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Optimization of Rice Husk Ash and Eggshell Powder to Enhance Mechanical and Dynamic Properties of Cellular Lightweight Concrete

by

Mubbashir Shafique

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I want to dedicate this research work to my family including my father, mother, brothers, and sisters. They helped me throughout my educational career and motivated me to face all the difficulties and challenges of life with courage and patience, which enabled me to successfully complete my educational career to this level.

CERTIFICATE OF APPROVAL

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Abstract

The construction of high-rise structures mostly involved the foundation, columns, beams, slabs and partition walls as important components. Among all these, partition walls are non-load-bearing components that can be modified as per modern-day requirements to be replaced with new concrete technologies due to certain drawbacks associated with conventional concrete to be used in nonstructural element like blocks of partition walls. Concrete drawbacks like high dead load, low heat insulation, less fire resistance and soundproofing and other non-sustainability issues associated with the huge quantity of construction material utilization in the nonstructural elements. On the other hand, due to the expansion of the construction industry, there is a drastic increase in the production of cement which is the most important constituent of the construction industry. From an economic and environmental perspective, cement production is very expensive and has a devastating impact on the environment. To overcome these issues cellular lightweight concrete is produced with the help of lightweight pumice aggregate, rice husk ash, and eggshell powder to make the structure having less dead load and are more sustainable and eco-friendly. The overall goal of this study is to utilize agricultural and organic waste materials to produce sustainable and environmental friendly cellular lightweight concrete for blocks. The specific aim of this research work is to improve the structural and dynamic properties of the cellular lightweight of concrete by partial replacement of cement and by utilization of agro-organic waste materials.

In this research work the utilization of pumice stone and foaming agent along with rice husk ash and eggshell powder enables us to produce cellular lightweight with a very low density ranging from 800 kg/m^3 to 950 kg/m^3. Eight different types of mix designs are cast having three cubes and three beamlets of each mix design namely CLC, RHAC15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5-ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC15 to replace cement content of cellular lightweight concrete up-to 15% maximum ratio. A combination of rice husk ash and eggshell powder is utilized to prepare this CLC for non-structural elements of the buildings. The foaming agent in a ratio of 1:19 of water and water to cement ratio (W/C) of 0.60 is adopted in a mix design of 1:2:3 of (cement: sand: pumice aggregate). The slump, harden density, linear shrinkage (Ls), water absorption (WA), mechanical and dynamic test are performed to check the different properties of cellular light weight concrete.

The slump test shows that the cellular concrete has very high slump value due to the presence of foam and high water to cement ratio that make its workability very high and due to presence of foam in this concrete a remarkable reduction in the harden density of concrete is observed along with the reduction of compressive and flexural properties of this cellular light weight concrete. The cellular concrete mix RHAC15 shows the least amount of compressive strength on the other hand RHAC12.5-ESC2.5 shows the highest amount of compressive strength due to the combined effect of both rice husk ash and eggshell powder. On the other hand for the flexural strength test, RHAC15 shows the minimum amount of flexural strength and RHAC7.5-ESC7.5 shows the highest value of flexural strength. The dynamic properties that are measured with the combination of hammer and accelerometer show that RHAC15 has minimum values of dynamic properties and contrary to this RHAC12.5-ESC2.5 shows the highest values of dynamic properties. As the cellular lightweight concrete produced from this research work possesses low density and hence lower mechanical and dynamic properties, therefore, it is recommended to use this CLC in non-structural elements of structure to reduce its dead load. The concrete that is produced in this research work is called CLC because it has pours inside and contains porous pumice as coarse aggregate in its structure. On the other hand, if this concrete is made up of only fine aggregates and pours then it will be called foam concrete.

Keywords: Agricultural Waste, Organic Waste, Cellular Lightweight Concrete, Eggshell Powder, Rice Husk Ash, Pumice Stone, Foaming agent.

Contents

List of Figures

List of Tables

Abbreviations and Symbols

ACI	American Concrete Institute
CLC	Cellular Light weight Concrete
CSH	Calcium Silicate Hydrate
CC	Conventional concrete
CE1	Compressive Energy before Crack
CE2	Compressive Energy after Crack
CTE	Total Compressive Energy
CTI	Compressive Toughness Index
EPS	Expanded Polystyrene
FE1	Flexural Energy before Crack
FE2	Flexural Energy after Crack
FTE	Flexural Total Energy
FTI	Flexural Toughness Index
ITZ	Interfacial Transition Zone
LEED	Leadership in Energy and Environmental Design
LFC	Light Foam Concrete
MOR	Modulus of Rupture
OPC	Ordinary Portland cement
POFA	Palm Oil Fuel Ash
PC	Plain Concrete
TS	Tensile Strength
TI	Toughness Index

Chapter 1

Introduction

1.1 Background

The foundations, columns, beams, partitions walls, and slabs are a few of the parts that make up a building. Among all these components, building walls are the most crucial component. Clay bricks are the main component of walls used to construct urban infrastructure in underdeveloped nations [1]. The requirement for lightweight concrete blocks stimulates the development of new block manufacturing techniques, among them the Cellular Lightweight Concrete (CLC) block is quite a new and remarkable technique. Sand, cement, water, and foam are the main ingredients in CLC blocks. There are many cavities in the CLC mortar's mixing design that reduce the strength of the bonds between molecules. As a result, CLC needs additional chemicals to make the molecular bonds stronger. He worked on CLC and explained Because CLC blocks are less dense than traditional clay bricks; engineers have utilized them to construct walls. Building loads may be decreased with the usage of CLC blocks. Thermal insulation, sound absorption, low cement and aggregate content, low density, and CLC are lighter than regular concrete. The CLC blocks offer the benefit of speeding up the construction of walls. Cellular lightweight concrete (CLC) is usually made up of cement, porous coarse aggregate, and porous internal structure that is created with a foam generator during the manufacturing of CLC [2]. On the other hand, foamed cellular lightweight concrete (FCLC) is a blend of portland cement with fine aggregate as a paste or mortar and is a cutting-edge building material. The air spaces are produced during the mixing procedure used to manufacture FCLC, which has a uniform cellular structure. There is a wonderful opportunity to further improve the sustainability and economic viability of this material because the FCLC offers a lightweight material with exceptional acoustic and heat insulation properties [3]. There is always a need to reduce the dead weight of buildings. To reduce dead weight we need to reduce the density of less important members. A flexible material, lightweight concrete ranges in density from 300 kg/m^3 to 1850 kg/m^3. Due to its versatility and lightness, lightweight foamed concrete, also known as aerated concrete, has introduced a different application of affordable building material for construction technology [4]. The fast development of civil engineering construction has increased the need for cement products. Cement, aggregates, and water are the three crucial elements of cementitious materials. Cement production uses a lot of energy and emits a lot of carbon dioxide into the atmosphere. Natural aggregate extraction also requires a lot of energy and results in higher CO2 emissions. Increased cementitious material use harms the environment and accelerates the loss of natural resources as a result [5].

Eggshells, the durable external shell of the egg, is an illustration of this type of agricultural waste. 10% of the weight of the egg is made up of chambers within the eggshell. The world's rapidly expanding egg business is projected to produce about 8 million tons of eggshell garbage every year. A substantial amount of eggshells are still thrown away despite the fact that they can be utilized for various things, mainly the production of calcium phosphate ceramics, as a source of bio diesel, as an adsorbent to remove ionic contaminants, and as fertilizer. Calcium carbonate (CaCO3), which is necessary for the development of the binder gel (calcium-silicate-hydrate [C-S-H]) in cement products, is abundant in eggshells [6]. Rice husk ash (RHA) is renowned for its pozzolanic properties, which stem from its amorphous silica content, specific surface area, and particle fineness. These characteristics can be further improved through processes like burning and grinding, making RHA a valuable additive in concrete. The microstructure of RHA particles often exhibits porous surfaces, non-uniform distribution, and distinct features.

When incorporated with cement, RHA plays a significant role in enhancing the fresh properties of concrete, including workability, consistency, and setting time. The presence of amorphous silica also leads to increased compressive, tensile, and flexural strength in concrete as the concentration of RHA rises to a certain threshold. Moreover, the utilization of RHA contributes to improved durability in concrete, as evidenced by enhanced traits such as reduced water absorption, increased chloride resistance, corrosion resistance, and sulphate resistance. RHA can effectively replace up to 10% to 20% of cement without compromising the quality of the concrete, thanks to its substantial pozzolanic characteristics. Overall, the use of RHA as a partial cement replacement in concrete offers the dual benefits of agricultural waste management and resource conservation, fostering a more sustainable and environmentally friendly approach within the construction industry [7].

To produce cellular lightweight concrete (CLC), the process involves using either a ready mix plant or a standard concrete mixer to blend specific quantities of cement, fly ash, water, and foam. Specialized equipment introduces a defined volume of air into the foam at a consistent pressure while it is being pumped. This results in the creation of millions of isolated, small air bubbles formed through protein hydrolysis. Unlike other foam generation methods, there is no chemical reaction that releases gas, so the foam does not expand and retains its density. CLC technology has been recognized for its sustainability benefits, as evidenced by environmental impact assessments conducted by LEED (Leadership in Energy and Environmental Design), a prominent green building certification organization in the United States. CLC production entails minimal direct CO2 emissions and utilizes waste by-products, such as fly ash from other industries, which, when applied in the right proportion, can enhance compressive strength.

Furthermore, CLC serves as an eco-friendly alternative to traditional red clay burnt bricks, as it generates no pollutants during the manufacturing process. In contrast, the production of burnt clay bricks typically requires the use of topsoil as a raw material and substantial amounts of firewood for direct thermal demand,approximately 50 tons for every 100,000 bricks. In addition to these environmental advantages, CLC offers features such as increased strength, reduced dead load, and improved thermal insulation [8]. Eggshells (ES), considered a bio-waste product, are typically sourced from bakeries and fast-food restaurants. Traditionally, this waste is disposed of in landfills, presenting both public health concerns and environmental hazards. A sustainable approach involves combining eggshell powder (ESP), rich in calcium content, with pozzolanic materials like fly ash, which are low in calcium. One of the prominent challenges in promoting environmental cleanliness is the management of egg waste, particularly the substantial quantity of eggshells generated. However, the efficient utilization of eggshells presents an opportunity to contribute to eco-friendly construction practices [9].

1.2 Research Motivation and Problem Statement

In present-day construction partitioning walls made up of conventional concrete blocks cause the huge dead weight of buildings due to their high density. To reduce this high density there is a need for the usage of lightweight concrete blocks that cause a huge reduction in the dead load of the building. We need to use lightweight materials like porous pumice as coarse aggregate along with a foaming agent to produce pours inside the structure of cellular lightweight concrete to reduce the density and increase the volume of concrete. In this research work, cement is partially replaced with agricultural and organic waste materials. These waste materials can be organic waste like "eggshells" and agricultural waste like "Rice husks". The abundance of Rice husk produced by the agriculture industry can be consumed in the form of ash to improve the mechanical and dynamic properties of cellular lightweight concrete. The combined effect of eggshell powder and rice husk ash is completely unknown. With the progress of the construction industry, conventional concrete needs to be replaced with lightweight concrete to improve the quality of structures and reduce the dead weight of the building.

Non-structural elements of buildings like blocks of partition walls made up of conventional concrete possess high density due to the presence of coarse aggregate and *due to densely packed particles of concrete. This high density of non-structural elements of the building makes it less suitable, to be used in high-rise buildings. To decrease the density of concrete, we need to use porous pumice as coarse aggregate and the foaming agent to create pours in the structure of cellular lightweight concrete that can be used in partitioning walls to reduce the dead load of high-rise buildings.*

1.2.1 Research Questions

- What are the limitations that need to be kept in mind while preparation of cellular lightweight concrete?
- What would be the combined effect of eggshell powder and rice husk ash on the mechanical properties of cellular lightweight concrete?
- What would be the combined effect of eggshell powder and rice husk ash on the dynamic properties of cellular lightweight concrete?
- How cellular lightweight concrete prepared with rice husk ash and eggshell powder can be used in real-life applications?

1.3 Overall Objective of the Research Program and Specific Aim of this MS Thesis

The objective of this research work is to produce cellular lightweight concrete for non-structural members of buildings having a density of $800kg/m^3$ to $900kg/m^3$ with the help of pumice aggregate, foaming agent, and partial replacement of cement with agricultural waste and organic waste namely rice husk ash and eggshell powder, to reduce the density of cellular lightweight concrete. Due to the reduced density of CLC that is produced in this research work, compressive strength of CLC will be lower as compared to conventional concrete due to its porous structure.

The specific aim is to produce cellular lightweight concrete to be used in non-structural parts of structures, with the help of pumice aggregate along with rice husk ash and *eggshell powder in different percentages ranging from 0 to 15 percent to partially replace cement content and to produce environment-friendly concrete. Then study the effect of these materials on the mechanical and dynamic properties of concrete.*

1.4 Scope of Work and Study Limitations

The scope of work is to identify the problem with conventional concrete that has a very high density and the associated problems with the manufacturing of cement, which is the main constituent of concrete and has devastating effects on the environment. Cellular lightweight concrete is produced to overcome the density issues associated with conventional concrete, along with the use of agricultural and organic waste materials, namely rice husk ash and eggshell powder respectively. The cellular lightweight concrete that is to be prepared through this research work will only be tested for fresh state, non-destructive and destructive testing. Insulation and fire-resistant testing is not part of this research work. ACI standard 211.2-98 is used to follow procedures for choosing and modifying the mixture proportions for lightweight concrete that are usually applicable. These techniques are also applicable to concretes made up of a mix of light and heavy aggregate [10]. Non-structural elements of buildings like partitioning walls contribute up to 35% in case of seismic loading. Therefore, keeping in view the importance of non-structural members of the structure; Mechanical and dynamic testing of cellular light weight concrete is to be used as non-structural members of structures, is preferred here in this research work.

The mix design selected for the preparation of this concrete is 1:2:3 with a 0.60 w/b ratio and superplasticizer 1.5% by weight of cement. Eggshell powder and rice husk ash are used as partial replacements for cement to manufacture cellular lightweight concrete. Cubes having measurement (152 mm x 152 mm) are prepared for water absorption, mass loss, densities, and compressive strength tests. For flexural strength, prisms of 102 mm by 102 mm by 457 mm are prepared there is only cube and prism testing in this research work for destructive testing. Mix design includes CLC, RHAC15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12 and ESC15. For each mix, an average of three samples will be used for flexural testing and three samples for compressive testing. All samples must be cured for 28 days. Curing is carried out in a water tank at the ambient temperature. For optimal use in concrete, eggshell and rice husk ash need to be processed. This experimental effort includes the study of mechanical properties, fresh and hardened concrete properties. The rice husk is obtained from the farms of Punjab and eggshells are obtained from restaurants. Table 1.1 lists the names of the tests, the batching ratio, the size, and the composition of the mixes.

1.5 Novelty of Work, Research Significance and Practical Implementation

The use of rice husk ash and eggshell powder in cellular lightweight concrete (CLC) is a quite new domain of research and there is still a need to learn about the performance and mechanical/dynamic properties of CLC. Sustainable building is an emerging trend in the building industry that tries to lessen the harm that the industry causes to the environment, including global warming, environmental deterioration, and resource depletion [14]. One of the largest industries in the world is the construction industry because it serves as the foundation for all other fields. The necessity for sustainable construction has increased in the modern era. Buildings, roads, and dams must be constructed to support the growing population. Sand, aggregates and cement are the three main materials utilised in the construction industry. Too many problems are being caused worldwide by continued use of natural products.Consequently, researchers have increasingly focused on finding practical applications for waste materials. Utilizing waste products, such as industrial and agricultural by-products like fly ash and rice husk ash along with pumice aggregate, is gaining prominence due to their ability to enhance the properties of blended cement concrete while also reducing costs and mitigating negative environmental impacts [16]

Table 1.1: Scope of Work

Sample	Mix Design for Casting							
Description	**CLC**	**RHAC-15**	**RHAC12.5-ESC2.5**	**RHAC10-ESC5**	**RHAC7.5-ESC7.5**	**RHAC5-ESC10**	**RHAC2.5-ESC12.5**	**ESC-15**
	Cement 100%	Cement 85%	Cement 85%	Cement 85%	Cement 85%	Cement 85%	Cement 85%	Cement 85%
	Rice husk ash 0%	Rice husk ash 15%	Rice husk ash 12.5%	Rice husk ash 10%	Rice husk ash 7.5%	Rice husk ash 5%	Rice husk ash 2.5%	Rice husk ash 0%
	Eggshell powder 0%	Eggshell powder 0%	Eggshell powder 2.5%	Eggshell powder 5%	Eggshell powder 7.5%	Eggshell powder 10%	Eggshell powder 12.5%	Eggshell powder 15%
Cubes 24	Cubes 3	Cubes 3	Cubes 3	Cubes 3	Cubes 3	Cubes 3	Cubes 3	Cubes 3
Beamlets 24	Beamlets 3	Beamlets 3	Beamlets 3	Beamlets 3	Beamlets 3	Beamlets 3	Beamlets 3	Beamlets 3
Cubes	w/c 0.60							
L = 152mm	Batching Ratio 1:2:3							
W= 152mm								
	Water Absorption, Mass Loss							
Beams								
	Compressive Strength, CE1, CE2, CTE and CTI							
W & H = 102mm								
L = 204mm	Fluxural Strength, FE1, FE2, FTE and FTI							

It's worth noting that even though different batches of rice husk ash may have varying levels of fineness, their chemical composition remains relatively consistent. Fine rice husk ash, when compared to its coarser counterpart, has been found to enhance mortar strength and reduce the water-to-binder ratio (W/B). Therefore, improving the fineness of rice husk ash holds promise for its development as a valuable pozzolanic material [17]. Furthermore, by substituting up to 15% of cement with eggshell powder and rice husk ash, we can contribute to environmental improvements by reducing carbon dioxide emissions during the production of ordinary Portland cement. Additionally, the use of these agricultural and organic waste materials, in combination with pumice stone and forming agents, enables the production of lightweight concrete, which can help reduce the dead weight of buildings and structures."

1.6 Brief Methodology

In this research, the use of eggshell powder and rise husk ash is studied along with the use of pumice stone as the coarse aggregate that is porous in nature; furthermore, adverse environmental effects for the manufacturing of cement are also analyzed. All types of samples are prepared by the partial replacement of cement with rice husk ash or eggshell powder or either the combination of both RHA and ESP up to a maximum of 15% to promote sustainability in the construction industry. Then destructive and non-destructive testing of samples are conducted. The best mix out of all the mixes is recommended for future research and real-life implementation. The method that is followed to carry out this research work is shown in Figure 1.1.

1.7 Thesis Outline

This thesis is divided into six chapters and the research work of this thesis is divided into two main parts namely optimization of rice husk ash and eggshell

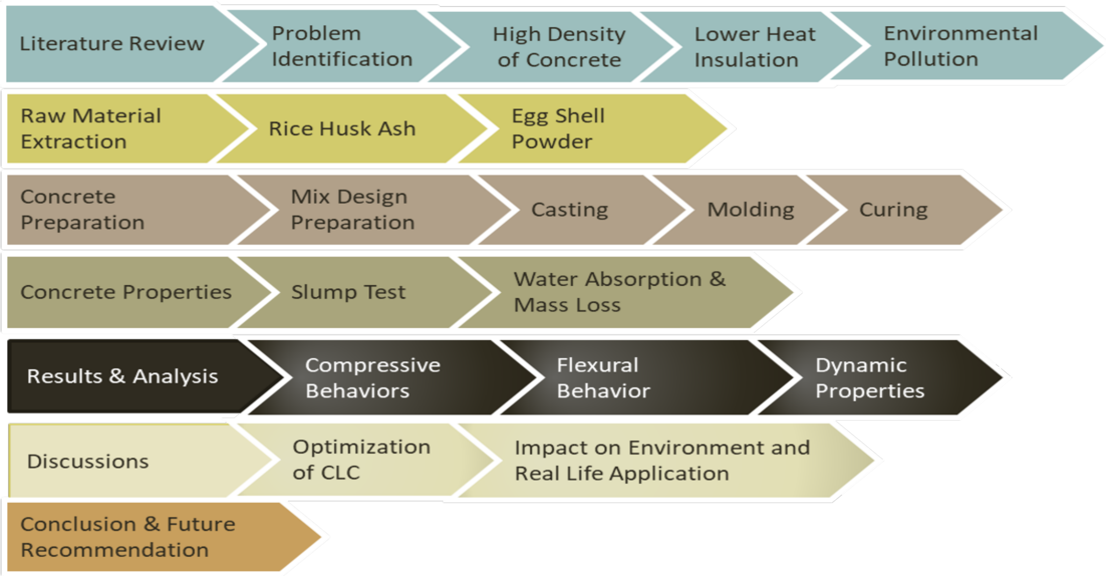

FIGURE 1.1: Brief Methodology

powder and their concrete mixes followed by the second part that is structural and dynamic performance of these mix designs:

Chapter 1 comprises on introduction, research motivation, problem statement, overall objective, specific aim, research methodology and thesis outline.

Chapter 2 this chapter contains an examination of concrete defects, like high density and dead weight of concrete, and environmental issues associated with the manufacturing of the cement industry. When taking into account various studies, it is also suggested that waste materials like eggshell powder and rice husk ash can be added as cement replacement along with the lightweight coarse aggregate to produce cellular lightweight concrete that ultimately reduces environmental pollution and improves the mechanical and dynamic properties of cellular lightweight concrete.

Chapter 3 consists of the experimental methodology that is adopted to complete this research. The background, materials used and optimization process of mix design, the procedure of casting of mixes and parameters to be followed to optimize the mix design are discussed in this chapter.

Chapter 4 In this chapter results and analysis of mechanical and dynamic properties are discussed in in detail.

Chapter 5 this chapter discusses optimization of mix design and their practical implementation.

Chapter 6 this chapter comprises on conclusion and future recommendations.

At the end, references are provided.

Chapter 2

Literature Review

2.1 Background

Light Weight Concrete (LWC), which has intrinsic qualities like design flexibility and low cost, has become highly popular in recent years and it's performance in diverse applications has been the subject of numerous studies in the field of LWC. [21]. Recent years have seen a tremendous rise in the use of lightweight concrete, which has some advantages over regular concrete. In terms of strength, density, and other mechanical and physical qualities, lightweight concrete has been the subject of much research into its potential applications. By carefully choosing the admixtures and grading the lightweight aggregate, the desired quality for lightweight concrete can be achieved [22]. The most important binder used in building is ordinary Portland cement. In combination with sand, it makes mortar for the preparation of concrete and mortar for masonry. From an economic and environmental perspective, cement production is expensive and cause environmental pollution. The remedial measure that can be adopted to reduce the environmental pollution issue is to use agricultural and organic waste material in combining with cement as partial replacement of cement. They are also cost and energy-effective. Utilizing ESP can increase the cementitious materials' compressive strength while also having a favorable impact on costs and the environment. The following building supplies can be made with less cement by using eggshell powder instead [23].

Numerous researchers have conducted studies to explore the potential of waste materials as viable substitutes for cement in concrete production. In addition to their various advantages, waste materials have proven effective in replacing cement due to their chemical and physical properties that positively impact concrete performance. These properties encompass factors such as compressive strength, flexural strength, tensile strength, and the long-term durability of test results. Furthermore, waste materials have exhibited notable pozzolanic characteristics, rendering them a favorable choice as alternatives to cement. A salient feature of a high-quality pozzolanic material is its capacity to engage in chemical reactions with calcium hydroxide during the hydration process of Portland cement at ambient room temperature [41].

2.2 Certain Flaws in Concrete and Their Remedial Measures

It's important to note that the choice between conventional concrete and cellular lightweight concrete depends on the specific project requirements, including load-bearing capacity, insulation needs, budget constraints, and environmental considerations. In many cases, a combination of both materials may be used to optimize performance and cost-effectiveness. Lightweight foamed concrete (LFC) consists primarily of ordinary Portland cement (OPC), fine aggregate, water, and artificially generated pore structures through the incorporation of foam. The addition of a foaming agent to cement mortar results in the creation of artificial air bubbles, differentiating lightweight concrete from conventional concrete [1]. Keeping in view the usage and properties of conventional and cellular lightweight concrete, certain flaws are associated with conventional concrete.

To remove these flaws of concrete that is to be used in non-structural elements of buildings, cellular lightweight concrete for blocks is produced as non-structural members of buildings having a density of 800 kg/m^3 to 900 kg/m^3 with the help of pumice aggregate, foaming agent, and partial replacement of cement with agricultural waste and organic waste, namely, rice husk ash and eggshell powder, to reduce the density of cellular lightweight concrete. Due to the reduced density of CLC that is produced in this research work, the compressive strength of CLC will be lower as compared to conventional concrete due to its porous internal structure.

2.2.1 High Density and Dead Weight of Concrete

Conventional concrete is notably denser than cellular lightweight concrete (CLC), resulting in a higher weight that may limit its suitability for specific applications. This weight concern becomes significant in scenarios such as lightweight construction projects or when building in areas with weak soil or substrata. Foam concrete, a type of lightweight concrete, falls under this category and consists of a cement paste or mortar infused with air voids through the use of a suitable foaming agent. Foam concrete exhibits several key characteristics, including high fluidity, reduced weight, decreased aggregate consumption, controlled low strength, and exceptional thermal insulation properties. By carefully controlling the dosage of foam, foam concrete can be produced across a wide density range, spanning from 1600 to 400 kg/m^3, making it suitable for a diverse range of applications, including non-structural, partitioning, insulation, and filling purposes. Interestingly, the concept of foam concrete was originally patented in 1923 [68].

The inherent qualities of lightweight concrete (LWC) offer a broad spectrum of potential applications in non-structural components of structures. LWC typically possesses a density ranging from 1400 kg/m^3 to 2000 kg/m^3, whereas standard or normal-weight concrete registers a higher density of 2400 kg/m^3. This density disparity makes lightweight concrete particularly valuable for reducing the dead load of structures and buildings. Lightweight materials can be employed as either coarse aggregates or fine aggregates in concrete mixtures to create LWC. In the construction of multi-story buildings, where the dead weight of non-structural components can become a significant factor, the adoption of lightweight components becomes crucial. This approach requires careful consideration to effectively reduce the dead weight of buildings, thereby enhancing the cost-effectiveness and overall economic viability of the structures [21]."

2.2.2 Lower Heat Insulation, Fire Resistance and Sound Proofing

Conventional concrete has poor insulation properties as compared to cellular lightweight concrete. CLC contains a significant number of air bubbles, which act as insulators, providing better thermal insulation. This makes CLC more energy-efficient in applications where insulation is critical. While foam concrete was originally conceived as a material for filling voids and providing insulation, there has been a resurgence of interest in its properties due to its reduced weight, material cost savings, and the possibility of utilizing waste materials such as fly ash on a larger scale [20]. At elevated temperatures, the heat transfer within porous materials is affected by radiation, which inversely correlates with the number of air-solid interfaces encountered. Consequently, due to its reduced thermal conductivity and diffusivity, foam concrete may exhibit improved fire resistance characteristics [69].

Fire resistance tests conducted on various foam concrete densities revealed an improvement in fire endurance as density decreased. In the case of lower-density foam concrete, there was a relatively smaller proportional loss of strength compared to regular concrete [70]. Additionally, lower-density foam concrete exhibited superior fire resistance when compared to vermiculite concrete, but this trend was reported to reverse with higher densities [71]. The impact of cement composition on foam concrete behavior at elevated temperatures is noted, and determined that foam concrete containing hydraulic cement with an Al2O3/CaO ratio exceeding two demonstrates the ability to withstand [2]. Elango et al., (2021) describe the comparative study of conventional and cellular lightweight concrete. As per this study, the oven-dry density of conventional concrete is 2100 kg/m^3 to 2500 kg/m^3, whereas the density of cellular lightweight concrete is 300 kg/m^3 to 2000 kg/m^3 [21].Elango et al., (2021) described the cube strength of cellular lightweight concrete as 1-60 MPa" Table 2.1 shows the comparative study of conventional and cellular lightweight concrete with respect to density, compressive strength, and thermal conductivity.

Table 2.1: Comparative study of conventional and cellular lightweight concrete properties [21],[70],[71]

Study Parameter	Property Results Range	
	Cellular light weight concrete	Conventional Concrete
Oven Dry Density	300-2000 kg/m^3	2100–2500 kg/m^3
Cube Strength	1 – 60 MPa	15–100 MPa
Thermal Conductivity	0.2–1.0 W/mK	1.6–1.9 W/mK

2.2.3 Higher Quantity of Raw Material Usage and Associated Environmental Impact

Compared to cellular lightweight concrete, conventional concrete typically demands a larger volume of raw materials for its production, including cement, aggregates, and water. This can result in increased costs and a heightened environmental impact, particularly when considering cement production, a major contributor to CO2 emissions. Cement manufacturing is a prominent source of greenhouse gas emissions, with approximately 7% of total global CO2 emissions attributed to the production of every 1 ton of cement [43]. The cement industry is also responsible for significant emissions of particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO2), volatile organic compounds, and other pollutants, in addition to greenhouse gases [44]. The release of carbon dioxide primarily occurs in the rotary kiln during the production of clinker, a key component of cement. The process involves heating calcium carbonate (CaCO3) to high temperatures (1450°C to 1600°C), triggering complex chemical reactions. Carbon dioxide is generated as a byproduct when carbonates are converted into oxides through calcination, which occurs at temperatures between 600°C and 900°C in the upper, cooler section of the kiln or pre-calciner [38]. Furthermore, the extraction of raw materials for concrete production often involves the depletion of natural resources, contributing to environmental degradation. Concrete casting itself presents challenges, and the separate extraction and manufacturing processes for cement constituents also have environmental repercussions. The cumulative effect of CO2 emissions during cement production is a significant concern, and the extraction of raw materials can lead to environmental damage, including harm to mountains and natural landscapes. Addressing these issues in the realm of concrete production is a pressing environmental imperative.

2.2.4 Possible Remedies

To address these challenges, researchers have undertaken investigations and proposed the utilization of agricultural and organic waste materials that share chemical properties with cement as partial replacements for cement in the preparation of cellular lightweight concrete. In the existing body of literature, the utilization of rice husk ash and eggshell powder ash has emerged as a promising approach. Accordingly, this paper aims to assess the effectiveness of rice husk ash and eggshell powder as partial replacements for cement.

In this research work pumice stone is also used along with RHA and ESP to reduce the density of concrete because of its porous and less dense structure. The foaming agent is used to create pours inside structure of concrete. A review of the literature indicates that concrete incorporating 5% to 15% of rice husk ash and eggshell powder demonstrates performance similar to that of conventional concrete in terms of compressive, flexural, and tensile strength. Consequently, rice husk ash and eggshell powder can serve as viable substitutes in concrete formulations, contributing to a reduction in pollution associated with cement production and open-fire rice husk burning.

2.3 Manufacturing Properties and Benefits of Cellular Light Weight Concrete (CLC)

The growth of building materials research is advancing at an accelerated pace, due to the development of various composite materials aimed at enhancing material strength. Presently, materials like gypsum board sheets, expanded polystyrene (EPS) panels, and cellular lightweight foam concrete (CLC) blocks are being used in high-rise buildings for non-load-bearing partition walls. Among these options, CLC blocks stand out as the most favored technique due to their comparatively superior strength, sound absorption capabilities, heat insulation properties, and positive impact on HVAC system efficiency [1]. To produce cellular lightweight concrete pumice is the most used material. It has a sponge-like structure with a high amount of air voids that cause plastic deformation of concrete by causing a bridging effect in case of breakage. As with conventional concrete beams, the LWC beam does not disintegrate faster. It shows lesser disintegration due to its enhanced deflection behavior, due to the presence of pumice in the structure of concrete [19], [21]. In the case of flexural absorbed energies, cellular lightweight concrete shows some bridging effect due to the presence of pumice stone and air voids that are created due to foam present in the structure of cellular lightweight concrete. Therefore, CLC absorbs some sort of energy after the cracking as well. Figure 2.1, shows the bridging effect shown by pumice stone inside a concrete structure.

The utilization of organic waste materials as partial replacements for cement in concrete represents a sustainable practice with several benefits. This approach not only reduces the environmental footprint of construction but also repurposes waste materials that would otherwise contribute to landfills or undergo incineration. For instance, fly ash, a byproduct of coal combustion in power plants, is frequently employed as a partial cement substitute in concrete. Similarly, Rice Husk Ash (RHA), a byproduct of rice milling, can serve as a pozzolan in concrete when finely ground. Palm Oil Fuel Ash (POFA), generated from the incineration of palm oil husks, can enhance concrete properties such as compressive strength

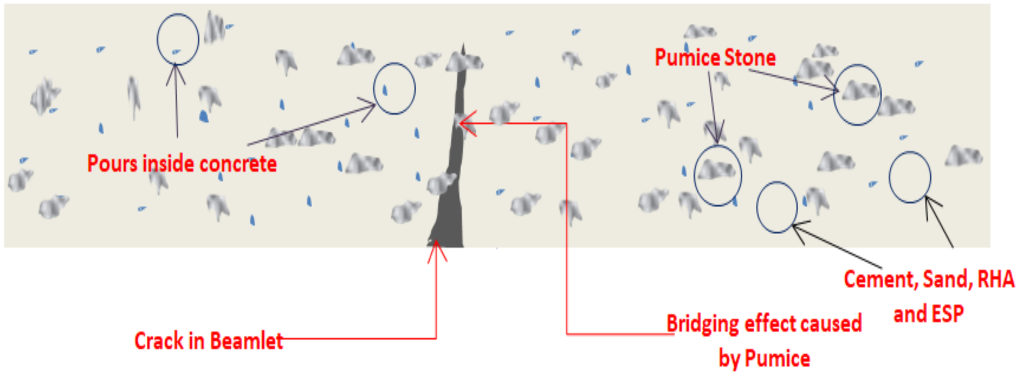

FIGURE 2.1: Bridging Effect Shown by Pumice Stone

and permeability when used as a partial cement substitute. Bagasse ash, originating from the sugar industry through the incineration of sugarcane waste, can be employed as a pozzolan in concrete to enhance its strength and durability. Coconut fiber ash, derived from the incineration of coconut fibers, can be used as a partial cement substitute in concrete, bolstering its strength and reducing the reliance on Portland cement. For testing of specimens, Bhosale et al., (2020) stated that "Codes and standards are not in agreement about the specimen sizes for the CLC units to be tested. As per ASTM C796/ C796M [8], a cylindrical specimen is required for the estimation of moisture content and dry density, whereas the same code recommends a prismatic brick specimen or a cube specimen for the assessment of compressive strength and Young's modulus. Indian Standard IS 2185 Part 4 [17] recommends prismatic brick specimens of various sizes for laboratory tests. Previous literature has used cube units of different sizes ranging from 50 to 150 mm for laboratory testing of lightweight masonry blocks. Accordingly, three different sizes of cube specimens, 50 mm, 75 mm, and 100 mm, are selected for all the laboratory experiments carried out in the present study on the CLC unit [80]. Agricultural wastes, also known as agro wastes, are the surplus or byproducts of crop production and are found in abundance in countries having agricultural-based economies [24]

2.4 Preparation of CLC with Agricultural and Organic Waste Materials

These agro wastes present a significant challenge as they require considerable land for disposal. They also have the potential to contribute significantly to the energy sector. Agro wastes currently account for approximately 9% of the total energy production but play a more substantial role in meeting energy demands in developing nations, contributing to about 35% of their total energy consumption. On a global scale, an astonishing 2.9 billion tons of crop straw are produced each year, with a staggering 66% of this straw being burned for energy purposes [25]–[27]. A wide variety of agricultural wastes exist, encompassing materials such as bagasse straw, olive stones, grape seeds, cotton stalks [30]–[32], pine sawdust [33], pecan, almond, hazelnut, sunflower shells [34], [35], jute, wheat straw, rice straw, rice husk, corncob, and cassava rhizome, among others [36]. An interesting fact is that rice crop residues consist of approximately 59% rice straw and 20% rice husk [37]. Unfortunately, the open burning of wheat straw not only squanders valuable natural resources but also poses serious environmental and health hazards. This practice contributes to air pollution and presents a severe threat to highway traffic, ultimately endangering human health and safety [26], [29]. Table 2.2 shows the organic waste materials to be used as partial replacement of cement in concrete.

Table 2.2: Organic waste materials as Partial Replacement of Cement

Sr No.	Product Name
1	Eggshell powder
2	Animal bone powder
3	Fly ash from poultry litter

This diversity in agro-waste materials underscores the importance of finding sustainable and environmentally friendly ways to manage and utilize these resources. Table 2.3 represents some of the agricultural materials to be used as partial cement replacement. From this table, it can be seen that agricultural waste products are mostly seasonal crops, that are abundantly grown in agricultural countries like

Pakistan. The Ash obtained from these crops was used previously as a partial replacement for cement.

TABLE 2.3: Agricultural Waste Products as Partial Replacement of Cement

Sr No.	Product Name
1	Rice husk ash
2	Palm oil husk ash
3	Coconut fibre ash
4	Wheat straw ash
5	Bagasse straw ash
6	Jute fibre ash
7	Sisal fibre ash

2.4.1 Rice Husk Ash And Eggshell Powder as Cement Replacement

Rice husk ash (RHA) plays several important roles in concrete due to its fine size (3–10 micrometers) and unique properties. RHA acts as a micro-filler in concrete, its fine particle size allows it to fill in the gaps and voids within the concrete matrix. This micro-filling effect helps to densify the concrete, making it more compact and reducing porosity [23]. Figure 2.2 shows the micro-filling effect of rice husk ash. RHA is considered a pozzolanic material. Pozzolanic materials are substances that, when combined with calcium hydroxide (lime) in the presence of water, react to form additional calcium silicate hydrate (CSH) gel. This reaction is known as pozzolanic reaction and is highly beneficial in concrete. This can be particularly useful in applications where workability and flow ability of the concrete are important factors.The micro-filling effect and pozzolanic activity of RHA contribute to refining the pore structure of the concrete matrix.

As RHA fills in the pores and the pozzolanic reaction produces more CSH gel, the overall pore size distribution becomes more uniform. This leads to improved durability, reduced permeability, and increased resistance to chemical attacks in the concrete [54]. Figure 2.3 shows the husking process of paddy grain to obtain rice husk. RHA can improve the interfacial transition zone (ITZ) between the cement paste and the aggregate particles in concrete. A well-refined ITZ is essential for the overall strength and performance of the concrete, and RHA's properties contribute to enhancing this zone. In summary, use of rice husk ash in concrete serves to improve its strength, durability, and performance by acting as a micro-filler, a pozzolanic material, a viscosity modifier, and by refining the pore structure and interfacial transition zone. This makes RHA a valuable additive in the construction industry, particularly in regions where rice husk waste is abundant [55].

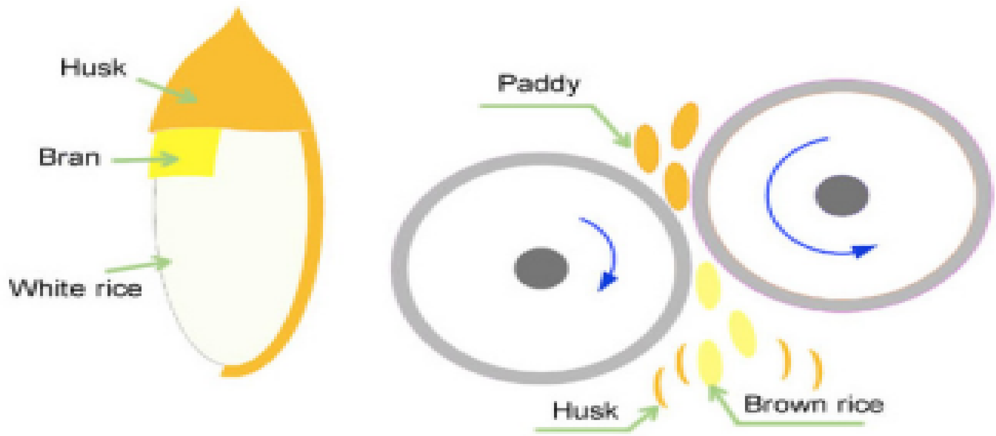

FIGURE 2.2: Final Products of Paddy Grain After Husking [40]

Eggshell waste can be used in a variety of ways, including as fertilizer and an element in animal feed, although the majority of it is now dumped in landfills. Due to its membrane connection, inappropriate eggshell waste disposal in landfills not only attracts vermin but also poses risks to the environment and public health. kg/m^3, there haven't been many thorough research on the utilisation of eggshell waste in the field of civil engineering [49].The chemical properties of poultry manure, in particular calcium-rich eggshells, closely resemble those of limestone. The use of eggshell waste as a replacement for natural lime in place of cement can have a number of advantages, including a decrease in cement use, the protection of natural lime resources, and a reduction in waste generation [66] . According to studies, India, the United States, and the United Kingdom produce 190,000, 150,000, and 11,000 tonnes of eggshell waste per year, respectively [66].

TABLE 2.4: Chemical Composition of Ordinary Portland Cement, Rice Husk Ash and Eggshell Powder by Different Researchers

Composition	OPC		RHA		ESP			Pumice stone
	Sari &	Yu	Rukzon	Siddika	Tan	Balamurugan &	Yu	Sari &
Name	Pasamehmetoglu	et. al.	et.al.	et.al.	et.al.	Santhosh	et. al.	Pasamehmetoglu
	[22]	[66]	[17]	[42]	[67]	[73]	[66]	[22]
CaO	51.26	60.1	1.45	0.67	52.15	47.49	52.1	4.03
SiO2	30.01	21.8	90.1	88.32	1.22	-	0.58	59.79
Al2O3	5.67	6.6	0.25	0.46	0.28	0.11	0.06	17.01
MgO	1.42	2.1	0.01	0.44	0.6	-	0.06	1.09
Fe2O3	3.92	4.1	0.1	0.67	0.16	-	0.02	1.98
SO3	2.52	2.2	0.92	-	-	0.38	0.62	0.37
Na2O	0.93	0.4	0.08	-	-	0.14	0.15	5.19
LOI	2.06	2.4	3.56	5.81	-	-	45.52	-
IR	0.9	-	-		-	-	-	-

Eggshells are made up of three separate layers that are all inorganic in nature: the mammillary, calcareous, and cuticle. A typical eggshell weighs about 94% calcium carbonate, with the remaining 4% or so made up of organic content and minor amounts of calcium phosphate and magnesium carbonate [50]. The concentrations of CaO can range from 32.5% to 99.8%, is the main ingredient in ESP. Higher CaO level in ESP improves the mechanical characteristics of cementitious materials, while lower CaO content can reduce the performance of the composite [51]. When finely ground rice husk ash and eggshell powder are combined with cement to partially replace it, RHA, which is high in silica and eggshell powder, contains the same amount of calcium oxide as contained by the cement. This reaction allows the silica of RHA to react with calcium oxide of ESP to form calcium silicates, that are responsible for giving higher strengths. The synergistic effect of combining RHA and eggshell powder results in more efficient use of these materials, leading to enhanced compressive strength and reduced permeability in concrete [92]. Table 2.4 shows the chemical composition of eggshell powder.

FIGURE 2.3: Eggshells and Eggshell Powder [65]

2.5 Summary

From above discussion it is concluded that conventional concrete possess high density and due this high density dead weight of the buildings and structures increases and to bear this high load there is need to design the foundation and structure of building in such a way that it can bear the heavy dead weight of the building. To bear this heavy dead load of building, steel reinforcement of foundation and structure need an enhancement to with stand heavy load of the building. This increment of steel in structure increases the cost of the building. To resolve this issue cellular light weight concrete CLC is suggested for the use in non-structural members like portioning walls to reduce the dead load of the building. Agricultural waste materials like rice husk ash and organic waste eggshell powder can be used as partial cement replacement to prepare this cellular light weight concrete. Utilization of these two waste materials, having cementatious properties can reduce the environmental pollution and pave the path towards the sustainable construction material manufacturing.

Chapter 3

Experimental Scheme

3.1 Background

As discussed previously egg shell powder and rice husk ash is used to improve environmental conditions by replacing cement content of cellular light weight concrete up-to 15% by volume of cement. Due to their environmental friendliness, accessibility, and ease of handling, the utilization of these commercial wastes in various combinations has typically increased over time. Tests such as slump cone, compact factor, mechanical, and water absorption tests are taken into consideration for this. These studies are performed to examine how eggshell powder and rice husk ash work together to create lightweight concrete. This chapter has provided an explanation of the treatment procedure, specimen preparation, etc.

3.2 Raw Materials of Cellular Light Weight Concrete

To assess the components of cellular lightweight concrete as well as its potential replacements, it is necessary to consider the raw materials. Sand, cement, and pumice aggregate are often used to make this concrete. To make cement work in the process of binding, water is supplied along with the addition of foam. Eggshell powder, rice husk ash, and super plasticizer are added as raw components in this study program. Materials having positive outcomes in prior research were chosen because increasing the amount of materials could influence the qualities of concrete.

3.2.1 Cement

One of the essential elements of concrete is cement. Various varieties of cement exist based on the processes used to create them. This study on locally purchased Fauji Cement utilized OPC cement. But chemical attacks are less resistant to it than breaking and shrinking. OPC is suggested for projects where the props will be taken down early because its initial setting time is quicker than PPC's. OPC cures more quickly than PPC, lowering the cost of cure. So it is indicated in cases where the expense of treatment is too high. OPC is produced using Fauji cements in accordance with EN 1971: 2011-CEM I 425N, meaning that it has a 28-day strength of 52 $\pm$3 MPa. The maker mentions each of these attributes. However, Table 2.1 provides information on the chemical makeup of cement.

3.2.2 Fine Aggregate

A high-quality concrete is produced with the help of fine aggregate. By fostering homogeneity, lowering cement and water consumption, and boosting the finished product's mechanical strength, it improves the workability of concrete mixtures. Additionally, it lessens the possibility of segregation during transit and aids in hardening the cement paste surrounding the coarse aggregate particles. Additionally, fine aggregate fills in any gaps left by the coarse aggregate, which raises the density of the concrete and lessens shrinkage of the binding material. The development of cracks in concrete is prevented by fine aggregate by enhancing the overall strength and endurance of the concrete. Sand from Lawrencepur was used as the fine aggregate in this investigation; it went through a 4.75 mm sieve size and was retained in sieve 100. To assure the creation of high-quality concrete, this sand has been carefully chosen based on its particle size distribution and other pertinent features. It is important to keep in mind that the final product can be significantly impacted by the caliber and characteristics of the fine aggregate used in the manufacturing of concrete. In addition to improving the quality of concrete, using the right fine aggregate can help reduce the production's negative environmental effects by using less resources.

3.2.3 Coarse Aggregate (Pumice Stone)

To make cellular light weight concrete, pumice stone is used as coarse aggregates. Pumice stones are volcanic-derived rocks that can be found all over the world. Pumice stone is a naturally occurring lightweight aggregate that can be used to create lightweight concrete since it is both light and robust. Their lightness is caused by gas that was released when molten lava erupted from a deep pit beneath the earth's summit. Due to its desired qualities, pumice stone is a very popular material as a light rock and has been utilized in civil engineering for decades around the world [56]. Separated from the bulk are aggregates passing through 25 mm and remaining on 9.75 mm. To get rid of contaminants and dust, these aggregates are extensively rinsed in a mixer. Aggregates are adequately air-dried after washing and used in the production of concrete. The washed pumice aggregates are depicted in Figure 3.1.

(a)

(b)

FIGURE 3.1: (a) Washed Pumice Stone (b) Air Drying of Pumice

3.2.4 Water

The preparation of the Specimen uses potable tap water. Having pH ranges from 6.5 to 8.5. There are no visible impurities or suspended particles in it.

3.2.5 Foaming Agent

Foaming agents are foam admixtures that produce a stable pre-foam under alkaline circumstances by using a foam generator [2]. As a result, it can be used to create mortars that contain foam. To reach the desired density, the pre-foam added to the premixed mortar should be managed. The foaming ingredient should be dissolved in water before use because it is a concentrated surfactant solution. The mortar may develop air pores as a result of the foaming agent's air bubbles being mixed into it. The stability of the foam, bulk density, microstructure, and the consequent compressive strength could all be impacted by the foaming agent's application in the foam concrete mixture [57],[58] The compressive strength of foam concrete may be impacted by a reduction in pore size [59].

For concrete additives, there are two types of foam agents: synthetic and protein-based. In this research synthetic foam agent is used having a density of approximately 40 kg/m3, and it has a 25-fold expansion capacity. With a foam-to-water ratio of 1:19, this foaming agent is particularly stable for density foam concrete above 1000 kg/m3 [67].

(a) (b)

FIGURE 3.2: (a) Foam Generator (b) Foam prepared with foaming agent

Figure 3.4 shows the foam generator and foam prepared with the help of a foaming agent and foam generator. for the preparation of foam, first of all, the foaming agent is added to water in the drum as the required quantity. Then this foam generator is turned on and the shaft of this generator is inserted inside the drum containing water and foaming agent. The shaft of the foam generator vibrates very fast and converts this mixture of water and foaming agent into foam that is to be added to prepared concrete at the lateral stage.

3.2.6 Super Plasticizer

Super plasticizer Sikament -512 PK is used as 1.5% by mass of cement. It is a high range concrete additive that reduces water content and delays setting time. Sikament -512 complies with EN 934-2: 2001 and ASTM C-494 Type G. Super plasticizer's chemical makeup is listed in Table 3.1.

Table 3.1: Technical Data of Superplasticizer

Parameter	**Range**
Density	1.16-1.2 kg/litre
PH Value	Approximately 7
Product Color	Brown Liquid
Type	Organic Polymer Blend

3.2.7 Rise Husk Ash

One of the waste products that can be utilised in place of cement is rice husk ash. In general, rice husk ash is an agricultural waste product that is produced in millions of tons annually by burning rice husk either in an open field or under controlled incineration circumstances [38]. The controlled temperature and burning environment, which results in a highly reactive rice husk ash, determine the particle size and surface area of rice husk ash. In the rice husk, there are between 75 and 90 percent organic materials such cellulose and lignin, as well as silica, alkali, and trace elements [60]. In comparison to other biomass fuels, rice husk has a very high ash content of 10–20%. The ash includes 87-97% silica, which is extremely light, highly porous, and has a large exterior surface area. It is a desirable material for use in industrial applications because of the large amount of silica present [61]. Pozzolanic characteristic is crucial for any additional cementing component in concrete. Due to the presence of amorphous silica, which has high specific surface area and fineness qualities, rice husk ash has been shown to have strong pozzolanic activities [62]. Rice husk is collected from rice mill then it is burnt in an incinerator to generate rice husk ash, the uncooked rice husk was retained in the incinerator for burning before being left to cool for 24 hours. Finally, the non-pulverized ash obtained from the incinerator is ground in a grinder to produce fine particles of rice husk ash.

(a) (b)

FIGURE 3.3: (a)Specimen in Mold (b) Cubes (c) Beamlets

3.2.8 Egg Shell Powder

Before it can be utilised as a replacement for cement, raw eggshell must go through a certain process. The eggshells are first cleaned with regular water. This procedure also removes the eggshell's thin membrane in addition to cleansing the eggshell of impurities. The eggshells are then dried after being cleaned [64]. The eggshells are then further processed using a blender after first being hand smashed. A mechanical grinder is used to grind the material to the required degree [63], [65], [66]. The final product is recovered as a fine cement powder after being sieved from

200. Figure 3.3 shows washed and crushed egg shells and egg shell powder. In terms of composition, cement and eggshell both include the same elements: CaO, SiO2, AL2O3, MgO, Fe2O3, SO3, and Na2O [66]. When part of the cement is replaced with eggshell powder, the reaction between the cement's silica and the powder's calcium oxide, which results in the secondary C-S-H gel formation when moisture is present continuously, is improved [65].

3.3 Mixing Procedure and Casting

For preparation of cellular light weight concrete extra care need to be taken for better workability and better results because it involves complex procedure as compared to the conventional concrete. Two ways motion, rotatory as well as two and fro motion, mixer is used for the preparation of CLC. Drill mixer is also used for the mixing of foam with concrete to make it cellular concrete. Figure 3.5 shows the two and fro motion mixer and drill mixer for the preparation of CLC.

3.3.1 Mix Design

For the mix design of cellular light weight concrete batching ratio 1:2:3 is selected with 0.60 w/b ratio and 1.5% super plasticizer by weight of binder. Synthetic foaming agent having ratio 1:19 of water is added to convert this concrete into foaming concrete and to create pores on lateral stage after setting of concrete [10], [67]. Rice husk ash and eggshell powder are used for partial replacement of cement up to 15% maximum percentage. A combination of percentages of these two elements are used in casting of specimens having combination with cement as 2.5%, 5%, 7.5%, 10%,12.5% and 15% in percentage alternatively for both the waste products. Eight different types of casting are completed namely PCLW-15, RHAC-15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12 and ESC-15 in this research work. According to Chong et al., [64], eggshells can substitute cement in varying amounts (0-15%, 0-20%, and 0-25%), which improves compressive strength. In most replacements, partial replacement at 10% proved to be ideal. Therefore, in order to accomplish sustainable building for a healthy environment, cement is replaced in combination with rice husk ash in variable percentages of eggshell powder (2.5, 5, 7.5, 10, and 15) % in consideration of the ideal proportion stated by Chong et al [64].

3.3.2 Mixing

For preparation of concrete coarse aggregate (pumice), sand, cement and partial replacement of cement with eggshell powder or rice husk ash either in 15% or either a combination of RHA and ESP in 2.5%, 5%, 7.5%, 10%, 12.5% or 15% making up to 15% in total is added to the mixer. First, these materials are dried and mixed then followed by the addition of water and super-plastisizer. Super plasticizer is added to enhance the workability of concrete with a lower water to binder ratio. Besides enhancement of workability, superplasticizer mitigates the risk of segregation and enhances ultimate strength by reducing the water content. The mixer is then set to rotate for five minutes then at the last stage foam generator is used to prepare foam from synthetic foam agent and added in the mixer. After the addition of foam, mixer is then again set to rotate for at least three minutes to prepare a homogeneous cellular light weight concrete mix. Table 3.2 shows all the detail of mix design for concrete casting.

3.3.3 Specimen Casting and Curing

For casting of specimens 24 numbers of cubes are used for the compressive strength test evaluation and 24 numbers of beamlets are casted for the evaluation of flexural strength test. Before usage of molds each mold is properly cleaned to remove any remaining concrete from previous batching. After cleaning used engine oil is applied to make the surface of mold smooth and to avoid honeycombing. Cubes and beams are prepared for casting, along with the lubrication and maintenance of moulds. For uniform shape and mixing, concrete is poured into each mould in three layers. The cubes used in casting are 152 mm x 152 mm and the beams used are 102 mm x 102 mm x 457 mm in dimension. All moulds have been meticulously cleaned to remove any contaminants and any adhered hardened concrete. To evaluate the compressive strength of concrete, there are two main kinds of standardized testing specimens i.e. cubes and cylinders. Cubes are more common in Singapore, Europe, the United Kingdom, and Canada, whereas cylinder specimens are typically used in the United States, Canada, France, Australia, and New Zealand. Test results for compressive strength from cube specimens typically yield higher values compared to cylinder specimens for both normal concrete and high-strength concrete. The compressive strength of concrete derived from cylinder specimens is roughly 0.8 times that of concrete derived from cube specimens, per BS 1881. In real-world applications, this ratio is not always accurate, though. It is generally believed that cube specimens in regular concrete have a 20–25% higher compressive strength, with the difference diminishing at higher or lower compressive strengths [93].

Each specimen is casted in three layers and a tamping rod is used on each layer for compaction and proper filling of concrete. All of the moulds are filled, and then they are set outside in the open. After casting specimens, they are left to dry in a shady place for 48 hours for final setting. Then molds are opened and observed, after 48 hours these specimens are completely dried and then marking on each specimen is done against its mix design. After marking these specimens are kept in a water tank for curing up to 28 days for preparation of specimens for harden concrete test. Concrete moulds are opened for curing in the water tank, once they have had enough time to final set. Figure 3.6 shows casted cubes and beams in mold and after demoulding.

(a) (b) (C)

Figure 3.4: (a) Molds of Cubes and Beamslets (b) Cubes (c) Beamlets

TABLE 3.2: Mix design of CLC

Mix Design	Binder	Fine Aggregate	Coarse Aggregate	W/C	SP 1.5%	Synthetic foaming Agent
	Binder = Cement + RHA * + ESP**	Sand	Pumice	Ratio	by weight of	Ratio 1:19
Name	(Kg)	(Kg)	(Kg)	0.60	Binder (Kg)	of water (Kg)
CLC	7.60+0.00+0.00 = 7.60	15.40	10.01	4.56	0.11	0.24
RHAC15	6.46+1.14+0.00 = 7.60	15.40	10.01	3.88	0.11	0.20
RHAC 12.5-ESC 2.5	6.46+0.95+0.19 = 7.60	15.40	10.01	3.88	0.11	0.20
RHAC 10-ESC 5	6.46+0.76+0.38 = 7.60	15.40	10.01	3.88	0.11	0.20
RHAC 7.5-ESC 7.5	6.46+0.57+0.57 = 7.60	15.40	10.01	3.88	0.11	0.20
RHAC 5-ESC 10	6.46+0.38+0.76 = 7.60	15.40	10.01	3.88	0.11	0.20
RHAC 2.5-ESC 12.5	6.46+0.19+0.95 = 7.60	15.40	10.01	3.88	0.11	0.20
ESC 15	6.46+0.00+1.14 = 7.60	15.40	10.01	3.88	0.11	0.20

* RHA Ratio 15%, 12.5%, 10%, 7.5%, 5%, 2.5%, 0%

** ESP Ratio 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%

3.4 Testing Methods

3.4.1 Miscellaneous Tests (Slump Test, Harden Density Test, Water Absorption Test, Linear Shrinkage Test)

Slump test is used to measure the workability of concrete. The ASTM standard C143/C143M-15 is used to perform slump test. Slump cone test is used for all the mix design and a collapsed slump is recorded for all the specimens because of the nature of cellular light weight concrete. Slump test apparatus was cleaned properly and lubricated prior to the start of test. Concrete is filled in three layers in cone and each layer is compacted by 25 strokes for proper filling.

After the curing process is completed, harden density test is to be performed to figure out how much concrete weighs per volume. To assess the qualities of the mix design, this test is performed. Harden density testing makes it possible to compare various concrete mixtures and determine whether they fall within the categories of light, regular, or heavy concrete. A weighing balance is required to determine the direct weight of a concrete cube or beam let, and then divide it by the volume of specimen.

To test the water absorption of concrete ASTM C1585 is followed, according to this when the samples are remolded then these samples are to be placed in water tank. After completion of 28 days these molds are taken out of the water tank and the dried in oven at 100 degree centigrade. Weights of these samples are taken and then these samples are again submerged in water for 24 hours. After passage of sometime these samples are taken out of the water and again their weights are taken. In this the quantity of water that the sample has absorbed is calculated. Difference of wet weight and dry weight of the sample is calculated then this difference is divided by the wet weight to calculate the water absorption of the specimen.

In the evaluation of linear shrinkage, the procedure outlined in ASTM C157 / C157M-08 is followed, along with the observation and measurement of changes in the length of specimens as prescribed by the OPSS standard LS-435. To conduct this test, a reference line of 6 inches is marked on the specimens' length before commencing the examination. After completing the standard procedure, any variation in length is carefully measured. The linear shrinkage is subsequently determined by calculating the percentage difference between the marked length before the test and the length observed after the procedure.

3.4.2 Mechanical Properties

Destructive testing like compressive strength test and flexural strength test are carried out in this research work for cellular lightweight concrete that will be used for non-structural elements of buildings because non-structural damage can limit the functionality of critical facilities, such as hospitals and hotel buildings.

3.4.2.1 Compressive Strength Test

As per British standard BS EN 12390-3, concrete cubes are used for testing of compressive strength of concrete. For compression strength of cubes, a Universal Testing Machine (UTM) is used having a high precision displacement transducer and a measurement range of 0-15000 mm and a resolution of 0.001 mm. Compressive strength (C-S), the point of compressive pre-cracking (CE1) and post-crack energy (CE2), total absorbed energy under compressive loading (CTE), and the compressive toughness index (CTI) of all the mix designs are evaluated with this test.

3.4.2.2 Flexural Strength Test

The flexural test is conducted in accordance with ASTM C78 standards, utilizing a three-point loading system. This examination is conducted on beamlets made of both PCLW and other types of mix designs. The key parameters investigated in this test encompass load-deflection curves, flexural strength (F-S), flexural pre-crack energy absorption (FE1), flexural post-crack energy absorption (FE2), flexural total energy absorption (FTE), and flexural toughness indexes (FTI)

3.4.3 Dynamic Testing

The dynamic testing procedure precedes the destructive mechanical testing of specimens, following the guidelines outlined in ”ASTM 215-14 [Table 3.2].” Response frequencies, including lateral (RFL), transverse (RFT), and rotational (RFR) frequencies, are determined using a combination of a hammer and accelerometer. This test is conducted on both cubes and beamlets. To determine the lateral response frequency (RFL), the accelerometer is affixed to one side of the cross-section of the cube and beamlets, while a hammer strike is applied to the opposite side of the cross-section. The accelerometer records these frequencies and transmits the data to a connected computer. The procedure for determining transverse (RFT) and rotational (RFR) response frequencies varies for cylinders and beamlets. In the case of cubes, for RFT, the accelerometer is attached to the side facing, at a minimum distance of 25 cm from the edge. A hammer strike is then applied to the same side, at the center point. For RFR in cubes, the accelerometer is attached to the top-facing surface, with the same edge-to-edge spacing as in RFT. The hammer strike is applied perpendicular to the accelerometer on the opposite edge of the cube.

For beamlets, in the determination of RFT, the accelerometer is attached to one side, maintaining the same edge margin as used for cube. The hammer strike is administered at the center of the same side where the accelerometer is attached. In the case of RFR for beamlets, the accelerometer is fixed to the top corner of the rectangle (the side face of the beamlet). A hammer strike is applied to the opposite bottom corner of the same side in a manner that creates a diagonal line connecting the point of the hammer’s strike and the accelerometer. From the recorded frequencies, various properties including damping ratio, dynamic modulus of elasticity, dynamic modulus of rigidity, and Poisson’s ratios are calculated. These calculated properties provide insights into the behavior and resistance of CLC, RHAC, ESC and various combinations of RHAS and EGC under dynamic loading conditions. These properties play a crucial role in designing structures that will withstand dynamic loads and earthquake forces.

Table 3.3: Standards Testing and Studied Parameters

Test	**Standards / References**	**Parameters Considered for the Study**
1. Dynamic Properties	ASTM 215-14	Resonant frequency longitudinal (RFL), Resonance frequency transverse (RFT), Resonance frequency torsional (RFR), damping ratio (), Poisson ratio, dynamic modulus of elasticity and dynamic modulus of rigidity (Ed)(Rd).
a. Water Absorption	ASTM C1585	Water absorption (%)
b. Linear Shrinkage	ASTM C157	Linear shrinkage (percentage decrease),
a) Compressive Properties	ASTM C39	Stress-strain curves, compressive strength (CS), modulus of elasticity (MOE) compressive pre-crack energy absorption (CE1).
		Compressive toughness indexes, compressive post-crack energy absorption (CE2), and compressive total energy absorption (CTE) (CTI).
c) Flexural Properties	ASTM C78	Load-deflection curves, flexural toughness indexes, flexural strength (FS), flexural pre-crack energy absorption (FE1), flexural post-crack energy absorption (FE2), and flexural total energy absorption (FTE) (FTI).

3.5 Summary

For the preparation of concrete coarse aggregate (pumice), sand, cement and partial replacement of cement with eggshell powder or rice husk ash either in 15% or either a combination of RHA and ESP in 2.5%, 5%, 7.5%, 10%, 12.5% or 15% making up to 15% in total is added for the preparation of cellular lightweight concrete. The water-to-cement ratio used is 0.60 for all the mixed designs. Total 48 numbers of specimens that are prepared out of which 24 are cubes and 24 are beamlets. ASTM standards are followed for the testing procedures of slump, dynamic and mechanical properties like compressive and flexural properties. The evaluated results of each test are discussed in detail in the next chapter (i.e. chapter 4)

Chapter 4

Results and Analysis

4.1 Background

In previous chapter No. 3, there was a discussion about the materials, preparation, and casting of concrete. Now in this chapter there are results and discussion of different types of mixes of cellular lightweight concrete that were prepared namely PCLW, RHAC-15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5-ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC-15. This chapter provides a thorough experimental evaluation of the mechanical, non-destructive, dynamic, and microstructural characteristics of all mixes in fresh and hardened states. ASTM standards are followed for mechanical and dynamic testing.

4.2 Miscellaneous Tests (Slump Test, Harden Density Test, Water Absorption Test, Linear Shrinkage Test)

The concrete slump test is a widely used method to assess the consistency and workability of a concrete mix design. In the case of CLC, there is always a collapsed slump due to the reason that it contains a high w/c ratio and foam, for the creation of pores. Like self-compacting concrete, the workability of CLC is also very high. Figure 4.1 shows the slump test of cellular lightweight concrete.

(a) (b)

FIGURE 4.1: (a) Slump Test of CLC (b) Water Absorption and Mass Loss Test

After the curing process is completed, harden density test is performed to for the calculation of concrete weight per volume. The qualities of the mix design are to be assessed through this test. AS this research work is for cellular light weight concrete, therefore, the densities of all mix design ranges from 819 kg/m^3 to 958 kg/m^3. Table 4.1 shows the values of harden density of all the mix designs.

The objective of this test is to assess how the water absorption changes in the samples over time. Water contains various harmful components that penetrate concrete, leading to its deterioration and increased water absorption. Among all the samples RHAC15 i.e., 16% water absorption rate, due to the highly absorptive nature of rice husk ash present in the specimen as cement replacement. Whereas reduction of water absorption is found in all other specimens. PCLW, RHAC 7.5-ESC 7.5, RHAC 5-ESC 10, ESC 15, RHAC 10-ESC 5, RHAC 2.5-ESC 12.5 and RHAC 12.5-ESC 2.5 are followed with absorption capacity of 15%, 14%, 13%, 13%, 12%, 10% and 9% respectively. This absorption capacity of cellular light weight concrete is in accordance with the literature as the cellular light weight concrete typically exhibits a greater ability to absorb water when compared to conventional concrete, it is important to consider using cellular light weight concrete masonry for exterior walls or walls exposed to moisture. On the other hand, the cellular light weight concrete capillary suction properties surpass those of conventional concrete, as indicated by its lower IRA and sorptivity values. These reduced IRA and sorptivity values contribute to enhanced bond strength in cellular light weight concrete block masonry [82]. Table 4.1 represents the water absorption capacity of all the specimens.

To assess linear shrinkage, the procedure outlined in ASTM C157 / C157M-08 is used, followed by the observation and measurement of changes in the dimensions of specimens (conforming to OPSS standard LS-435). To carry out this evaluation, a reference line of 6 inches is first marked on the specimen's length before initiating the test. The change in length is then determined following the standard procedure. Linear shrinkage is subsequently calculated as the percentage difference between the marked length before and after the test procedure. Table 4.1 shows the linear shrinkage values of all the mix designs.

4.3 Mechanical Properties

4.3.1 Properties Under Compressive Loading

4.3.1.1 Compressive Behaviour

The relationship between stress and strain graphs of PCLW, RHAC-15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC-15 are shown in Figure 4.3. The density of cellular light weight concrete has a major impact on its strength under compression. The increase in density of cellular lightweight concrete ultimately increases the compressive strength of concrete [76]. The density of CLC depends upon the water-to-cement ratio, quantity of foaming agent, density of coarse aggregate, mixing procedure and time required to cast the specimens.

Table 4.1: Slump Test, Harden Density and Water Absorption Capacity of Mix Designs

			Water Absorption				
Specimens	w/c Ratio	Slump of Fresh Concrete	Wet Weight	Dry Weight	Percentage Absorption	Linear Shrinkage	Harden Density
		(mm)	(Kg)	(Kg)	%	%	Kg/m^3
CLC	0.60	282	4.82	4.09	15.15	0.149	831
RHAC15	0.60	266	4.79	4.03	15.87	0.156	819
RHAC 12.5-ESC 2.5	0.60	241	5.20	4.71	9.42	0.072	958
RHAC 10-ESC 5	0.60	247	5.08	4.48	11.81	0.083	911
RHAC 7.5-ESC 7.5	0.60	259	4.89	4.21	13.91	0.138	856
RHAC 5-ESC 10	0.60	257	4.97	4.32	13.08	0.123	878
RHAC 2.5-ESC 12.5	0.60	243	5.16	4.65	9.88	0.076	945
ESC 15	0.60	254	4.99	4.36	12.63	0.097	886

In figure 4.3 it can be shown that RHAC2.5- ESC12.5 shows the maximum compressive strength as compared to all other specimens. The compressive strengths of RHAC10-ESC5, ESC-15, RHAC5-ESC10, RHAC12.5-ESC2.5, RHAC7.5- ESC7.5, PCLW and RHAC-15 are reduced by 11%, 29%, 33%, 33%, 45%, 54% and 55% respectively. While compressive strength is undoubtedly a crucial factor in assessing a material's suitability for construction, it's essential to recognize that it isn't the sole determining factor. Toughness, in conjunction with compressive strength, holds equal significance. Indeed, a modest reduction in material strength can be counterbalanced by a substantial enhancement in toughness and energy absorption capabilities. This, in turn, contributes to an overall improvement in performance. Although cellular lightweight has undergone extensive research, it still faces limitations, particularly in terms of its low strength, which restricts its broader applications [79]. The strength of cellular lightweight concrete is influenced by various factors, including the types of cementitious materials used; cement dosage, mix proportions, water-cement ratio, foam volume, foaming agent, curing methods, additives, and density of concrete. [80].

To a certain extent, the density of cellular light weight concrete governs its strength. Therefore, there is a constant pursuit of achieving a balance between strength and density, with the aim of maximizing strength while minimizing density as much as possible. This can sometimes be accomplished through the optimization of cementitious materials selection and the use of high-quality foaming agents and ultra-light aggregates. The choice of filler types determines the water-solid ratios when cellular light weight concrete's density remains constant, and reducing the particle size of sand can contribute to strength improvement [81].The compressive strength of Cellular Lightweight Concrete (CLC) units and masonry assemblies is observed to be approximately 80% lower compared to that of conventional clay brick units and masonry assemblies. Consequently, CLC units are deemed unsuitable for application in load-bearing walls [82]. The stress-strain relationship for CLC under compressive loading is similar to that of regular concrete. Initially, as the load is applied, there is elastic deformation, where the material returns to its original shape upon unloading. However, if the load continues to increase, CLC will eventually reach its compressive strength limit and begin to undergo plastic deformation. Beyond this point, it may experience crushing and failure. CLC's ability to absorb energy under compressive loading is relatively lower than that of regular concrete. This makes it less suitable for applications where energy absorption and deformation before failure are critical.

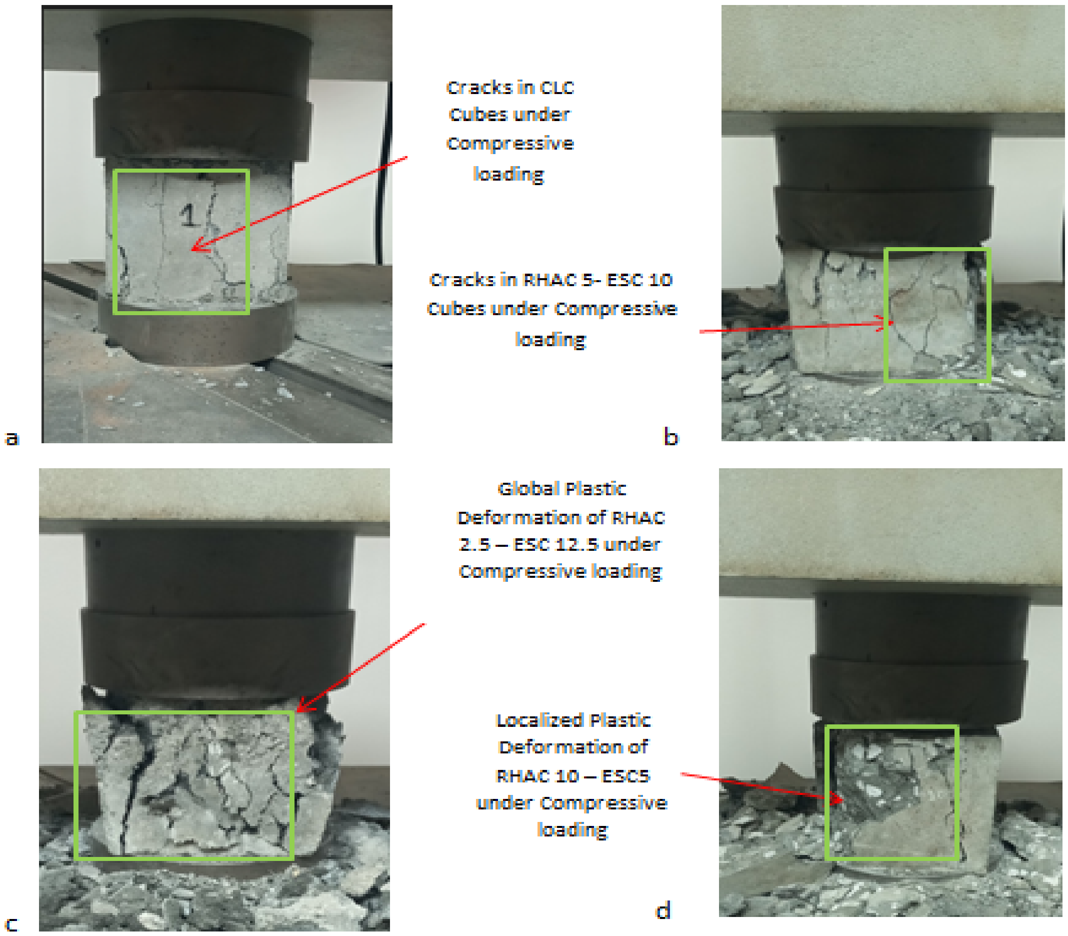

FIGURE 4.2: Cracking Pattern of Cubes Under Compression loading

4.3.1.2 Compressive Strengths, Compressive Energy Absorption and Compressive Toughness Index

Table 4.2 shows a tabular display of energy absorption values, including both total energy (CTE) and toughness index (CTI). The calculations for compressive pre-crack absorbed energy (CE1) involve analyzing the area under the stress-strain curve from the initial point to the point of maximum stress. In contrast, the post-cracking energy (CE2) is determined by examining the region under the stress-strain curve from the onset of initial fracture to the point of failure. RHAC2.5-

ESC12.5 shows highest value of modulus of elasticity (MOE) as compared to the all other specimens. The modulus of elasticity of RHAC10-ESC5, ESC-15, RHAC5-ESC10, RHAC12.5-ESC2.5, RHAC7.5- ESC7.5, PCLW and RHAC-15 is reduced by 6%, 16%, 16%, 18%, 26%, 32%, and 33% respectively. This observation underscores the fact that compromising compressive strength can increase energy absorption capacity, thereby enhancing the overall material toughness. For a visual representation of the cracking pattern, please refer to Figure 4.2.

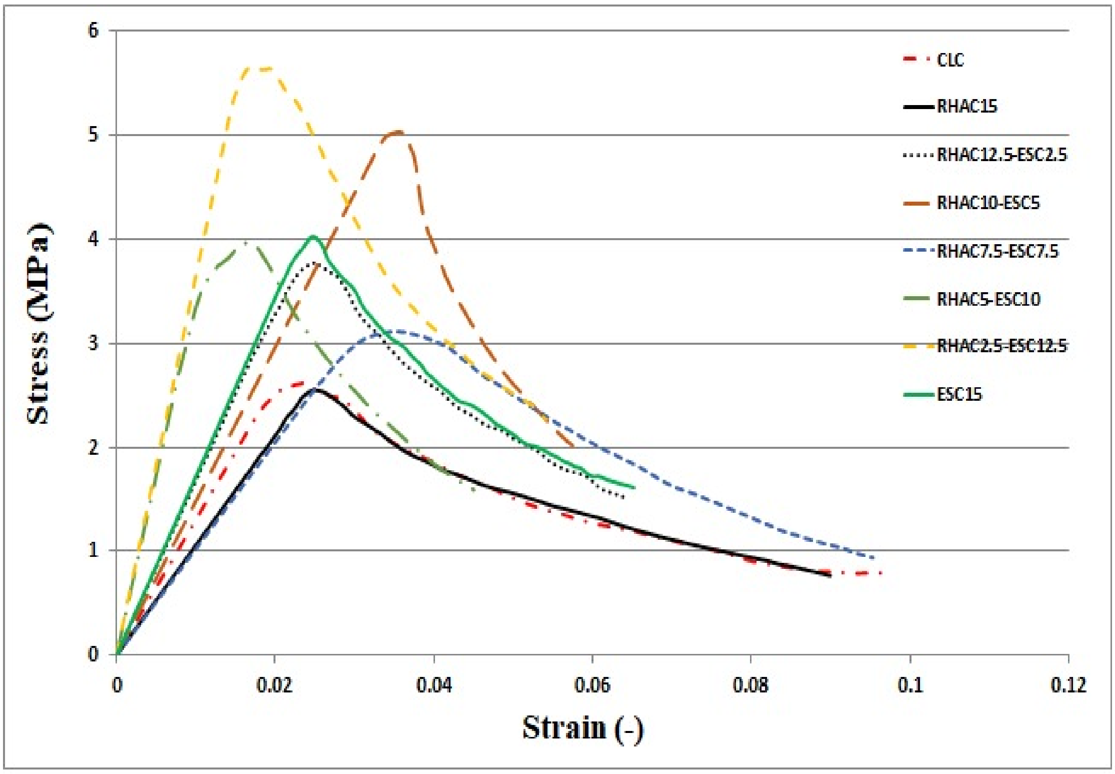

FIGURE 4.3: Compressive Response of all Mix Designs

Properties under compressive loading describe the different kinds of failure modes that can occur during the compressive strength test. Three distinct failure modes have been identified for the CLC unit under uniaxial compression load, as Figure 4.3 illustrates these failures, (a). The development of vertical columnar cracks along the loading direction (b).The occurrence of a vertical crack under compression, resulting in material crushing (c). Failure is attributed to non-uniform loading or reaction, developing from the uneven distribution of materials due to the presence of air voids within the specimen. As per IS Code 3495 Part-1; the compressive strength of first-class fly ash brick is 10MPa, while the minimum compressive strength of second-class fly ash brick is 7.5MPa. The minimum and maximum CS for CLC obtained for this experimental work are 2.55MPa and 5.66MPa respectively.

4.3.2 Properties Under Flexural Load

4.3.2.1 Flexure Properties

The load-displacement curves of all the specimens for flexure behavior are shown in Figure 4.5. For load deformation of PCLW, RHAC-15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC-15 it may be noted that RHAC7.5-ESC7.5 shows maximum value of load because it resists maximum flexural load as shown in figure 4.5. In the section on flexural properties, Table 4.2 presents the data on flexural strength (FS), flexural pre-crack absorbed energy (FE1), Flexure post crack absorbed energy (FE2), flexural total energy absorption (FTE), and flexural toughness index (FTI) for different types of cellular lightweight concrete. Pre-crack Absorbed Energy (SE1), Splitting Tensile Post-Crack Absorbed Energy (SE2), To create lightweight concrete, pumice is the preferred material of choice. Similar to traditional concrete beams, lightweight concrete (LWC) beams do not exhibit rapid disintegration. Instead, they demonstrate reduced disintegration due to their improved deflection characteristics [21]. Cellular light weight concrete exhibits lower flexural strength compared to conventional concrete due to its lower density and the presence of air bubbles. The flexural strength of CLC can vary widely depending on the mix proportions and curing methods but is generally in the range of 1 to 4 MPa.

4.3.2.2 Flexural Strengths, Flexural Energy Absorption and Flexural Toughness Index

Splitting Tensile Post-Crack Absorbed Energy (SE2), To create lightweight concrete, pumice is the preferred material of choice. Similar to traditional concrete beams, lightweight concrete (LWC) beams do not exhibit rapid disintegration. Instead, they demonstrate reduced disintegration due to their improved deflection characteristics [18]. Cellular light weight concrete exhibits lower flexural strength compared to conventional concrete due to its lower density and the presence of air bubbles. The flexural strength of CLC can vary widely depending on the mix proportions and curing methods but is generally in the range of 1 to 4 MPa.

The Flexural Energy absorbed and Flexural toughness index are given in table 4.2.For flexural strength test, it is noted that the maximum load is taken by RHAC7.5-ESC 7.5 i.e. 1.66 MPa, followed by ESC15 and RHAC 5-ESC 10 with 1.65 MPa and 1.5 MPa. On the other hand RHAC15 shows the minimum amount of load that is 0.84 MPa. RHAC2.5-ESC12.5 absorbs the highest amount of energy and also depicts the highest amount of compressive toughness index that again shows that a combination of rice husk ash and eggshell powder is beneficial for the enhancement of properties of CLC. The lowest compressive toughness index is noted for RHAC10-ESC5. In the case of flexural absorbed energies cellular lightweight concrete shows some bridging effect due to the presence of pumice stone and air voids that are created due to foam in CLC. Therefore CLC absorbs some sort of energy after the cracking also. The flexure toughness index is highest for RHAC 10- ESC 5 i.e. 1.43 and RHAC2.5- ESC shows the minimum amount of flexural toughness i.e. 1.06. Hence cellular lightweight concrete shows plastic deformation as shown in Figure 4.5. After the crack originates pumice stone shows some bridging effect due to its plastic deformation qualities.

The advancement of performance-based earthquake engineering depends on the alignment of performance levels between structural and non-structural components. Even when a structure's structural elements achieve a continuous or immediate occupancy performance level following a seismic event, the failure of non-structural elements and architectural components can lower the performance level of the entire building system. This reduction in performance brought on by the susceptibility of non-structural components has been observed in a variety of structures during earthquakes. Therefore it is necessary to perform dynamic testing of cellular lightweight concrete to be used as non-structural members of buildings[90].

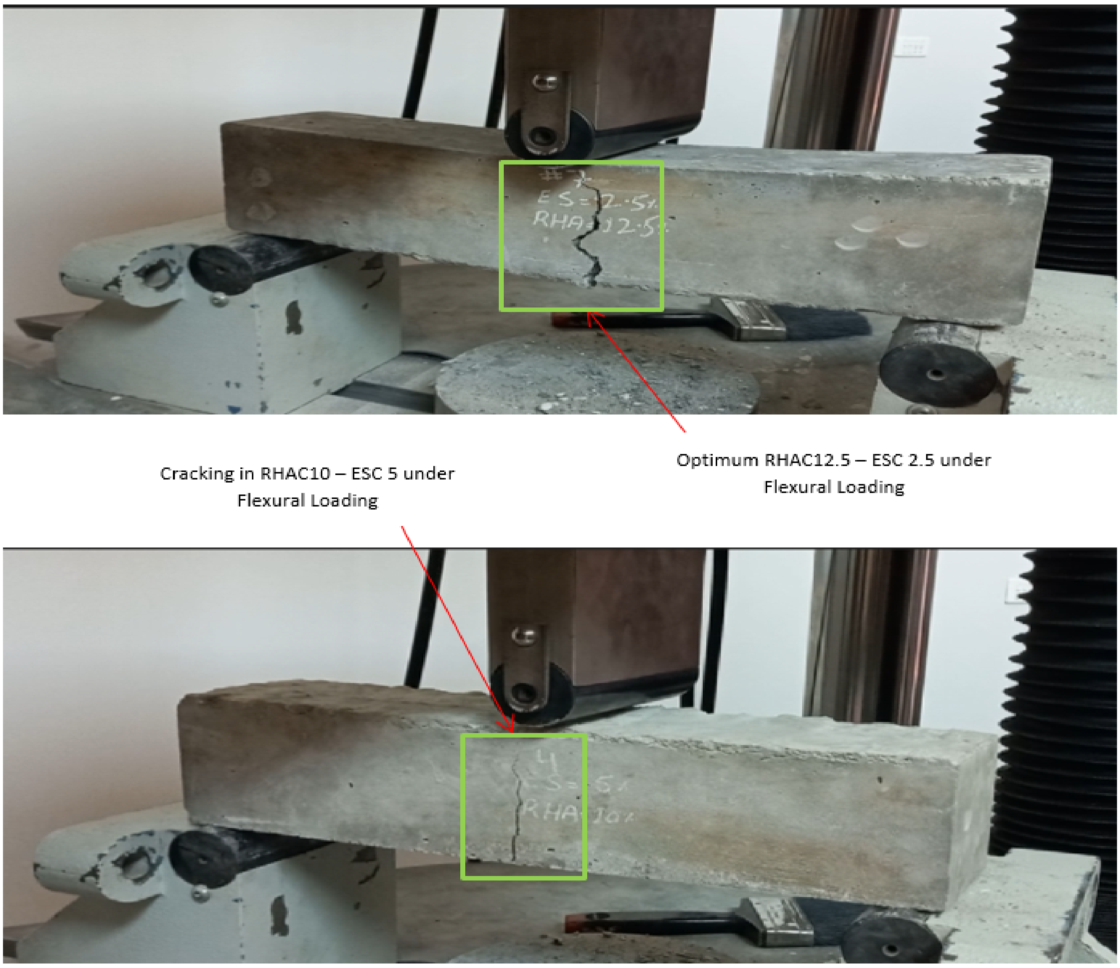

FIGURE 4.4: Beamlets Under Fluxural Loading

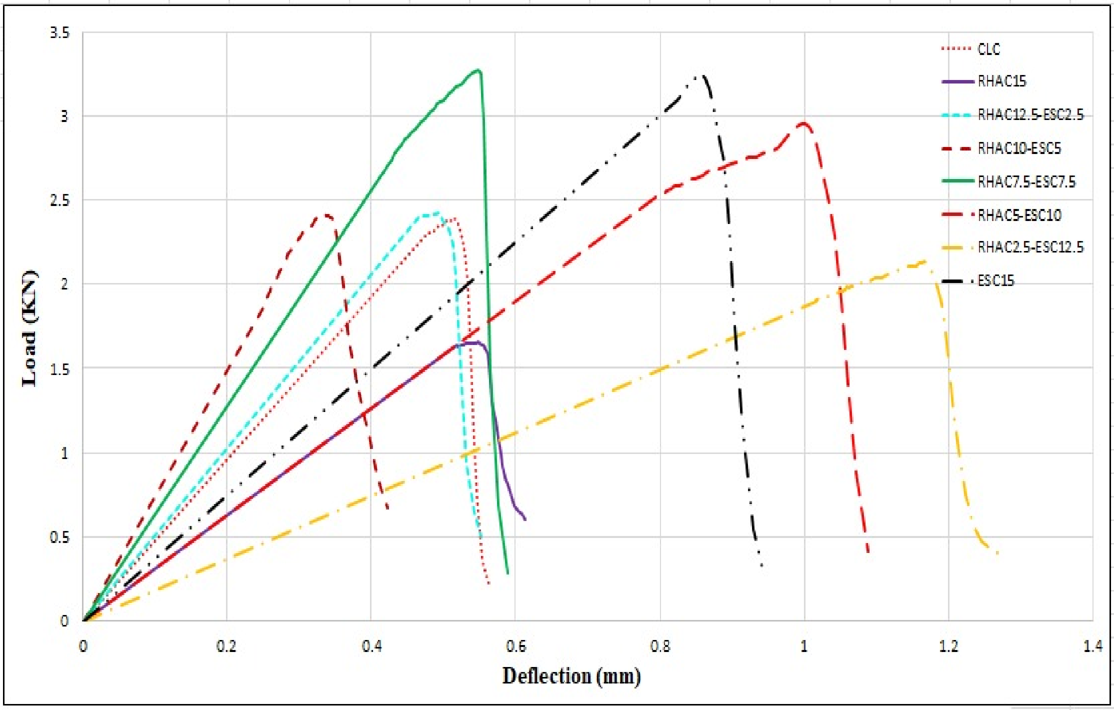

FIGURE 4.5: Flexural Response of all Mix Designs

Table 4.2: Compressive and Flexural Properties of PC and RHAC-ESCs

Concrete Type	Parameters: Compression Properties						Flexural Properties					
	CS (MPa)	**MOE** (GPa)	**CE1** (MJ/m^3)	**CE2** (MJ/m^3)	**CTE** (MJ/m^3)	**CTI** (-)	**FS** (MPa)	**Δ** (mm)	**FE1** (Nm)	**FE2** (Nm)	**FTE** (Nm)	**FTI** (-)
PCLW	**2.62**	**9.23**	**0.04**	**0.06**	**0.10**	**2.79**	**1.22**	**0.58**	**0.64**	**0.08**	**0.72**	**1.13**
	± 0.3	± 0.5	± 0.01	± 0.01	± 0.01	± 0.02	± 0.2	±0.02	± 0.01	± 0.01	± 0.01	± 0.1
RHAC15	**2.55**	**9.1**	**0.03**	**0.06**	**0.09**	**2.80**	**0.84**	**0.63**	**0.47**	**0.07**	**0.54**	**1.15**
	± 0.2	± 0.4	± 0.01	± 0.01	± 0.01	± 0.03	± 0.1	±0.03	± 0.01	± 0.01	± 0.01	± 0.1
RHAC12.5-	**3.78**	**11.08**	**0.05**	**0.09**	**0.14**	**2.80**	**1.23**	**0.57**	**0.62**	**0.12**	**0.74**	**1.20**
EGC2.5	± 0.4	± 0.5	± 0.01	± 0.01	± 0.01	± 0.02	± 0.1	±0.02	± 0.01	± 0.01	± 0.02	± 0.1
RHAC10-	**5.04**	**12.79**	**0.09**	**0.07**	**0.16**	**1.78**	**1.22**	**0.43**	**0.42**	**0.18**	**0.60**	**1.43**
EGC5	± 0.2	± 0.6	± 0.01	± 0.01	± 0.01	± 0.02	± 0.2	±0.01	± 0.01	± 0.01	± 0.01	± 0.1
RHAC7.5-	**3.12**	**10.06**	**0.06**	**0.07**	**0.13**	**2.12**	**1.66**	**0.59**	**0.95**	**0.10**	**1.05**	**1.11**
EGC7.5	± 0.2	± 0.6	± 0.01	± 0.01	± 0.01	± 0.02	± 0.2	±0.02	± 0.02	± 0.01	±0.02	± 0.1
RHAC5-	**3.97**	**11.35**	**0.04**	**0.06**	**0.10**	**2.60**	**1.5**	**1.09**	**1.55**	**0.33**	**1.88**	**1.21**
EGC10	± 1.0	± 0.6	± 0.01	± 0.01	± 0.01	± 0.01	± 0.1	±0.05	± 0.01	± 0.01	± 0.03	± 0.1
RHAC2.5-	**5.66**	**13.56**	**0.05**	**0.14**	**0.19**	**3.80**	**1.09**	**1.26**	**1.27**	**0.08**	**1.35**	**1.06**
EGC12.5	± 0.3	± 0.5	± 0.01	± 0.01	± 0.01	± 0.02	± 0.1	±0.1	± 0.03	± 0.01	±0.03	± 0.1
EGC15	**4.03**	**11.44**	**0.05**	**0.067**	**0.117**	**1.94**	**1.65**	**0.95**	**1.38**	**0.26**	**1.64**	**1.19**
	± 0.3	± 0.4	± 0.01	± 0.01	± 0.01	± 0.01	± 0.2	±0.1	± 0.02	± 0.01	± 0.2	± 0.1

4.4 Dynamic Properties

The analysis of dynamic characteristics aims to assess how the qualities of cellular light weight concrete specimens are influenced with the addition of rice husk ash and egg shell powder as a partial replacement of cement. The dynamic attributes of these concrete specimens are determined using the ASTM C215-14 standard. Table 4.3 represents the computed dynamic characteristics of the PCLW, RHAC-15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC-15. To obtain representative results for each specimen's dynamic property, an average is calculated from two measurements. The discrepancies in damping ratios () between all the specimens are minimal. For cubes the damping ratio of RHAC15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC15 is decreased by 60%, 3%, 2%, 2%, 8%, 9%, and 19% respectively. In the case of RHAC15, there is a maximum decrease of 60% as compared to all other specimens that show values ranging from 2% to 19%, because of the similar nature of the ingredients of the mix design. The damping ratios of RHAC15, RHAC12.5-ESC2.5, RHAC10-ESC5, RHAC7.5- ESC7.5, RHAC5-ESC10, RHAC2.5- ESC12.5 and ESC15 are increased by 5%, 45%, 39%, 37%, 35%, 34% and 32% respectively for the beamlets. Except RHAC15 which shows an increase of 5% all other specimens show very similar values ranging from 32% to 45% maximum.

These dynamic properties make cellular lightweight concrete a preferred choice in a wide range of construction applications, from residential buildings to infrastructure projects, where lightweight, insulation, and resilience are key considerations. As non-structural elements of a building like partitioning walls contribute up to 35% in the case of seismic loading. The reduction in performance caused by the vulnerability of non-structural components has been observed in several buildings during earthquakes and non-structural damage can limit the functionality of critical facilities, such as hospital buildings. Therefore non-structural elements need to be tested for dynamic properties during the construction of the building so that they can perform better in case of seismic loading.

TABLE 4.3: Dynamic Properties of PC and RHAC-ESC

Concrete Specimen Type	Parameters RFL (Hz)	 RFT (Hz)	 RFR (Hz)	 ζ (%)	 Ed (GPa)	 Rd (GPa)	 Poisson Ratio (-)
Cylinders*							
PCLW	3331±44	3347±45	3288±22	2.98±0.104	3.30±0.040	3.40±0.165	0.42±0.005
RHAC15	3352±23	3388±48	3252±23	1.28±0.058	3.28±0.019	3.01±0.045	0.37±0.008
RHAC 12.5-ESC 2.5	3306±23	3337±23	3275±44	2.93±0.056	2.70±0.015	3.91±0.006	0.43±0.005
RHAC 10-ESC 5	3535±89	3255±42	3263±65	2.83±0.203	2.68±0.014	3.80±0.022	0.41±0.015
RHAC 7.5-ESC 7.5	3378±22	3284±82	3272±28	2.81±0.211	3.10±0.035	3.00±0.033	0.39±0.003
RHAC 5-ESC 10	3435±89	3154±42	3163±65	2.63±0.203	2.48±0.014	3.60±0.022	0.38±0.015
RHAC 2.5-ESC 12.5	3288±22	3181±82	3172±28	2.61±0.211	3.00±0.035	2.91±0.033	0.36±0.003
ESC 15	3312±52	3105±66	3102±62	2.49±0.017	3.00±0.023	2.70±0.748	0.36±0.012
Beamlets**							
PCLW	3285±88	3331±67	3296±26	1.66±0.022	19.3±1.785	24.6±0.645	0.50±0.004
RHAC15	3338±65	3254±66	3192±35	1.67±0.051	20.3±1.151	24.3±0.412	0.48±0.003
RHAC 12.5-ESC 2.5	3145±25	3240±38	3232±57	2.95±0.052	19.6±0.486	25.5±0.002	0.51±0.010
RHAC 10-ESC 5	3188±38	3318±28	3198±86	2.63±0.057	20.3±0.745	23.9±0.112	0.47±0.018
RHAC 7.5-ESC 7.5	3252±78	3308±98	3257±24	2.58±0.033	20.5±0.552	22.6±0.052	0.44±0.014
RHAC 5-ESC 10	3335±89	3260±55	3305±36	2.52±0.014	20.9±0.912	22.3±0.122	0.45±0.012
RHAC 2.5-ESC 12.5	3178±38	3218±28	3108±86	2.43±0.057	18.1±0.745	21.9±0.112	0.41±0.018
ESC 15	3222±78	3208±98	3157±24	2.38±0.033	18.5±0.552	20.6±0.052	0.35±0.014

4.5 Fractured Internal Surface of Specimens

The fractured internal surfaces of two samples RHAC 12.5- ESC 2.5 and RHAC 7.5- ESC 7.5 are shown in Figure 4.6. It can be seen clearly that the internal surface of cellular lightweight concrete has numerous air voids that range between a few micrometers to a few millimeters which is the basic reason for the huge reduction of the density of cellular lightweight concrete. From the figure broken pumice aggregate can also be seen that is white colour and contains pours as well, which depicts that these pumice stones are obtained from some kind of volcanic eruption. Hence from these pictures, we come to know about the internal structure of cellular lightweight concrete that is extremely porous.

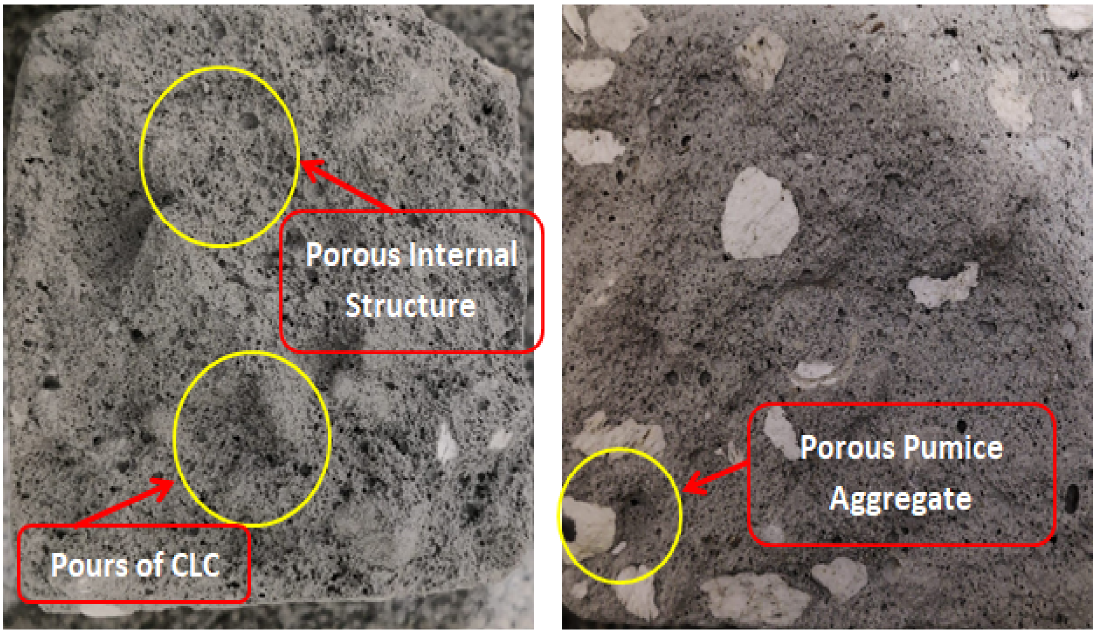

FIGURE 4.6: Fractured Internal Surfaces of RHAC 12.5-ESC 2.5 and RHAC 7.5-ESC 7.5

4.6 Summary

In this chapter, the combined effect of eggshell powder and rice husk ash along with pumice stone is discussed. Different proportions of these waste materials were utilized to substitute cement content up to a maximum percentage of 15% with an individual percentage of: 2.5%, 5%, 7.5%, 10%, and 12.5%. The findings regarding compressive and flexural strength, as well as toughness, along with an assessment of various other properties, encompassing both fresh and hardened states are also discussed in this chapter. The dynamic properties of cellular lightweight concrete are investigated because the dynamic response of numerous structures was shown to be significantly influenced by non-structural components, as demonstrated by the experimental analysis of these structures. These results show that non-structural aspects must be explicitly taken into account for any structure to be accurately represented.

Chapter 5

Guidelines for Practical Implementation

5.1 Background

The results were obtained after conducting physical and mechanical tests on samples of all blends. The amount of eggshell powder and rice husk ash varied in proportion of 2.5%, 5%, 7.5%, 10%, 12.5%, and 15% in an alternative combination of each other. The outcomes of the physical and mechanical tests reveal the combined impact of ESP and RHA as partial replacements for cement in cellular lightweight concrete (CLC). The data obtained from the aforementioned tests is used to determine the most efficient mixture. This chapter also provides a thorough discussion of the practical implementation of this study and the optimized blend.

5.2 Optimization of Cellular Lightweight Concrete

Table 5.1 gives the maximum and minimum values obtained from mechanical and dynamic tests. Infrastructure advancement has seen the incorporation of novel construction materials within the sector. Among these materials is Lightweight concrete, which can be categorized into two types: cellular concrete and lightweight aggregate concrete. This concrete offers versatility, as it can be tailored for various purposes, including low-strength applications with a density below 800 Kg/m^3, medium-strength applications with densities ranging from 800 Kg/m^3 to 1200 Kg/m^3, and structural applications with densities ranging from 1200 Kg/m^3 to just under 2000 Kg/m^3 [73]. The advancement of performance-based earthquake engineering depends on the alignment of performance levels between structural and non-structural components. Even when a structure's structural elements achieve a continuous or immediate occupancy performance level following a seismic event, the failure of nonstructural elements and architectural components can lower the performance level of the entire building system. This reduction in performance brought on by the susceptibility of non-structural components has been observed in a variety of structures during earthquakes. Therefore it is necessary to perform dynamic testing of cellular lightweight concrete to be used as non-structural members of buildings[90].

Non-structural elements can significantly affect a structure's stiffness and dynamic response, according to recent experimental research on the real dynamic response of buildings The dynamic properties of cellular lightweight concrete are investigated because the dynamic response of numerous structures was shown to be significantly influenced by non-structural components, as demonstrated by the experimental analysis of these structures. These results show that non-structural aspects must be explicitly taken into account for any structure to be accurately represented. Non-structural elements can have a considerable effect on the dynamic responsiveness of floor systems in buildings. In the process of determining thin floor systems' dynamic characteristics. It was shown that non-structural factors contributed most to structural stiffness when compared to other metrics such as Young's modulus. It was discovered that internal walls can significantly improve the stiffness and damping of flooring [89]. The impact of rice husk ash, on concrete strength when used as a substitute for cement by using 15% rice husk ash as a cement substitute resulted in a significant 26% increase in compressive strength at the 28-day curing mark.

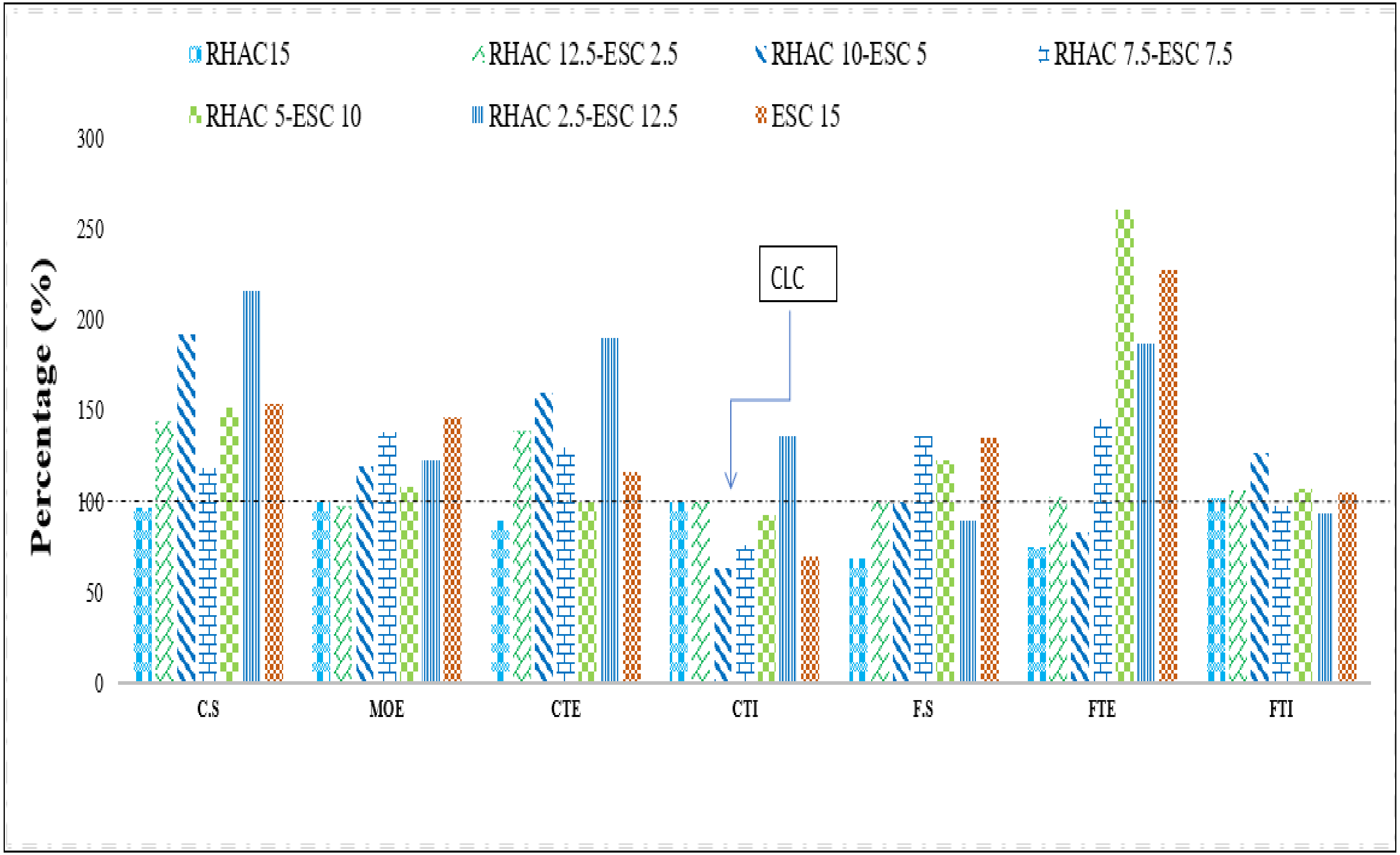

FIGURE 5.1: Dynamic Properties of PCLW, RHAC and ESC

Table 5.1: Optimization of RHA and ESP

Concrete Type	Parameters														
	Compression Properties						**Flexural Properties**						**Dynamic**		
	CS (MPa)	**MOE** (GPa)	**CE1** (MJ/m3)	**CE2** (MJ/m3)	**CTE** (MJ/m3)	**CTI** (-)	**FS** (MPa)	(mm)	**FE1** (Nm)	**FE2** (Nm)	**FTE** (Nm)	**FTI** (-)	**ζ** (%)	**Ed** (GPa)	**Rd** (GPa)
CLC	**2.62**	**9.23**	**0.04**		**0.10**	**2.79**	**1.22**			**0.08**	**0.72**	**1.13**	**1.66**	**19.3**	**24.6**
	± 0.3	± 0.5	± 0.01	± 0.01	± 0.01	± 0.02	± 0.2	±0.02	± 0.01	± 0.01	± 0.01	± 0.1	±0.022	±1.785	±0.645
Minimum values	**2.55**	**9.1**	**0.03**		**0.09**	**2.80**	**0.84**			**0.07**	**0.54**	**1.15**	**1.67**	**20.3**	**24.3**
	± 0.2	± 0.4	± 0.01	± 0.01	± 0.01	± 0.03	± 0.1	±0.03	± 0.01	± 0.01	± 0.01	± 0.1	±0.051	±1.151	±0.412
	RHAC15						**RHAC15**						**RHAC15**		
Maximum values	**5.66**	**13.56**	**0.05**		**0.19**	**3.80**	**1.66**			**0.08**	**1.05**	**1.11**	**2.95**	**19.6**	**25.5**
	± .3	± 0.5	± 0.01	± 0.01	± 0.01	± 0.02	± 0.2	±0.1	± 0.03	± 0.01	±0.02	± 0.1	±0.052	±0.486	±0.002
	RHAC2.5-EGC12.5							**RHAC7.5-EGC7.5**					**RHAC2.5-EGC12.5**		

Furthermore, when 20% of rice husk ash was used as a replacement, there was an equivalent or slightly higher increase of approximately 2% and 3% in strength observed at 56 and 91 days of curing, respectively. [30], [44]. Rice husk ash as 5% cement replacement would increase 12% strength. However, the strength starts to decrease with the increasing percentage of rice husk ash. The decreasing flexural strength might be due to the effect of hydration [45]. The result of the flexural strength showed an increase in strength with 10% and 20% replacement of rice husk [24]. Figure 5.1 shows the comparative result of mechanical and dynamic properties of cellular lightweight concrete.

5.3 Real Life Application

Cellular Lightweight Concrete (CLC) is a very unique construction material that offers several advantages, including lower density, improved insulation properties, and reduced environmental impact compared to traditional concrete. When combined with partial replacements of rice husk ash and eggshell powder, CLC can be used in various real-life applications. CLC blocks and panels are lightweight and have good thermal insulation properties. By incorporating rice husk ash and eggshell powder, we can enhance the material's sustainability and reduce its environmental footprint. These blocks and panels can be used in residential, commercial, and industrial construction.

Cellular lightweight concrete mixed with rice husk ash and eggshell powder can be used as an excellent insulating material for roofs. It helps in maintaining comfortable indoor temperatures by reducing heat gain in hot climates and heat loss in cold climates. This application can lead to significant energy savings in heating and cooling. Cellular lightweight concrete with the mentioned additives can be used as an effective soundproofing material. It is especially useful in applications where noise reduction is critical, such as theaters, recording studios, or residential walls shared between apartments. Cellular Lightweight blocks incorporating rice husk ash and eggshell powder can be used for pavements and walkways. Their lower weight reduces the overall load on the ground, making them suitable for areas with weak soil conditions. CLC can be molded into various shapes and sizes, making it suitable for decorative architectural elements like cornices, columns, and façades. Adding rice husk ash and eggshell powder can give these elements a unique texture and appearance.

As per IS Code 3495 Part-1; The minimum Compressive strength of first class fly ash brick is 10MPa, while the minimum compressive strength of second class fly ash brick is 7.5MPa. The minimum compressive strength for cellular lightweight concrete that is obtained for this experimental work is 2.55MPa and the maximum compressive strength obtained is 5.66MPa respectively. In areas with soft or marshy soils, CLC blocks with enhanced stability due to additives can be used for bridge abutments and embankment construction. The reduced weight of CLC can also reduce the overall load on the bridge structure.

Incorporating rice husk ash and eggshell powder into CLC promotes sustainability by utilizing waste materials. This not only reduces the environmental impact but also lowers the cost of production. CLC blocks with added materials can be used for fencing and boundary walls around residential and industrial properties. Their lightweight nature makes them easy to handle and install. CLC blocks with these additives can be used in agricultural settings for constructing animal enclosures, storage sheds, and farm buildings. The insulating properties help in maintaining stable internal temperatures. It can also be used in repair and rehabilitation projects, especially in situations where the existing structure's load-bearing capacity needs to be considered.

When using CLC with partial replacement of rice husk ash and eggshell powder, it's essential to conduct material testing and ensure that the mix meets the required properties and thermal performance standards for specific applications. Proper engineering and construction practices should always be followed to ensure the safety and durability of the structures.

5.4 Summary

Cellular lightweight concrete (CLC) is a versatile construction material known for its low density and high insulation properties. Its utilization in various applications, such as building construction and insulation, significantly reduces non-structural weight and energy consumption. CLC's eco-friendly nature, combined with its excellent thermal performance, makes it a sustainable choice for modern construction projects, contributing to energy efficiency and reduced environmental impact. Incorporating rice husk ash and eggshell powder in cellular lightweight concrete offers a sustainable approach to enhance its properties. The rice husk ash acts as a pozzolanic material, improving the concrete's strength and durability, while the eggshell powder contributes to its lightweight characteristics. This combination not only reduces the environmental footprint but also enhances the insulation and thermal properties of the concrete. Overall, the utilization of these waste materials presents a promising solution for producing eco-friendly, lightweight, and efficient construction materials

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Cellular lightweight concrete is prepared in this research work is for non-structural elements of the buildings, to reduce the dead load of structure by replacing the conventional concrete with this relatively new type of concrete having less density. This concrete is prepared with the help of pumice stone and varying percentages of waste materials like rice husk ash and eggshell powder are used in combination as a partial replacement of cement. The idea was developed to make the structure more cost-effective and environmental friendly by adopting a sustainable approach. Eight types of different mix designs are prepared with proper supervision and results are compiled for the different types of tests performed for evaluation of quality of these mix designs. The results of these tests are compiled and discussed below:

- All the mix design that are prepared of cellular lightweight concrete possess very high slump value that ranges from 241mm for RHAC 12.5-ESC 2.5 to 282mm for normal CLC mix, because of the presence of foam in the blend of concrete and due to high W/C ration of concrete.

- Because of the presence of low density material like pumice, RHA, ESP and due the presence of pores created by foam, all the mix designs shows very low density. Among all RHAC 12.5-ESC 2.5 shows the highest value of harden density i.e. 958Kg/m3 and minimum value of harden density is shown by 819 Kg/m3. The difference in the densities of CLC is due to the behavior of foaming agent that tends to settle down with the passage of time hence causing an increase the density of concrete.

- This is the property of CLC as compared to the conventional concrete to absorb more amount of water therefore; in this research work the prepared CLC has shown high values of absorption. Among all the samples, RHAC 12.5-ESC 2.5 showed the minimum amount of absorb water i.e., 9.42% and on the other hand RHAC has shown the maximum absorption water value i.e. 15.87%.

- The compressive strength of cellular lightweight concrete is very low as compared to conventional concrete because of the presence of air voids and due to the porous pumice stone RHAC 12.5-ESC 2.5 shows the maximum compressive strength of 5.66 MPa, on the other hand, CLC and RHAC15 shows a reduction of 54% and 55% respectively. This shows that the combination of rice husk ash and eggshell powder is useful in the increment of compressive strength of CLC.

- RHAC2.5-ESC12.5 absorbs the highest amount of energy and also depicts the highest amount of compressive toughness index again showing that a combination of rice husk ash and eggshell powder is beneficial for enhancement of properties of CLC. The lowest compressive toughness index is noted for RHAC10-ESC5.

- For the flexural strength test, it is noted that the maximum load is taken by RHAC7.5-ESC 7.5 i.e. 1.66 MPa, followed by ESC15 and RHAC 5-ESC 10 with 1.65 MPa and 1.5 MPa. On the other hand, RHAC15 shows the minimum amount of load that is 0.84 MPa.

- In the case of flexural absorbed energies cellular lightweight concrete shows some bridging effect due to the presence of pumice stone and air voids that are created due to foam in CLC. Therefore CLC absorbs some sort of energy after the cracking also. Flexure toughness index is highest for RHAC 10-ESC 5 i.e. 1.43 and RHAC2.5- ESC shows the minimum amount of flexural toughness i.e. 1.06.

- In case of dynamic loading RHAC 12.5- ESC 2.5 shows the maximum value of damping ratio there for it is recommended as per dynamic testing. So, overall from all testing results it is concluded that rice husk ash and eggshell powder when used in a combination of each other then it performs well in compressive, flexural and dynamic testing. In in most case the lower quantity of one additive reacts better with higher quantity of other additive as cement replacement.

6.2 Future Works

Keeping in view the research on cellular lightweight concrete (CLC) using pumice, foam, rice husk ash (RHA), and eggshell powder, we can produce non-structural concrete that will take us towards sustainable and innovative construction materials. Future works for this research work is listed below along with two titles of next MS Thesis.

- To utilize Wheat Straw Ash and Eggshell Powder to Enhance the Mechanical and Dynamic Properties of foam concrete. .

- To produce cellular lightweight blocks by use of Rise husk ash and eggshell powder.

- To produce cellular lightweight concrete for façade work by utilizing bagasse ash and Eggshell Powder .

- To test the blocks of size 4"x8"12" or 6"x8"x12" or any other suitable size with actual ratios.

- A study should be conducted, to prepare cellular lightweight concrete with a ratio of 1:2:3 but different mix designs to increase the density and hence improve the strength of CLC. .

- Chemical testing of eggshell powder and rice husk ash is recommended to validate the incorporation of these materials in CLC.

- Investigation for the thermal properties of CLC with pumice, RHA, and eggshell powder, including thermal conductivity, specific heat, and thermal insulation capabilities.

- Conduct a life cycle assessment (LCA) to evaluate the environmental impact of CLC using these materials compared to traditional concrete. Assess factors such as energy consumption, carbon emissions, and resource usage.

- Investigate the compatibility of pumice, RHA, and eggshell powder with various fibers and pozzolanic materials to enhance specific properties of CLC.

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