained with Lime sludge and Fly ash only at 10%.
3. The optimum percentage of strength is attained at 10% partial replacement with Lime sludge and Fly ash, and it is observed that the compressive strength is 7.63% for 7 days and 10.66% for 28 days more when compared with conventional concrete for 7 and 28 days.
4. It is observed that the partial replacement of cement at 20%, the compressive strength is increased by 5.45% for 7 days and 7.78% for 28 days.
5. The partial replacement at 30% the compressive strength is decreased by 1.66% for 7 days and increased by 1.82% for 28 days.
6. For 7 and 28 days, it is observed that the compressive strength is decreased at 40% partial replacement of Lime sludge and Fly ash, 10.51% for 7 days and 7.26% for 28 days when compared with conventional concrete.
7. The maximum tensile strength is attained at 10% partial replacement with Lime sludge and Fly ash, with an increased percentage of 1.19% for 28 days and a decreased 21.23% for 7 days.
8. It is observed that there is a decrease in tensile strength at 20%, 30% and 40% partial replacement with Lime sludge and Fly ash, 17.69%, 18.58% and 22.12% for 7 days and 3.58%, 7.17%, and 18.32% tensile strength for 28 days, respectively.
9. The maximum flexural strength is attained at 10% partial replacement with Lime sludge and Fly ash, with an increased percentage of 8.58% for 28 days.
10. For 28 days, it is observed that the flexural strength is increased at 20% and 30% partial

replacement with Lime sludge and Fly ash, with an increased percentage of 6.92% and 6.37%, respectively.

11. The flexural strength is also increased at 40% partial replacement with Lime sludge and Fly ash, with an increased percentage of 4.15% compared with conventional concrete.
12. Concrete specimens with Lime sludge and Fly ash exclusively obtained better strength characteristics. At 10%, 20%, and 30% partial replacement of cement with Lime sludge and Fly ash, better results were shown due to the generation of excess formation of C-S-H gel with the calcium content in Lime sludge.
13. The partial replacement of cement with Lime sludge and Fly ash in concrete increases the compressive strength due to the presence of calcium in the concrete mix.
14. The cement can be partially replaced with Lime sludge and Fly ash up to 30% (15% LS + 15% FLS) without any loss of compressive strength. Up to 30% of the partial replacement's compressive strength is more than the target strength of conventional concrete.
15. From this experimental study, we can conclude that Lime sludge and Fly ash can be used as partial replacement materials for cement to produce sustainable concrete.

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