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Structural Stability and Strength Analysis of Lightweight Cellular Concrete

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Abstract: *Concrete is most important construction materials. Concrete is a material used in building construction, consisting of a hard, chemically inert particulate substance, known as an aggregate that is bonded together by cement and water. Lightweight concrete maintains its large voids and not forming laitance layers or cement films when placed on the wall. This research was based on the performance of aerated lightweight concrete. Lightweight Cellular Concrete (LCC), known for its low density and thermal insulation properties, is increasingly used in modern construction. However, concerns remain regarding its structural stability and mechanical strength, especially when modified with foam agents and recycled materials. The incorporation of waste crushed CLC (Cellular Lightweight Concrete) blocks as a partial replacement for fine aggregates presents a sustainable solution to construction waste, but its impact on the structural performance of LCC is not fully understood. This study aims to analyze the structural stability and strength characteristics of LCC modified with varying proportions of foam agent and crushed CLC waste, to determine optimal mix ratios that balance sustainability with performance*

Keywords: CLC, Lightweight Cellular Concrete, waste, foam agents, Concrete, Compressive Strength

I. INTRODUCTION

Concrete is most important construction materials. Concrete is a material used in building construction, consisting of a hard, chemically inert particulate substance, known as an aggregate that is bonded together by cement and water. In upcoming years there has been an increasing worldwide demand for the construction of buildings, roads and an airfield which has mitigate the raw material in concrete like aggregate. In some ruler areas, the huge quantities of aggregate that have already been used means that local materials are no longer available and the deficit has to be made up by importing materials from other place. Therefore, a new direction towards Cellular Lightweight Concrete in building and civil engineering construction is used.

Lightweight concrete maintains its large voids and not forming laitance layers or cement films when placed on the wall. This research was based on the performance of aerated lightweight concrete. However, sufficient water cement ratio is vital to produce adequate cohesion between cement and water. Insufficient water can cause lack of cohesion between particles, thus loss in strength of concrete. Likewise, too much water can cause cement to run off aggregate to form laitance layers, subsequently weakens in strength

CLC Waste Block

Cellular Light Weight Concrete (CLC) is also known as a Foam Concrete. Cellular Light Weight Concrete (CLC) is a very light in weight that is produced like normal concrete under ambient conditions. CLC Blocks area cement bonded material made by blending slurry of cement. It very lightweight with density ranging from 300 to 1800 kg/m3. Which was three times less weight than fly ash or clay brocks. It is Environment-friendly. Foam concrete is made by eco-friendly material as fly ash and other industrial waste material are used in part of manufacturing blocks to protect the environment. The production process of Foam concrete or its use does not release any harmful effluents to water, ground or air.

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Fig 1 CLC Waste Block

Concrete Foaming Agent

A concrete foaming agent is a chemical substance used to produce foam in concrete, resulting in a lightweight and insulating material. The foam is typically created by mixing the foaming agent with water and air, which is then incorporated into the concrete mix. This process helps in reducing the overall weight of the concrete while maintaining its structural integrity and providing additional benefits like thermal and acoustic insulation. Marjanol Concrete Foaming Agent is a specific brand of concrete foaming agent designed to create lightweight and durable foamed concrete. Like other foaming agents, it is used to produce foam, which is incorporated into concrete to reduce its density while maintaining essential properties like strength and insulation

Fig 2 Marjanol Foaming Agent- (389 Rs / liter)

II. REVIEW OF LITERATURE

Zdenek P. Bazant et. al. (2000). The paper provides a comprehensive overview of structural stability, covering a wide range of topics including elastic and inelastic behavior, static and dynamic responses, linear and nonlinear systems, energy methods, thermodynamic considerations, creep, and instability caused by damage or fractures. It highlights the significance of stability analysis across different engineering and scientific disciplines and briefly traces the development of the field. Major achievements are summarized, with a particular focus on recent advances in analyzing damage localization and fracture-related instability. The paper includes a selective list of references to support the discussion.[1]

Dhiraj Bhople et. al. (2021) This paper focuses on Cellular Lightweight Concrete (CLC), also known as Foamed Concrete, which is increasingly used in construction due to its many advantages over traditional concrete. CLC is made by mixing Portland cement, sand (with or without fly ash), and a stable foam, resulting in a material with a significantly lower density (ranging from 300 kg/m³ to 1850 kg/m³) compared to regular cement. The foam creates millions of small voids or air bubbles throughout the concrete, making it lightweight while maintaining comparable quality to regular concrete blocks. CLC is available in various densities, typically from 400 kg/m³ to 1,800 kg/m³. This paper examines CLC blocks with a smaller thickness compared to traditional blocks, and explores the potential cost savings in structural design, particularly in terms of dead load reduction. The research also identifies significant savings in steel usage due to the lighter weight of CLC blocks, with the shaft portion of the structure weighing just 8.635 kg.[2]

Devansh Jain et. al. (2019) Cellular Lightweight Concrete (CLWC) is a new material made by incorporating foam into a cement-based mix, resulting in varying densities from 300 kg/m³ to 1850 kg/m³. It is commonly used in non-load bearing elements, insulation, and partition walls due to its light weight but lower strength compared to conventional concrete. To improve its strength, materials like fly ash and silica fume are added. This study explores the mechanical and physical properties of CLWC, including dry density, water absorption, and compressive strength, by varying fly ash content (50%-80%) and reducing cement content (50%-20%). Foam content is adjusted to achieve target densities, and silica fume is added to further enhance the mix's properties.[3]

Anubhav Kumar Hindoriya et. al. (2016) Light weight cellular concrete is not a new technology, its first use recorded in early 1920s. Its applications are limited due least knowledge about its properties and stability. Light weight cellular concrete is type of aerated concrete having cellular structure in it which makes it lighter, good thermal and sound insulator material. This paper is attention to study the properties, applications and production method of light weight cellular concrete.[4]

Gagandeep et. al. (2019) Lightweight concrete is increasingly used in various structural applications due to its numerous advantages, including reduced dead load, smaller structural member dimensions, and lighter pre-cast elements that are easier and cheaper to handle, cast, and transport. It also offers more usable space, lowers the risk of earthquake damage, and provides better thermal insulation and fire resistance. This dissertation focuses on studying the properties of cellular lightweight concrete blocks, which are made with 65% fly ash and 35% cement, with 1.5% foam content by total weight. To enhance its strength, sand and quarry dust are added, replacing up to 30% of the fly ash at 5% intervals.[5]

Vikash Bhatt et. al. (2023) The usage of cellular light weight concrete blocks in civil engineering gives a best solution to building construction industry. CLC Blocks gives a better solution to reduce the dead weight of the building. This paper gives an attempt to made, the study on characteristic strength of CLC based on different proportion of their composite materials and recommend as it can be used in construction industry. It also gives an idea about Ratio and Density by which CLC may characterise according to IS2185 (PART-4) 2008.[6]

Riyal Yadav et. al. (2023) Foam concrete, also known as lightweight cellular concrete or low-density cellular concrete, is defined as a cement-based slurry with at least 20% foam by volume mixed into the plastic mortar. It typically has a density ranging from 400 kg/m³ to 1600 kg/m³, as no coarse aggregates are used in its production. The density is controlled by replacing part or all of the fine aggregate with foam. Foam concrete reduces the dead weight of structures, with compressive strength ranging from 6 MPa to 14 MPa. The air bubbles formed during mixing enhance its strength as the concrete sets and dries. Foam concrete offers several benefits, including reduced structural dead load, energy conservation, lower production and labor costs, and easier transportation. This paper provides a comprehensive review of foam concrete, covering its components, preparation, and key properties such as drying shrinkage, compressive strength, and durability, with the aim of addressing consumer concerns and promoting wider adoption of foam concrete in civil engineering.[7]

Susan Tighe et. al. (2020) Protecting the pavement subgrade to extend the service life of road pavements is a key area of research. Lightweight Cellular Concrete (LCC), a sustainable material made with industrial by-products, has emerged as a promising alternative for pavement subbases due to its low weight and ease of use. This paper reviews the potential application of LCC as a subbase material, focusing on important properties such as modulus of elasticity, compressive and tensile strength, water absorption, and freeze-thaw resistance. It also examines its use in Canada, considering local design methods. The study identifies limitations and gaps in the current application of LCC in pavements and provides recommendations for improving its use and performance. The review concludes that while LCC shows potential as a subbase material, further research on mechanical properties, particularly its fatigue life, and a comparative field study to monitor performance are needed for better understanding and wider adoption.[8]

Summary and Gap Identification

From detailed literature review many previous researchers study the replacement of cement by various type of cementations materials and try to improve compressive strength of concrete. Form previous studies foaming agent were used only in CLC block casting, instead of that use foaming agent with minimal percentage of cement to create light weigh concrete with conventional concrete mix design in further study. Many of the past studies on the focus about the recycled aggregate to avoid unnecessary dumped demolished concrete in fertile land. The authors found that the density of recycled concrete decreased with an increase in the rate of change of all levels of water cement, Therefore, for that examination, the CLC recycled aggregate will be mixed with cement paste and dried for two to three days then, use as a replacement.

Objectives

1. To check Feasibility of the cellular lightweight concrete for the RCC structure with varying voids %.
2. To check Strength and density of concrete after replacement of aggregate with waste CLC blocks.

III. METHODOLOGY

The methodology for Lightweight Cellular Concrete (CLC) focuses on examining the effects of varying percentages of foaming agent and waste CLC as aggregate on key mechanical properties. The analysis includes experimental tests to determine the impact on density, compressive strength with a systematic approach as outlined below.

1. **Preparation of CLC Mixes:**

- **Foaming Agent (%)**: Seven different foaming agent percentages are considered (0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, and 1.5%). Each sample is prepared by incorporating different amounts of foaming agent into the cement-based slurry, ensuring the foam is well-distributed throughout the mix.

Table 1 Mix proportion for Foaming Agent

Percentage of Foaming agent (%)	Cement (kg)	Sand (kg)	Aggregates (kg)	Water ml	Foaming agent ml
0%	1.8	2.85	5.82	810	0.00
0.25%	1.8	2.85	5.82	808	2.03
0.50%	1.8	2.85	5.82	806	4.05
0.75%	1.8	2.85	5.82	804	6.08
0.1%	1.8	2.85	5.82	809	0.81
1.25%	1.8	2.85	5.82	800	10.13
1.5%	1.8	2.85	5.82	798	12.15

- **Waste CLC as Aggregate (%)**: Seven different percentages of waste CLC as aggregate are used (0%, 10%, 15%, 20%, 25%, 30%, and 35%). The waste CLC is added as a partial replacement for natural aggregates to assess its effect on the overall performance of the concrete.

Table 2. Mix proportion for Waste CLC

Percentage of Waste CLC as Agg (%)	Cement (kg)	Sand (kg)	Aggregates (kg)	Waste CLC as Agg Approx Kg	Water ml
0%	1.8	2.85	5.82	0	810
10%	1.8	2.85	5.238	0.582	810
15%	1.8	2.85	4.947	0.873	810
20%	1.8	2.85	4.656	1.164	810
25%	1.8	2.85	4.365	1.455	810
30%	1.8	2.85	4.074	1.746	810
35%	1.8	2.85	3.783	2.037	810

2. **Mix Design:**

- **Cement and Fly Ash**: The base mix consists of a known ratio of cement and fly ash to provide a consistent matrix for comparison across the various foam and waste CLC aggregate content.

- **Water-to-Cement Ratio**: The water-to-cement ratio is kept constant across all mixes, ensuring the hydration process remains consistent for each sample.
- **Preparation of Foam**: Foam is generated using a foaming agent diluted in water, ensuring uniform consistency for accurate testing.

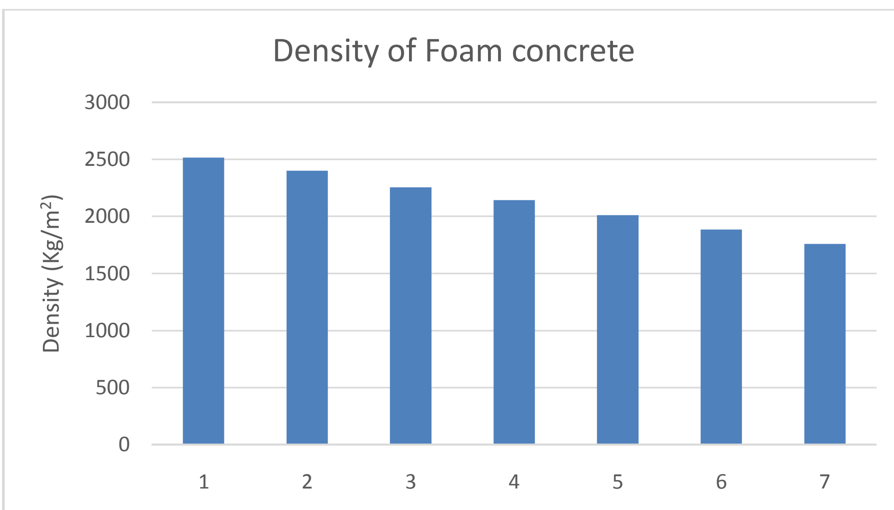
3. **Casting of Samples:**
   - Cubes and cylinders are cast using the different foam and waste CLC aggregate contents. The samples are cast in molds of standard sizes (e.g., 100mm cubes for compressive strength testing and 150mm cylinders for other tests).
   - The curing period for the samples is set at 28 days under controlled conditions (ambient temperature and humidity).
4. **Testing and Evaluation:**
   - **Density Test**: The dry density of the samples is measured using the weight-to-volume ratio to assess the impact of foaming agent and waste CLC on the density.
   - **Compressive Strength Test**: Compressive strength is determined by applying axial load to the concrete samples using a compression testing machine. The failure load is recorded, and compressive strength is calculated based on the cross-sectional area.

IV. RESULTS AND DISCUSSION

Results for Density of Foam concrete.

Table 3 Density of Foam concrete

Percentage Replacement	**0%**	**0.25%**	**0.50%**	**0.75%**	**0.10%**	**1.25%**	**1.50%**
M20 (Kg/m^2)	2515	2400	2255	2142	2012	1885.6	1759.2



Graph 1 Density of Foam concrete

The density of Foam concrete decreases with the increase in percentage addition of foaming agent by 8-12%. Hence Foam concrete can be considered as light weight concrete which results in smaller dead loads. There is Need to check strength of the cube for better understand.

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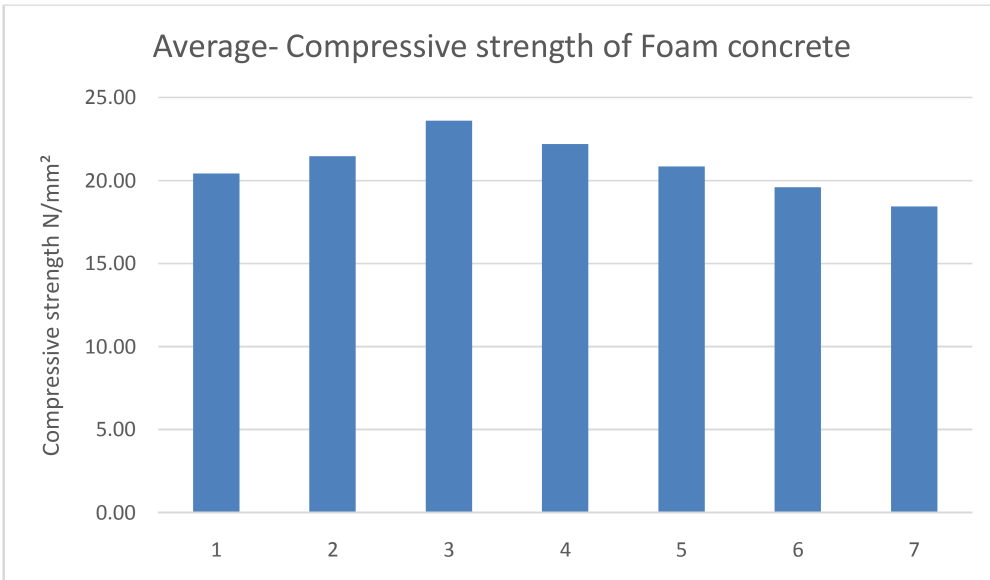
Compressive strength of Foam concrete

Table 4. Compressive strength of Foam concrete

Percentage Replacement	0%	0.25%	0.50%	0.75%	0.10%	1.25%	1.50%
Specimen 1	20.5	21.53	23.68	22.26	20.92	19.67	18.49
Specimen 2	20.09	21.96	24.15	21.81	21.34	20.06	18.12
Specimen 3	20.71	20.88	22.97	22.48	20.30	19.08	18.67
Average	20.43	21.46	23.60	22.19	20.85	19.60	18.43



Graph 2 Average- Compressive strength of Foam concrete

The above graph represents the average compressive strength of foam concrete specimens at varying foam content percentages (0%, 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, and 1.5%). From the graph, it is observed that the compressive strength of foam concrete increases steadily up to 0.5% foam content. This indicates that the incorporation of foaming agent up to this level enhances the concrete's performance, likely due to improved workability and a more uniform distribution of fine air voids without compromising the structural integrity.

However, beyond 0.5%, a noticeable decline in compressive strength is observed. As the foam content increases past this point, the presence of excessive air voids reduces the density and strength of the concrete, resulting in weaker specimens. Therefore, it can be concluded that the use of foaming agents in foam concrete is optimal up to 0.5%, and is not recommended beyond this percentage for applications where compressive strength is a key requirement.

Results for Waste Clc Blocks.

Preparation of Crushed Waste CLC Blocks

An important part of this study is the Crushed Waste CLC Blocks collected from the CLC block manufacturing industry and nearby residential and commercial construction sites. Perform sieve analysis and select Crushed blocks of up to 20 mm. Because Waste CLC Blocks is taken from a sites and it have good water absorption capacity, the CLC recycled aggregate will be mixed with cement paste and dried for two to three days then, use as a replacement. To compensate for excess water absorption, Crushed Waste CLC Blocks is coated with a 1: 4 cement slurry (a measure of cement in water).

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(a)

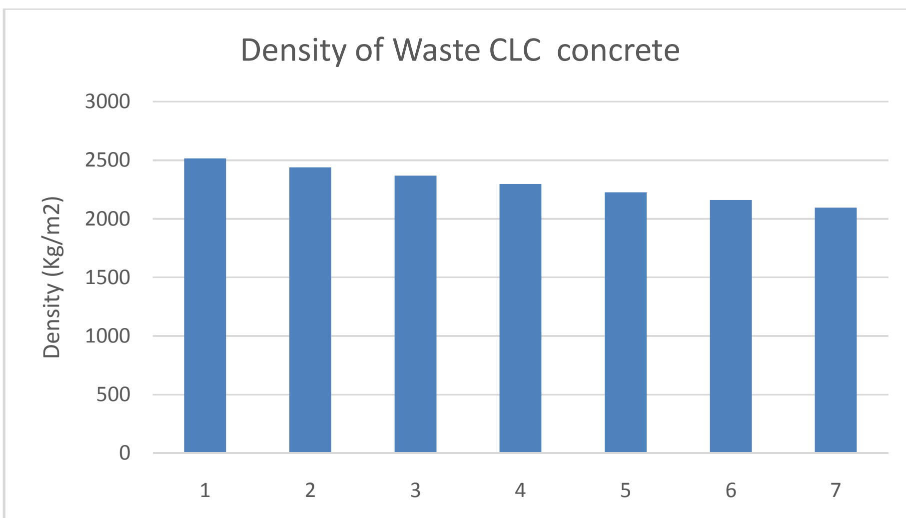

(b)

Fig 3. a) Collection of Crushed Waste CLC Blocks b) Coated with a 1: 4 cement slurry

Density of Waste CLC concrete

Table 5 Results For Density of Waste CLC concrete

Percentage Replacement	**0%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**
M20 (Kg/m^2)	2515	2439.55	2366.36	2295.37	2226.51	2159.72	2094.92



Graph 3 Density of Waste CLC concrete

The density of Waste CLC concrete decreases with the increase in percentage addition of Waste CLC by 5-6%. Hence Waste CLC concrete can be considered as light weight concrete which results in smaller dead loads. There is Need to check strength of the cube for better understand.

Compressive strength of Waste CLC concrete

Table 6 Compressive strength of Waste CLC concrete

Percentage Replacement	**0%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**
M20 (N/mm²)	20.71	21.43	22.19	22.96	22.66	22.37	22.08

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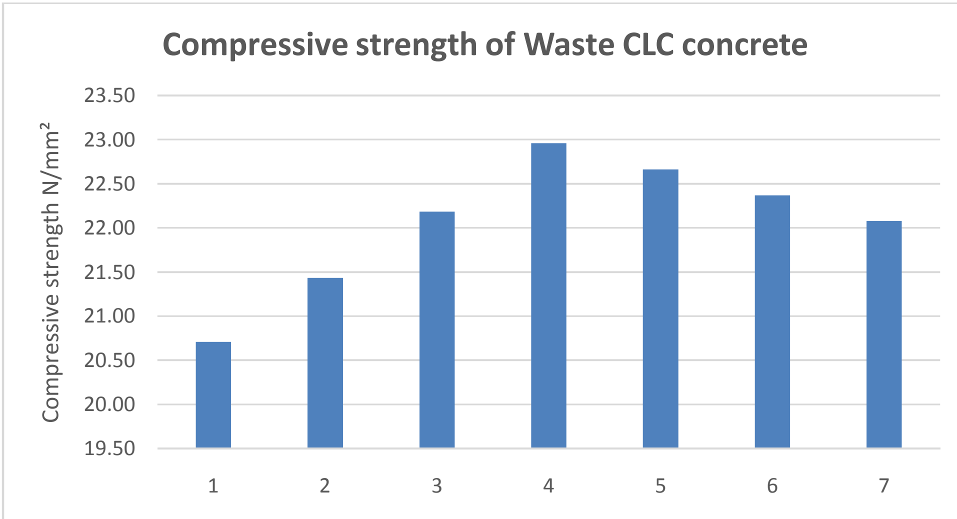

Graph 4 Compressive strength of Waste CLC concrete

The above graph illustrates the compressive strength of Waste CLC (Cellular Lightweight Concrete) concrete at different replacement levels: 0%, 10%, 15%, 20%, 25%, 30%, and 35%. From the data, it is evident that the compressive strength of Waste CLC concrete increases progressively up to 20% replacement, achieving its peak performance at this level. This suggests that incorporating waste material into the CLC mix up to 20% improves strength characteristics, likely due to better particle packing and optimized internal structure. Beyond 20% replacement, a slight decrease in compressive strength is observed. However, even at higher replacement levels (25% to 35%), the compressive strength remains higher than that of conventional concrete, indicating the continued structural viability of Waste CLC concrete

V. CONCLUSION

- The experimental study on Lightweight Cellular Concrete (LCC) focused on evaluating the structural stability and compressive strength characteristics of two types of LCC: foam concrete and Waste CLC concrete. Based on the analysis of test results, the following key conclusions are drawn:
- While both foam concrete and Waste CLC concrete provide the benefits of reduced density, Waste CLC concrete demonstrates better compressive strength and structural reliability.
- Waste CLC concrete offers a superior balance of strength, stability, and sustainability, making it more suitable for light structural applications.
- Foam concrete remains valuable for specific use cases, such as insulation layers, partition walls, and areas with minimal structural load.
- The compressive strength of foam concrete increases as the foam content rises up to 0.5%, indicating improved workability and internal structure. The optimum foam content for maintaining structural stability while achieving reduced density is identified as 0.5%.
- Lightweight Cellular Concrete can effectively replace conventional concrete in various applications where reduced weight, adequate strength, and sustainability are desired.
- Among the two, Waste CLC concrete is recommended for broader structural use, particularly when optimized at 20% replacement.
- Further studies are encouraged to explore durability, long-term performance, and cost-efficiency of LCC in real-world construction scenarios.

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