<u>Effect of Limestone Calcined Clay Cement (LC3) on properties of concrete</u>

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by

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ABSTRACT

For a long time, to decrease the effect of cement production and CO2 emission many research has been carried out on alternative binders like Supplementary cementitious materials (SCMs) such as slag and fly ash that are collected mostly from industries as waste products which have the energy to decrease the content of cement's clinker. The main drawback of high replacement levels of these materials is the effect on early strength and also increased setting time, minor improvement of increase in later age strength.

This study describes effect of use of Limestone Calcined Clay Cement (LC3) in concrete in different proportion (10%, 15%, 25%, and 30%) and the results are compared with concrete made using OPC. On basis of 7 days testing, concrete with LC3 has shown higher compressive strength than concrete with OPC.

However, it is observed that using LC3 workability of concrete has decreased. Also, it is proposed to carry out experiment on concrete using cellulose-graphene in different proportion.

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CHAPTER – 1

INTRODUCTION

1.1 General

General Cement is considered the first to be used in homes and buildings around the world. Ordinary Portland Cement (OPC) is a type of cement that is widely used in construction, especially where such structures as dams and bridges are needed. There is a growing need for the production and use of cement in many construction projects around the world to meet the ever-increasing demand for housing and general infrastructure. OPC production requires extensive use of raw materials of nature and energy. The OPC production process also results in a greater release of carbon dioxide (CO_2) into the atmosphere. The study estimates that the cement industry is responsible for 5-8 percent of global CO_2 emissions. CO_2 is a greenhouse gas that causes global warming and climate change. In addition, during the production of Portland cement, argillaceous and calcareous materials are inter-ground, either wet or dry and placed in a variable furnace at a temperature above 1300 C, fuelled by petroleum or coal oil. The resulting clinkers combine between 5 percent gypsum ($CaSO_4.2H_20$) to give Portland cement. This process is very expensive, mainly due to the high demand for fuel during the milling and milling process. The need to meet the sustainable development needs of sustainable measures aimed at reducing carbon emissions in the cement industry is a global priority. There is a growing concern in the construction industry to reduce the amount of clinker in cement. Therefore, reducing clinker content in cement by adding calcined clay and limestone has been reported as an effective way to reduce the cost of cement and reduce the amount of CO_2 emitted. However, baked clay bricks, when used in construction show a shorter service life. This has also led to an increase in slums in many areas where fired bricks are used. This requires regular repairs or replacement of baked clay bricks. This later results in the production of Forbidden Burnt Bricks (FRCB) which is often considered a waste of resources leading to: labour misuse, contractor financial losses, significant health impacts, aesthetics and environmental degradation. In addition, large amounts of FRCB are produced annually due to improper calculations or demolition of houses made of clay bricks. The FRCB is heavily depleted in open areas leading to land pollution. The current study therefore aims to evaluate the use of FRCB in cement production. This has the potential to effectively reduce the cost of cement, reduce carbon footprint in the cement industry and provide an eco-friendly waste disposal system to ensure sustainable development. Limestone Calcined Clay Cement (LC3) is a new composite cement produced from a mixture of limestone, compacted clay, clinker and gypsum at specified rates. LC3 is also eco-friendly as it can effectively reduce CO2 emissions by 30 percent. Additionally, the production of LC3 cement does not require as much investment as can be done by modifying existing cement plants. Extensive research has been done on the use of mineral-based clay and low-grade industrial clay, where such clay is considered pure enough to be used in their products. However, little attention has been paid to the ability to use broken clay bricks as a source of calculated clay for use in LC3 production.

1.2 Materials

The quality of concrete can be achieved through the selection of suitable materials, mixtures, and selection of mixing rates, w / c ratio and the application of appropriate methods of placement and curing.

1.2.1 Cement

Cement is a composite material where water is present. Natural cement is obtained by heating and crushing stones containing clay, carbonate of lime and a certain amount of carbonate magnesia. Natural cement is very similar to lime. It sets up very quickly after the addition of water. The cement is almost identical to that of the sandstone, which is commonly found in Portland, England. So, it is sometimes called Portland cement. It is not as strong as synthetic cement. Synthetic cement was developed by Mason Joseph of England. Fig no.1.1 is showing the ordinary Portland cement.

The basic ingredients of cement are calcareous and argillaceous products usually containing lime (62-67%) and silica (17-25%), alumina (3-8%), calcium sulphate (3-4%), iron oxide (3-4%), magnesia (0.1-3%), sulphur (1-3%) and alkalis (0.1-2%). Fig no.1.2 is showing the photograph of cement bag.

The ratings of the four combinations above vary from different Portland cement. Tri calcium silicate and di calcium silicate have a significant impact on energy retention. The initial set of Portland cement is due to tri calcium aluminate. Tri calcium silicate hydrates quickly and contributes significantly to initial energy. Di calcium silicate donation is made after 7 days and can continue for up to one year. Tri calcium aluminate hydrates quickly, produces a lot of heat and makes only a small contribution to energy within the first 24 hours. Tetra calcium alumino-ferrite is relatively inactive. All four compounds produce heat when mixed with water, aluminium produces high temperatures and di calcium silicate which produces minimal. As a result, tri calcium aluminate is responsible for many unwanted concrete properties. Cement with a small C3A will have higher strength, less heat production and less cracking. The table 1.1 given below shows the composition and percentage of compounds obtained for normal and rapid hardening and low temperature of Portland cement.

Table 1.1. Composition and compound content of Portland Cement:

	Normal	**Rapid hardening**	**Low heat**
(a) Composition:	**Percent**	**Percent**	**Percent**
Lime	63.1	64.5	60
Silica	20.6	20.7	22.5
Alumina	6.3	5.2	5.2
Iron Oxide	3.6	2.9	4.6
(b) Compound:	**Percent**	**Percent**	**Percent**
C3S	40	50	25
C2S	30	21	35
C3A	11	9	6
C4A	12	9	14

Fig no. 1.1 Ordinary Portland cement

Fig no.1.2. Cement Bag

Ordinary Portland Cement is best suited for use in conventional concrete construction where there is no exposure to sulphate in soil or groundwater and it is showing in fig no.1.3. This cement mainly contains silicates and aluminates of lime found in stone and clay. The mixture is ground, blended, and refrigerated at a temperature of 1400 degrees Celsius and obtained by a product called clinker.

Clinker is cooled and ground into a cement. Cement is produced in greater quantities than other cement due to its durability and resistance to atmospheric and other aggression. It is produced by grinding Portland clinker with a possible amount of gypsum, water or both less than 1% of the air in it.

Fig no. 1.3. Ordinary Portland cement

1.2.2 Aggregates

1.2.2.1 Coarse aggregate

Aggregates such as stone, sand and bricks are ineffective. Their structures have a great influence on the behaviour of concrete as they occupy about 80% of the total amount of concrete. It makes sense to use more aggregates as they are less expensive than cement and are naturally free. Aggregates are classified as standard and stable and comply with the requirements of IS383-1970

For maximum strength and durability, the amount should be cemented and packed as compactly as possible. For this reason, the separation of particle size into aggregate to produce packaging is very important. It is necessary that the amount should be of good strength, durability and weather resistance, their environment is free of contaminants such as mud and organic matter which may weaken the bond by attaching the cement and no adverse chemical reactions occur between them and the cement.

Fig no. 1.4. Coarse aggregate

1.2.2.2 Fine aggregate

Concrete as composite material, the workability and development of strength depend upon the age, the properties of constituent materials and their combined action. The role of fine aggregate on strength and workability has to be deciphered before examining the possibility of total replacement of fine aggregate. The purpose of mix proportioning is to produce the required properties in both plastic and hardened by the most economical and practical combination of materials available. There has been very little use reported of the vast quantities of waste generated by mixing quarrying industries. Only small amount of these wastes has been used in road making and in manufacture of building materials such as light weight aggregated bricks and auto cleaved blocks.

It is evident that the concrete strength development depends on the strength of cement mortar and it’s synergetic with coarse aggregates. Pebbles as coarse aggregates due to smooth surface structure impart lower mortar aggregates bond strength than that imparted by crushed coarse aggregates. In the present work, fine aggregate consisting of natural sand conforming to grading zone 2 of IS 383-1970 is used.

Fig no. 1.5. Fine aggregate

1.3 Admixtures

Admixtures are materials other than cement, aggregate, and water that are added to concrete either before or during mixing to alter its properties, such as workability, curing temperature range, set time or colour. Some admixtures have been in use for a long time, such as calcium chloride to provide a cold weather setting concrete. Other are most resent and represent an area of expanding possibilities for increased performance. Not all admixtures are economical to employ on a particular project. Also, some characteristics of concrete, such as low absorption, can be achieved simply by consistently adhering to high quality concreting practices.

Admixtures are used to alter the properties of concrete in such a way as to make it more suitable for the work at hand or for economy, or for other purposes such as saving energy or increasing durability. In some instances, admixture is the only means of achieving the desired results.

CHAPTER 2

LITERATURE REVIEW

2.1 General

SHCC-based composites are a special class of highly efficient fibre-reinforced composites, which exhibit stiffness and strong quasi-ductile behaviour. High tensile ductility results in the formation of many small, solid cracks bound by short polymer microfiber. In addition, the high cement content causes excessive heat hydration and a significant decrease in autogenous and plasticity, which may adversely affect the performance, performance and durability of HS-SHCC. In addition, due to the very low water-to-binder content, a large percentage of cement clinker remains waterless, eventually acting as an expensive additive. Similar to ultra-high-performance concrete (UHPC), cement content can be reduced by using silica fume as a supplementary, pozzolanic binder, while ground silica, limestone powder and other materials can be used as an excellent filler. To obtain uniform distribution of highly efficient polymer micro-fibres (diameter 13 to 20 μm) and to maintain the low fracture of the matrix, no solid components are used in the HS-SHCC. Instead, quartz or silica sand with a particle size less than 600 μm is used in limited quantities. In short, the literature review highlights the stated need for the continued development of HS-SHCC technology for sustainable and economical solutions. Limestone Calcined Clay Cement (LC3) has recently emerged as an ongoing solution to reduce clinker content in cement.

2.2 Building materials

The cement matrix that served as the basis for this study was designed in previous works by the authors to achieve the highly ductile HS-SHCC reinforced with ultra-high molecular weight polyethylene (UHMWPE, short PE) fibres. The matrix was supposed to ensure high mechanical strength and low break resistance. The binding included cement (1460 kg / m3) and silica smoke (292 kg / m3), while fine quartz sand (145 kg / m3) was used as the composite. To ensure adequate performance without increasing the water level to the binder, a high dose of superplasticizer (35 kg / m3) was used. The resulting amount of water to the binder (w / b) including water from the superplasticizer was 0.192.

2.3 Experimental program

Considering the high content of the binder and the low w / b content in the matric cement under investigation, strong mixing was needed not only to achieve an equal consistency and to break the fines after the water installation, but also to obtain a cohesive consistency. and a short mixing time. For this reason, Erich EL1's high volume 1 L mixer was used for the investigation of the blank matrix and the production of compatible models; 0.5 L cakes mixed. The mixer provided data on various mixing parameters, including the rotor power history, which served as an indicator of the different mixing phases and the corresponding mixing power. The process of integrating the plain matrix is presented in the diagrams in Section 4.1. The flow of new pastes was assessed using the H¨ agermann flow, while the initial setting time and final cement paste were measured by Vicat Apparatus according to ASTM C807 standard [25]. The reaction kinetics of pastes was assessed using an isothermal calorimeter (Calmetrix CAL 4000) at 20 ◦C for 72 hours.

2.4 Outlook

In this study, strong cement-reinforcing compounds (HS-SHCC) were developed with a gradual replacement of Portland cement (OPC) with limestone, composite clay and gypsum to LC3 standards. Replacement of OPC with LC3 requires higher bonding strength due to extended dry switching stages in order to attach and increase LC3 content. Changing the LC3 component shortened the set-up time of the mixtures, which resulted in a greater need for water of compacted clay to reduce the amount of free water in the matrix. At 28 years of age, blank matrices 0.2LC3 and 0.6LC3 (OPC switches of 10% and 30%, respectively) and the corresponding SHCC showed slightly lower compression strength compared to reference samples made with OPC. This was explained by the very low content of C-A-S-H gel in the combined LC3 samples as revealed by the TGA and QXRD analyses. However, such replacement of the OPC component has resulted in significant improvements in flexibility, resulting in the production of polymerized CASH gel as indicated by the 29Si MAS NMR and the formation of additional AFt - which may serve as "nano-reinforcement". - as indicated. by QXRD ratings. A 50% conversion of OPC to LC3 has resulted in a significant decrease in compressive strength and lower dynamic energy values compared to songs with low replacement rates. This can be traced back to the many particles of uncooked composite clay and limestone particles in the LC3 matrix and the high volume of the related hole as found in the BSE and MIP analysis. In contrast, OPC replacement with LC3 increased the bond strength between the fibre and the matrix, and facilitated the formation of a said pattern that tightened the slip, resulting in higher pulling strength as seen in single fibre pull tests. In short, the LC3-based SHCC demonstrated similar mechanical properties and fragment behaviour compared to the OPC-based SHCC, thus, providing a more sustainable alternative to the same engineering performance. In future studies, a detailed investigation into the rheological properties of new compounds and fibre and error size (larger than 100 μm) distribution of combined LC3 matrices will be performed. The impact of LC3 on matric fracture and the interaction between fibre matrix and LC3 should be further investigated and the impact of years of testing should be investigated. Decreased behaviour, durability (wet drying cycle, ice melting cycle, chloride infiltration, sulphate invasion, etc.) and LC3 -SHCC self-efficacy should be evaluated before a new compound can be recommended for use in practical applications.

CHAPTER 3

DESCRIPTION OF LC3

3.1 Limestone calcined clay Cement

3.1.1. Introduction:

LC3 is a new type of cement based on a combination of limestone and synthetic clay. LC3 can reduce CO2 emissions by up to 40%, made using limestone clay and low-quality clay that is widely available, cost effective and does not require significant monetary conversion of existing cement plants.

The purpose of the LC3-Project, through research and testing, is to make LC3 a widely used and common cement in the global cement market.

The main research activities focus not only on specific areas with cement research topics but also on the production, environmental sustainability and cost-effectiveness of this new cement. The compositions of LC3 are showing in Fig no.3.1

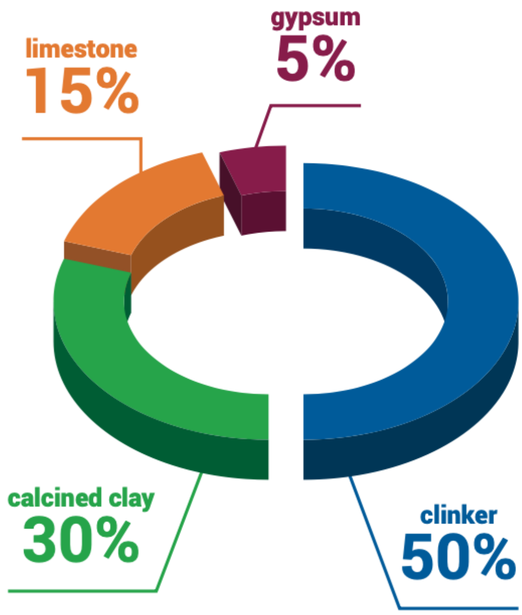


Fig no. 3.1 LC3 Concrete Composition

LC3 is a Portland cement blend that combines the addition of metakaolin (a compound kaolinite compound) and limestone. The main components of LC3 are clinker, synthetic clay, limestone and gypsum.

Combined clay and limestone are already commonly used as Supplementary Cementitious Materials (SCMs). A major innovation in LC3 combines the use of kaolinite clay found in low-volume mass with another 15% limestone, which together has a synergetic effect and achieves the same performance as OPC.

The extra alumina in metakaolin combines with low limestone, which leads to a non-abrasive substance, and as a result provides equal strength and higher clinker conversion rates.

- **<u>Suitable clay</u>**

Clay is a climate product of all types of rocks and, as a result, is found in close proximity to the Earth's surface in all geological conditions. They are made of silicon and aluminum oxides, which together form of the Earth's crust. The most suitable types of clay, which contain kaolinite, are common in tropical and subtropical regions, where most of the increase in demand for cement is predictable. Kaolinite clay occurs mainly in soils formed due to chemical weathering on rocks in hot and humid climates.

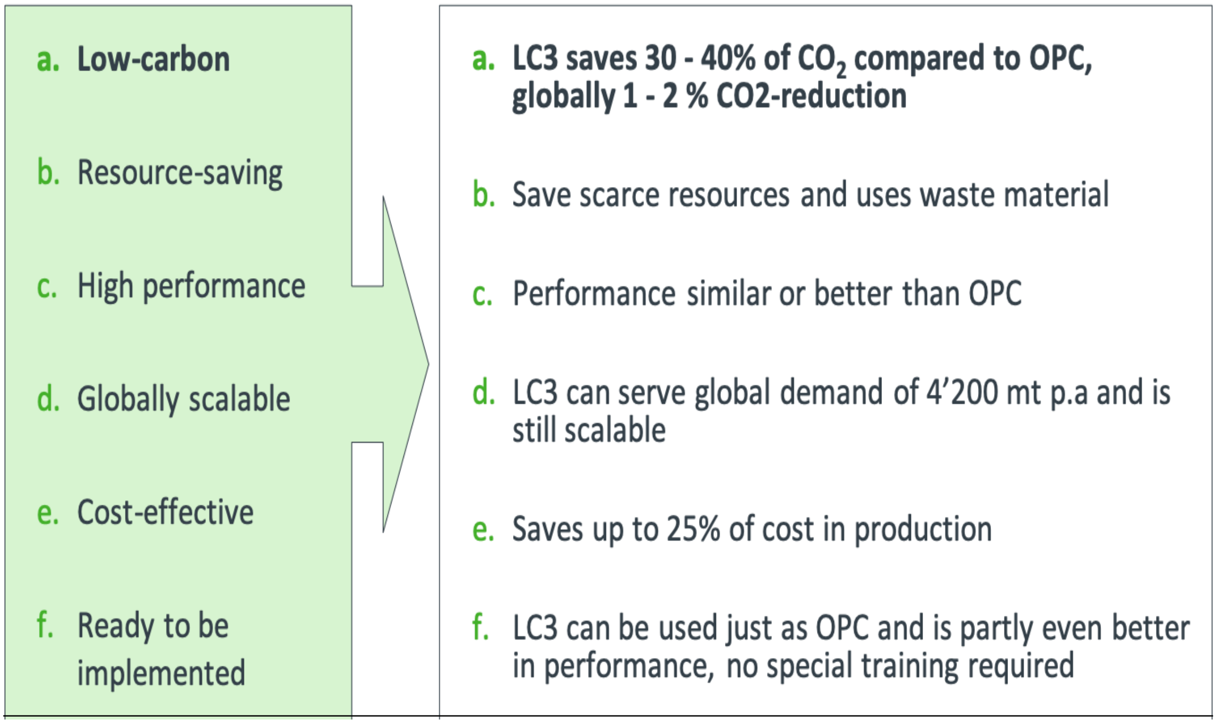
The kaolinite content required for LC3 is much lower than that of pure kaolinitic clay used in ceramic or paper industries so the use of such 'low quality' will not compete with the demand for resources in other industries. Our experience in India has shown that large quantities of low-grade clay exist as a heavy burden on existing quarries, currently considered as waste. The use of such resources will not require the opening of new quarries or the excavation of arable soil.

- **<u>Limestone</u>**

Limestone is always available at cement plants.LC3 mixtures usually contain about 15% limestone, but materials that are not suitable for clinker production can be used. For example, high dolomite content produces periclase during clinker production, resulting in an increase. Such materials can be safely used in groundbreaking, leading to the efficient use of limestone quarries. Depending on the specific situation, the amount of cement that can be produced in the same storage area of the identified limestone can double.

3.1.2 LC3 as a Material

The all properties of LC3 are given below in sequential order.



a. Low Carbon

LC3 saves up to 40% of CO2 as compared to Ordinary Portland Cement. Most of the CO2 comes from the clinkerisation process. Therefore, reducing the clinker factor and replacing it with SCMs is the fastest intervention to save high numbers of CO2. Within the clinker production, there are two main sources of CO2. Firstly, clinker needs to be burnt at very high temperatures between 1400 and 1500°C. Secondly, CO_2 embodied in limestone is released during production. Reducing the clinker content therefore means to save both energy-related and embodied CO2.

b. Resource-savings

LC3 material is utilize where lower grade cement is required such as:

- Clay waste e.g., ceramic or cosmetic industry
- Less purity of limestone required, e.g., dolomite presence

c. High performance

For more than 10 years, the respected research institutes EPFL, IIT Delhi and Madras and CIDEM have tested LC3 in all different aspects and achieved the result LC3 achieves OPC performance - CEM I. Not only in laboratory conditions but and in industrial inspections and applications these findings are confirmed. They are constantly monitored for existing LC3 systems in different parts of the world and in the surrounding areas (e.g., marine or higher-level applications).

d. Globally scalable

The raw materials limestone and calcined clay are abundantly available worldwide. Other commonly used Supplementary Cementitious Materials like fly ash or slag are already fully used and cannot be scaled for the use in cement. Furthermore, with increasing focus on sustainability more and more coal power and steel production plants are expected to be closed. This will further cut the supply of these materials as SCMs.

e. Cost- Effective

The various conditions for LC3 production were financially analyzed in a study conducted by cement market experts. Their results showed that with cement plant, milling plant or Greenfield condition LC3 production is beneficial. The key to driving profit is getting closer to the right clay. Overall, production costs could be 25% lower in LC3 than OPC due to energy and material savings..

f. Ready to be implemented

LC3 is a market-ready technology and is being produced in a few plants around the world. As soon as the technology is distributed worldwide it can be avoided by emitting more CO2 emissions. The ready readiness of industrial capture technology is an important difference compared to other green technologies. In addition, LC3 can be used without additional training by the manufacturers. In India, demo construction was built without providing training.

3.1.3 Chemical Composition of LC3

The chemical composition of clinker, limestone, ground fired clay (broken clay bricks), PPC and gypsum are shown in Table 1.

In addition, Table 2 gives the description of various cements used. The description of various materials used in this study is given in Table 2.

Table 2.1 Chemical composition of materials

Chemical Composition of Clinker, Limestone, FRCB and Gypsum.

Chemical composition	Clinker	FRCB	Limestone	Gypsum	PPC
SiO_2	21.78	58.13	1.85	2.44	31.59
Al_2O_3	4.55	15.55	0.98	0.87	6.23
Fe_2O_3	3.97	9.88	1.63	0.79	3.29
CaO	62.97	1.66	68.63	34.25	45.77
MgO	1.05	0.83	1. 86	1.79	1.25
SO_3	2.07	0.04	0.02	40.82	1.66
K_2O	0.6	4.78	2.79	0.05	0.57
Na_2O	0.17	3.18	2.15	0.05	0.18
H_2O	2.33				2.13
Cl^-	0.01				0.047
Sum (SiO_2 ,Al_2O_3, Fe_2O_3)		83.56			
Loss on Ignition (LOI)	0.96	2.92	10.26	12.99	0.88
Blaine fineness, m^2/Kg	339	445			425

Table 2.2 Description of Cements

Description of Various Cements used.

Cement Type	Description
OPC	Ordinary Portland Cement (OPC) [42.5 N/mm]. OPC was prepared by blending and inter-grinding of clinker and 5 % gypsum in a laboratory ball mill.
PPC	Commercial Portland Pozzolana Cement (PPC) [32.5 N/mm^2]. It is locally manufactured using volcanic ash as pozzolana.
LC3	A blend of 50 % of clinker, 30 % of ground fired clay bricks, 15 % limestone and 5 % gypsum inter-ground in a laboratory ball mill.

3.1.4 Details of LC2

The different parameters of LC2 with its chemical analysis are given in table no.3.3

Table 3.3 Details of LC2

Parameter	Unit	Observation
Appearance	-	Brownish red
Specific Gravity	-	2.75
Sieve Retentively	% On 90µ	< 2
Lime Reactivity	MPa	≥ 7
Blaine Fineness	m^2/kg	580
Chemical Analysis		
SiO2	%	34.28
CaO		30.35
Al2O3		19.45
Fe2O3		3.43
MgO		1.38
SO3		1.58
Na2O		0.31
K2O		0.27
Chloride		0.027
LOI		8.21

CHAPTER 4

METHODOLOGY

4.1 Mix Design

4.1.1 Introduction

The process of selecting the right concrete ingredients and determining their related values for the purpose of producing the required concrete, strength, durability, and efficiency is possible, is called concrete mix design. The concentration of the concrete ingredient is controlled by the required performance of the concrete in 2 regions, namely plastic and solid regions. If the plastic concrete does not work, it cannot be properly laid and bonded. Functional material, therefore, becomes a very important factor.

The compressive strength of solid concrete generally considered an indication of some of its characteristics depends on many factors, e.g., quality and quantity of cement, water and aggregate, coagulation and mixing, laying, compaction and curing. The cost of concrete is determined by the cost of materials, plants and labour. The variability in the cost of the material comes from the fact that the cement costs several times more than the aggregate, so the goal is to produce as soft a mixture as possible. From a technical point of view, rich mixtures may lead to high cracks and cracks in the concrete of the building, as well as high temperature fluctuations in the hydration of large concrete that may cause cracks.

The actual cost of concrete is related to the cost of materials required to produce a small amount of energy called the element strength specified by the architect. This depends on quality control measures, but there is no doubt that quality control adds to the cost of concrete. The level of quality control is usually an economic compromise, and depends on the size and type of work. The cost of the work depends on the performance of the mix, e.g., a combination of inadequate concrete performance may result in higher labour costs in order to determine the degree of integration of the available materials.

It is proposed to use M20 level concrete and OPC component replacement with LC3.

4.1.2 Requirements of concrete mix design

The requirements that form the basis for the selection and classification of mixed ingredients are:

a) Minimum compression strength required in structural considerations

b) The adequate workability necessary for full compaction with the compacting equipment available.

c) The maximum amount of water cement and / or cement content provided sufficient firmness of the conditions of a particular site

d) The amount of cement to avoid cracking due to temperature perimeter with large concrete.

4.1.3 Factors affecting the selection of mixed scales

The various factors that affect the structure of a mixture are:

1. Compressive strength

It is one of the most important concrete structures and influences many other descriptive features of solid concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. Another factor affecting the strength of concrete in a given age and treated at a certain temperature is the degree of bonding. According to Abraham's law the strength of fully reinforced concrete is inversely proportional to the degree of water cement.

2. Workability

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. The desired workability depends on the compacting equipment available at the site.

3. Strength

The strength of concrete is resistant to aggressive environmental conditions. High-strength concrete usually lasts longer than low-strength concrete. In cases where high strength is not required but exposure conditions such as high durability are important, the stiffness requirement will determine the amount of cement that should be used.

4. Maximum integration size

Generally, the larger the size of the aggregate, the smaller the requirement for cement of a certain amount of water-cement, as the performance of concrete increases with the increase of the larger aggregate size. However, the compressive strength tends to increase with the decrease in aggregate size.

IS 456: 2000 and IS 1343: 1980 recommend that aggregate word size should be as large as possible.

5. Grading and aggregate type

Quantitative planning influences specific performance mix rates and water cement ratio. More and more grading leaner will be a mix that can be used. A very thin mixture is not desirable as it does not have enough material to make the concrete come together.

The type of aggregate greatly influences the aggregate-cement ratio to the desired performance and the set amount of water cement. An important feature of a satisfactory aggregate is the similarity of grading which can be achieved by mixing fractions of different sizes.

6. Quality Control

The level of control can be statistically measured by the variability of the test results. The variability in strength results in variations in the properties of the ingredients and the lack of precision control in mixing, mixing, setting, curing and testing. At lower the difference between the medium strength and the lower the minimum mixture will be the required cement content. The factor that controls this difference is called quality control.

4.1.4 Mix Proportion Design

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass.

4.1.5 Factors to consider in order to compose a combination

- A distance position that provides the required aspect of concrete strength.
- The type of cement affects the level of development of the concrete pressure.
- The maximum size measurement to be used for concrete may be as large as possible within the limits set by IS 456: 2000.
- The contents of the cement should be limited from shrinking, cracking and crawling.

The effectiveness of concrete in laying and assembling satisfactorily is related to the size and shape of the section, the quantity and the reinforcement spaces and the methods used for transporting, laying and assembling.

4.1.6 Procedure

1. The mean target strength is determined from the specified characteristic compressive strength at 28-day f_{ck} and the level of quality control.

   $f_t = f_{ck} + 1.65\ S$

   Where S is the standard deviation obtained from the Table 8 of IS 456-2000.

2. The amount of cement water of the target value is obtained using the operating relationship between the compressive power and the cement scale of the water. The selected water cement rating is assessed against the water cement rating which limits the stiffness requirements given in table 5 of IS 456-2000 depending on exposure conditions and locations.

3. Water content is selected for the required performance and large aggregate size (for aggregates in the dry zone full area) from table 2 of IS 10262-2009.
4. The content of the cement is calculated by the ratio of the water content to the ratio of the water cement and also considered by the minimum content of the cement from Table 5 of IS 4562000 with different exposure conditions. The limit of both values is considered.
5. The percentage of rough aggregate in total aggregation is determined on a concrete table using a crushed aggregate of wages.
6. Estimated volume for each unit volume of total volume is determined.

CHAPTER 5

EXPERIMENTAL PROGRAMME

5.1 General

Concrete is recognized as an excellent building material that can withstand heat. Fireproof concrete insulation material minimizes damage to concrete structures in the event of an accident. In most cases concrete stays the same and has only minor damage. Due to the low thermal conductivity of concrete at high temperatures, the penetration depth of fire damage is limited. But when the concrete is below high temperatures for a long time, the deterioration of the concrete occurs. Therefore, it is important to understand the strength and aging properties of concrete under high temperatures over a long period of time.

HPC use is increasing day by day due to its efficient structure, environmental friendliness and energy saving effects. The oil, gas, nuclear, and energy industries are among the largest users of HPC. In addition to the general fire hazard, this concrete exposed to high temperatures and long-term pressures in the industries listed above. Although concrete is generally believed to be an excellent fire-retardant material, many recent studies have shown significant damage or catastrophic failure at high temperatures, especially in high-strength concrete. Over the past decade there has been extensive research on the performance of Fire of Common Power Concrete and High-Power Concrete. However, many studies have focused on the types of bonding, fiber addition, temperature and temperature and testing methods. Very little research work is available on the comparative performance of composite concrete at high temperatures. Therefore, in the present study it is proposed to conduct an experimental study to study the behaviour of HPC-produced fenugreek at high temperatures.

The mixture can be defined as a chemical product, which is added to a concrete mixture at a rate not exceeding 5% by the weight of the cement. Added to the batch immediately before or during mixing for the purpose of achieving some modification or modification of common concrete structures. Mixtures may be organic or inanimate but their chemical character is an important factor. Certain organic compounds (mixtures) are used in concrete as active agents. A new compound called Fenugreek comes under this category used as working agents in a compound made up of different percentages of the mixture, and its effects are seen in improving concrete performance and simultaneous concrete behaviour during pressure testing. Nano admixture has also been used in conjunction with organic admixture. Nano Silica helps to gain long-term energy. This mixture needs to be mixed with cement first and then added to other concrete materials.

5.2 Property

5.2.1 Cement

Ordinary Portland Cement Ultra-tech 53 grade compliant with IS: 12269 was used. Cement properties are tested by laboratory testing.

- ✓ Compliance tests were performed according to IS 8112-1976 code and the accuracy was found to be 31% with a 6mm reading of the Vicat apparatus.
- ✓ The exact weight of the concrete is obtained at 3.15 and this test is performed according to the test procedure specified in code IS 269-1989
- ✓ Filter cement per filter is available at 6%
- ✓ The initial time to lay the cement is 32 minutes.
- ✓ The final cement time is 10 hours

5.2.2 Fine aggregate

Natural sand is used locally. Tests have been performed in the laboratory on sand structures.

- ✓ The unit of weight of the fine aggregate is 1.64 gm / cc
- ✓ Specific gravity of fine aggregate is 2.62
- ✓ Fineness modulus of fine aggregate is 2.516

5.2.3 Coarse aggregate

A combination of crushed stone was used. Laboratory tests are performed on concrete structures. The fig no.5.1 is showing the carse aggregate I and II.

- ✓ The unit weight of the solid aggregate is 1560 kg / $m3$
- ✓ Specific gravity of coarse aggregate is 2.61
- ✓ Fineness modulus of coarse aggregate is 7.11

5.3 Mix

It is proposed to use M20 level concrete and OPC component replacement with LC3.

The design of the mix is based on the recommendation of IS: 10262-2009.

5.4 Casting and Curing of test specimens

5.4.1 Batching

Batching is the process of weighing the ingredients of concrete needed for mixing. Usually, when designing a mix, the proportions of the various concrete ingredients are cut into one cum of concrete. In the mixing process, we initially charge a concrete volume that will be prepared for the extraction of cubes based on the volume of cubes obtained by a certain number of cubes. In this concrete roll, weights of cement, coarse and fine aggregates are calculated. Based on the amount of water and cement, the amount of water needed for mixing is also estimated. The weights of the mixtures, if any are found in the weight of the cement. The Fig no.5.2 and 5.3 are showing the materials after batching the process.

5.4.2 Mixing

Estimated aggregate values of rough aggregate and good collection are still distributed in other layers. Cement is poured over it and the contents are mixed dry with a shovel, turning the mixture over and over until a uniform consistency is obtained. Water is taken in the required quantity and sprinkled over the mixture and at the same time diluted. Work continues until fine concrete, uniform, and even concrete is obtained. Fig no. 5.4 and 5.5 are showing concrete mixer for mixing the concrete.

Fig no. 5.1 Coarse Aggregate I and II

Fig no. 5.2. Sand and Coarse Aggregate I

Fig no. 5.3.LC3 and Cement

Fig no. 5.4. Concrete Mixer

Fig no. 5.5. Mixing of concrete

5.4.3 Placing and compacting

The cubical moulds are cleaned, and all care was taken to avoid any irregular dimensions. The joints between the sections of mould were coated with mould oil. A similar coating of mould oil was applied between the contact surfaces of the bottom of the moulds. The base plate in order to ensure that no water escapes during the filling. The interior surfaces of the assembled moulds were thinly coated with mould oil to prevent adhesion of concrete and for easy removal of moulds after casting. The mix was placed in three layers; each layer was compacted using table vibrator to obtain dense concrete. Fig no. 5.6 is showing compaction of concrete in concrete mould.

Fig no. 5.6. Compaction of concrete

5.4.4 Casting

Conventional concrete cubes (0% LC3) and cubes with partial replacement of OPC with LC3 (10%, 15%, 25%, 30%) having size 150mm x 150mm x 150mm were casted and tested for compression test after 7- and 28-days curing. The casted cubes and beams are showing in the fig no. 5.7, 5.8 and 5.9.

Also, beams of size 100mm x 100mm x 600 mm were casted and are kept in curing and will be tested for flexure after 28 days.

5.4.5. Casting of Concrete Cubes and Beams

Fig no. 5.7- Photograph showing preparation of concrete cubes

Fig no. 5.8 - Photograph showing preparation of concrete beams

Fig no.5.9 Concrete Cubes and Beams

5.4.6 Curing

Experimental samples were stored locally, non-vibrating, 90% humid air and a temperature of 27 degrees +/- centigrade 24 hours from the time the water was added to the dry ingredients. After 24 hours the specimens were removed from the tank and immediately immersed in fresh, clean water for 28 days. The curing of the concrete cubes and beams are showing in fig no.5.10.

5.4.7 Test Program

Concrete cubes are inserted into the inner diameter 150 × 150 × 150 mm. All materials such as cement, fine aggregate, solid aggregate is well mixed by hand. In all experimental models, the mould was kept in a table vibrator and the concrete was poured into the moulds in three layers by stepping with a rod and vibration was done with a table vibrator and kept unchanged in all samples. As a control group 6 cubes for each grade M30 and M50 were prepared without admixture.

Fig no.5.10. Curing of concrete specimen

The mould was removed after 24 hours and all specimens were kept immersed in a fresh water tank. After treating the specimens in water for 28 days, the specimens were removed and allowed to dry in the shade. The models were tested for 28 days of compression strength using a digital compression test machine such as fig.6 and fig.7 Similarly the same process was repeated by adding 2%, 5% and 7% of Nano Silica by the weight of the concrete mixing M30 and M50. The percentages associated with the maximum compression strength of both M30 and M50 distances are noted. Then sample cubes were made by adding 0.3% and 0.35% fenugreek by weight of cement to the M30 and M50 respectively and the corresponding percentage of Nano Silica. These specimens were stored for 28 days of water treatment and were tested for the effect of acid, alkaline and seawater, on cubes after allowing the cubes to heal somewhere for 90 days. In addition to the above test's cubes are tested for freezing and thawing as well as water infiltration tests for specimens. The fig no.5.11 is showing the AIMIL Compression Testing Machine for testing the specimen.

Fig no.5.11. AIMIL Compression Testing Machine

5.5. Testing of Concrete Cubes

Conventional concrete cubes were tested for 7 and 28 days and cubes with partial replacement of cement with LC3 (10%, 15%,20%, 25%, 30%,40%50%,100%).

The Fig no.5.12- Photograph showing Compression Testing Machine and Testing of Concrete Cube

Fig no. 5.12- Compression Testing Machine and Testing of Concrete Cube

CHAPTER 6

EXPERIMENTAL OBSERVATION

6.1. Compression Test- After7Days curing

6.1.2 Replacement of cement with LC3

The cubes with partial replacement of OPC by 10%,15%,20%,25%,30%,50%,100% LC3 are tested after curing 7 days. The Table no. 6.1 to 6.9 are showing the results of concrete.

Table 6.1 Concrete with (0% LC3) Result

Conventional concrete	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.360	244.2	10.8
C2	8.095	370.6	16.4
C3	8.175	308.4	13.7
		Avg	13.63

Table 6.2 Concrete (10% LC3) Result

10% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.450	468.3	20.8
C2	8.455	389.2	17.2
C3	8.455	412.3	18.3
		AVG	18.77

Table 6.3 Concrete (15% LC3) Result

15% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.295	426.4	18.9
C2	8.255	406.4	18.0
C3	8.385	311.3	13.8
		AVG	16.90

Table 6.4 Concrete (20% LC3) Result

20% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.250	310	13.78
C2	8.490	300	13.33
C3	8.280	260	11.55
		AVG	12.89

Table 6.5 Concrete (25% LC3) Result

25% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.400	310.8	13.8
C2	8.430	318.2	14.1
C3	8.515	286.6	12.7
		AVG	13.53

Table 6.6 Concrete (30% LC3) Result

30% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.405	432.4	19.2
C2	8.340	447.1	19.8
C3	8.260	405.9	18.0
		AVG	19.0

Table 6.7 Concrete (40% LC3) Result

40% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.470	310	13.78
C2	8.240	310	13.78
C3	8.320	320	14.22
		AVG	13.92

Table 6.8 Concrete (50% LC3) Result

50% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.280	150	6.67
C2	8.190	170	7.55
C3	8.300	260	11.55
		AVG	8.6

Table 6.9 Concrete (100% LC3) Result

100% LC3	Weight (Kg)	Load (kN)	Stress (Mpa)
C1	8.195	140	6.22
C2	8.175	120	5.33
C3	8.180	130	5.77
		AVG	5.77

The 7 days testing was done on concrete cubes in which cement was partially replaced by Limestone Calcined Clay Cement (LC3) in by 10%,15%,20%,25%,30% 50% and 100% weight to find out the behaviour of LC3 compound and the optimum replacement percentage in which the desired outcome is achieved.

The results of 7 days testing by replacing 10%,15%,20%,25%,30%,50% and 100% cement by LC3 are shown above.

6.2. Compression Test- After 28 Days curing

6.2.2 Replacement of cement with LC3

Concrete cubes with partial replacement of OPC by 10%,15%,20%,25%,30%, 50% and 100% LC3 are tested after curing 28 days. The Table no. 6.10 to 6.18 are showing the results of concrete.

Table 6.10 Concrete with (0% LC3) Result

Conventional concrete	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.195	460.575	20.47
C2	8.205	447.75	19.9
C3	8.245	488.25	21.7
		Avg	20.69

Table 6.11 Concrete with (10% LC3) Result

10% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.315	633.4	28.2
C2	8.290	763.8	33.9
C3	8.300	699.3	31.08
		Avg	31.06

Table 6.12 Concrete with (15% LC3) Result

15% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.380	664.4	29.5
C2	8.240	716.5	31.8
C3	8.390	552.7	24.6
		Avg	28.63

Table 6.13 Concrete with (20% LC3) Result

20% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.44	350	15.55
C2	8.290	350	15.55
C3	8.310	340	15.11
		Avg	15.40

Table 6.14 Concrete with (25% LC3) Result

25% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.455	457.9	20.4
C2	8.355	561.6	25.0
C3	8.220	533	23.7
		Avg	23.03

Table 6.15 Concrete with (30% LC3) Result

30% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.332	703.7	31.3
C2	8.270	744.2	33.1
C3	8.301	726.75	32.3
		Avg	32.23

Table 6.16 Concrete with (40% LC3) Result

40% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.33	360	16
C2	8.45	370	16.44
C3	8.360	350	15.55
		Avg	15.99

Table 6.17 Concrete with (50% LC3) Result

50% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.350	270	12
C2	8.530	250	11.36
C3	7.950	160	7.11
		Avg	10.15

Table 6.18 Concrete with (100% LC3) Result

100% lc3	Weight (kg)	Load (kN)	Stress (Mpa)
C1	8.180	200	8.88
C2	8.190	160	7.11
C3	8.170	150	7.55
		Avg	7.84

The 28 days testing was done on concrete cubes in which cement was partially replaced by Limestone Calcined Clay Cement (LC3) in by 10%,15%,20%,25%,30% 50% and 100% weight to find out the behaviour of LC3 compound and the optimum replacement percentage in which the desired outcome is achieved.

The results of 28 days testing by replacing 10%,15%,20%,25%,30%,50% and 100% cement by LC3 are shown above.

6.3 Comparison of Results

- **Compression Test**

The results of compressive strength for 7 days and 28 days are compared and compiled below in Table no.6.19. Also, the Fig no. 6.1 is showing the Compression test analysis. Compression tests are used to determine the material behaviour under a load. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined.

Compression testing is often done to a break (rupture) or to a limit. When the test is performed to a break, break detection can be defined depending on the type of material being tested. When the test is performed to a limit, either a load limit or deflection limit is used.

Table 6.19- Average results of compressive strength after 7- and 28-days curing

LC3 Percentage	7 Days Stress (MPA)	28 Days Stress (MPA)
0%	13.63	20.69
10%	18.77	31.06
15%	16.9	28.63
20%	12.89	15.40
25%	13.53	23.03
30%	19.00	32.23
40%	13.92	15.99
50%	8.60	10.15
100%	5.77	7.84

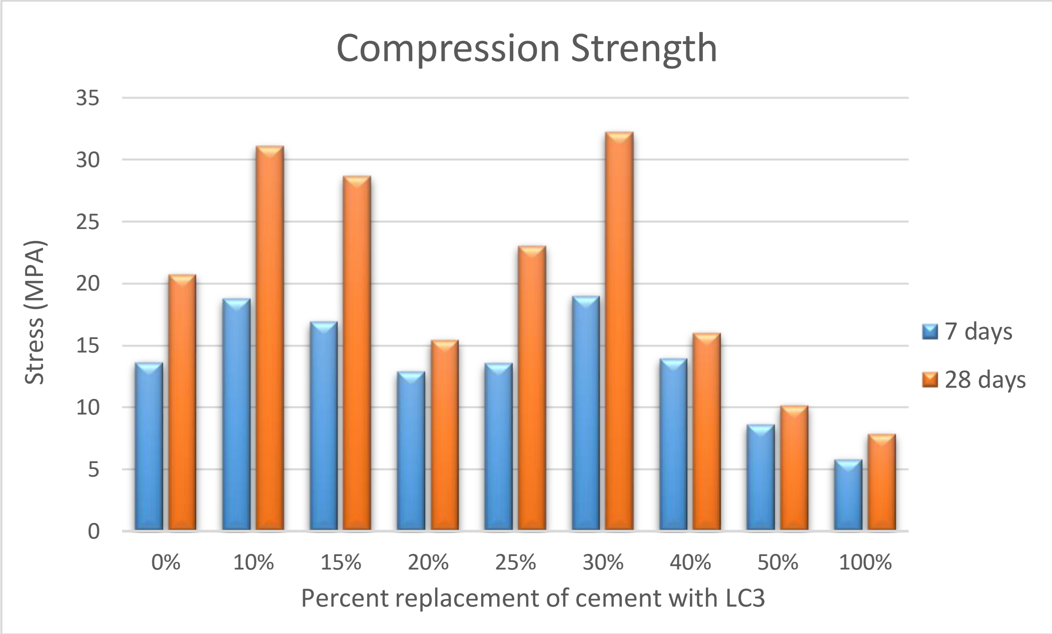


Fig no.6.1 Compression Strength Result

- **Flexural Test**

Flexural testing measures the force required to bend a beam of plastic material and determines the resistance to flexing or stiffness of a material. Flex modulus is indicative of how much the material can flex before permanent deformation. Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending.

The table no. 6.20 and Fig no. 6.2 are showing the Flexural Strength of beams.

Table 6.20 Average flexural strength (beam)

LC3 Percentage	28 Days Stress (MPA)
0%	3.92
10%	4.25
15%	4.88
20%	4.55
25%	5.84
30%	5.08
40%	6.54
50%	5.20
100%	3.06

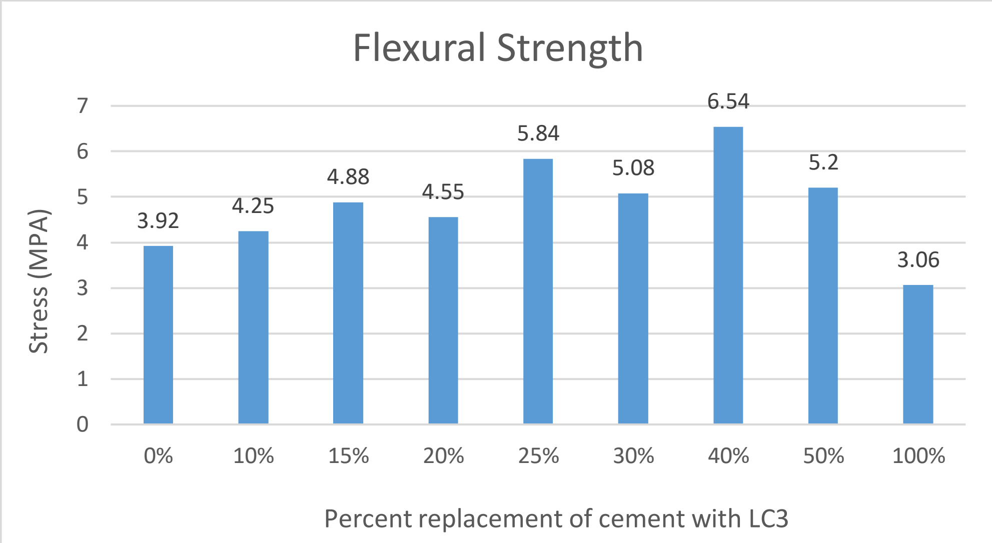


Fig no.6.2 Flexural Strength Result

- **Split Tensile Test**

The split tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. The concrete is not usually expected to resist the direct tension due to its low tensile strength and brittle nature. However, the determination of split tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The split tensile strength results of all the samples were approximately 10% of the compressive strength.
The table no. 6.21 and Fig no. 6.2 are showing split tensile strength of cylinder.

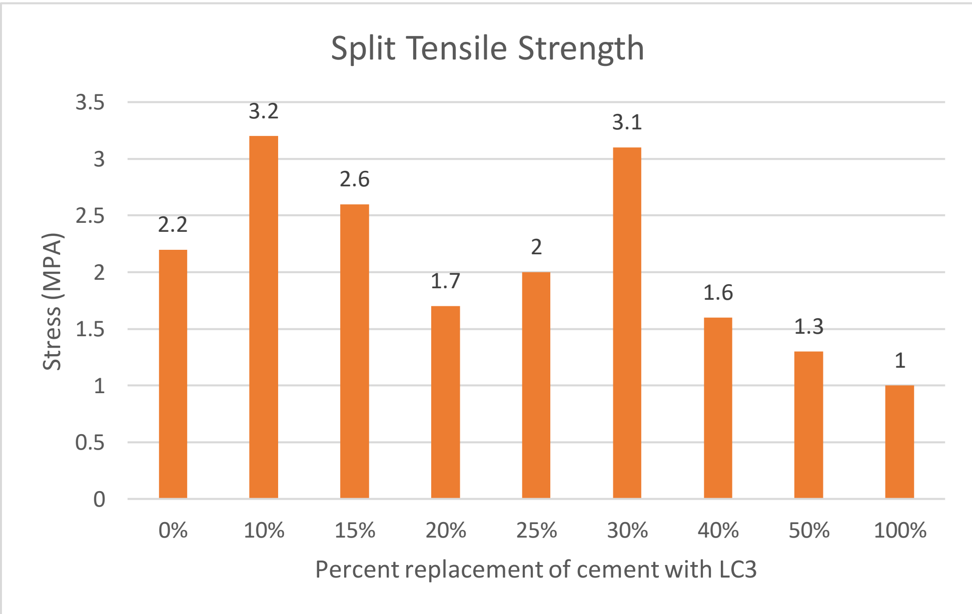


Fig no.6.3 Split Tensile Strength Result

Table 6.21 Average split tensile (cylinder)

LC3 Percentage	28 Days Stress (MPA)
0%	2.2
10%	3.2
15%	2.6
20%	1.7
25%	2.0
30%	3.1
40%	1.6
50%	1.3
100%	1.0

- Strength of concrete using LC3 is found to be increased after curing of 7 days.
- Optimum results are achieved by replacing OPC by LC3 and it is observed from results that when OPC is replaced by 10% and 30% with LC3 the compressive strength of concrete is improved to about 19 MPa.
- Also, when OPC is replaced with LC3 by 15% and 25% the stress is improved to about 13.5 to 17 MPa.

6.4. Advantages of using LC3

- When OPC was replaced partially by LC3, the 28 days strength was found to be improved.
- LC3 Concrete is made by just replacing the cement with LC3 and no other significant modifications are required.

CONCLUSION

By comparing the results, it can be concluded that replacement of cement with LC3 by 10% and 30% gave the results 27.38% and 28.26% respectively in all the three-test performed as compared to conventional concrete.

It was observed that, replacing cement with 10% and 30% LC3 gives compression strength 27.38% and 28.26% respectively more at 7 days. Also, 33.4% and 35.6% respectively more at 28 days compared to conventional concrete

By replacing cement with 10% and 30% LC3 flexure strength increased by 7.76% and 22.83% respectively over conventional concrete at 28 days strength.

Also, partial replacement of cement with 15%,20%,25%,40%,50% LC3 have shown higher flexural strength over conventional concrete mix with 0% LC3.

Split tensile test of 10% and 30% was 31.35% and 29.33% respectively more than conventional concrete mix after 28 days.

LC3 saves up to 40% of CO2 as compared to Ordinary Portland Cement. LC3 can be a green alternative for users.

Different scenarios of producing LC3 were analysed financially in a study by the cement market experts Cementous. Their results showed that with a cement plant, grinding plant or Greenfield scenario the production of LC3 is profitable.

Overall, the production cost can be up to 25% lower for LC3 than for OPC due to savings for energy and material.

Among other contributions, LC3-Low Carbon Cement can be directly associated with 5 of the 17 Sustainable Development Goals: •Industry, Innovation and Infrastructure

•Sustainable cities and communities

•Responsible consumption and production

•Climate Action

•Partnership for the goals

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