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Strength of Concrete using Clay as a Partial Replacement of Binder Content with and Without Lime

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Abstract: Materials are the most important component of building construction. The demands of construction material are increasing day by day significantly. This demand is increasing the material prices and scarcity of material in construction industry. To achieve economical and eco-friendly criteria naturally occurring material is selected. Clay is a natural material and it can be available easily. This paper interprets the experimental investigation on strength of concrete using clay as a partial replacement to binder content (cement) in concrete. The replacement percentages are grouped as 0%, 10%, 20%, 30%, 40% of clay and 5% of hydrated lime with cement in each series in M25 grade of concrete. To achieve the pozzolanic property of clay hydrated lime was added. Different tests are performed to determine the optimum percentage of clay as a replacement for binder content (cement) in concrete. The Compressive strength test, split tensile strength test and flexural strength test were performed on the specimens. Total 90 cubes of size 150 mm were prepared for compressive strength test, 30 cylinders of 150 mm diameter and 300 mm height were prepared for split tensile strength test and 30 beams of size 150 mm x 150 mm x 1000 mm were prepared to carry out the flexural strength test. The results are compared to find the ideal proportion of clay as a replacement for cement. It is found that 10% replacement with 5% hydrated lime gives satisfactory results.

Keywords: Clay, Concrete, Hydrated lime, Partial replacement, Pozzolanic property, Replacement percentage.

I. INTRODUCTION

In construction industry concrete is used very widely. It provides good strength, durability, impermeability, resistance to fire and abrasion, etc. Cement is the main component for making concrete. The environmental degradation took place by the use of various materials in the building construction. These materials are cement, sand, bricks, steel, wood, glass, tiles, etc. Sometimes harmful pollutants are released by building materials damaging the environment [1]. In the production of cement, there is a large magnitude of creation of CO2 gas which is hazardous to our environment [2]. Today, the rise in demand for materials in building construction has resulted in significant degradation of natural resources. For this, it is beneficial to choose eco-friendly materials to achieve the structural economy. The mud concrete can be prepared by taking into account strength and durability parameters [3]. Clayey soil performs a vital role in increasing the strength and ductility of stabilized soil [4]. In some cases, calcined material is used to improve the initial and final strength of Portland cement. But it is required to find its long-term durability effect [5], [6].

Marine clay stabilization can be done by replacing cement with wood – ash. The parameters considered are unconfined compressive strength, shear modulus at the initial stage and shear strength [7]. The termite clay as a replacement to cement in roofing tile is investigated and optimum 10% replacement in cement is found appropriate [8]. Cement can be replaced by fly ash and lime sludge (as a water softening sludge) in the preparation of mortar [9]. In some cases, Indian calcium bentonite is used as a replacement for cement [10]. The industry-produced quicklime can be used for activation of clay as a cementitious material [7]. Such replacement will decrease the production of greenhouse gases and cement production costs [11]. The construction industry is using clay as a natural abundantly available material. It is a natural pozzolana available on earth [12]. Soil efficiency can be improved using clay minerals formulating epoxy resin cement clay mixtures [4].

Clay is an economical and effective alternative for the construction of low-cost housing units. It is widely used in tropical regions where very limited resources are available [3]. Clay is used as a binder in construction for many years and still worked well. The particle size of clay is less than 2 microns which exhibits plasticity characteristics by absorbing water and shrinks after removing the water. The three main clay minerals are Kaolinite, illite, and montmorillonite. Kalins pozzolanic reactivity with calcareous montmorillonite can be used [2]. Kaolinite clay can be used as an admixture in concrete to improve strength, workability and chloride diffusion coefficient [13]. The cement paste is verified for its porosity characteristics and microstructure is assessed. The most stable clay is Kaolinite. Montmorillonite soils are quite expansive and swelling in nature whereas illite clay comes in between. An optimum dose of 20% bagasse ash with soft clay is found suitable for the replacement of Ordinary Portland Cement [14]. To activate the clay as a cementitious material, industry-produced quicklime is required [11].

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Renewable energy sources are utilized for the construction of walls. Biomass is one of the sustainable walling materials for the manufacturing of bricks [1]. Natural and synthetic fibers can be used to prepare soil blocks as an alternative to conventional bricks. [15]

Clay is an eco-friendly material and is available on-site easily. It has binding property hence; it can be used in the replacement of cement. Using a stabilizer the strength of clay can be increased. The compressive strength was taken on cubes, split tensile strength on cylinders, and flexural strength on beams. To check the strength of concrete using partial replacement of binder content (cement) with clay, it is taken in five test groups viz. 0%, 10%, 20%, 30%, 40% in two sets. The first set was without hydrated lime whereas the second set was with hydrated lime.

II. MATERIALS AND METHODOLOGY

The step-by-step procedure of experimental program is shown in Fig. 1. First of all, materials like cement, sand and aggregates are collected. These materials were tested in a laboratory to find their mechanical properties. The chemical formula of Calcium hydroxide is $Ca(OH)_2$ acting as an organic compound. It is obtained from quicklime (calcium oxide) in the form of a colorless crystal or white powder mixing or slaking with water. Hydrated lime and quicklime are calcium compounds. Quicklime is a calcium hydroxide in a hydrated state or pure state.

The design mix is prepared for M25 grade of concrete. The concrete cubes, beams and cylinders were cast by taking sets with and without hydrated lime. The dose of hydrated lime is taken as 5% while casting specimens. The clay was added as 0%, 10%, 20%, 30% and 40%. The curing of specimen was done for 28 days and then tested.

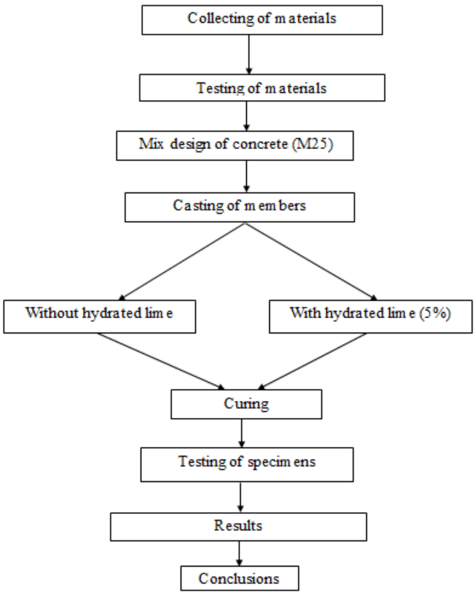

Fig. 1: Methodology

A. Materials

Materials such as cement, sand and aggregate were collected from different sources. For cement, tests like standard consistency, initial and final setting time, soundness test and compressive strength test were conducted. Sieve analysis and water absorption tests were conducted on fine aggregates as well as coarse aggregates.

Cement: - 53 grade OPC
Specific gravity: - 3.15
Fine aggregate: - natural sand from river
Specific gravity: - 2.65
Coarse aggregate: - nominal size of 20 mm
Specific gravity: - 2.74

B. Mix Proportions

Table- I: Design mix proportion (M25)

Descriptions	Cement	Fine aggregate	Coarse aggregate	Water
Mix proportion by weight	1	1.789	3.02	0.5

C. Casting procedure

The design mix ratio of M25 was adopted as shown in Table – I for preparing specimens. A total of 90 cubes were prepared for both cases with and without hydrated lime respectively. The tests on cubes were conducted for 3 days, 7 days and 28 days. 30 cylinders and beams for both with and without hydrated lime were prepared as shown in Table – II and Fig. 2. For the case of with hydrated lime, 5% of hydrated lime with cement in each series was added. The specimens were removed from the mold after 24 hours and placed in water for curing.

Table- II: Number of specimens prepared

Sr. No.	Particular	Cube			Cylinder	Beam
		3 Days	*7 Days*	*28 Days*	*28 Days*	*28 Days*
1	0%	6	6	6	6	6
2	10%	6	6	6	6	6
3	20%	6	6	6	6	6
4	30%	6	6	6	6	6
5	40%	6	6	6	6	6
Total		Cubes = 90			Cylinders = 30	Beams = 30

Fig.2: Casting of specimen

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III. TEST RESULTS

Different tests were conducted on concrete. The 150 mm size cubes were tested for compressive strength test. The split tensile test was carried out on cylinders of 300 mm height and 150 mm diameter. The flexural strength test was performed on beams of size 150 mm x 150 mm x 1000 mm. The experimental results for various tests are mentioned below.

A. Compressive Strength Test

The compressive strength test was done on standard cubes for all five groups in two cases which are with and without hydrated lime as per IS: 516-1959. The concrete cubes are tested as shown in Fig. 3. These tests were conducted at 3 days, 7 days and 28 days of curing. The observations of experimental program are shown in Table – III and Table – IV. Fig. 4, 6 and 8 are indicating the graphical comparison of cube compression test, split tensile strength and flexural strength test with and without hydrated lime after 28 days respectively. With the addition of clay with or without lime, all strengths are significantly decreased. Still there in no huge difference between 0% and 10% replacement results. It indicate that up 10% cement can be replaced by clay.

Fig. 3: Compression test

Case I: Without hydrated lime

Table- III: Compressive strength test result without hydrated lime

Cement Replacement	Sr. No.	3 days Comp. Strength (MPa)	7 days Comp. Strength (MPa)	28 days Comp. Strength (MPa)
0%	1	12.84	18.53	26.58
	2	12.67	17.69	26.75
	3	12.48	17.78	26.53
	Avg.	12.66	18.00	26.62
10%	1	10.84	17.69	25.29
	2	11.16	17.38	25.02
	3	10.93	17.60	24.80
	Avg.	10.98	17.55	25.04
20%	1	8.04	15.82	23.82
	2	7.82	15.51	23.56
	3	7.96	15.64	23.64
	Avg.	7.96	15.66	23.67
30%	1	6.49	12.62	22.84
	2	6.27	13.11	23.20
	3	6.00	12.93	23.02
	Avg.	6.25	12.89	23.02
40%	1	5.87	10.67	20.98
	2	6.13	10.36	21.13
	3	5.42	10.89	20.71
	Avg.	5.81	10.64	20.94

Case II: With hydrated lime

Table- IV: Compressive strength test result with hydrated lime

Cement Replacement	Sr. No.	3 days Comp. Strength (MPa)	7 days Comp. Strength (MPa)	28 days Comp. Strength (MPa)
0%	1	12.80	17.87	27.20
	2	13.16	18.76	27.82
	3	13.50	18.58	28.62
	Avg.	13.15	18.40	27.88
10%	1	11.47	17.96	26.00
	2	11.67	17.60	25.95
	3	11.29	17.78	26.09
	Avg.	11.48	17.78	26.01
20%	1	9.24	16.53	24.67
	2	8.71	16.80	24.62
	3	8.44	15.73	24.89
	Avg.	8.80	16.29	24.73

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30%	1	6.76	13.15	23.77
	2	7.47	13.42	23.68
	3	6.31	13.51	23.91
	Avg.	6.85	13.36	23.79
40%	1	5.91	11.29	21.69
	2	6.22	12.36	20.80
	3	6.04	11.82	22.32
	Avg.	6.05	11.83	21.60

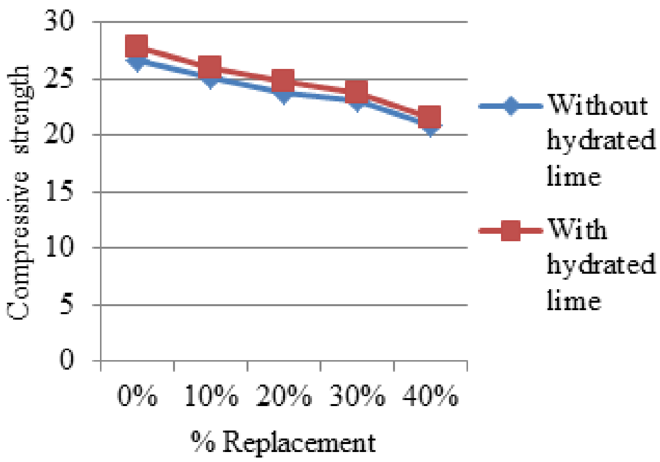

Fig. 4: Compressive strength of concrete without and with hydrated lime

B. Split tensile strength test

The failure of a cylindrical specimen is checked in a split tensile strength test. The test is taken on the cylinder by splitting along its middle plane parallel to the edges. The load is applied to opposite edges as per IS: 516-1959. Fig. 5 shows the split tensile strength of the cylinder. Test results are given in Table – V and Table – VI. Formulation of Split tensile strength is as follows,

$$f_t = \frac{2P}{\pi DL}$$

Where,

f_t = Spilt tensile strength (N/mm^2),

P = Load at failure (N),

L = Length of Cylinder (mm),

D = Diameter of a cylinder (mm).

Fig. 5: Spilt tensile test

3.2.1 Case I: Without hydrated lime

Table- V: Split tensile strength results without hydrated lime

Sr. No.	Replacement	Specimen 1	Specimen 2	Specimen 3	Average
1	0%	2.69	2.73	2.75	2.72
2	10%	2.60	2.63	2.59	2.61
3	20%	2.34	2.27	2.38	2.33
4	30%	2.27	2.21	2.30	2.26
5	40%	2.08	2.17	2.03	2.07

3.2.2 Case II: With hydrated lime

Table- VI: Split tensile strength results with hydrated lime

Sr. No.	Replacement	Specimen 1	Specimen 2	Specimen 3	Average
1	0%	3.05	3.03	2.97	3.02
2	10%	2.87	2.89	2.86	2.87
3	20%	2.53	2.62	2.57	2.57
4	30%	2.36	2.31	2.40	2.36
5	40%	2.17	2.20	2.15	2.17

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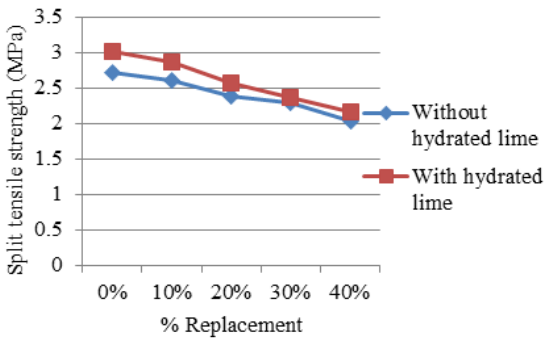

Fig. 6: Split tensile strength of concrete without and with hydrated lime

C. Flexural strength test

The beams were tested for 28 days strength. The central point load is applied on the specimen. Fig. 7 shows the experimental setup for flexural strength test. The test results are given in Table – VII and Table – VIII for without and with hydrated lime respectively. With the increasing percentage of clay, the flexural strength is getting reduced in both the cases. The flexural strength is determined by the following formula,

$$f_{bt} = \frac{3PL}{2bd^2}$$

Where,

f_{bt} = Flexural strength (MPa),
P = Load at failure (N),
L = Span of specimen (mm),
b = Width of specimen (mm),
d = Depth of specimen (mm).

Fig.7: Flexural strength test

Case I: Without hydrated lime

Table- VII: Flexural strength results without hydrated lime

Sr. No.	Replacement	Specimen 1	Specimen 2	Specimen 3	Average
1	0%	3.07	3.12	2.95	3.05
2	10%	2.90	2.93	2.97	2.93
3	20%	2.77	2.83	2.81	2.80
4	30%	2.64	2.71	2.69	2.68
5	40%	2.38	2.41	2.39	2.39

Case II: With hydrated lime

Table- VIII: Flexural strength results with hydrated lime

Sr. No.	Replacement	Specimen 1	Specimen 2	Specimen 3	Average
1	0%	3.29	3.21	3.34	3.28
2	10%	3.08	3.05	3.09	3.07
3	20%	2.88	2.91	2.92	2.93
4	30%	2.79	2.83	2.86	2.83
5	40%	2.47	2.52.	2.54	2.51

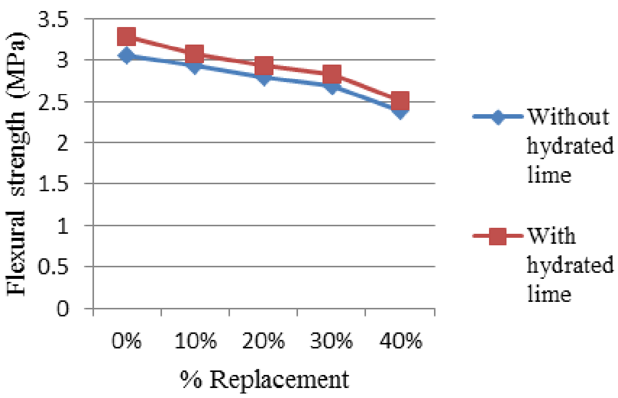

Fig. 8: Flexural strength of concrete without and with hydrated lime

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IV. CONCLUSIONS

After varying the percentage of clay as a replacement to cement with and without hydrated lime following conclusions are made,

1) With the rise in the percentage of clay, the strength of specimens getting decreased. In case of hydrated lime, significant improvement in strength is found compared to the case of without hydrated lime
2) Clay can be modified slightly by adding industry-produced lime to form concrete.
3) The strength of concrete in compression is decreased around 5% to 6% with an increase in the percentage of clay in both the cases such as with and without hydrated lime.
4) For 0 % replacement of clay, concrete strength of with hydrated lime is 4.5 % more compared to without hydrated lime. When 10 % cement is replaced by clay, the hydrated lime improves the compressive strength up to 3.73 % when compared to without hydrated lime.
5) In split tensile strength, about 9.9% increase in strength is seen for 0% cement replacement with hydrated lime. With the increase in the percentage of clay, a gradual loss in split tensile strength is found.
6) For the flexural strength test, there is a reduction in the strength of concrete with a rise in the percentage of clay. When compared to without hydrated lime case up to 4% to 8% increase in flexural strength is noticed using hydrated lime.
7) For 10% replacement of clay with hydrated lime gives satisfactory results for compressive strength test, split tensile strength test as well as flexural strength test.

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