Limestone Calcined Clay Cement (LC^3) as an alternative supplementary cementitious material

[1]Rajesh Mourya J N, [2]S Vijaya, [3]Ashwin C A.
[1] PG Student, [2]Assistant Professor
[2] Department of Civil Engineering,
[1] Dr Ambedkar Institute of Technology, Bengaluru, Karnataka, India

Abstract- Ordinary Portland cement is extensively utilized in the construction sector due to its adequate strength bearing ability under the load and hydraulic behavior. However its manufacture contributes five percentages of the world's carbon dioxide emissions, which is serious concern. Hence the need for alternative cementitious materials is essential. There are numerous research projects underway to replace OPC with limestone calcined clay cement, which has physical and chemical properties comparable to those of traditional OPC. LC^3 a form of blended cement called limestone Calcined clay cement (LC^3) is made primarily of Calcined clay and limestone. Calcined clay and limestone are combined to improve the cement's overall sustainability by lowering its carbon footprint and preserving natural resources. In this research, performance of limestone Calcined clay cement as an alternative supplementary cementitious material will be evaluated. The tests on fresh properties of concrete test such as slump test and tests on hardened properties of concrete such as mechanical properties test (compression test and split tensile test), durability tests (permeability test and carbonation test) for 7,14 and 28 days is conducted. Optimum percentage replacement of LC^3 with fly ash is evaluated.

Keywords: OPC, Limestone Calcined Clay Cement, flyash, mechanical properties.

I. INTRODUCTION

In earlier days the soil clay is usually used as the binder material for construction of small structures. As the infrastructures developed from generation to generation the use of soil clay in construction is reduced due to its poor strength. After so many researches the ordinary Portland cement was invented and used in the construction of all types of structures. From then to till now it is used in the construction because of its promising strength and other main properties like, setting time, durability, workability, bonding and etc. Though it has all these good properties towards construction, there are some researches going on about replacement of OPC with alternative binders. The main reason for this replacement is, during the production of ordinary Portland cement it emits 5% to 7% of carbon-di-oxide to environment, of which 50% is from chemical process and 50% from burning of fuels. The application of supplementary cementitious materials (SCMs), such as flyash, rice husk, Ground Granulated Blast Furnace Slag (GGBS) which decreases the quantity of ordinary Portland cement for constructions.

In last few years, Limestone Calcined Clay has gained attention in Western Europe and china for its exemplary setting property and durability. A form of blended cement called limestone Calcined clay cement (LC^3) is made primarily of Calcined clay and limestone. This cutting-edge cement was created as a greener substitute for traditional Portland cement, which is the most popular cement in the building sector but has a negative impact on the environment due to its high carbon emissions.

The essential elements of LC^3 are:

Calcined Clay: Calcined clay is a type of clay that has undergone the calcination process, which involves heating clay to extremely high temperatures (usually between 600°C and 900°C). Through this procedure, the clay is forced to release the chemically coupled water and other volatile components, producing a substance having pozzolanic qualities. Pozzolanic materials combine with calcium hydroxide (lime) in the presence of water to create new cementitious compounds that increase the cementitious matrix's strength and endurance.

Limestone: Limestone is a type of natural rock that is primarily made up of calcium carbonate. Clinker, one of the main components of traditional Portland cement, is largely replaced in LC^3 by the use of limestone as an additional cementitious element. Clinker production's carbon emissions can be lowered by partially substituting limestone for clinker because calcining limestone typically uses less energy than clinker production does. In LC^3, Calcined clay and limestone are combined to improve the cement's overall sustainability by lowering its carbon footprint and preserving natural resources. The high-temperature clinker formation process, which occurs during the production of traditional Portland cement, is mostly to blame for the significant amount of carbon dioxide emissions.

II. LITERATURE SURVEY

H. Zhu et al. (2022): The sustainability potential of OPC is further destroyed by the growing scarcity of traditional supplemental cementitious ingredients like fly-ash (FA) and ground granulated blast furnace slag (GGBS). Thankfully, recent research has shown that limestone-Calcined clay (LC^2) is a workable replacement. In this work, LC^2 was utilized as an SCM to investigate the characteristics of blended cement, and its differences from FA and GGBS were also compared and discussed. Energy consumption and carbon emission evaluation indices were proposed. Results reveal that LC^2 has a detrimental influence on normal consistency and workability, in contrast to the beneficial effects of FA and GGBS. At normal consistency, LC^2 somewhat reduced the setting time; however, at huge content, the growth in consistency led to a significant extension of the setup time. LC^2 is superior to FA and GGBS and reduced drying shrinkage. LC^2 cements more effectively than FA and GGBS, and it is more visible in young children. According to the environmental impact estimate, LC^2 reduces cement's relative energy consumption and carbon emissions by nearly half at a substitution rate of 45 to 60%.

Q.D.Nguyen et al. (2022): This study examines the engineering characteristics of fresh and cured concrete that contains fluctuating quantities of limestone and Calcined clay. Two concrete grades—50 MPa or 30 MPa average 28-day compressive strength—were taken into consideration. Calcined clay of low grade was employed, containing around 50% amorphous phase. With the increased use of General Purpose (GP) cement, a decrease in concrete workability was seen. To get a slump similar to that of reference GP cement concrete, superplasticizer was needed. The 28-day compressive strength produced with a 15% GP cement replacement rate was greater than reference grade 50 MPa concrete, reaching 58 MPa. However, with 30% and 45% GP cement replacement, the average 28-day compressive strength dramatically decreased, reaching about 35 MPa. Results demonstrated that the limestone and Calcined clay substitution had a minimal impact on the 7-day compressive strength of concretes with equal 28-day compressive strengths. Outcomes from mercury intrusion porosimetry showed that adding Calcined-clay and limestone significantly refined the porosity, increasing the quantity of pores smaller than 0.01 mm and decreasing the quantity of coarse pores (with size > 0.1 mm).
The study focuses on investigating the P-Delta (second-order) effect on a reinforced concrete frame structure subjected to changes in eccentricity. The primary aim is to comprehend how these effects influence the seismic behavior of the structure, in accordance with IS 1893:2016 standards. Response Spectrum Analysis, a widely accepted seismic analysis method, is employed using the ETABS software. The research involves systematically varying the eccentricity of applied loads on the frame members. The study evaluates the structural response in terms of lateral displacements, storey drifts. The Results are crucial for understanding the importance of considering P-Delta effects in seismic design and ensuring the safety and stability of RC frame structures under varying eccentricities.
For this study, three building models, each having G+10, G+20 and G+30 storey is considered. Each type of building has consisted steel bracing at corner. Response spectrum analysis is performed for these models with and without steel bracing. The structure was modelled in ETABS Software by considering the parameter shown in Table 1.

III. METHODOLOGY

Methodology of this project includes the following steps:
Procurement of materials: The materials that are used for project (i.e., LC^3, Fly ash, OPC, Fine aggregate, Coarse aggregate) to be procured from the available places.
Conduction of basic tests: Basic tests should be conducted to the procured materials to understand their characteristics. The basic tests on binder are fineness test, standard consistency test, setting time test, specific gravity test. The basic tests on aggregates are specific gravity test, sieve analysis test, water absorption test, bulking test.
Mix design: As per the IS code 10262 the mix design is done. The mix design is used to determine the total quantity of the materials required for casting.
Preparation of cubes: The materials are weighed according to the mix design are mixed in the concrete mixer along with the calculated amount of water. Then the concrete is filled into cleaned and oiled moulds. Leveling and finishing work is done for proper casting. After air dried for 24hours the moulds are demoulded. Now the concrete cubes are ready for curing.
Curing: As soon as the demoulded, concrete cubes are under taken for water curing. Curing duration includes 7days, 14days and 28days.
Testing: The mechanical properties tests and durability tests are done for the concrete cubes after completion of 28 days curing.

IV. RESULTS AND DISCUSSIONS

1. COMPRESSION STRENGTH TEST (IS CODE 516-1959)

(For M_{25} grade concrete, 28 days compressive strength is 25 N/mm^2)

Below [Table 1] and graph shows the compressive strength of concrete cubes with LC^3 and fly ash in varied proportion and OPC.

Table 1: Compressive Strength of Concrete

Mix Ratio	Compression Strength (N/mm2)			
	Trial 1	Trial 2	Trial 3	Average
OPC	35.28	35.02	35.1	35.1
100% LC3	30.16	31.03	30.2	30.46
20% FA + 80%LC3	24.24	23.54	23.9	23.89
25% FA + 75%LC3	28.56	25.98	28.26	27.6
30% FA + 70%LC3	32.82	34.87	34.62	34.01
35% FA + 65%LC3	26.95	29.79	27.95	28.23
40% FA + 60%LC3	25.23	25.68	25.11	25.34

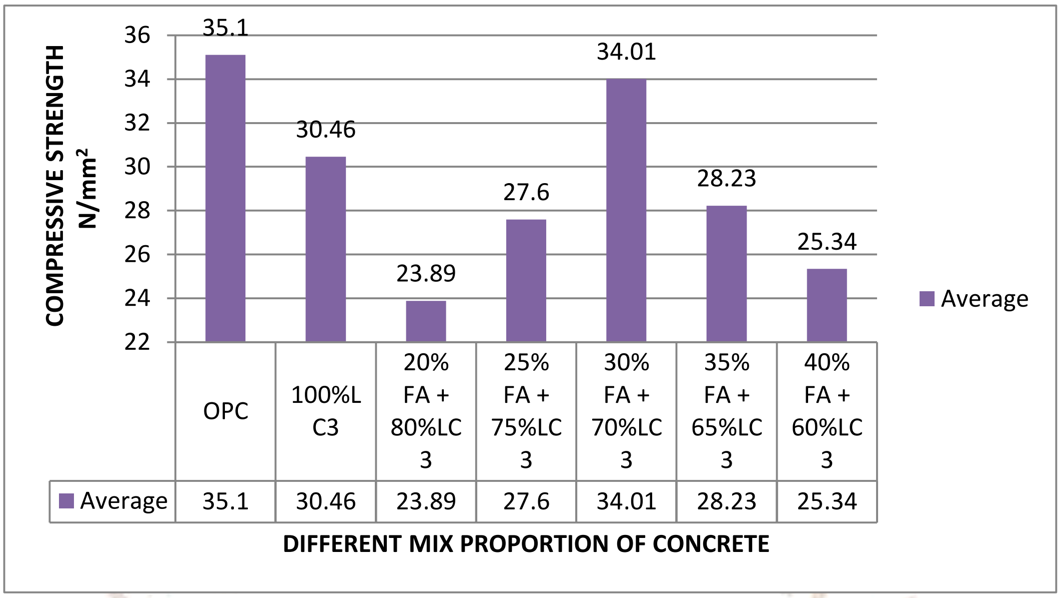

Figure 1. Compressive strength of concrete graph

We may infer from the table and graph that, among the provided combinations, the blend of 30% fly ash (FA) and 70% limestone calcined clay cement (LC^3) produces the maximum compression strength of 34.01 N/mm^2. This ratio works better than other mixes like 40% FA + 60% LC^3 (25.34 N/mm^2), 35% FA + 65% LC^3 (28.23 N/mm^2), 25% FA + 75%LC^3 (27.6 N/mm^2), 20% FA + 80% LC^3 (22.97 N/mm^2), 100% LC^3 (28.47 N/mm^2) and OPC (35.1 N/mm^2). Although the compression strength somewhat declines as the FA percentage increases, the 30% FA + 70% LC^3 mix performs better. It is essential to remember that compression strength, which defines the material's capacity to bear pressure, plays a crucial role in concrete applications. Therefore, it can be said that the mix ratio of 30% FA + 70% LC^3 is ideal for producing concrete buildings that are both strong and long-lasting.

2. SPLIT TENSILE STRENGTH (IS: 5816-1999) (Limited strength:2 to 5N/mm^2)

The below [Table 2] and [Figure 2] shows the split tensile strength of concrete cubes with LC^3 and fly ash in varied proportion and OPC.

Table 2. Split Tensile Strength

Mix Ratio	Split Tensile Strength (N/mm^2)			
	Trial 1	Trial 2	Trial 3	Average
OPC	3.17	3.31	3.4	3.29
100% LC^3	12.21	12.01	12.34	12.1
20% FA + 80%LC^3	9.98	10.14	10.25	10.12
25% FA + 75%LC^3	11.42	11.32	11.56	11.43
30% FA + 70%LC^3	13.07	12.6	12.86	12.84
35% FA + 65%LC^3	10.26	10.11	10.32	10.23
40% FA + 60%LC^3	8.45	8.32	8.26	8.34

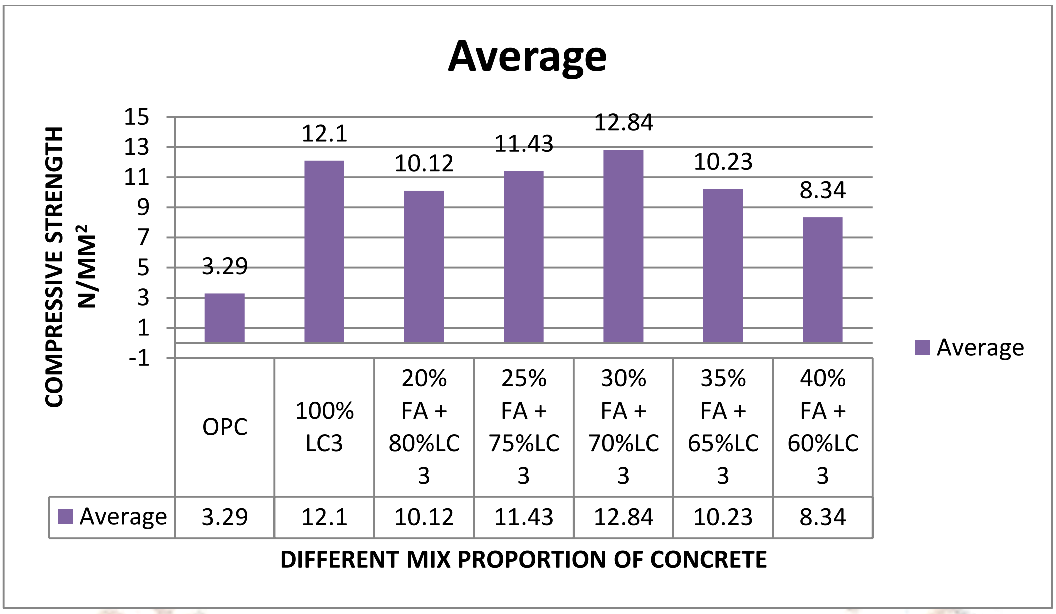

Figure 2. Split Tensile Strength

The findings of the analysis show that the mixture of 30% fly ash (FA) and 70% limestone calcined clay cement (LC^3) produces the maximum split tensile strength of 12.84 N/mm^2. This specific mixture outperforms other mix ratios, such as OPC (3.29 N /mm^2), 100% LC^3 (12.1 N/mm2) and 20% FA + 80% LC^3 (10.12 N/mm^2), 25% FA + 75% LC^3 (11.43 N/mm^2), 35% FA + 65% LC^3 (10.23 N/mm^2), 40% FA + 60% LC^3 (8.34 N/mm^2) in terms of split tensile strength. Even while increasing FA concentration causes a little drop in split tensile strength, the 30% FA + 70% LC^3 mix typically performs admirably. The 30% FA + 70% LC^3 mix ratio is a great option for creating strong, resilient concrete buildings with increased tensile qualities since split tensile strength is essential in assessing a material's resistance to splitting under stress.

3. CARBONATION TEST (IS CODE 516 part 5)

(Least 4 mm from the top surface and 6 mm from the lower surface.)

The below [Table 3, Table 4] and [Figure 3] shows the carbonation test results of concrete cubes with LC3 and fly ash in varied proportion.

Table 3. Carbonation Depth of concrete

Mix Ratio	Carbonation Depth (mm)			
	Trial 1	Trial 2	Trial 3	Average
OPC	1.5	2	1.7	1.73
100% LC^3	2.1	1.7	1.5	1.77
20% FA + 80%LC^3	2	2	3	2.33
25% FA + 75%LC^3	4	4.5	3.8	4.1
30% FA + 70%LC^3	2	2.2	2	2.07
35% FA + 65%LC^3	4.1	3.8	3.6	3.83
40% FA + 60%LC^3	6.2	5.8	6.4	6.13

Table 4. Compression Strength of Carbonated Cube

Mix Ratio	Compression Strength of Carbonated Cube (N/mm^2)			
	Trial 1	Trial 2	Trial 3	Average
OPC	40.2	41.2	40.1	40.5
100% LC^3	29.21	28.23	27.98	28.47
20% FA + 80%LC^3	23.23	22.98	22.69	22.97
25% FA + 75%LC^3	26.97	26.24	26.63	26.61
30% FA + 70%LC^3	32.02	30.15	30.98	30.97
35% FA + 65%LC^3	26.96	29.12	28.32	28.13

40% FA + 60%LC³	25.16	25.64	24.82	25.21

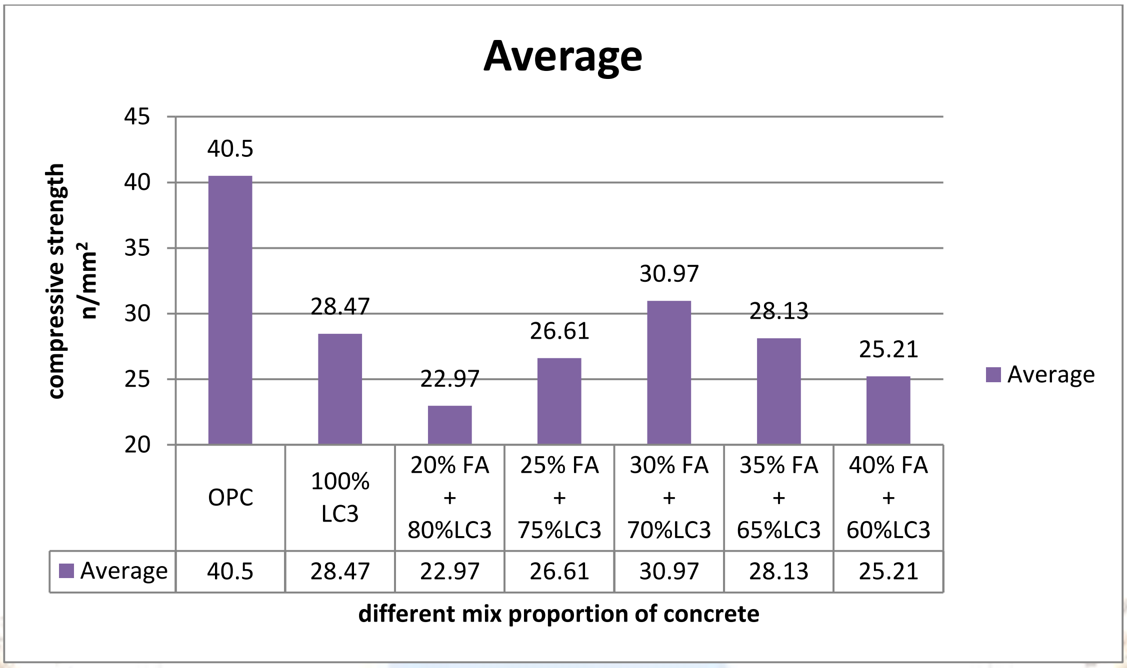

Figure 3. Compression Strength of Carbonated Cube

When choosing a mix ratio for a given project's needs, it is crucial to find a balance between producing high compression strength and controlling carbonation depth. In order to achieve the appropriate strength and durability of concrete buildings in carbonation-prone areas, we must take into account both aspects.

According to the findings, the mix ratio of 30% fly ash (FA) and 70% limestone calcined clay cement (LC^3) produces carbonated cubes with the maximum compression strength of 30.97 N/mm^2. In comparison to other combinations, this ratio performs better than OPC (40.5 N/mm^2), 100% LC^3 (28.47 N/mm^2), 20% FA + 80% LC^3 (22.97 N/mm^2), 25% FA + 75% LC^3 (26.61 N/mm2), 35% FA + 65% LC^3 (28.13 N/mm2), and 40% FA + 60% LC^3 (25.21 N/mm^2). The blend of 30% FA and 70% LC^3 routinely outperforms other mixtures in terms of compression strength, making it the best option for creating robust and long-lasting carbonated concrete cubes.

The ratio of 40% FA + 60% LC^3 has the deepest depth (2.07 mm), whereas 100% LC^3 has the shallowest depth (1.77 mm). A modest depth of 2.07 mm is provided by the 30% FA + 70% LC^3 ratio. Deeper carbonation depths are the result of higher fly ash (FA) percentages. Deeper carbonation depths, which may have an effect on the concrete's long-term durability.

4. PERMEABILITY TEST (IS 3085:2006)

(The depth of penetration of water should not be more than 25mm)

The below [Table 5] and [Figure 4] shows the permeability test results of concrete cubes with LC^3 and fly ash in varied proportion

Table 5. Compression strength after permeability of concrete

Mix Ratio	Compression strength After permeability (N/mm2)			
	Trial 1	Trial 2	Trial 3	Average
OPC	27.9	29.2	29.8	28.9
100% LC^3	29.79	30.26	30.54	30.20
20% FA + 80%LC^3	26.18	24.32	24.43	24.98
25% FA + 75%LC^3	27.52	27.68	26.72	27.31
30% FA + 70%LC^3	28.94	29.67	30.12	29.58
35% FA + 65%LC^3	27.42	27.22	27.68	27.44
40% FA + 60%LC^3	23.56	24.67	24.34	24.19

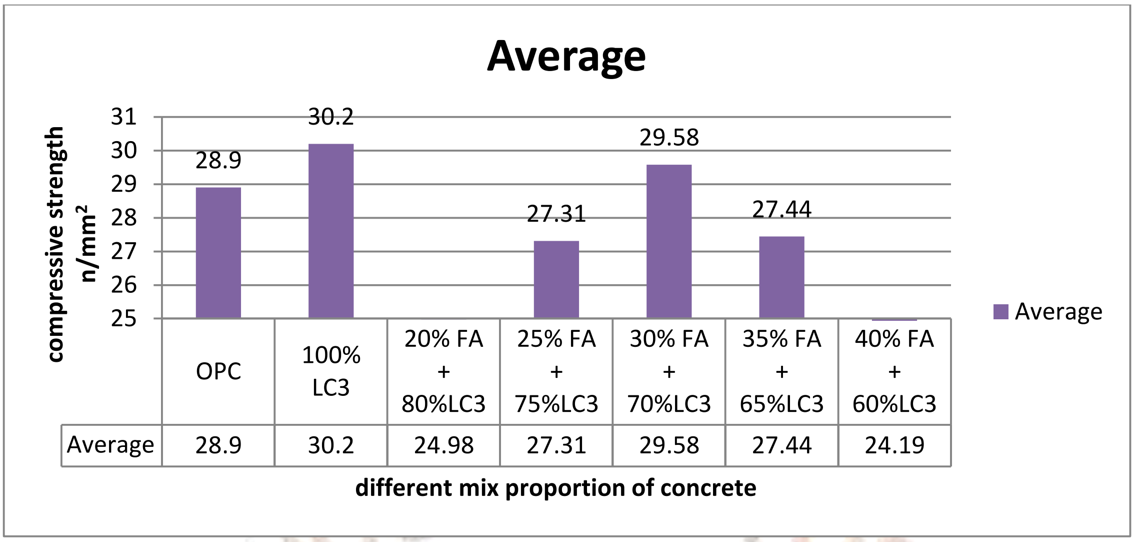

Figure 4. Compression strength after permeability of concrete

Tables and a graph show that mix ratios with a greater fly ash (FA) component have higher levels of permeability. While 100% LC^3 and 30% FA + 70% LC^3 ratios have very low permeabilities, the 35% FA + 65% LC^3 and 40% FA + 60% LC^3 ratios have much greater permeabilities.

After permeability testing, the mix ratio of 30% fly ash (FA) and 70% low-calcium cement (LC^3) produces the maximum compression strength, with a value of 29.58 N/mm². This ratio works better than the following mixtures: OPC (28.9 N/mm²), 100% LC^3 (30.20 N/mm²), 20% FA + 80% LC3 (24.98 N/mm²), 25% FA + 75% LC^3 (27.31 N/mm²), 35% FA + 65% LC^3 (27.44 N/mm²), and 40% FA + 60% LC^3 (24.19 N/mm²). Even after permeability testing, the combination of 30% FA and 70% LC^3 continually performs better in terms of compression strength, demonstrating its capacity to endure fluid infiltration and preserve structural integrity. Consequently, the 30% FA + 70% LC^3 mix ratio is advised for applications needed strong compressive strength and resistance to permeability.

V. Conclusions

- The following findings may be made from experimental tests on LC^3 with fly ash in various proportions of concrete mixtures, including mechanical qualities and durability metrics,
- The blend of 30% fly ash (FA) and 70% limestone calcined clay cement (LC^3) outperforms other ratios, producing the maximum compression strength of 34.01 N/mm². Despite a little reduction in strength with increasing FA concentration, the 30% FA + 70% LC^3 mix is the best option for sturdy and long-lasting concrete constructions.
- The blend of 30% fly ash (FA) and 70% limestone calcined clay cement (LC^3) outperforms other ratios, producing the maximum split tensile strength of 12.84 N/mm². The combination of 30% FA and 70% LC^3 is the best option for producing strong, resilient concrete structures with improved tensile qualities.
- In comparison to other mix ratios, the 30% FA + 70% LC^3 mix ratio offers the best compression strength (30.97 N/mm²) to assure strength and longevity in carbonated concrete buildings. Deeper carbonation depths are a result of higher FA percentages, emphasizing the necessity for a balanced approach when choosing a mix ratio.
- Increased fly ash (FA) concentration in mix ratios results in increased permeability, whereas the blend of 30% FA and 70% LC^3 has a superior compression strength of 29.58 N/mm² following permeability tests. The 30% FA + 70% LC^3 mix ratio is advised for applications needing strong strength and permeability resistance.
- Based on the findings of our experiment, it is determined that 30% fly ash and 70% LC^3 is the ideal replacement percentage for fly ash and limestone calcined clay cement (LC^3). The performance of this mix routinely outperforms the competition in terms of a variety of mechanical and durability qualities.

VI. References

1. Nguyen, Q. D., Khan, M. S. H., & Castel, A. (2018). Engineering properties of limestone calcined clay concrete. *Journal of Advanced Concrete Technology*, V0l *16*, 343-357.
2. Nair, N., Haneefa, K. M., Santhanam, M., & Gettu, R. (2020). A study on fresh properties of limestone calcined clay blended cementitious systems. *Construction and Building Materials*, *254*, 119326
3. Zhu, H., Chen, W., Cheng, S., Yang, L., Wang, S., & Xiong, J. (2022). Low carbon and high efficiency limestone-calcined clay as supplementary cementitious materials (SCMs): Multi-indicator comparison with conventional SCMs. *Construction and Building Materials*, *341*, 127748.
4. Dhandapani, Y., Sakthivel, T., Santhanam, M., Gettu, R., & Pillai, R. G. (2018). Mechanical properties and durability performance of concretes with Limestone Calcined Clay Cement (LC3). *Cement and Concrete Research*, *107*, 136-151.
5. Liu, J., An, R., Jiang, Z., Jin, H., Zhu, J., Liu, W., & Sui, T. (2022). Effects of w/b ratio, fly ash, limestone calcined clay, seawater and sea-sand on workability, mechanical properties, drying shrinkage behaviour and micro-structural characteristics of concrete. *Construction and Building Materials*, *321*, 126333.
6. Han, Y., Lin, R., & Wang, X. Y. (2021). Performance and sustainability of quaternary composite paste comprising limestone, calcined Hwangtoh clay, and granulated blast furnace slag. *Journal of Building Engineering*, *43*, 102655.