MECHANICAL CHARACTERIZATION OF LIMESTONE CALCINED CLAY CEMENT (LC_3) CONCRETE

Session: 2017

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DEDICATION

This thesis is dedicated to: **The Allah Almighty**, Our Creator & Our Lord, Our great teacher and prophet, **Hazrat Muhammed** (Peace Be Upon Him), who educated us the purpose of life. Our parents, who always supported us in numerous ways.

ACKNOWLEDGEMENTS

First, we would like to thank **Allah SWT** that he enabled us with the knowledge and ability to carry out this research. Without his blessings, the completion of this project would be impossible.

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Lastly, we must acknowledge once again our Parents, teachers, classmates, and all those who helped us in our project, and they have been so supportive along the way of doing our thesis.

ABSTRACT

Second to water, cement is most used resource on earth. Globally 4.1 billion metric tons cement is produced. For Every 1 ton, 0.8-to-0.9-ton Carbon dioxide is produced. In 2012 and 2013 China has produced more cement than USA did in entire twentieth century. Cement product has a massive carbon footprint and enormous release of CO_2 is causing greenhouse effect and increase in Earth temperature.

To cope with problem of CO_2 emissions, a tertiary blend of cement was produced in an international collaboration. This blend is called Limestone calcined clay cement LC_3. To protect our ecosystem, clinker use can be reduced up to 50 percent by replacing it with LC_3. Because the production of clinker requires 1400 **°C** temperature but kaolin clays require 600 **°C** to 800 **°C** to form Metakaolin as pozzolanic material. Therefore, LC_3 formation require 800 **°C** which is less than 1400 °C and hence less CO_2 emission than that in Clinker formation.

In proposed mix 46% of cement was replaced with Limestone calcined clay to form LC_3. For mechanical characterization, Compression tests, split tensile tests and flexural tests were conducted on LC_3 concrete and results were compared with control concrete PCC. Finally, we come up with that their Compressive, Split Tensile and Flexural strength are much like each other almost same. Results show mechanical characteristics of LC_3 concrete are identical to PCC.

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INTRODUCTION

1.1 WORLD CEMENT CONSUMPTION

Concrete is one of the man-made objects which is being used on very large scale. Second to water, concrete is extensively put to use. The major component of concrete is cement. Cement production leads to massive carbon dioxide production. Think Tank Chatham House states that, Cement production on world scale is a source of 8% of world's carbon dioxide emissions. In one year, cement production accounts for approximately 4.1 Billion-Metric Tons world-widely. On an average, 0.8 to 0.9 ton of carbon dioxide is produced out of 1 Ton of the production of cement. Third largest source for Carbon dioxide emission is cement production industry. Cement production has increased significantly since 1950. In 2011 to 2013, China has used more cement than the United States of America did in entire Twentieth Century.

1.2 ROAD MAP TO REDUCE CO_2 EMISSIONS

Concrete technologists and cement industry leaders are continuously researching for various ways to reduce carbon dioxide emissions and a sustainable development of cement industry.

Four significant carbon dioxide reduction controls in the cement production industry that need to be applied effectively are given below:

- By improving energy efficiency in cement production sector.
- By switching to alternate fuels with less carbon intensity.
- By reducing clinker formation content.
- By implementation of advanced technologies such as capturing of carbon.

By using supplementary cementitious materials (SCMs), carbon dioxide emissions can be reduced significantly. However, due to unavailability or limited supply of SCMs they cannot be used widely. Slag, Fly Ash and Limestone are the supplementary cementitious materials, which are mostly used to reduce clinker factor in cement. Reduction in clinker formation is most effective approach to regulate CO_2 emissions.

1.3 LIMESTONE CALCINED CLAY CEMENT

Several research studies suggested that mixture of limestone powder and China-Clay (calcined) powder can replace a large portion of clinker-mass significantly. In an international collaboration, a new ternary blend cement was developed recently. This final product is LIMESTONE CALCINED CLAY CEMENT (LC_3). LC_3 substitutes clinker formation without affecting cement properties. In LC_3 clinker formation is low up to 50 percent. Limestone was already used in cement but without slag or other additives, it cannot be used more than 15% as it deteriorates cement properties. In India and Cuba pilot scale production trials of this LC_3 was done. Compressive strength, durability, workability, and all tests performed on LC_3 gave similar or better results than Portland cement. According to International Energy Agency (IEA): By 2050, 27 percent of Global cement production will contain Limestone and Calcined-Clay. The mechanical properties of this cement were encouraging but the commercial viability of this cement is still a question.

1.4 BACKGROUND, PAKISTAN CEMENT INDUSTRY

Since 1947, the cement production industry of Pakistan has developed a lot. The annual production of cement after Partition was 300,000 tons per year while per annum installed capacity for production was 470,000 tons. In 1921, the first cement factory of Subcontinent was established at Wah, Punjab, Pakistan. With time, it became clear that installed capacity can't fulfill demand for cement. The annual supply was 660,000 tons while 1million tons were required annually. Pakistan Industrial Development Corporation (PIDC) took necessary steps for expansion of cement industry to cater the shortage.

Two cement factories at Zeal Pak with capacity of 240,000,000 Kg and Maple Leaf with capacity of 100,000,000 Kg were established. Today, approximately the capacity of cement manufacturing is 46- 49 million tons. In two years, the rate at which the cement is produced will be increased up to 15%.

Pakistan is world's 14^{th} largest cement producer. With Urbanization, CPEC and other ongoing infrastructure projects cement production is increasing day by day. The amount of cement used each year is a sign of country's pace of social and economic progress. However, per capita use of cement in Pakistan is 140 Kg as compared to 400 Kg per capita, globally. It indicates this industry has a huge potential of growth. Keeping in mind the deteriorating environmental conditions of Pakistan we have to regulate cement industry with alternate solutions like Limestone clay cement (LC_3).

1.5 OBJECTIVES

- To replace the clinker which is a major cause of CO_2 emission and energy consumption in the production of cement.
- The use of locally available materials such as Kaolin clay and limestone to make Limestone Calcine Clay cement (LC_3) concrete.
- To compare the LC_3 concrete with the PCC concrete whether it gives same result as that of PCC concrete or not.

CALCINED CLAYS AS SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMS)

The usage of calcined clays as a substitute of ordinary Portland cement has an extensive history. Mielenz et al, examined the calcination mechanism of pozzolan and their potential use for concrete applications in the early 1950's. Metakaolin as supplementary cementitious material was reported to be used for first time in Brazil in Jupia dam construction in 1960's. Metakaolin was used in substitution of cement by volume up to 30%. Calcined clay was used in industrially as a replacement for cement. But, compared to other additional cementitious materials like slags or fly-ashes, its use was negligible. Some Clays have unique properties among the SCMS because of their global availableness on the earth's crust.

2.1 DIFFERENT CLAY TYPES

Earth minerals begin from the enduring of silicate minerals in rocks (feldspar, micas, and so forth…). They are named phyllosilicates that typically happen in molecule sizes of 2μm or less}. Yet, such a size order is excessively uncertain. Some dirt particles are likewise of bigger molecule size and non-mud minerals may happen in particles extensively under 2mm in breadth.

Precious stone construction and synthetic creation are what truly separates clay from other Minerals as they characterize their trademark actual properties like plasticity. Earth particles are comprised of a few tens or even many layers, whose construction is a mix of silica and alumina sheets. As can be found in Figure a silica sheet is made from Silicon molecules in tetrahedral coordination, where three of the four oxygen in every tetrahedron are shared to frame a hexagonal net. Alumina sheets, as addressed in Figure are made from aluminum molecules in octahedral coordination with oxygen or hydroxyls.

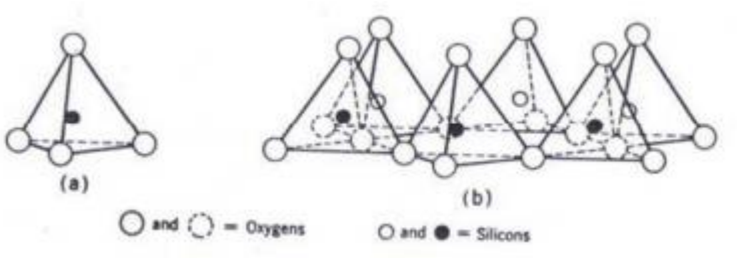

Figure 2.1 a) Tetra hederal silicon b) sheet

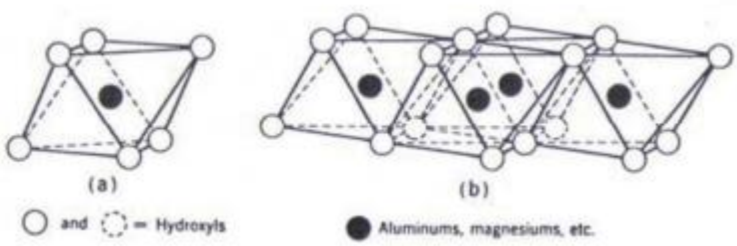

Figure 2.2 a) Octahedral aluminum b) sheet

The alumino-silicates minerals address 74% of the world's outside layer and they address subsequently an exceptionally intriguing contender for development materials since they are accessible all over. Diverse earth mineral gatherings are described by the stacking courses of action of sheets and the way in which progressive a few sheet layers are held together. The three earth sorts of significant value are kaolinite, illite and montmorillonite (smectite). The design of these clays is displayed in Figure

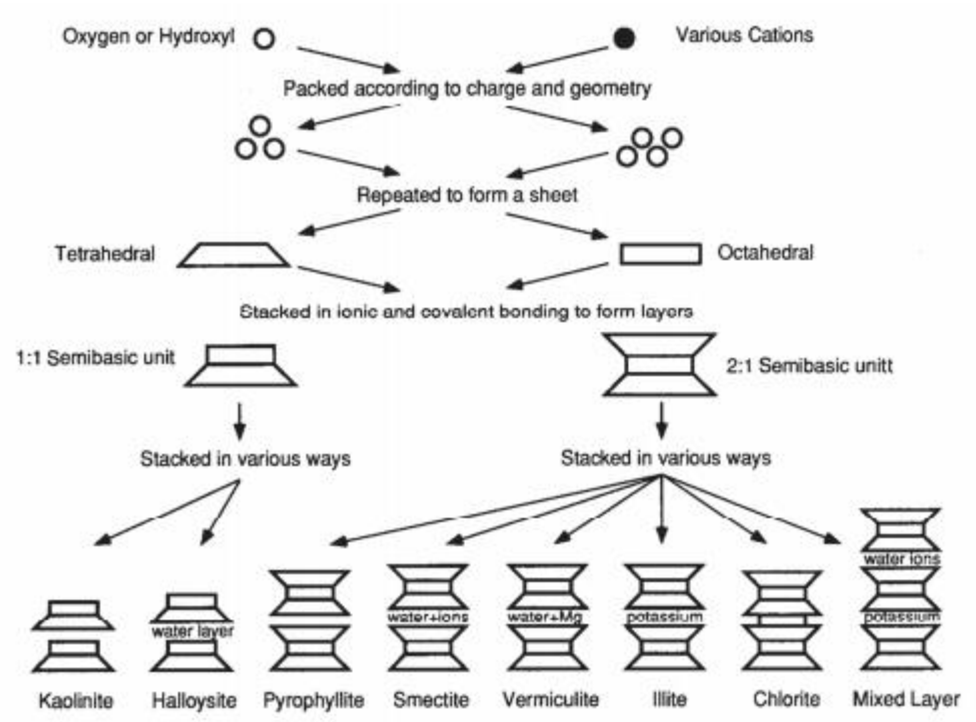

Figure 2.3 Structural mosaic of various clays

2.2 THERMAL ACTIVATION OF CLAYS

Whenever clays are heated at a specified temperature it causes the removal of water which is structurally attached to it. This process is named as dihydroxylation of clays. It can also be called calcination. When Kaolinite is passes through this development it converted into more firm state and Kaolin is formed.

2.3 REACTIVITY OF CLAYS

The rate of reactivity of clay is dependent on how much dihydroxylation has been done. If the dihydroxylation is to the level of 95% or more then the clay is reactive. In order to check this, various tests can be performed, and one is Thermo Gravimetry Analysis (TGA).

2.4 METAKAOLIN AS POZZOLANIC MATERIALS

The utilization of different responsive pozzolans as (SCM) is quickly developing in the advancement of more solid and superior cement. Kaolin earth is a characteristic hotspot for improvement of metakaolin which can be utilized as valuable solidifying material. Assembling of concrete includes primer pounding of crude materials, warming to exceptionally high temperatures lastly crushing it to fine powder, consequently making it as an energy concentrated material. Fractional substitution of concrete by Pozzolans saves concrete as well as works on the nature of cement. As per ACI 116R, Pozzolan is characterized as "siliceous and aluminous material, which in itself has almost no cementitious worth except for will, in finely separated structure and within the sight of dampness, synthetically respond with calcium hydroxide at common temperatures to structure compounds having cementitious properties".

In clays their most active part is Kaolin which is pozzolanic in nature is formed when it is heated between temperature of **650-800** Celsius under natural pressure.

$$Al_2Si_2O_5(OH)_4 \rightarrow Al_2Si_2O_7 + 2H_2 \tag{2.1}$$

This formed material is very active with regard to acting as a binding material and can be used as a replacement to clinker. If the temperature increases more than the 800 till 850 Celsius it can cause the roughening of metakaolin ultimately reduction of reactivity.

$$2Al_2Si_2O_7 \rightarrow Si_3Al_4O_{12} + SiO_2 \tag{2.2}$$

Further heating (above) of clay will direct the clay to the formation of further tough structure of clay mullite and cristobalite which are very less reactive.

$$3Si_3Al_4O_{12} \rightarrow 2\ (3\ Al_2O_3 + 2\ SiO_2) + 5\ SiO_2 \tag{2.3}$$

Above discussion shows that metakaolin will formed only when the temperature is 650-800Celsius while in the formation of clinker required temperature is 1400 which is far more. Therefore, replacing clinker with metakaolin can cause less eruption of CO2 which is one of the major causes in the climate change.

2.5 BASICS OF CEMENT HYDRATION

There are many steps are involved in thy hydration of cement which explains how the bonding occurs in the cement.

2.5.1 Ordinary Portland Cement

The manufacturing process of Ordinary Portland Cement is a complex process. First it involves the fine grinding of raw-materials such as clays and limestone, known as Raw-Meal and then temperature of 1450 °C is provided in a rotary kiln. The material obtained is called clinker. Grinding of clinker is done to convert it to fine powder in a cement chamber and gypsum is added to produce Ordinary Portland Cement OPC.

Portland clinker is mainly composed of these oxides CaO, SiO2, Al2O3 and Fe2O3. These oxides are the main components of clinker.

2.5.2 Blended Cements with SCMS

When metakaolin replaces cement, it has two effects on early Cement hydration. Metakaolin provokes a dilution effect just as any other SCM will do. During the first day of hydration, it hardly reacts. This influences the strength gaining property negatively, at first 24 hours significantly. With increasing rate of substitution, this effect becomes more and more prominent.

While at the same time, it speeds up the hydration of the cementitious stages due to its fineness. This happens because it provides extra surfaces for heterogeneous nucleation.

2.6 INFLUENCE OF CALCINED CLAYS ON DURABILITY

Durability is not an inherent property of a material, but it depends to the environmental conditions and exposure of the material. Most of durability issues happen due to ions' leaching or entrance of aggressive ions.

There are different types of problems related to durability occurring in cementitious materials that can be distinguished easily. As stated earlier, movement of ions in the cementitious environment causes durability issues.

The use of calcined clays is advantageous for concrete's durability. Porosity refinement like another SCMs, is produced by the pozzolanic reaction. This is reason behind the improvement of concrete's durability.

There are other threats related to durability like sulfate attacks. These attacks have been reduced with high metakaolin addition. Cement containing 25% Metakaolin show reasonable resistance to sulfate attacks.

2.7 SUMMARY

The summary of previous literature assures that metakaolin, as a pozzolan, behaves better among various calcined clays. The typical temperature range for kaolinitic clays is usually 600°C to 850°C. The optimized temperature is different for different clays.

Durability of Calcined-Clays is satisfactory, but replacement is not allowed more than 20%. Detailed studies are to be done for higher percentage of substitution.

The concept of blending three components including limestone calcined clays and cement needs detailed investigation to explore the potential of this capable binder. This ternary blend could be a strong foundation to a whole new era of developments and application.

METHODOLOGY

This chapter includes the discussion how various steps were performed in order to prepare the samples.

3.1 SELECTION OF AGGREGATES

For the selection of aggregates some ASTM tests were performed to check either they are according to the standards or not.

3.1.1 Sieve Analysis For Aggregates & Fineness Modulus (Coarse + Fine) (ASTM C 136m-14)

First, aggregate should be well-graded. For this requirement we perform sieve analysis. For coarse aggregates we follow the guidelines of ASTM. ASTM provide us with two different particle size gradation curves (Range) for well-graded coarse aggregates. Coarse aggregates for which the particle size gradation curve lies between these two curves are well-graded aggregates. We select coarse aggregate and perform sieve analysis. The particle size gradation curve of our selected aggregates is with the range (between Curve 'A'& curve 'B') of ASTM.

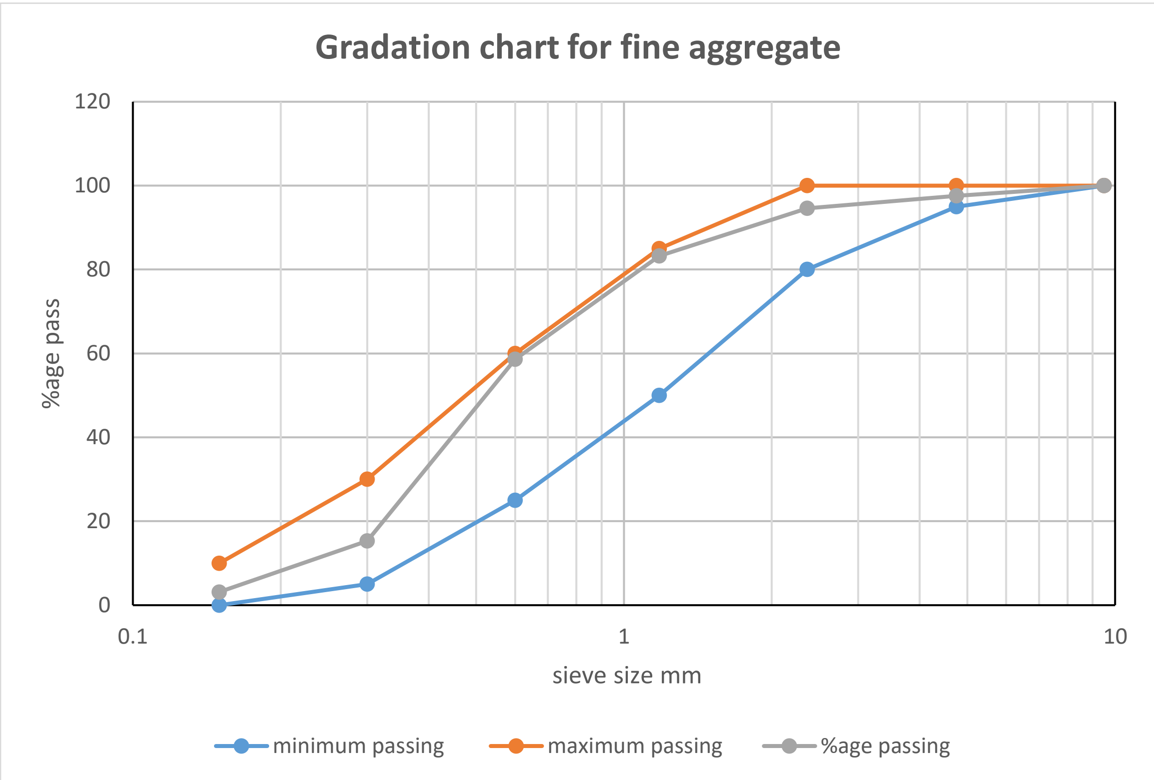

Figure 3.1 Gradation chart for fine aggregate

Table 3.1 Fineness modulus of fine aggregate

Fineness Modulus =	$\frac{\text{Commulative \% Wt. Retained}}{100}$
Fineness Modulus	2.475
FM should be between 2.3 and 3.1 (ASTM Range for fine aggregates)	
Above range is given by PCA (higher FM coarser aggregate)	

Figure 3.2 Set of standard sieves

Table 3.2 Fine Aggregate Sample

Fine aggregate sample 700g	700						
Sieve #	**Wt. Retained**	**% Wt. Retained**	**Cum. % Wt. Retained**	**Cum. % Passing**	**Minimum %Passing**	**Maximum % Passing**	**% Passing**
	(g)	**(%)**	**(%)**	**(%)**			
3"	0	0	0	100			
1"	0	0	0	100			
1.5"	0	0	0	100			
3/4″	0	0	0	100			
3/8"	0	0	0	100	100	100	100
# 4	16.8	2.4	2	98	95	100	98
# 8	21.2	3.0	5	95	80	100	95
# 16	79	11.3	17	83	50	85	83
# 30	172	24.6	41	59	25	60	59
# 50	303.1	43.4	85	15	5	30	15
# 100	84.8	12.1	97	3	0	10	3
#200	18	2.6	99.4	1			
Pan	4	0.6	100.0	-			
	698.9		247.50				
CHECK1:							
Loss after sieving	1.1	g					
original wt.	700	g					
Percent loss	0.16	< than 0.3%	OK as per ASTM				

Mesh No. 200 is **not** included in calculation of FM as per ASTM 128

Table 3.3 Coarse Aggregate Sample

Coarse aggregate sample 2kg		2000					
Sieve Size	**Wt. Retained**	**% Wt. Retained**	**Cum. % Wt. Retained**	**cum. % Passing**	**Minimum %Passing**	**Maximum % Passing**	**% Passing**
	(g)	**(%)**	**(%)**	**(%)**			
3"	0	0.0	0.0	100			
1"	0	0.0	0.0	100			
1.5"	0	0.0	0.0	100			
3/4″	0	0.0	0.0	100	100	100	100
1/2"	106	5.3	5.3	94.7	90	100	95
3/8″	910.5	45.5	50.8	49.2	40	70	49
#4 (4.75mm)	807.5	40.4	91.2	8.8	0	15	9
#8 (2.36mm)	173.7	8.7	99.9	0.1	0	5	0.15
#16 (4.75mm)	0	0.0	99.9	0.1			
#30	0	0.0	99.9	0.1			
#50	0	0.0	99.9	0.1			
#100	0	0.0	99.9	0.1			
Pan	3	-	-	-			
sum of retained	**2000.7**		**646.5**				
Check 1:							
loss after sieving	-0.7						
original weight	2000						
percent loss	-0.035	< than 0.3%					

Fineness Modulus = $\frac{\text{Commulative \% Wt. Retained}}{100}$

Fineness Modulus	6.5

Table 3.4 ASTM range of fineness modulus for coarse aggregates

FM should be between 6 to 8.5 (ASTM Range for coarse aggregates)

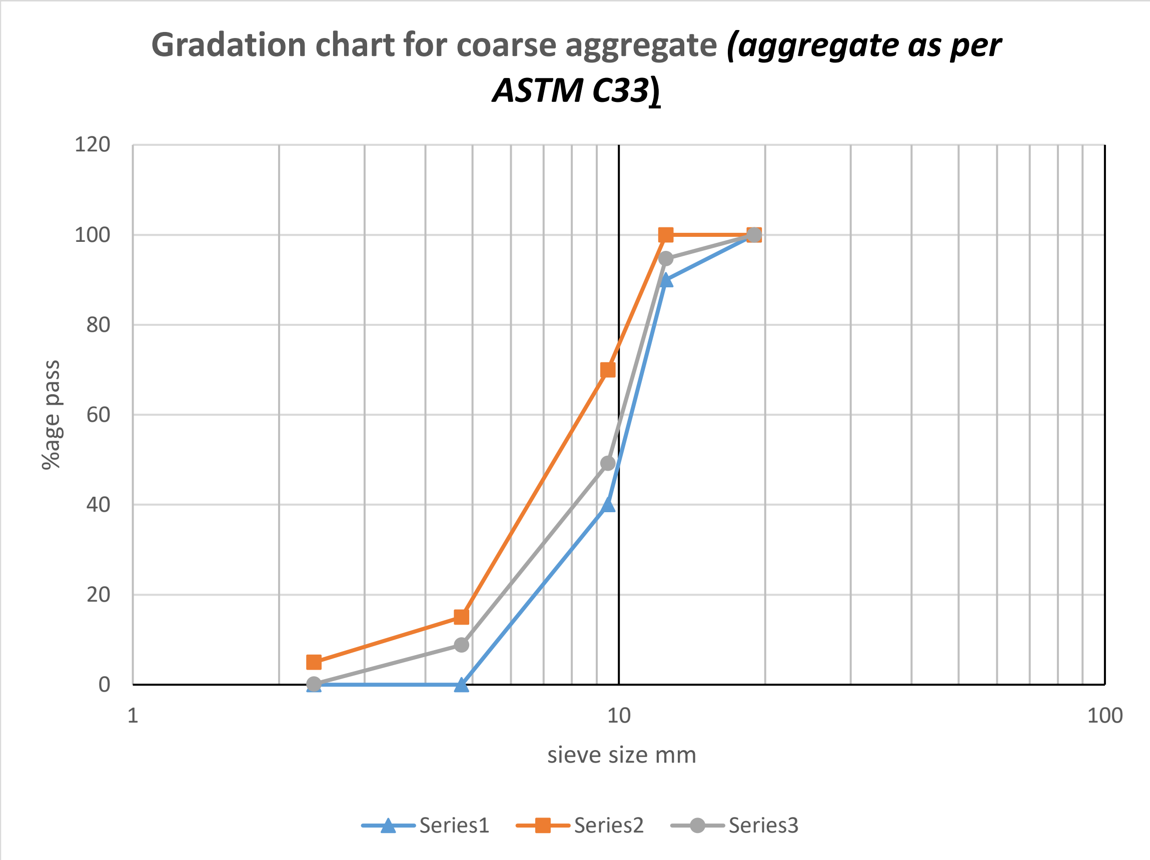

Figure 3.3 Gradation chart for coarse aggregate

3.1.2 Bulk Density

It is mass per unit volume of bulk aggregate material. Higher bulk density means that there are few voids which are to be filled by the fine aggregate and cement. Thus, bulk density also depends upon the degree of packing. We follow the guidelines of ASTM Method to determine the bulk density of coarse aggregates.

Table 3.5 PCA range for bulk density

Range by PCA (for normal weight concrete)	**1200-1750 kg/m3**

Table 3.6 Bulk density

Sample State	Type	weight of cylinder	vol. of cylinder	wt. of agg. + cylinder	Bulk density (unit wt.)
		kg	m3	kg	kg/m3
Compacted	Coarse Trail 1	7.4	0.014156	29	1525.9
	Coarse Trail 2	7.4	0.014156	29	1525.9

Coarse Aggregate (bulk density): CHECK

Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 2.5 lb/ft3 [40 kg/m3]

3.1.3 Specific gravity test and water absorption (ASTM c 127-15)

We perform specific gravity test for coarse aggregates. ASTM provide guidelines for the range of specific gravity. Water Absorption should be within limits.

Figure 3.4 Balance to measure the weight of aggregate in water

Figure 3.5 Towel to make the aggregate dry

Table 3.7 Specific Gravity Test For Fine Aggregate

For fine aggregate	
Weight of flask + sample	335.2
Weight of flask + sample + water	573.6
Weight of empty flask	163.4
Weight of flask + water	473.3
Weight of SSD sample	171.8
Weight of oven dry sample	167.6
Specific gravity of (SSD)	2.69
Specific gravity of (OD)	2.67
Specific gravity (Apparent)	2.74
%Age water absorption	0.94

Table 3.8 Specific Gravity Test For Coarse Aggregate

For coarse aggregate	
Weight of empty mesh bucket in water	2057
Weight of bucket + sample in water	3286.5
Weight of SSD sample in air	1950.8
Weight of oven dry sample	1409
Specific gravity of (SSD)	2.66
Specific gravity of (OD)	2.64
Specific gravity (Apparent)	2.69
%Age water absorption	0.70

3.2 CEMENT

Cement used was of the local company which is named as Bestway Cement.

3.2.1 Normal Consistency Test (ASTM C 187-16)

We perform Standard VICAT test to determine the amount of water required of Normal Consistency of Hydraulic Cement Paste.

3.2.2 Setting Time of Hydraulic Cement (ASTM C 191-13)

We preformed the standard test methods for Time of Setting of Hydraulic Cement by VICAT Needle.

Figure 3.6 Cement Bag

3.3 MIX DESIGN

AC1 211.1

MIX DESIGN FOR LC3 (MATHCAD SHEET)

STEP 1: Required material information:-

Cementitious Material:

$SG_{cem} := 3.15$ *Cement specific gravity*

Coarse aggregate (Margalla crush):

$SG_{OD} := 2.64$ *Oven-dry specific gravity of coarse aggregate*

$SG_{SSD} := 2.66$ *SSD specific gravity of coarse aggregate*

$Absorption := 0.7\%$

$MC_{CA} := 0\%$ *Moisture content of coarse aggregate*

$\gamma_{bulk} := 1526 \frac{kg}{m^3}$ *Unit weight of coarse aggregate*

well graded, 1/2" nominal maximum size sub-angular aggregate

Fine aggregate (Lawrencepur sand):

$FSG_{OD} := 2.67$ *Oven-dry specific gravity of fine aggregate*

$FSG_{SSD} := 2.69$ *SSD specific gravity of fine aggregate*

$F.Absorption := 0.94\%$

$MC_{FA} := 0\%$ *Moisture content of fine aggregate*

$F.M := 2.475$ *Fineness modulus of fine aggregate*

STEP 2: Evaluate strength requirement:-

$fc' := 20\ MPa$ *assumed*

$fcr' := fc' + 7\ MPa = 27\ MPa$

STEP 3: selection of slump:-

$slump := 75\ mm$ *slump range = 25-75 mm*

Table 9-6. Recommended Slumps for Various Types of Construction

Concrete construction	Slump, mm (in.) Maximum*	Slump, mm (in.) Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

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Figure 3.7 Step 1 to 3 of Mix Design procedure for LC$_3$ Concrete

STEP 4: Selection nominal maximum aggregate size:-

$NMAS := 12.5\ mm$ *nominal maximum aggregate size*

STEP 5: Selection of water and air content:-

Table 12-5 (Metric). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, mm	Water, kilograms per cubic meter of concrete, for indicated sizes of aggregate*							
	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm	50 mm**	75 mm**	150 mm**
	Non-air-entrained concrete							
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average total air content, percent, for level of exposure:†								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure (Class F1)	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe exposure (Class F2 and F3)	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cementitious material contents for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

** The slump values for concrete containing aggregates larger than 37.5 mm are based on slump tests made after removal of particles larger than 37.5 mm by wet screening.

† The air content in job specifications should be specified to be delivered within −1 to +2 percentage points of the table target value for moderate and severe exposures.

Adapted from ACI 211.1 and ACI 318. Hover (1995) presents this information in graphical form.

Using above table, for 12.5mm NMAS, entrapped air in non-air-entrained concrete is 2.5%

$air.content := 2.5\%$

using above table, for slump of 75 mm and NMAS of 12.5mm, the water content is 216 kg/m3

$$W_{water2} := 216\ \frac{kg}{m^3}$$

STEP 6: selection of water-cementitious material ratio:-

$x := fcr' = 27\ MPa$

$x1 := 25\ MPa$

$x2 := 30\ MPa$

$y1 := 0.61$ *w/cm ratio for 25 Mpa*

$y2 := 0.54$ *w/cm ratio for 30 Mpa*

$$y := \frac{y2 - y1}{x2 - x1} \cdot (x - x1) + y1 = 0.582$$ *Linear interpolation*

Table 12-3 (Metric). Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, MPa	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
45	0.38	0.30
40	0.42	0.34
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

Strength is based on cylinders moist-cured 28 days in accordance with ASTM C31 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about 19 to 25 mm.
Adapted from ACI 211.1 and ACI 211.3.

water/cementitious material ratio for target strength of 29.5 Mpa is:

$water.to.cem.ratio := y = 0.582$

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Figure 3.8 Step 4 to 6 of Mix Design procedure for LC_3 Concrete

STEP 7: calculation of cementing materials content:

$$W_{cement} := \frac{W_{water2}}{water.to.cem.ratio} = 371.134\ \frac{kg}{m^3}$$

calcined clay dosage of **30%** and **limestone** dosage of **15%** by mass of cement are as follows:-

$$W_{calcined.clay} := 0.3 \cdot W_{cement} = 111.34\ \frac{kg}{m^3}$$ *calcined clay*

$$W_{limestone} := 0.15 \cdot W_{cement} = 55.67\ \frac{kg}{m^3}$$ *limestone*

$$W_{cement2} := 0.54 \cdot W_{cement} = 200.412\ \frac{kg}{m^3}$$ *cement*

$$W_{gypsum} := 0.01 \cdot W_{cement} = 3.711\ \frac{kg}{m^3}$$ *gypsum*

STEP 8: Calculation of coarse aggregate content:

For fineness modulus of **2.475** and NMAS of **12.5mm**, b/bo factor is **0.582**

$$factor := 0.582$$

Oven dry mass of coarse Agg. for **1** cubic meter of concrete

$$W_{CA} := factor \cdot \gamma_{bulk} = 888\ \frac{kg}{m^3}$$

Table 12-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

Nominal maximum size of aggregate, mm (in.)	Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate*			
	2.40	2.60	2.80	3.00
9.5 (⅜)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
19 (¾)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (1½)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

*Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C29 (AASHTO T 19). Adapted from ACI 211.1.

STEP 9: Calculation of fine aggregate content:

weight method

$$W_{conc} := 2281\ \frac{kg}{m^3}$$

$$W_{FA} := W_{conc} - W_{CA} - W_{water2} - W_{cement} = 805.734\ \frac{kg}{m^3}$$

$$W_{FA} = 806\ \frac{kg}{m^3}$$ *fine aggregate content*

TABLE A1.5.3.7.1 — FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)

Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m³*	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

*Values calculated by Eq. (A1.5.3.7) for concrete of medium richness (330 kg of cement per m3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 75 to 100 mm slump in Table A1.5.3.3. If desired, the estimate of unit mass may be refined as follows if necessary information is available: for each 5 kg difference in mixing water from the Table A1.5. 3.3 values for 75 to 100 mm slump, correct the mass per m^3 8 kg in the opposite direction; for each 20 kg difference in cement content from 330 kg, correct the mass per m^3 3 kg in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete mass 60 kg in the same direction. For air-entrained concrete the air content for severe exposure from Table A.1.5.3.3 was used. The mass can be increased 1 percent for each percent reduction in air content from that amount.

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Figure 3.9 Step 7 to 9 of Mix Design procedure for LC_3 Concrete

STEP 10: Calculation of admixture content:

SIKAMENT-520 BA

- ***0.8 to 2.5 %*** *by weight of cement as per supplier*
- *Up to* ***20%*** *water reduction as per supplier*

using 1% by wt. of cementitious materials

$$water.reducer := 1\% \cdot W_{cement} = 3.711 \frac{kg}{m^3}$$

The mixture has following proportions before moisture adjustments for one cubic meter of concrete:

$$W_{water2} = 216 \frac{kg}{m^3}$$

$$W_{cement2} = 200.412 \frac{kg}{m^3}$$ *Cement,* ***54%*** *of total cement*

$$W_{calcined.clay} = 111.34 \frac{kg}{m^3}$$ *Clay,* ***30%*** *of total cement*

$$W_{limestone} = 55.67 \frac{kg}{m^3}$$ *Limestone,* ***15%*** *of total cement*

$$W_{gypsum} = 3.711 \frac{kg}{m^3}$$ *Gypsum,* ***1%*** *of total cement*

$$W_{FA} = 805.734 \frac{kg}{m^3}$$ *Dry weight before moisture adjustment*

$$W_{CA} = 888.132 \frac{kg}{m^3}$$ *Dry weight before moisture adjustment*

C : S : G
1 : 2.171 : 2.393 *cement, sand and gravel ratio*

STEP 11: Moisture adjustment:

$$wet.W_{CA} := W_{CA} \cdot (1 + MC_{CA}) = 888 \frac{kg}{m^3} \qquad MC_{CA} = 0$$

$$wet.W_{FA} := W_{FA} \cdot (1 + MC_{FA}) = 806 \frac{kg}{m^3} \qquad MC_{FA} = 0$$

Note: if the moisture content of content of Coarse or fine aggregate is less than absorption level, the mixing water need to be increased. on the contrary, if the moisture content of coarse or fine aggregate is higher than absorption, the mixing water need to be decreased

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Figure 3.10 Step 10 to 11 of Mix Design procedure for LC_3 Concrete

$$Excess.absoption_{CA} := -MC_{CA} + Absorption = 0.007$$

$$Excess.absoption_{FA} := -MC_{FA} + F.Absorption = 0.009$$

$$W_{corrected.water} := W_{water2} + Excess.absoption_{CA} \cdot W_{CA} + Excess.absoption_{FA} \cdot W_{FA} = 230\ \frac{kg}{m^3}$$

Estimated batch weights after moisture adjustments for 1 cubic meter of concrete are as follows:

$W_{corrected.water} = 230\ \frac{kg}{m^3}$ — *water before moisture adjustment is **216** kg/m3*

$W_{cement2} = 200.412\ \frac{kg}{m^3}$ — *Cement, **54%** of total cement*

$W_{calcined.clay} = 111.34\ \frac{kg}{m^3}$ — *Clay, **30%** of cement*

$W_{limestone} = 55.67\ \frac{kg}{m^3}$ — *Limestone, **15%** of cement*

$W_{gypsum} = 3.711\ \frac{kg}{m^3}$ — *Gypsum, **1%** of total cement*

$wet.W_{FA} = 805.734\ \frac{kg}{m^3}$

$wet.W_{CA} = 888.132\ \frac{kg}{m^3}$

C	:	S	:	G
1	**:**	**2.171**	**:**	**2.393**

$$W_{total} := W_{corrected.water} + W_{cement} + wet.W_{CA} + wet.W_{FA} = 2295\ \frac{kg}{m^3}$$

Note: water reducer is a part of mixing water

ACI-212.3R-10

Most water-reducing admixtures are water solutions. The water they contain becomes a part of the mixing water in the concrete and should be considered in the calculation of *w/cm*, if the added amount of water is significant.

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Figure 3.11 Estimated batch weights after moisture content adjustment

Casting Requirement

Cylinder dimension 300 x 150

$height := 0.3\ m$
$diameter := 0.15\ m$

$vol.1.cylinder := \dfrac{\pi \cdot diameter^2}{4} \cdot height = 0.005\ m^3$ *volume of 1 cylinder*

$vol.6.cylinder := vol.1.cylinder \cdot 6 = 0.032\ m^3$ *volume of 6 cylinder*

Increasing volume **20%** to account for wastage:

$dry.vol1 := vol.6.cylinder \cdot 1.20 = 0.038\ m^3$ *dry volume of conc. for 4 cylinder and 2 prism*

Prism dimension 100 x 100 x 500

$length := 0.5\ m$
$width := 0.1\ m$
$thickness := 0.1\ m$

$vol.1.prism := length \cdot width \cdot thickness = 0.005\ m^3$ *volume of 1 prism*

$vol.3.prism := vol.1.prism \cdot 3 = 0.015\ m^3$ *volume of 3 prism*

Increasing volume **20%** to account for wastage:

$dry.vol2 := vol.3.prism \cdot 1.2 = 0.018\ m^3$

Blended specimen quantities for 6 cylinders:

$water1 := W_{corrected.water} \cdot dry.vol1 = 8.771\ kg$ ***note: 0.563*** *kg of water will be absorbed by aggregate.*

$cement1 := W_{cement2} \cdot dry.vol1 = 7.65\ kg$

$calcined.clay1 := W_{calcined.clay} \cdot dry.vol1 = 4.25\ kg$

$limestone1 := W_{limestone} \cdot dry.vol1 = 2.125\ kg$

$gypsum1 := W_{gypsum} \cdot dry.vol1 = 0.142\ kg$

$sand1 := wet.W_{FA} \cdot dry.vol1 = 30.755\ kg$

$gravel1 := wet.W_{CA} \cdot dry.vol1 = 33.9\ kg$

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Figure 3.12 Casting Requirement for blended concrete specimen

Blended specimen quantities for 3 Prisms:

$water1 := W_{corrected.water} \cdot dry.vol2 = 4.136\ kg$

$cement1 := W_{cement2} \cdot dry.vol2 = 3.607\ kg$

$calcined.clay1 := W_{calcined.clay} \cdot dry.vol2 = 2.004\ kg$

$limestone1 := W_{limestone} \cdot dry.vol2 = 1.002\ kg$

$gypsum1 := W_{gypsum} \cdot dry.vol2 = 0.067\ kg$

$sand1 := wet.W_{FA} \cdot dry.vol2 = 14.503\ kg$

$gravel1 := wet.W_{CA} \cdot dry.vol2 = 15.986\ kg$

Control specimen quantities for 6 cylinders:

$water2 := W_{corrected.water} \cdot dry.vol1 = 8.771\ kg$

$cement2 := W_{cement} \cdot dry.vol1 = 14.166\ kg$ $\qquad W_{cement} = 371\ \frac{kg}{m^3}$

$sand2 := wet.W_{FA} \cdot dry.vol1 = 30.755\ kg$

$gravel2 := wet.W_{CA} \cdot dry.vol1 = 33.9\ kg$

Control specimen quantities for 3 prisms

$water2 := W_{corrected.water} \cdot dry.vol2 = 4.136\ kg$

$cement2 := W_{cement} \cdot dry.vol2 = 6.68\ kg$

$sand2 := wet.W_{FA} \cdot dry.vol2 = 14.503\ kg$

$gravel2 := wet.W_{CA} \cdot dry.vol2 = 15.986\ kg$

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Figure 3.13 Casting Requirement for control concrete specimen

3.4 MATERIAL COMPOSITION

We used cement, sand, calcine clay, limestone, and superplasticizer in different specified percentages which shown in following chart.

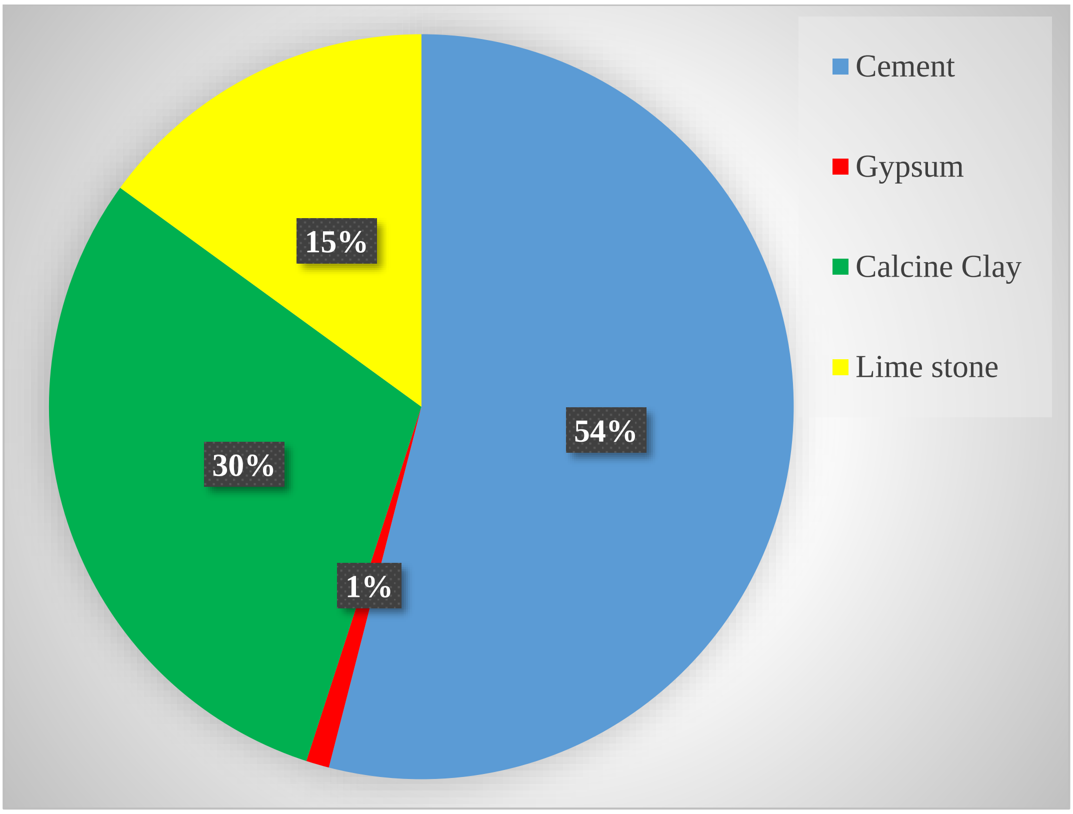

Figure 3.14 Material Composition

Table 3.9 Mix Design Ratio

CEMENT	SAND	GRAVEL
1	2.171	2.393

3.5 PLASTICIZER

1.7% SIKAMENT 520 BA Plasticizer was used to Control the water absorption of limestone and Clay and to obtain required Slump-Value.

Figure 3.15 Sikament 520 ba superplasticizer

3.6 GRINDING OF OVEN DRIED CLAY + LIMESTONE (SIEVE#200 PASSING)

First, Limestone and Clay were placed in the oven for 24 hours at 90 degrees. we grind the OVEN-DRIED Limestone & Clay in grinding machine. Then Grinded Limestone and Clay were passed from Sieve#200. We take the sieved material for our test.

Figure 3.16 Grinding of oven dried clay

3.7 CALCINATION OF CLAY AT 800 C

Oven-dried and grinded (sieve #200 passed) clay was used for calcination process. We used NABERTHERM Electric Heater (30c to 3000c). We place our sample into Oven for calcination of Clay at 800c Max Temperature.

Figure 3.17 Nabertherm electric heater

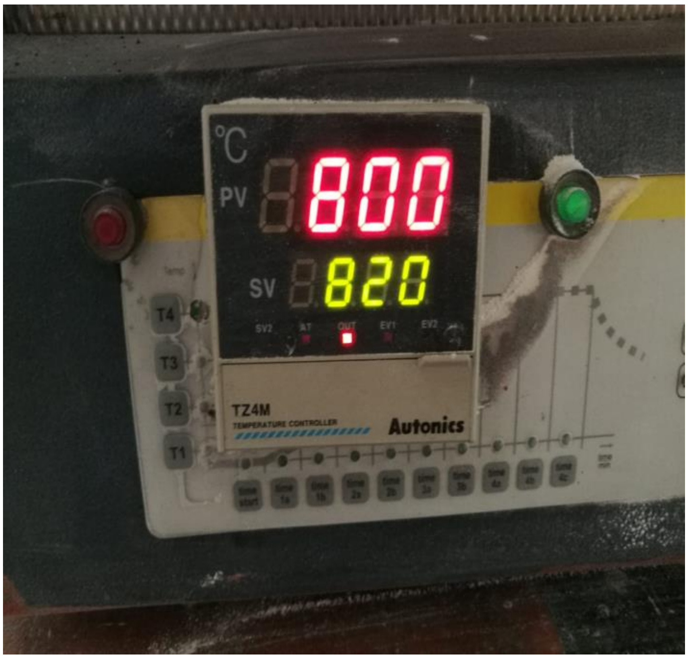

Figure 3.18 Temperature in electric heater for calcination

Figure 3.19 Sample pots for calcination

Figure 3.20 Calcination

3.8 TRIAL TESTS FOR REQUIRED SLUMP-VALUE

We did several trial tests in a row to achieve our required slump value. Moreover, by varying the percentage of superplasticizer for each trial in order to attain our desired slump value.

3.8.1 Trial

Cement, sand and gravel ratio (1 : 2.171 : 2.393) were used for our first trial. Cement content contains 54% Ordinary Portland cement, 15% Limestone, 30% Clay, and 1% Gypsum. At first Trial concrete do not form (Failed).

Figure 3.21 1st trial for slump value

3.8.2 Trial

Same cement, sand and gravel ratio and plasticizer 1% of water content was added with same Cementous contents. But Concrete do not form again.

Figure 3.22 Second trial for slump value

3.8.3 Trial

Same cement, sand and gravel ratio and we added plasticizer 1.5% of water content was used with same Cementous contents. But Slump value was very small.

3.8.4 Trial

Same cement, sand and gravel ratio and we added plasticizer 1.7% of water content with same Cementous contents. This Trial was successful, and we achieved our required slump value.

Figure 3.23 Final trial with required slump value

3.9 PREPARATION OF REQUIRED MOLDS

For sample casting, 12 cylindrical Molds for Blended Concrete with Clay and 12 Molds were required for controlled (PCC) concrete. In addition, 6 prism molds for Blended and 6 molds for Controlled Volume Concrete were also required. Selected required molds of required sizes. Then hardened material from molds was cleaned and lubricated the molds with suitable oil. Then they were put into assemble by screwing their bolts & nuts. Ready for Casting.

3.10 WEIGHING REQUIRED AMOUNTS OF MATERIAL PER BATCH

Material for one batch was decided and every constituent was weighed accurately in required amount.

Figure 3.24 Weighing Balance

Figure 3.25 Weighing the Cement

Figure 3.26 Digital Weighing Balance

3.11 DRY MIXING & WET MIXING

First, we put sand of required quantity into mixer, then gravels, then Cementous content. Mixer started for Dry-Mixing for 2 minutes. After dry mixing we added required amount of water as per mix design in 3 increments. At the end we added plasticizer in last 1/3 water and mix in concrete. We kept running mixer for 2-5 minutes for wet mixing.

Figure 3.27 Constituents in Batch Mixer

Figure 3.28 Prepared batch

Figure 3.29 Dry Mixing

Figure 3.30 Wet Mixing

3.12 SLUMP CHECK

After each Batch mixing, we apply slump-value check. It was OK. Slump value was within range (25mm to 75mm).

Figure 3.31 Slump Test no.01

Figure 3.32 Slump Test no.02

3.13 CASTING, TEMPING AND VIBRATIONS

After mixing, Sample were casted in prepared molds. Molds were filled in 3 layers by temping each layer. Then molds were placed on vibrator to remove air-bubbles.

Figure 3.33 Filling and Temping of Cylinder Samples

Figure 3.34 Filling and Temping of Prism Samples

3.14 DE-MOLDING & CURING

After 24 Hours samples were de-molded carefully and sample were placed for proper curing.

Figure 3.35 Curing of Casted Samples

Figure 3.36 Final Casted samples

TESTS AND RESULTS

Total 24 cylinders and 12 prisms were casted.12 were made of LC3 while 12 were made of OPC concrete and 6 prisms of LC3 while 6 of OPC concrete. Our plan was to test 3 of cylinders to be tested for compression of each concrete and same was the case for split cylinder test and for flexural test.

4.1 COMPRESSION TEST

For compression test code followed was ASTM C39. The machine used was **Universal Testing Machine.** 3 cylinders of each concrete at 7 days and at 28 days were tested. The results are illustrated with the help of bar charts.

Figure 4.1 Compression Test

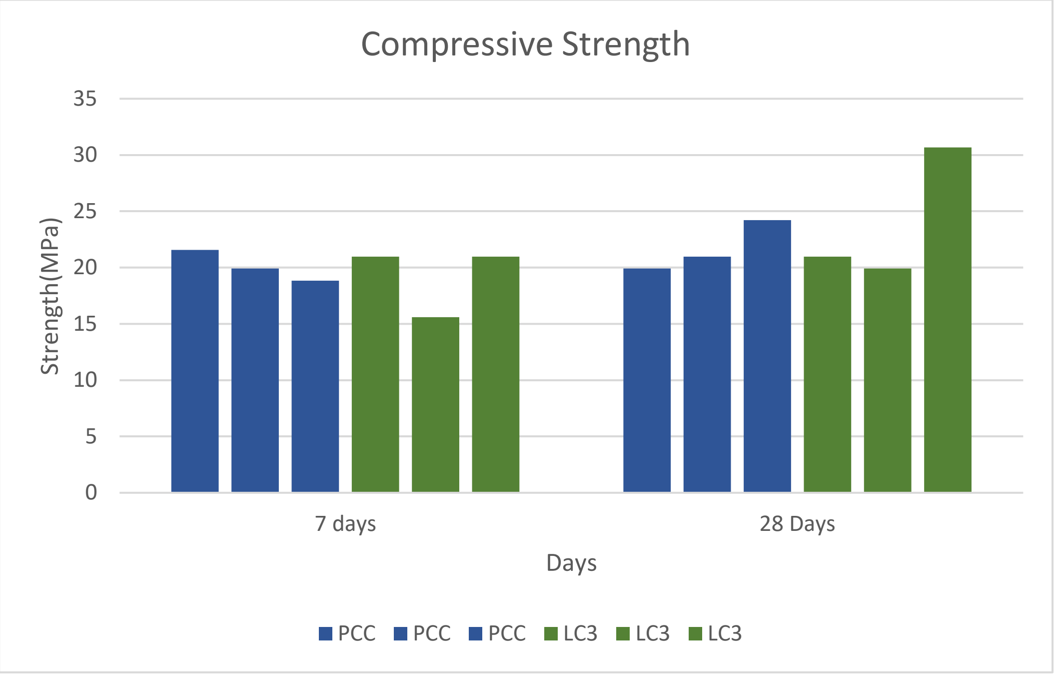

Figure 4.2 Compressive Strength of Each Cylinder

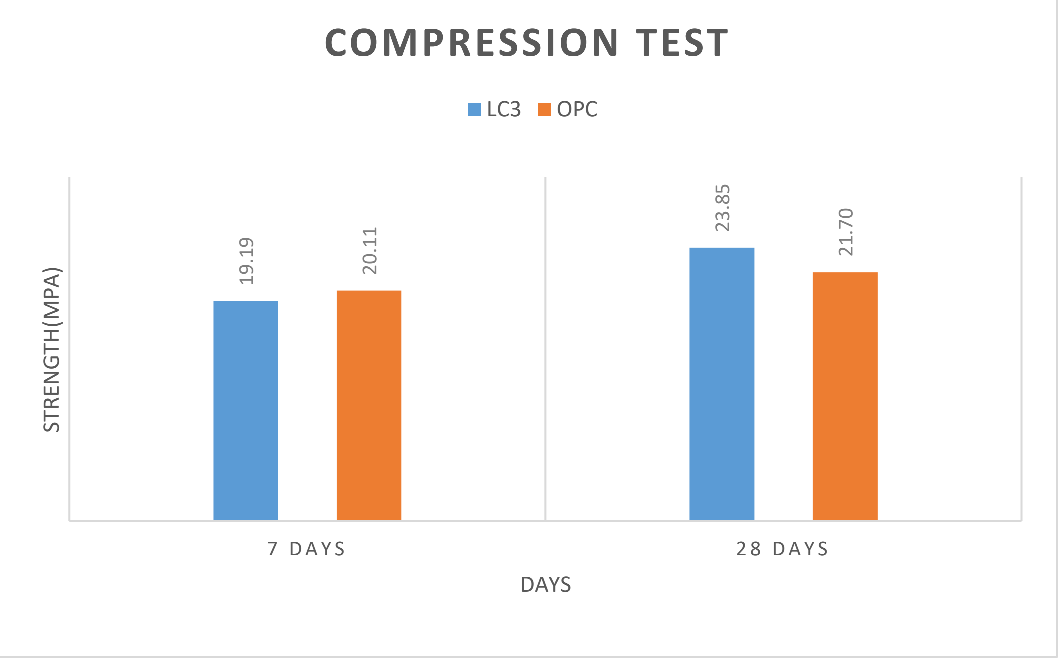

Figure 4.3 Average Compressive Strength of Concrete

As it is obvious from both of charts that LC3 at 7 days shows less strength as compared to OPC concrete. The reason is that the hydration process in LC3 was started later as compared to OPC concrete, but the values were slightly closer. However, LC3 at 28 days behaves better as compared to OPC Concrete and the reason is that LC3 was having more fines as compared to OPC. Therefore, the pozzolanic action was much better than OPC.

4.2 SPLIT CYLINDER TEST

Code used was ASTM C 496/C 496 M-04

This test is usually performed to check the split tensile strength of concrete. Test was performed using **UTM**. 3 cylinders of each concrete at 7 and 28 days were tested. The results are being expressed with the help of bar charts which are given below. The cracks in following picture shows the pure split tensile behavior of concrete.

Figure 4.4 Spilted Cylinder Sample

Figure 4.5 Split Cylinder Test

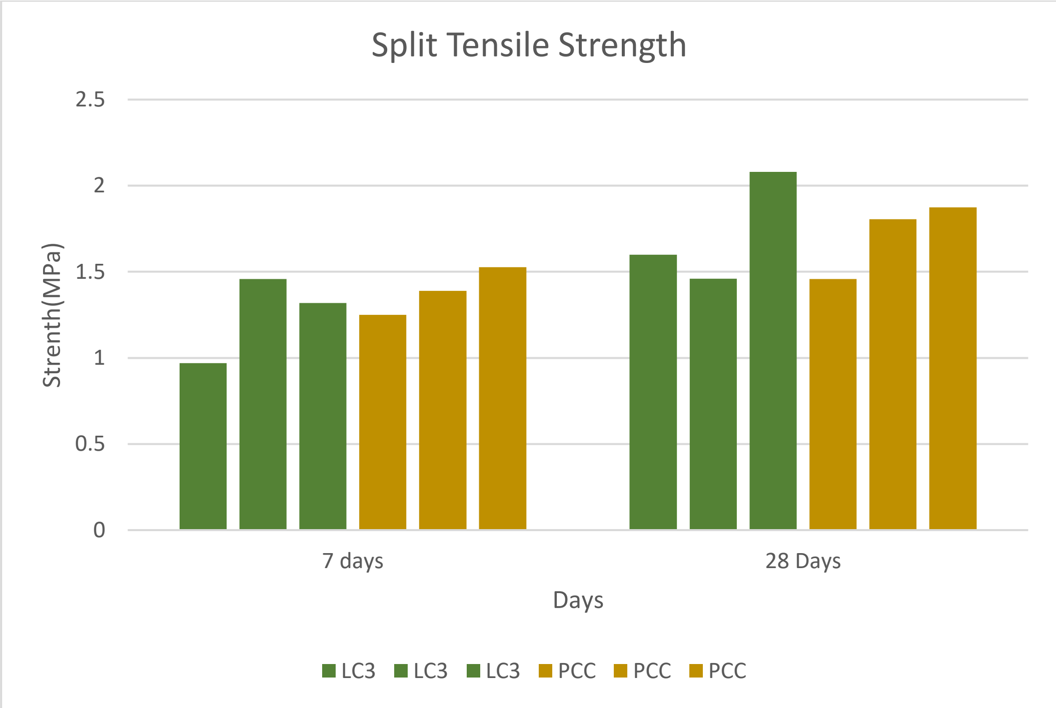

Figure 4.6 Split Tensile Strength of Each Cylinder

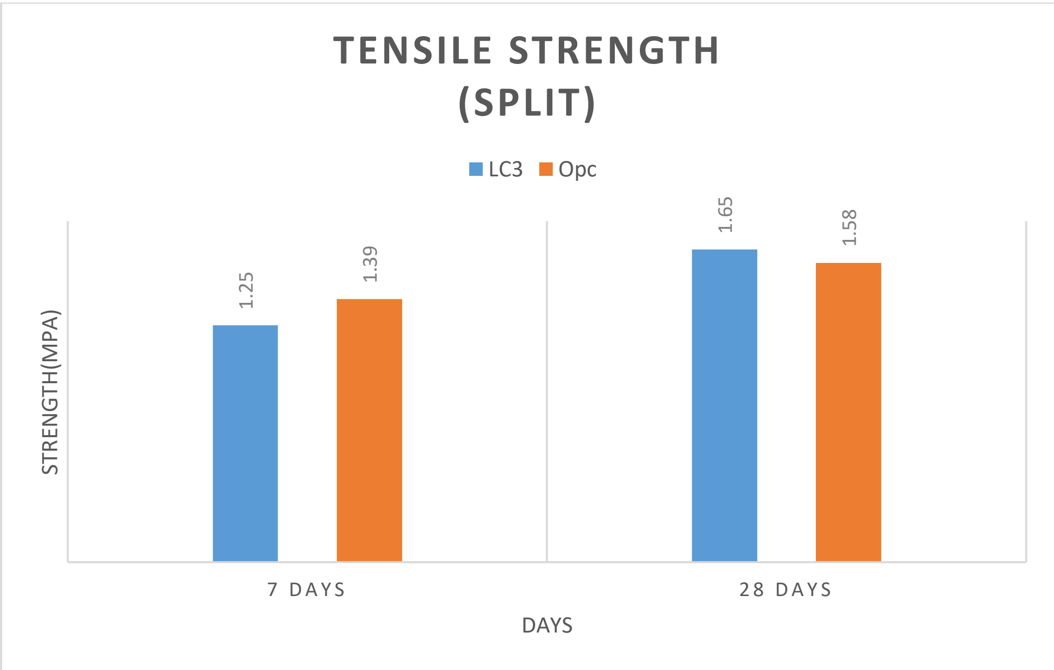

Figure 4.7 Average Split Tensile Strength

The behavior of LC3 and OPC is same as we observed for the compressive strength. Therefore, there split strength was not as much different, and these were much close to each other.

4.3 FLEXURAL TEST

Casted prisms were used to check the flexural behavior of LC3 and compare it with the OPC concrete.

ASTM 78-02 was used.

The machine which used was Shimadzu Universal testing machine. Three-point loading arrangement was used, and different combination of rollers and hinges were used, and it is obvious from the picture.

Figure 4.8 Assembly for Flexural Test

Figure 4.9 Flexural Test

When test was performed on both LC3 and OPC the crack started to appear at about the mid of prism and it penetrated upward which shows the pure flexural behavior of concrete. The results are being expressed with the help of bar charts.

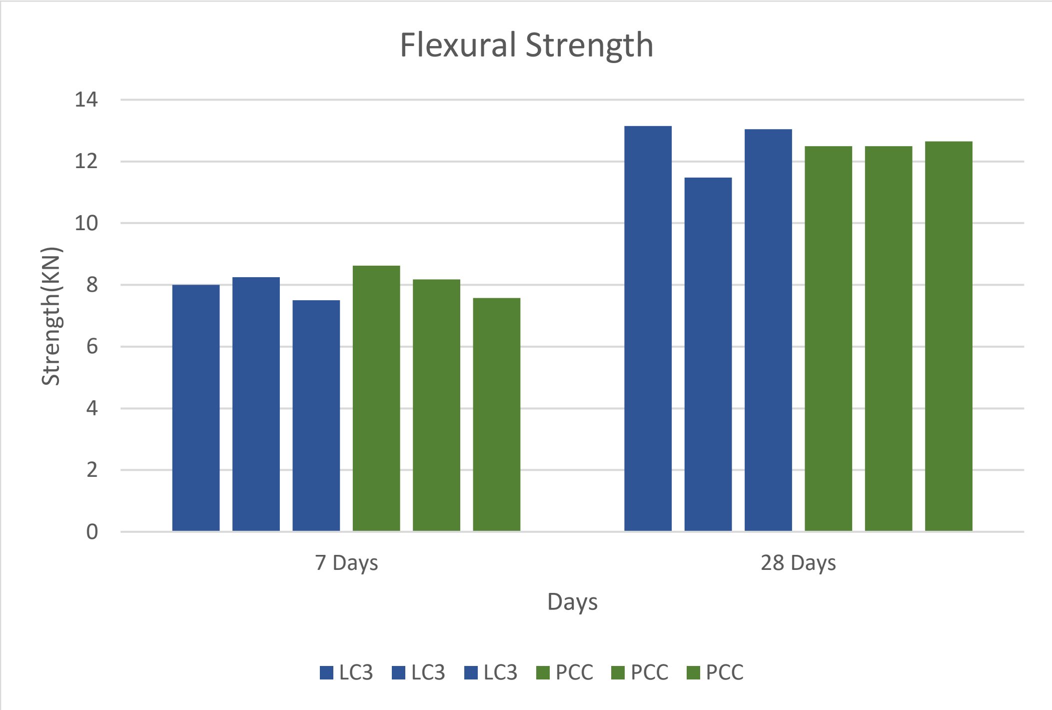

Figure 4.10 Flexural Strength of Each Prism

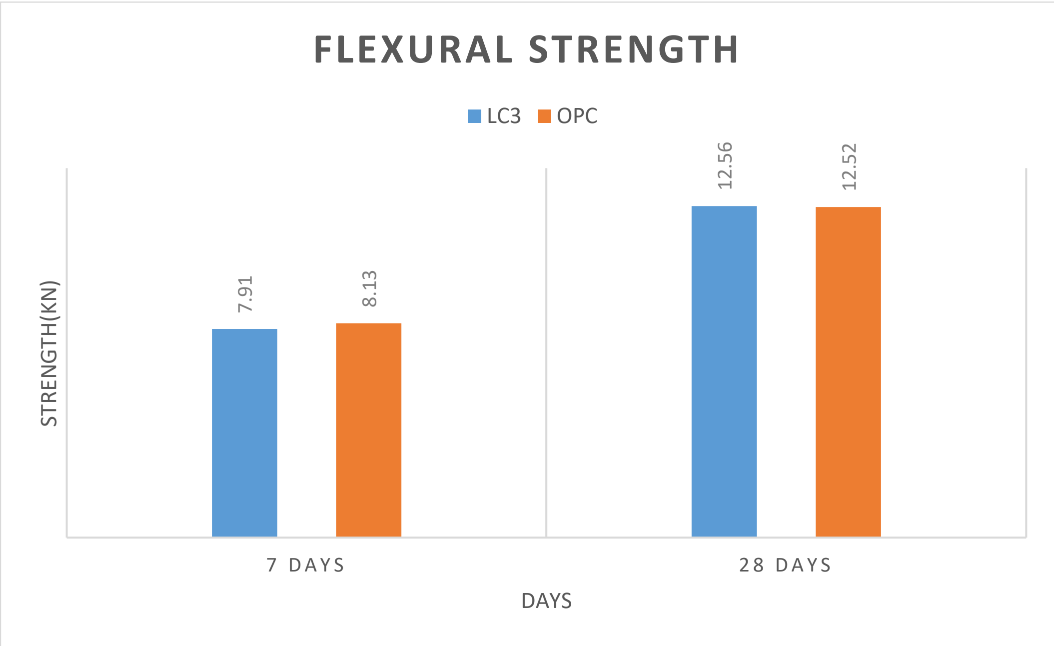

Figure 4.11 Average Flexural Strength

We observed the almost same behavior which we observed in the compression and split test. The reason is same delay in hydration process at the beginning at the start for LC3 and better pozzolanic reaction after 7 days. The strength was same for both LC3 and OPC concrete.

CONCLUSIONS AND RECOMMENDATIONS

- Water content required for the LC3 found to be more than the OPC concrete by performing the initial trials and checking the slump. The reason is that in LC3 number of fines are more which lead to more water absorption.
- Cement production contributes to the 8% of CO_2 emissions in the world and clinker is main reason behind it. So, reducing clinker can reduce CO_2 production. As we replaced 50% of clinker with the calcine clay and limestone which can reduce CO_2 secretion by about 40% of the clinker production. In this way an environmentally friendly cement can be produced.
- Mechanical properties i.e., compressive strength, flexural strength and split strength LC3 concrete are almost identical to the OPC concrete. Hence, it can be recommended to use LC3 for our future construction as a replacement of OPC.
- Materials used for the production of LC3 are naturally available and are in excess quantity almost in every country. Moreover, the production of metakaolin does not require any complex process and it requires less energy (800 Celsius) as compared to clinker production (1400 Celsius). These points are the markers that if we manufacture LC3 on large scale LC3 will be more economical than the OPC.

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