An Experimental Investigation on Influence of Calcination Condition on Strength of Lc3 Concrete

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ABSTRACT

A new kind of low-carbon cement called limestone calcined clay cement (LC3) may match the performance requirements of regular cement while using less energy and emitting less carbon dioxide. Waste resources are now being used more often as prospective replacements for conventional materials in the effort to produce cementitious materials for concrete more sustainably. This study has looked at how calcined clay affects cementitious mortars' engineering qualities. Calcined clay was used as a partial replacement for Portland cement at 50%, 47%, and 45% after being created by heating raw clay to temperatures between 700oC to 900oC. Seventy two LC3 concrete cubes and twelve M20 grade concrete cubes of size 15 x 15 x 15 mm were casted and curing was done for 28 days. The compressive strength after 3, 7, 14 and 28 days of curing was identified and compared the result with standard M20 grade concrete cube. The outcomes demonstrated that calcined clay was appropriate for strengthening the characteristics of concrete if it is calcined properly. Despite having a little impact on the mortar's workability, a greater strength was attained when 47% of Portland cement was replaced with calcined clay and limestone powder.

Keywords: Limestone calcined clay cement (LC3), Limestone, Compressive strength, Curing, Mix design

1 INTRODUCTION

Around the world, cement is regarded as the primary material used in residential and general construction. The most popular type of cement used in building, particularly when civil projects like dams and bridges are required, is ordinary Portland Cement (OPC). In order to meet the rising need for housing and general infrastructure, there is a growing demand for the manufacture and usage of cement in the majority of construction operations worldwide. Massive amounts of energy and natural resources must be used in the manufacturing of OPC. Additionally, a large amount of carbon dioxide (CO_2) is released into the atmosphere during the OPC manufacturing process. According to studies, the cement sector contributes between 5-8 percent of the world's total man-made CO_2 emissions (Scrivener, 2014). The principal greenhouse gas that contributes to climate change and global warming is CO_2. Additionally, calcareous and argillaceous materials are mixed together during the production of Portland cement, either in a wet or dry state, and then heated to a temperature of more than 1300 ^{0}C in a rotary furnace using coal or petroleum oil as fuel. Portland cement is created by mixing the clinkers that are produced with around 5% gypsum (Neville, 2011).

In a recently developed ternary blended cement called limestone calcined clay cement (LC3), in addition to the traditional pozzolanic reaction of calcined clay and the filler effect of limestone, the alumina from the calcined clay and the carbonate from the limestone also react with each other, creating a interaction between the three main components (clinker, calcined clay and limestone). Due to the formation of a finer and less linked microstructure and increased clinker replacement rate, the cement exhibits good mechanical and durability-related performance. With clinker factors as low as 40% to 50%, ternary cement LC3 can attain strengths comparable to OPC Crushed limestone and calcined clay are combined to make the remaining cement. Even with clinker factors as low as 0.40, LC3 utilizes the synergetic hydration of clinker, calcined clay, and crushed limestone to produce the performance expected from commercial cements. The LC3 blend's low quality limestone and clay ensure that the cement may be produced for less money than even PPC without running the risk of being unsound. This cement can decrease raw material waste and lengthen the life of mines since low kaolinite clays can be combined with low calcite limestone with impurities like quartz and dolomite after being calcined at relatively lower temperatures of 700°C to 800°C. Additionally, because LC3's constituents require less processing, less capital is needed to achieve the same incremental growth (Marangu, 2020)

1.2 Statement of the Problem

In a developing country like Nepal cement is the most crucial component in the construction of high-rise buildings, dams, bridges, and highways. OPC and PPC cement are most frequently used. However, a lot of energy and natural resources are used in the production of this cement. The rate of CO_2 emissions and the use of fossil fuels like coal or oil as a fuel are both high. One of the main causes of the world's climate issues is the 5-8% of anthropogenic carbon dioxide emissions that occur during the production of OPC and PPC cement. In recent decades, the production of cement has increased significantly in developing nations, including Nepal. In 2020, Nepal produced fewer than 500 kg of cement per capita; by 2025, production is expected to increase. As a result, by 2025, annual production may be greater than 25 million tons. By 2030, the nation wants to have achieved its sustainable development goals; therefore there will likely be a lot of construction work done. The introduction of the technology for creating novel limestone-calcined clay-cement (LC3) appears highly promising from a financial, energy, and environmental standpoint because clay is extensively dispersed throughout most of Nepal (Yongzheng Tao, 2022).

1.3 Objectives of the Study

The objective of our research focuses on the preparation of LC3 cement and comparing the strength with pure OPC M20 grade concrete. The main aims of the study are pointed below:

General objective:

To analyze the influence of calcinations condition on the performance of lime calcined clay cement (LC3).

Specific objective:

i. To prepare the LC3 cement by using locally available soil from different district.
ii. To study the physical properties of concrete constituents.
iii. To compare the strength of LC3 concrete with the pure M20 grade concrete.
iv. To examine the various factors that influences the performance of LC3.

1.4 Scope of the Study

This study is implicated on the influence of calcinations condition on the performance of lime calcined clay cement (LC3). The basic idea of this research is to reduce the percentage of cement by Limestone Calcined Clay Cement (LC3). With clinker factors as low as 40% to 50%, ternary cement LC3 can attain strengths comparable to OPC. After collecting the samples from different areas of Nepal it will be calcined properly in a kiln and crushed limestone and calcined clay are combined to make the remaining cement. The compressive strength will be checked by varying the percentage of cement, sand and aggregate.

1.5 Sample Collection

The samples that were taken for the study was based on the previous study titled Characterization and reactivity of Nepali clays as supplementary cementitious material conducted by (Yongzheng

Tao, 2022). Kaolinite content (finer particles obtained from #200 sieves), chemical composition and mineral composition were also taken as a reference.

S.N.	Sample	District	GPS
1	S2	Syangja	E00478131, N03109756
2	G2	Gulmi	E00417896, N03112739

Table 1: Collection of samples from different districts of Nepal

Sample	SiO2	Al2O3	Fe2O3	K2O	MgO	Na2O	CaO	LOI
S2	41.8	23.1	14.3	1.2	1.6	0.1	0.1	14.8
G2	54.9	25.2	8.6	2.5	0.8	0.1	0	6.4

Table 2: Chemical compositions of the samples

Sample	Mk (%)
S2	32.7
G2	19.0

Table 3: Kaolinite content of the samples (finer particles obtained from #200 sieves)

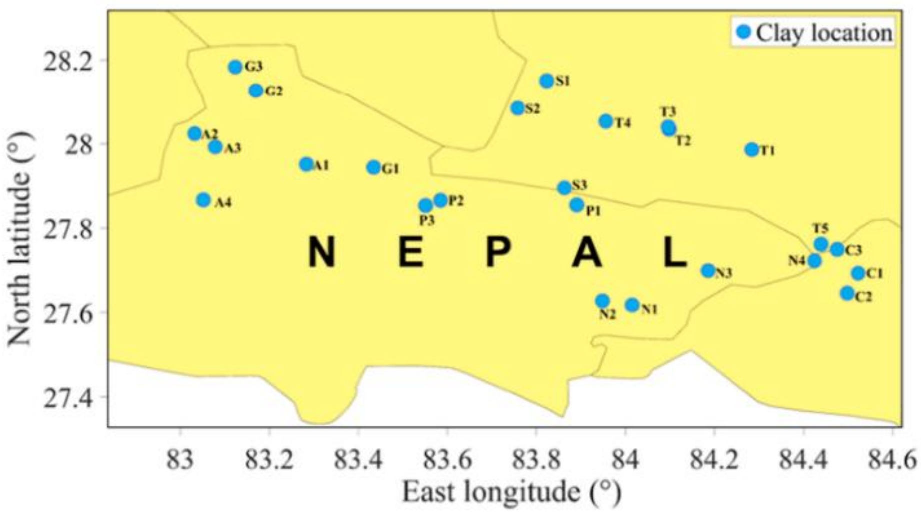

Fig 1: Locations of collected clay in Nepal (Yongzheng Tao, 2022)

Fig 2: Collection of samples from different districts of Nepal

2 LITERATURE SURVEY

Many methods that are extensively utilized worldwide have been developed as a result of worries about the sustainability of cement manufacturing. While the initial set of innovations aimed to lower the energy needed to produce clinker, the majority of contemporary clinker kilns are already operating at or near their maximum thermodynamically feasible efficiency. One such recently created ternary blended cement is limestone calcined clay cement (LC3), in which the alumina from the calcined clay and the carbonate from the limestone also react with one another, in addition to the calcined clay's traditional pozzolanic reaction and the filler effect of the limestone. This results in a synergy between the three main components (clinker, calcined clay, and limestone). In turn, a finer and less linked microstructure develops, giving the cement good mechanical and durability-related performance (M. Antoni, 2012)

2.1 Limestone Calcined Clay Cement (LC3)

A new variety of cement called LC3 is built from a mixture of calcined clay and limestone. The production of LC3 is cost-effective, does not necessitate capital-intensive changes to existing cement facilities, and can reduce CO_2 emissions by up to 40%. It uses abundant limestone and low-grade clays. It contains as little as 50% clinkers by employing calcined clay and limestone.

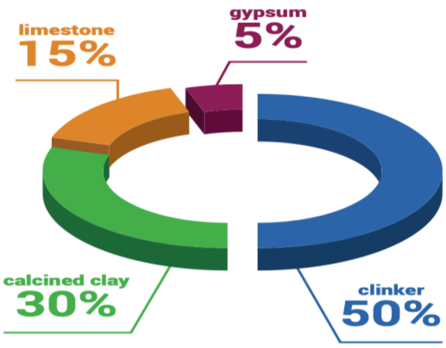

Fig 3 : Composition of Limestone Calcined Clay Cement LC3 (https://lc3.ch/)

When assessed according to Annex-B of IS-1344 and activated through thermal calcinations, the raw clay material used in the manufacture of the clay shall contain at least 50–60% kaolinite. According to the process outlined in Annex-B, the loss of mass on igniting of the raw clay cannot be less than 5.6 percent of the clay's weight. Clays can be calcined at temperatures between 700 and 800 °C to remove their chemical hydroxyl groups, which turns them amorphous and reactive.

The introduction of the technology for creating novel limestone-calcined clay-cement (LC3) appears highly promising from a financial, energy, and environmental standpoint because clay is extensively dispersed throughout most of Nepal. Raw clay undergoes a heat process called calcination that changes it into various amorphous or crystalline forms. At a temperature of around 500°C, kaolinite dehydroxylizes to become metakaolinite, and at a temperature of more than 1,000°C, metakaolinite crystallizes to become mullite. By removing organic materials by calcination, kaolin becomes more brilliant and the clay is organized into aggregates. The most typical calcining apparatus is a rotating kiln, also called a calciner. The calcination procedure improves the clay's electrical characteristics, increases its whiteness and hardness, and modifies the size and form of the kaolin particles. The powder becomes whiter and more chemically inert after calcination. The properties of calcined clay are influenced by the various calcination procedures, which in turn affect how well they function as SCM. As a result, the impact of calcined clay properties on the ideal Portland cement replacement level and on chloride diffusion resistance has not been well assessed.

2.2 Limestone Calcined Clay Cement (LC3) Materials

Clinker, Calcined clay, Limestone, and Gypsum are the primary ingredients utilized in the creation of LC3 blend.

2.2.1 Clinker

When calcareous and aluminous materials are heated to a temperature of 14000°C, clinker is formed. During this heating process, 60 to 62% of carbon dioxide is released. After heating, clinker will be generated in lump form. Accordingly, carbon dioxide emissions in LC3 were lowered to levels that were 30% and 11% lower than those in OPC and PPC, respectively. In this investigation, different clinker content amounts of 40%, 50%, and 60% were employed (Garg, 2006).

2.2.2 Calcined Clay

Clay that contains more than 40% of the kaolin material is acceptable for LC3. Traditional rotary kilns, flash calcination units, roller hearth kilns, shuttle kilns, and muffle furnaces can all be used to calcined clay. Metakaolin, which contains aluminum silicate and is created when kaolin-containing clay is calcined, combines with calcium hydroxide to produce standard Pozzolana, ash gel, and aluminum hydrate. Additionally, the Alumina and limestone can interact to create carboalumination hydrates (B. Lothenbach, 2008).

2.2.3 Limestone

Limestone that is not suited for clinker manufacture can also be utilized in LC3, along with low calcite limestone that contains impurities like dolomite and quartz. In order to create a novel ternary mixed cement, low-grade clay and limestone rich in dolomite were combined with Portland cement, calcined clay, and limestone, which is typically regarded as waste in traditional manufacture. At a temperature that is half that of clinkerization, burning occurs. Because the limestone has not been calcined, it does not increase CO_2 emissions. The additional alumina produced by the calcined clay and the calcium carbonate added to the system via limestone will further react to form alumina phases. (S. Krishnan G. H., 2019)

2.3 Comparison between OPC and LC3

The concept of LC3 is based on the finding that alumina-containing cements react with carbonate phases to produce hard, crystalline carboaluminate phases, which aid in the formation of the microstructure. The idea of mixing the two to obtain higher clinker replacement levels was first published in 2012 (M. Antoni, 2012) despite the fact that calcined clays are well-established as pozzolanic materials and limestone is also frequently utilized as a filler in cements (V.M. John, 2018). Fig. 2.2 compares the composition of LC3 and regular Portland cement (OPC) in terms of composition. This combination was found to significantly increase the formation of the carboaluminate phases, which served as the foundation for performance that was comparable to Portland cement. Although NMR findings indicate that the water content in the C-A-S-H in LC3 is comparable to that in other cements and that there is no such difference in density, it has also been proposed that the production of a lower density C-A-S-H is the cause of the comparable performance (Krishnan, 2019)

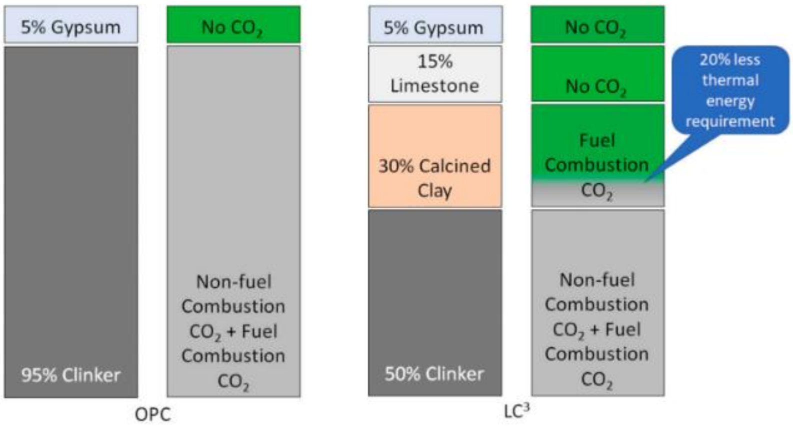

Fig 4: Comparison of composition of OPC and LC3 (https:// www.lc3.ch/why-lc3/, 2021)

Fig 2.3 compares the heat of hydration experienced by LC3 during its first 24 hours to that of an OPC made from the same clinker. OPC was partially replaced with a mixture of limestone and calcined clay (LC2) to create LC3.

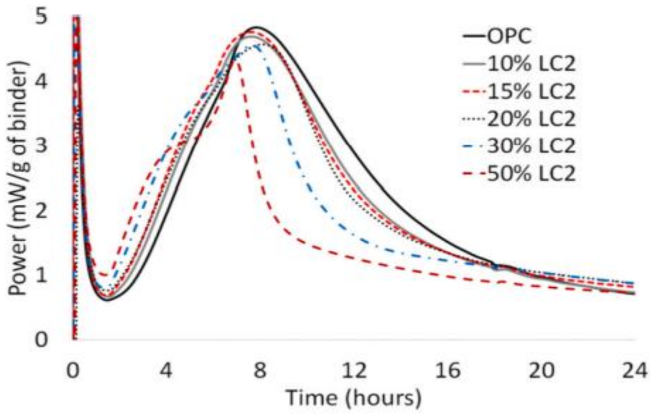

Fig 4: Influence of replacement level of LC2 on the heat of hydration of paste adapted from (V. Shah, 2020)

The graph demonstrates that the acceleration following the induction period is quicker in the case of LC3, and that there is an additional sharp peak that follows the initial peak and resembles C3A in OPC. The heat released during the first 72 hours has also been demonstrated to be less than OPC (S. Krishnan, 2019). The second peak is attributed to the alumina that originates from either the clinker or the calcined clay, with the first peak, which is gentler, generally being that of the silicate phases in the clinker.

Fig 4 compares the heat of hydration of OPC with LC, having different amount of gypsum. It is preferable to adjust the amount of sulphate so that this peak occurs at least one hour after the silicate peak because the early occurrence of the aluminate peak has been linked to lower long-term strength development. Following the aluminate peak at around 34 hours, a third peak associated with the formation of carboaluminates has also been reported (A. Parashar, 2021). While the vast majority of research published in the literature used a mixture of LC3 that contained 50% clinker and a 2:1 mass ratio of calcined clay to limestone, it has been hypothesized that the ideal ratios would depend on the clinker's physical and chemical characteristics (S. Krishnan S. B., 2020).

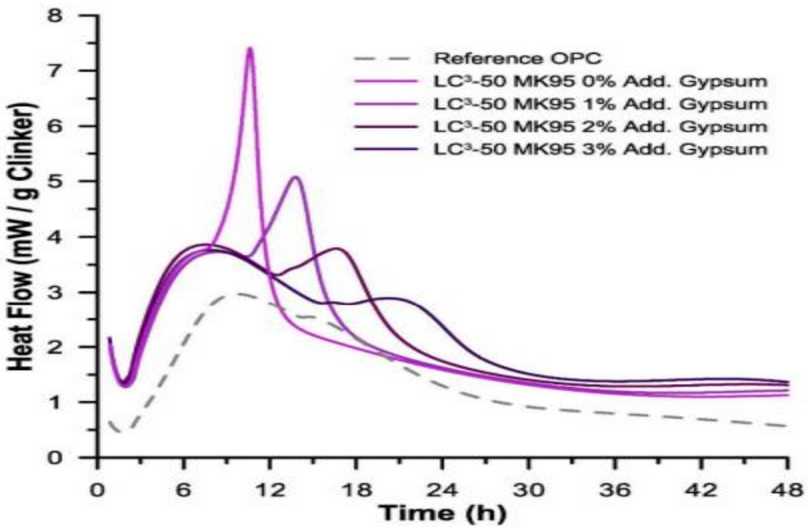

Fig 5: Comparison of the heat of hydration of OPC with LC3, having different amount of gypsum

(F. Zunino, 2019)

The amount of calcined clay that can react will be influenced by the alite and belite content in the clinker since both the reaction of calcined clay and limestone depends on the presence of lime (CH) in the system (M. Antoni, 2012). According to Krishnan et al., the amount of calcined kaolinite that can react in LC3 relies linearly on the percentage of alite and belite (S. Krishnan S. B., 2020). Low internal relative humidity of LC3 has also been linked to lower reactivity of clays at later ages in addition to low CH concentration.

2.4 Calcination and Grinding of Calcined Clay

It is possible to generate calcined clay by a variety of thermal methods. This comprises flash calcination and calcination in rotary kilns, which seem to be the most promising solutions on a large scale. In comparison to calcination in a rotary kiln, flash calcination exposes the material to substantially larger temperature gradients (103-105 ^{0}C/s) for brief periods of time (typically 0.2-1 s). This results in a higher specific surface area. Thus, as compared to static or rotary calcination, flash calcination has been found to generate calcined clay with a somewhat higher reactivity. This difference, though, is only noticeable at very young ages because the kaolinite content then takes over (Salvador, 1995).

LC3 constituents are typically processed independently in an open-circuit grinding setup in laboratory settings. The intergrinding of cement ingredients in closed-circuit units, on the other hand, is the grinding procedure that occurs the most frequently in cement plants. The interaction between the components occurs during intergrinding, which is the primary distinction between separate and separate grinding. Their disparities in grindability are primarily to blame for these interactions. Calcined clay and limestone have better grindabilities (softer particles) than clinker in the case of LC3 (harder particles). Intergrinding causes calcined clay and limestone to become considerably finer, which may negatively impact workability while clinker tends to remain concentrated in the coarse fraction (limiting its reactivity). Separate grinding and optimizing the process might increase workability and reactivity (Weerdt, 2007).

2.5 Properties of Concrete

The most common building material is concrete. It can be molded into any shape, is adaptable, has desirable engineering features, but most importantly, it is made from materials that are affordable. Although concrete has been replaced by plastics and other lighter materials in some applications as a result of recent innovations, the usage of concrete overall has expanded dramatically, particularly because it has improved the performance and use of concrete in constructions. Concrete is a composite material created from a variety of easily accessible materials (aggregates, sand, cement, water). It is a versatile substance that can be mixed to quickly satisfy a range of specific purposes and molded into almost any shape. The three fundamental characteristics of concrete are workability, strength, and durability.

3 METHODOLOGY

Through the different mix design and varying the percentage of cement, calcined clay and limestone powder number of concrete blocks will be prepared and there compressive strength will be studied. The compressive strength will be further checked with the pure concrete block without using LC3. The quantities of each material were precisely weighed in accordance with the planned raw material ratios. The cementitious materials were then added to the mixtures and agitated for two minutes to ensure that they were thoroughly combined. The flowchart that follows depicts the rough outline of the research study's work schedule.

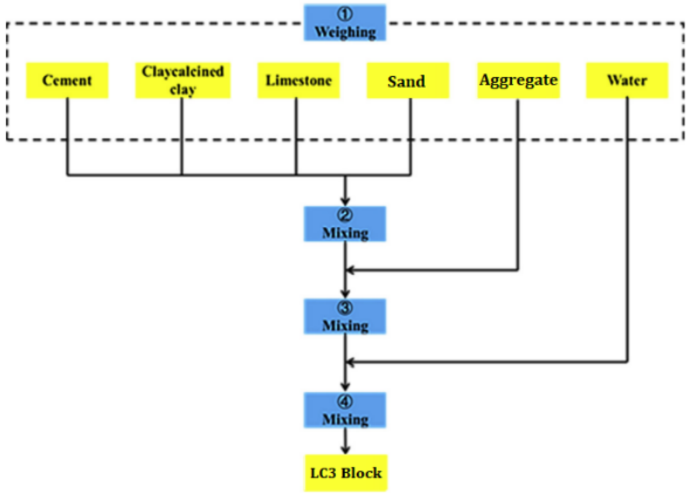

Fig 7: Production process of the LC3 concrete block (Jun Liu, 2021)

3.2 Sample Collection

The samples used in the study were based on a prior work by the teams of (Yongzheng Tao, 2022) and taken from Syanja and Gulmi district of Nepal. These samples were then moved to Chitwan where further calcination is carried out. Additionally the kaolinite content (finer particles extracted from #200 sieves), chemical composition, and mineral composition for the calcined clay were also taken as a reference from their research which is already discussed in Chapter 1.

Fig 8: Collection of samples from different districts of Nepal

3.3 Preparation of Sample

After gathering samples from several districts throughout Nepal, the chosen sample was calcined at the brick kiln known as Anamol Brick Industry, which is situated in Chainpur, Ratnanagar, and then underwent two cooling processes. The samples were placed inside a unique form of rectangular metal box that had been designed in the workshop. The box was then buried inside the brick kiln and the temperature was increased by using firewood along with the coal. The temperature was maintained 700 to 900 ^{0}C as mentioned in the different literatures. Using a thermocouple, the temperature was also monitored during the calcination process. It was a natural cooling process. Before beginning the calcination process in the brick kiln, a rough plan was created, which is listed below.

S.N.	**Name**	**Quantity (Kg)**	**Temp (^{o}C)**	**Time (min)**	**Remarks**
1	Trail 1 (S2)	10	750	20	Quick Check
2	Trail 2 (S2)	25	900	30	Quick Check
3	Adhi-1 (S2)	50 (2 @ 25)	750	80	Simultaneously Check
4	Adhi-1 (G2)	50 (2 @ 25)	750	80	Simultaneously Check

Table 4 : A tentative calcination plan before going to the site

Fig 8: Photographs from the brick kiln site located at Chainpur, Ratnanagar

The calcinated samples were then grinded into smaller pieces maintaining the same particle size as that of cement that we are going to mix with i.e. around 40 µm. This was carried out at a nearby cement plant in Bharatpur, Chitwan. Finally, the calcinated clay samples were ready for the use in the lab.

RESULTS AND DISCUSSIONS

In this chapter the result obtained from our research work were studied and discussed. The observed result from the compressive strength test were compared and interpreted with different other samples.

Test No.	Age of Cube	Cross Sectional Area(mm^2)	Observed Load (KN)	True Load (KN)	Compressive Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
1	3	4900	163	163.8	33.43	**33.33**
2		4900	162	162.8	33.23	
1	7	4900	200.3	201.3	41.08	**39.04**
2		4900	180.4	181.3	37	
1	28	4900	231.43	232.9	47.53	**45.76**

4.2 Properties of Concrete Constituents

The chemical and mechanical qualities of the constituents used, as well as the quantities of the concrete mix, all affect the compressive strength of concrete. Different concrete constituents were examined thoroughly to determine their appropriateness and to get the key physical characteristics needed for concrete mixture proportioning. The summary of results of physical properties of cement, fine aggregates and coarse aggregates are tabulated below.

S.N	Physical Properties of Cement	Test Result
1	Initial Setting Time	135 min
2	Final Setting Time	188 min
3	Consistency	30%
4	Specific Gravity	3.14
5	Soundness	1.76 mm
6	Fineness Modulus	4.9%

7	Color	Grey
8	Name	Sarbottam-43 grade OPC
S.N	**Physical Properties of Fine Aggregates**	**Test Result**
1	Specific Gravity	2.57
2	Soundness	3%
3	Silt Content	3.52%
4	Fineness Modulus	2.72
5	Deleterious Materials	2.422%
S.N	**Physical Properties of Coarse Aggregates**	**Test Result**
1	Specific Gravity	2.59
2	Soundness	1.17%
3	Fineness Modulus	6.99
4	Water Absorption	0.01
5	Flakiness Index	21.15%
6	Elongation Index	10.45%
7	Abrasion Percent	37%
8	Crushing Value	28.59%
9	Impact Value	29%
10	Deleterious Materials	0.81%

Table 5: Physical properties of concrete constituents

4.3 Compressive Strength of LC3 Concrete

The calcinated clay and limestone powder is added along with the cement and mixed thoroughly with sand, aggregate and water to form a M20 grade of mix proportion. The calcinated clay obtained from both Syangja and Gulmi district of Nepal were used to prepare the cubes. Replacement percentage of cement by calcined clay and limestone was taken as 50%, 45% and 47%. The compressive strength test result of concrete cubes with different proportion of LC3 and curing days are discussed below.

a. Design Mix: C50:$S_2$30:LS20

This mix is prepared by using 50% of cement, 30% of calcined clay from Syangja and 20% of limestone powder. Three cubes were casted and compressive strength test was done for 3, 7, 14 and 28 days of curing. It is seen that the cubes are gaining strength slowly and reached to average strength of 11.32 N/mm^2 after 28 days of curing. The reason for low strength is temperature fluctuation during the process of calcination due to which clay doesn't calcined properly. Also the smell was not felt during the time of mixing which may also conclude the low calcination of clay.

Design Mix: C50:$S_2$30:LS20										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.108	7.956	7.886	31.3	33.3	31.1	1.39	1.48	1.38	1.42
7 days test	8.186	8.148	8.14	80.8	81.2	81.9	3.59	3.61	3.64	3.61
14 days test	8.064	7.992	7.948	135.2	135.7	124.4	6.01	6.03	5.53	5.86
28 days test	8.08	8.18	8.152	238	254	272	10.58	11.29	12.09	11.32

Table 6: Compressive strength of M20 grade concrete with 50% replacement of cement after 3 to 28 days of curing

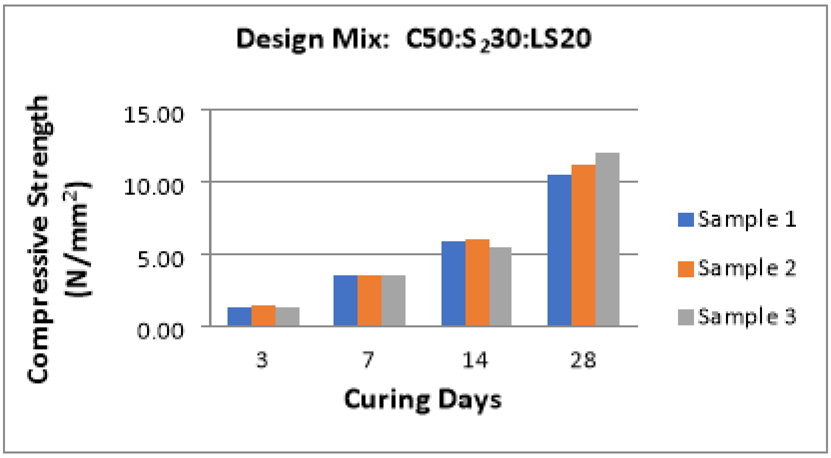

Fig 4.1: Compressive strength of M20 grade concrete with 50% replacement of cement after 3 to 28 days of curing

b. Design Mix: C55:$S_2$30:LS15

In this mix 55% of cement, 30% of calcined clay from Syangja and 15% of limestone powder is used. The percentage of calcined clay is kept constant as before and only the percentage of limestone powder is reduced. At the 3rd day of testing the strength was 10.34 N/mm^2 which later increased to 26.28 N/mm^2 after 28 days of curing. This batch of clay seemed to be calcined properly than before.

Design Mix: C55:$S_2$30:LS15										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.298	8.29	8.416	230	228	240	10.22	10.13	10.67	10.34
7 days test	8.46	8.128	8.382	333	292	296.8	14.80	12.98	13.19	13.66
14 days test	8.376	8.318	8.19	460	464	504	20.44	20.62	22.40	21.16
28 days test	8.91	8.72	8.86	592	590.4	591.5	26.31	26.24	26.29	26.28

Table 7: Compressive strength of M20 grade concrete with 45% replacement of cement after 3 to 28 days of curing

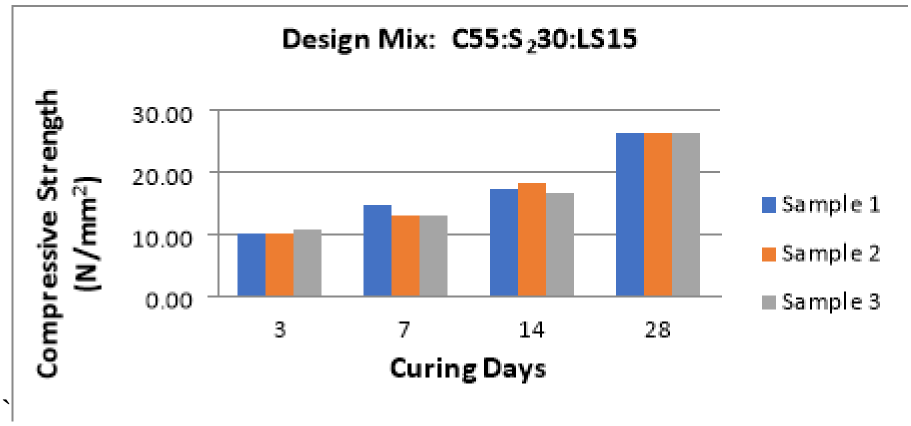

Fig 9: Compressive strength of M20 grade concrete with 45% replacement of cement after 3 to 28 days of curing

c. <u>Design Mix: C53:$S_2$32:LS15</u>

This mixture contains 53% cement, 32% Syangja calcined clay, and 15% limestone powder. The variation is done in calcined clay whereas limestone powder is kept constant. From the table we found that the average compressive strength of the concrete for 28 days of curing increases to 25.84 N/mm^2. This shows that there is only slight variation in strength by changing the proportion of calcined clay and limestone.

Design Mix: C53:$S_2$32:LS15										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.282	8.318	8.496	161.8	167.9	166.2	7.19	7.46	7.39	7.35
7 days test	8.306	8.404	8.448	256	228	265	11.38	10.13	11.78	11.10
14 days test	8.32	8.32	8.12	401	410	392	17.82	18.22	17.42	17.82
28 days test	8.72	8.73	8.76	579	581.4	583.42	25.76	25.84	25.93	25.84

Table 8: Compressive strength of M20 grade concrete with 47% replacement of cement after 3 to 28 days of curing

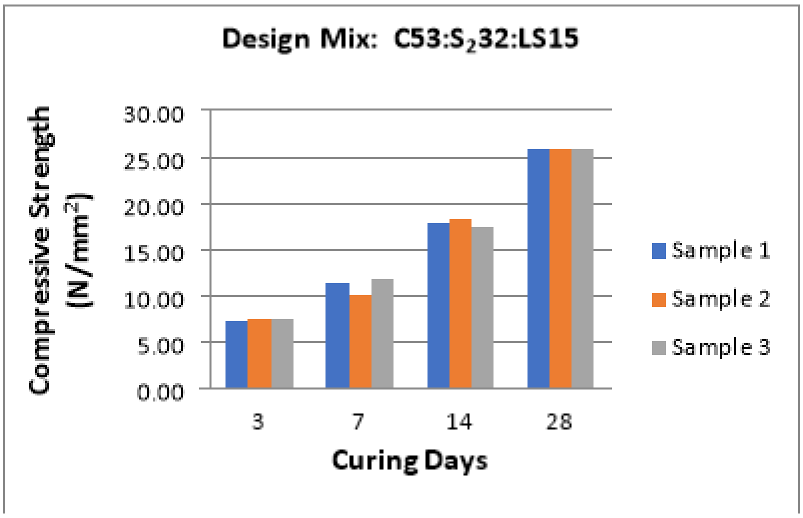

Fig 10: Compressive strength of M20 grade concrete with 47% replacement of cement after 3 to 28 days of curing

d. Comparison of Different Proportion of Syangja Calcined Clay

From the graph we found that the initial compressive strength of the concrete for 3 and 7 days of curing for 45% replacement of cement is greater than 47% replacement. But later after 28 days of curing both the proportion achieves similar strength. Meanwhile the compressive strength of 50%

replacement of cement concrete is much low then other two mix proportion due to poor calcination of clay. This also concludes that proper calcination in appropriate temperature is necessary in order to achieve good strength of concrete.

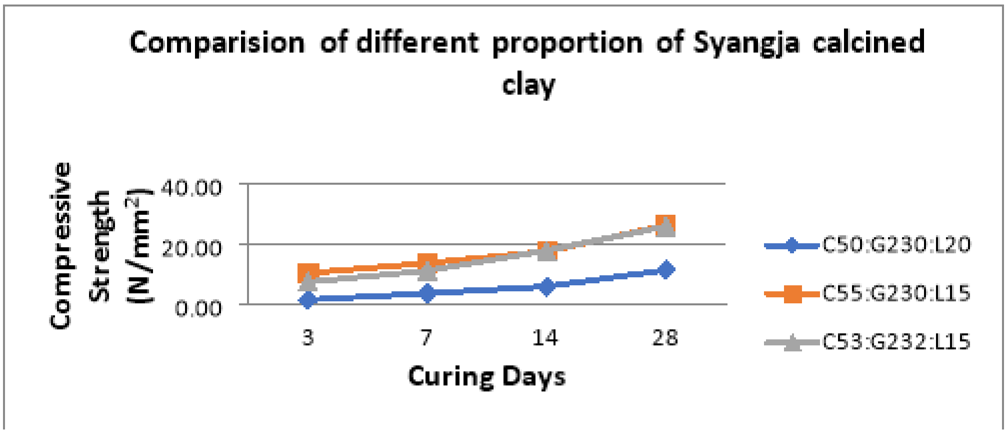

Fig 11: Comparison of different proportion of Syangja calcined clay

e. Design Mix: C50:$G_2$30:LS20

This mix is prepared by using 50% of cement, 30% of calcined clay from Gulmi and 20% of limestone powder. Three cubes were casted and compressive strength test was done for 3, 7, 14 and 28 days of curing. From the graph we can see that the strength is increased by 145% after 28 days of curing. As the average strength is around 26 N/mm^2 this tells that this batch of clay is calcined properly in the kiln.

Design Mix: C50:$G_2$30:LS20										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.224	8.172	8.222	221	249	247	9.82	11.07	10.98	10.62
7 days test	8.17	8.132	8.192	281	257	266	12.49	11.42	11.82	11.91
14 days test	8.25	8.2	8.215	446	451	441	19.82	20.04	19.60	19.82
28 days test	8.71	8.82	8.74	583	584.3	583.2	25.89	25.97	25.92	25.93

Table 9: Compressive strength of M20 grade concrete with 50% replacement of cement after 3 to 28 days of curing

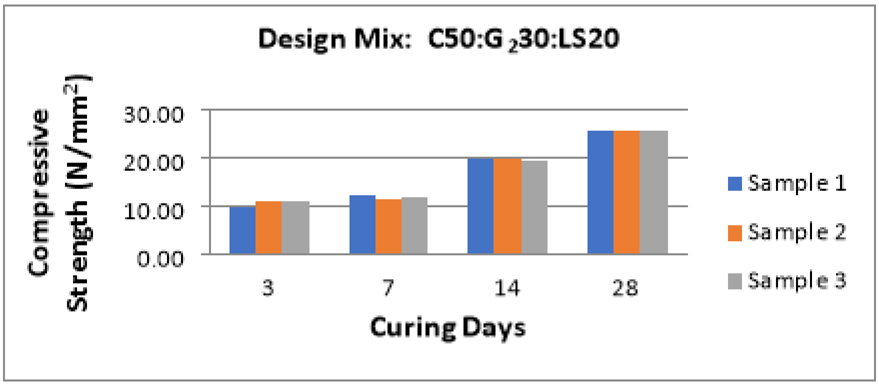

Fig 12: Compressive strength of M20 grade concrete with 50% replacement of cement after 3 to 28 days of curing

f. Design Mix: C55:$G_2$30:L15

In this mix 55% of cement, 30% of calcined clay from Gulmi and 15% of limestone powder is used as a LC3 cement. The percentage of calcined clay is kept constant as before in first mix proportion and only the percentage of limestone powder is reduced by 5%. The average initial strength of concrete obtained from three samples after 3 days of curing is seen to be 8.75 N/mm^2. With the period of time strength seemed to be increased by 2.1% after 28 days of curing than before 50% replacement of cement with calcined clay of Gulmi and limestone powder.

Design Mix: C55:$G_2$30:LS15										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.376	8.36	8.369	196.5	201.7	192.2	8.73	8.96	8.54	8.75
7 days test	8.32	8.104	8.112	297	288	286	13.20	12.80	12.71	12.90
14 days test	8.39	8.48	8.33	451	472	461	20.04	20.98	20.49	20.50
28 days test	8.52	8.57	8.54	594.4	598	597.1	26.42	26.59	26.54	26.51

Table 10: Compressive strength of M20 grade concrete with 45% replacement of cement after 3 to 28 days of curing

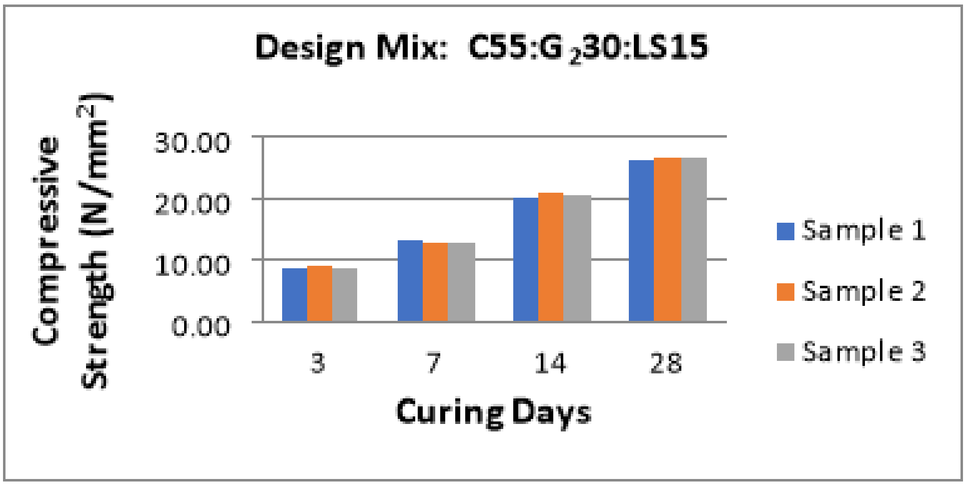

Fig 13: Compressive strength of M20 grade concrete with 45% replacement of cement after 3 to 28 days of curing

g. Design Mix: C53:$G_2$32:L15

53% cement, 32% Gulmi calcined clay, and 15% limestone powder make up this composition. While limestone powder is maintained constant, calcined clay undergoes fluctuation. According to the chart, the concrete's average compressive strength rises to 27.08 N/mm^2 after 28 days of curing which is found to be more than overall mix proportion of LC3 concrete.

Design Mix: C53:$G_2$32:LS15										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.04	8.21	8.22	183	185	188	8.12	8.16	8.34	8.21
7 days test	8.12	8.26	8.34	287	293	299	12.72	13.01	13.25	12.99
14 days test	8.21	8.36	8.43	408	423	426	18.12	18.76	18.92	18.60
28 days test	8.31	8.59	8.54	604	608	616.9	26.82	27.01	27.42	27.08

Table 11: Compressive strength of M20 grade concrete with 47% replacement of cement after 3 to 28 days of curing

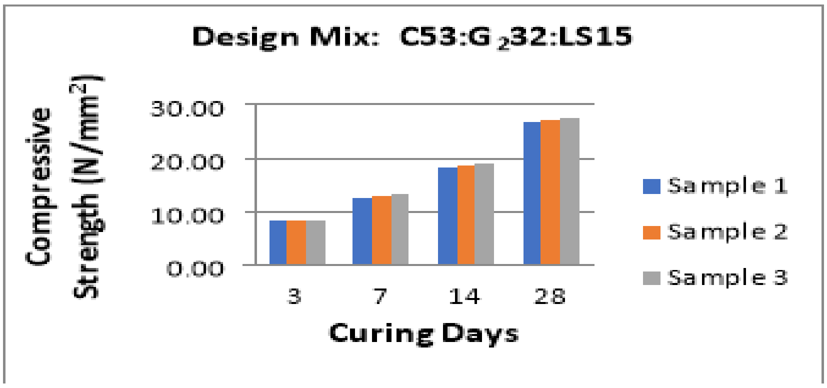

Fig 14: Compressive strength of M20 grade concrete with 47% replacement of cement after 3 to 28 days of curing

h. Comparison of Different Proportion of Gulmi Calcined Clay

The comparison graph of compressive strength of various mix proportion of calcined clay from Gulmi district of Nepal is shown in figure below. The graph shows the linear variation of strength of all three mix proportion. Proper curing and good calcination of clay is the main reason behind this variation. The strength with 47% replacement of cement by calcined clay and limestone is found to be higher among all.

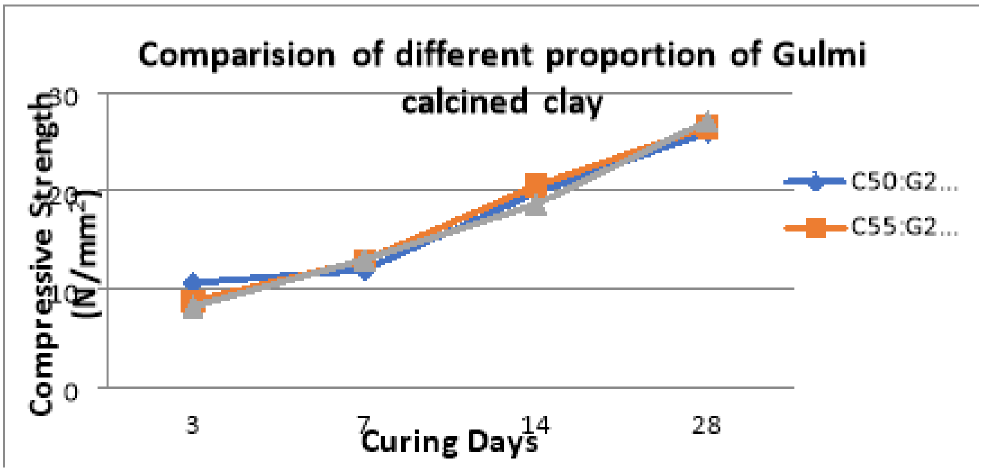

Fig 15: Comparison of different proportion of Gulmi calcined clay

i. Comparison of compressive strength between Syangja and Gulmi LC3 concrete

The comparison graph of compressive strength between different proportion of Syangja LC3 concrete and Gulmi LC3 concrete is shown below. The variation is seen linear and strength increases gradually with the period of time. From above graph we found that the compressive strength of the Syangja LC3 concrete with mix designs C55:$S_2$30:LS15 gives better result of compressive strength whereas for the Gulmi LC3 concrete the mix designs C53:$G_2$32:LS15 shows improved result after 28 days of curing. At 28 days, the average difference between C55:$S_2$30:LS15 mix design concrete and C53:$G_2$32:LS15 mix design concrete is cements compressive strength is 0.8 N/mm^2.

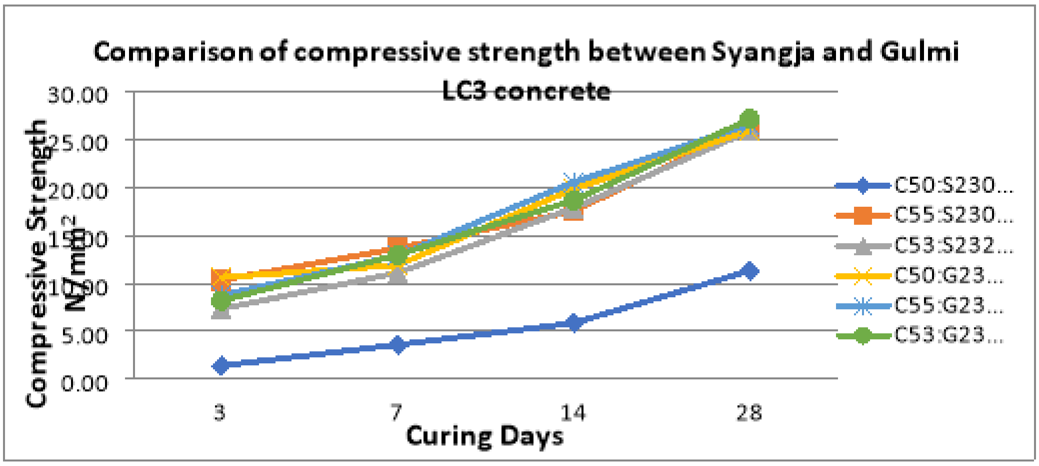

Fig 16: Comparison of compressive strength between Syangja and Gulmi LC3 concrete

4.4 Compressive Strength of M20 Grade Concrete

The compressive strength of the cements utilized at 28 days is exactly related to the compressive strength of the concrete. To fully use the various types of cements' qualities, different concrete mix amounts must consequently be employed. The compressive strength of M20 grade concrete was also determined in the lab in order to compare the results with LC3 concrete. This gives idea about the behavior in strength of concrete due to partial replacement of cement with calcinated clay and limestone powder.

C:S:A in 1:1.5:3 (M20)										
Casting Day	**Weight**			**Weight in kN**			**Strength N/mm^2**			**Avg. Strength N/mm^2**
3 day test	8.16	8.11	8.23	251	249	248	11.16	11.07	11.02	11.08
7 days test	8.28	8.21	8.14	471	467	451	20.93	20.76	20.04	20.58
14 days test	8.38	8.32	8.26	508	478	589	22.58	21.24	24.12	22.65
28 days test	8.42	8.38	8.29	632	630	663	28.12	28.01	29.43	28.52

Table 12: Compressive strength of M20 grade concrete after 3 to 28 days of curing

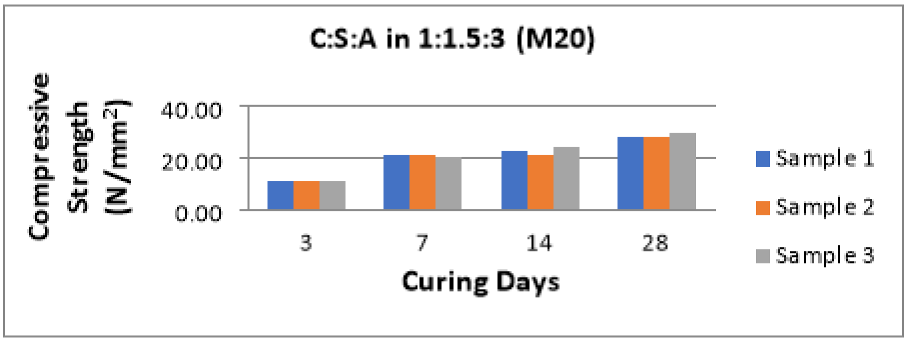

Fig 17: Compressive strength of M20 grade concrete after 3 to 28 days of curing

The experiment was carried out under controlled workmanship. A mix ratio of 1:1.5:3 reached the goal concrete strength at 28 days. From the result the average compressive strength of M20 grade concrete after 28 days of curing is found to be 28.52 N/mm^2. This demonstrates that the mix design ratio employed was appropriate for the cements and that its application results decent strength of concrete.

CONCLUSIONS

Our research and analysis led to the following conclusions:

i. In accordance with the requirements of the IS code, the material qualities of the cement, fine aggregates, and coarse aggregates are within the permitted ranges, thus test results seems to be more accurate.

ii. In this research, calcined clay from Gulmi gave better result as compared to calcined clay from Syangja.

iii. The appropriate calcination of clay under high temperature and sufficient time period plays an important role in the strength of LC3 concrete. From our study the mix proportion C50:$S_2$30:LS20 only achieved 11.32 N/mm^2 after 28 days of curing due to poor calcination.

iv. On 47% cement replacement by calcined clay Gulmi, compressive strength on 28 days is superior and gave the maximum value when compared with calcined clay Syangja on 47%.

v. This study demonstrates that adding LC3 is a highly effective method for increasing hydration of cement. Increased in calcined clay increases the compressive strength of concrete.

vi. Concrete is strong in compression and weak in tension. The tensile property of the concrete can be improved by use of LC3 since LC3 concrete blocks were found to be less brittle by studying the nature of crack formation during the compressive strength test.

vii. The average compressive strength of all the mix proportion were found to be almost 25 N/mm^2 after 28 days of curing which is almost close to M20 grade concrete.

viii. The fine aggregates with smooth, coarse, and rounded texture requires less water to achieve the required slump, thus it causes lowering of the water/cement ratio and raising the compressive strength of concrete.

ix. In general, LC3's mechanical and durability performance suggested that it may be employed in construction settings comparable to those for PPC and OPC.

x. Through this research, the issue of trash disposal and waste-related environmental difficulties may be lessened, and the environment can become more environmentally friendly.

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