Experimental Study of Light Weight Concrete using Perlite

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***Abstract*— Structural Low Density Aggregate Concrete (LDAC) offers significant advantages in reducing the self-weight of structures and mitigating earthquake damage, as seismic forces are proportional to the mass of the structure. For structural applications of lightweight concrete, achieving a low density is often more critical than attaining high strength. A lower density at the same strength level leads to reduced self-weight, smaller foundation sizes, and lower construction costs. This study focuses on designing structural lightweight aggregate concrete using natural Perlite aggregate, aiming to reduce the dead weight of structures. The research involves comparing the strength of normal concrete with Perlite concrete by fully replacing coarse aggregate with Perlite and varying the water-cement ratio. Various tests, including compressive and split tensile tests, were conducted. The results indicate that Perlite concrete is suitable for non-load bearing and in-fill walls, significantly reducing the dead load of structures while maintaining adequate strength for these applications.**

***Index Terms*— Perlite, Low Density Concrete, Perlite Aggregate, Compressive Strength, Tensile Strength.**

I. INTRODUCTION

1.1 GENERAL

Perlite is a versatile material used across various industries, including construction, agriculture, and the medical and chemical sectors. Expanded perlite aggregate (EPA), in particular, has been integrated into construction elements such as bricks, plaster, pipes, and wall and floor blocks, though it has yet to see widespread use in concrete. Known for its lightweight and heat and sound insulation properties, EPA offers economic benefits in construction. High-temperature kilns, operating between 700–1100°C, are used to manufacture these materials, ensuring that well-burnt bricks maintain their integrity even when immersed in water. This chapter delves into the manufacturing of clay bricks and the methods for testing their suitability in building construction.

Perlite's chemical composition is as follows: 70–75% Silicon Oxide (SiO_2), 12–15% Aluminum Oxide (Al_2O_3), 3–4% Sodium Oxide (Na_2O), 3–5% Potassium Oxide (K_2O), 0.5–2% Iron Oxide (Fe_2O_3), 0.2–0.7% Magnesium Oxide (MgO), 0.5–1.5% Calcium Oxide (CaO), and 3–5% loss on ignition (chemical/combined water). Perlite finds applications in various sectors, including industries, agriculture, horticulture, building construction products, fillers, filter aids, and as a component in hot tops and risers. This paper summarizes the study of the chemical and physical properties of Perlite and its applications in India.

1.2 PERLITE

Perlite is a type of volcanic rock known for its pearly luster. When heated, it expands and becomes porous. The color of crude perlite ranges from light grey to glossy black, while expanded perlite is snowy white to greyish white. Perlite's unique characteristic is its ability to expand 4 to 20 times its original volume when heated to about 850-900°C, due to the vaporization of 2 to 5% combined water in the rock. This expansion results in a lightweight material with exceptional physical properties. Unexpanded perlite has a bulk density of around 1100 kg/m³ (1.1 g/cm³), whereas expanded perlite typically has a bulk density of about 30-150 kg/m³. Perlite is utilized in both its crude and expanded forms across various industries. The process of expansion involves crushing and screening crude perlite to different size fractions before heating.

1.3 EXPANDED PERLITE

Expanded perlite aggregate (EPA) has found applications in construction elements such as bricks, plaster, pipes, walls, and floor blocks, though it has not been extensively used in concrete. Perlite is a glassy form of rhyolitic or dacitic magma containing 2–5% water. Upon rapid heating, perlite transforms into a cellular material with low bulk density. As the chemical water within perlite boils at temperatures between 900–1,100°C, the resultant steam forms bubbles within the softened rock, creating a frothy structure. This bubbling process allows perlite to expand up to 4–20 times its original volume.

Thermal conductivity, defined as "the rate of flow of heat per unit area per unit temperature gradient under steady state conditions" (Tennent 1997), is a critical property of porous materials. The thermal conductivity of these materials depends on various factors, including the thermal properties of the constituent phases and microstructure parameters such as volume fractions, geometrical distribution, particle size and size distribution, and the geometry of individual particles.


1.4 PHYSICAL PROPERTIES OF EXPANDED PERLITE

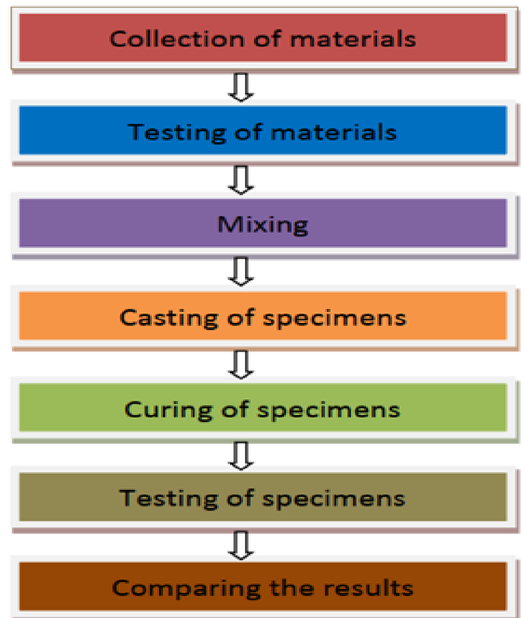
Property of EPA	Determined limits
Color	White
Specific gravity	0.28
Unit weight kg/m³	30–190
Porosity %	90
Specific heat kCal/kg °C	0.20–0.23
Melting point °C	1,300
Thermal conductivity W/mK	0.039–0.046
Thermal expansion mm/m °C	0.004–0.011

1.5 CHEMICAL PROPERTIES OF EXPANDED PERLITE

Component	Content in %
SiO_2	70.68
Al2O3	13.04
Na_2O	3.54
K_2O	4.34
Fe2O3	1.04
CaO + MgO	3.78
Other	3.38

II. METHODOLOGY

2.1. FLOWCHART



2.2. METHODOLOGY

The methodology of this project involves several key steps to ensure the successful completion and validation of the experimental work related to the manufacturing and testing of Concrete Cubes, Cylinder & Prism using specific materials.

2.2.1. *Literature review and document collection*

Conduct an extensive literature review to gather existing research, standards, and relevant documents. Collect all necessary documents and resources required to guide the experimental work.

2.2.2. *Collection of Material*

- Description: This step involves gathering all the raw materials needed to prepare the concrete mix. These typically include cement, fine aggregates (such as sand), coarse aggregates (such as gravel or crushed stone), water, and any admixtures (chemical additives) that might be required.
- Importance: The quality and properties of these materials significantly affect the final properties of the concrete, so it's crucial to source them carefully.

2.2.3. *Material Testing and Verification*

- Description: Before mixing the concrete, individual materials are tested to ensure they meet the required standards and specifications. Tests may include checking the purity of the cement, the gradation and cleanliness of the aggregates, and the quality of the water.
- Importance: Ensuring the quality of materials helps in achieving the desired properties in the final concrete mix and ensures consistency in performance.

2.2.4. *Mixing*

- Description: In this step, the collected materials are combined in specific proportions as per the mix design to form the concrete mixture. This can be done manually or using mechanical mixers to ensure a uniform mix.
- Importance: Proper mixing is essential to ensure that the cement paste coats all the aggregate particles, leading to a homogeneous and workable concrete mix.

2.2.5. *Casting of specimens*

- Description: The freshly mixed concrete is poured into molds to create test specimens, such as cubes or cylinders. The molds are filled in layers, and each layer is compacted to remove air bubbles and ensure density.
- Importance: Correct casting techniques are necessary to produce specimens that accurately represent the potential performance of the concrete in actual structures.

2.2.6. *Curing of Specimens*

- Description: After casting, the concrete specimens are allowed to cure, typically in a controlled environment with adequate moisture and temperature. This process continues for specific periods (e.g., 7 and 28 days) to allow the concrete to develop its strength and durability.
- Importance: Proper curing is crucial for the hydration process of cement, which directly affects the strength and longevity of the concrete.

2.2.7. *Testing of Specimens*

- Description: The cured concrete specimens are then subjected to various tests to measure their properties. Common tests include compressive strength tests, tensile strength tests, and flexural strength tests. These tests are usually conducted using specialized machines.
- Importance: Testing provides quantitative data on the concrete's performance, ensuring that it meets the required standards and specifications for its intended use.

2.2.8. *Comparing the Result*

- Description: The results obtained from the tests are analyzed and compared to assess the performance of different concrete mixes. This comparison helps in understanding the impact of different materials and mix designs on the concrete properties.
- Importance: Comparing results allows for the optimization of the concrete mix design for specific applications and ensures that the concrete used in construction will perform adequately under expected conditions.

This detailed process ensures that the concrete used in construction is of high quality and suitable for its intended structural applications, thereby contributing to the safety and durability of the built environment.

III. MATERIAL PROPERTIES

3.1. GENERAL

In this research, seven types of materials are used for casting construction products, which are listed and described below.

3.1.1. *Cement*

Cement is an adhesive substance used extensively in building and civil engineering construction. In a narrower sense, it refers to the binding materials that set and harden when mixed with water, forming a hard mass. This process, known as hydration, involves a chemical combination of cement compounds with water, resulting in sub-microscopic crystals or a gel-like material with a high surface area. Due to their hydrating properties, constructional cements can set and harden even under water, and are often referred to as hydraulic cements. The most commonly used hydraulic cement is Portland cement, which comes in different grades. In this study, Coromandel cement of OPC 53 Grade was used.

Table-1: Properties of Cement

Properties	Result
Initial setting time	45 minutes
Final setting time	466 minutes
Specific gravity	3.15

Fineness	8%
Consistency	30%

3.1.2. *Fine Aggregate*

Fine aggregates are natural sand particles obtained through mining processes. These aggregates consist of natural sand or crushed stone particles that are 3.75mm or smaller in size. For this study, crusher sand procured locally was used after being sieved according to Indian standards.

Table-2: Properties of Fine Aggregates

Properties	Result
Grading zone	Zone III
Water absorption	2.2
Specific gravity	2.44
Fineness modulus	2.7

3.1.3. *Coarse Aggregate*

Coarse aggregates are construction materials made from rock quarried from ground deposits. They typically consist of larger particles compared to fine aggregates. In this study, 12mm aggregate, sourced locally, was used for casting.

Table-3: Properties of Coarse Aggregates

Properties	Result
Water absorption	0.5%
Specific gravity	2.98
Fineness modulus	3.44

3.1.4. *Perlite*

Perlite is a type of volcanic rock characterized by its pearly luster. It expands and becomes porous when heated. The colour of crude perlite ranges from light grey to glossy black, whereas expanded perlite is snowy white to greyish white. A distinguishing feature of perlite, compared to other volcanic glasses, is its ability to expand 4 to 20 times its original volume when heated to about 850-900°C. This expansion occurs due to the presence of 2 to 5% combined water in crude perlite, which vaporizes upon heating, forming countless tiny bubbles. Expanded perlite is remarkably lightweight and has exceptional physical properties. Unexpanded (raw) perlite has a bulk density of around 1100 kg/m³ (1.1 g/cm³), while typical expanded perlite has a bulk density of about 30-150 kg/m³. Perlite is used in various industries in both its crude and expanded forms.

Table-4: Properties of Perlite Aggregates

Properties	Result
Size	10mm
Water absorption	1.5%
Specific gravity	0.15
Color	White
Fineness modulus	5.17

IV. MIX DESIGN

4.1. MIX DESIGN FOR M25 CONCRETE

The mix design for M25 concrete is determined following the guidelines from IS 10262-2009, considering the properties of cement, fine aggregates, and coarse aggregates. The water-cement ratios are selected to achieve the desired mix proportions and target strength.

4.1.1. *Target Strength for Mix Proportioning*

Grade Designation: M25

Target Mean Strength: f'ck= fck + 1.65s

Where fck is the characteristic compressive strength at 28 days (25 MPa) and s is the standard deviation (assumed as 4 MPa for M25 concrete).

Target Mean Strength = 25 + 1.65 × 4 = 31.6 MPa

4.1.2. *Conventional Concrete Mix Proportion*

For 1m³ of conventional concrete, the mix proportion is as follows:

- Water: 208 litters
- Cement: 411 kg
- Fine Aggregate: 721.35 kg
- Coarse Aggregate: 1098.39 kg

4.1.3. *Perlite Concrete Mix Proportion*

For 1m³ of perlite concrete, the mix proportion is adjusted to replace the coarse aggregate with perlite aggregate. The proportions are as follows

- Water: 208 liters
- Cement: 411 kg
- Fine Aggregate: 721.35 kg
- Perlite Aggregate: 655.77 kg

4.2. DETAILED STEPS FOR MIX DESIGN

4.2.1. *Target Mean Strength Calculation*

Target mean strength f'ck = 31.6 MPa

4.2.2. *Selection of Water-Cement Ratio*

Based on durability requirements and IS 456-2000, the water-cement ratio is selected as 0.50.

4.2.3. *Calculation of Cement Content*

- Cement content = Water content / Water-cement ratio

- Cement content = 208 liters / 0.50 = 416 kg/m³ (rounded to 411 kg/m³ for practical purposes)

4.2.4. *Calculation of Aggregate Content*
- Volume of Cement:
- Volume of cement = Mass of cement / (Specific gravity of cement × 1000)
- Volume of Water:
- Volume of water = 208 liters / 1000 = 0.208 m³
- Volume of Entrapped Air:
- Assuming volume of entrapped air as 2% for nominal mix = 0.02 m³
- Total Volume of Aggregates:
- Volume of aggregates = 1 - (Volume of cement + Volume of water + Volume of entrapped air)

4.2.5. *Mix Calculation for Conventional Concrete*
- Water: 208 liters
- Cement: 411 kg
- Fine Aggregate: 721.35 kg
- Coarse Aggregate: 1098.39 kg

4.2.6. *Mix Calculation for Perlite Concrete*
- Water: 208 liters
- Cement: 411 kg
- Fine Aggregate: 721.35 kg
- Perlite Aggregate: 655.77 kg

4.3. SUMMARY

The mix proportions for conventional and perlite concrete are designed to achieve the target mean strength of 31.6 MPa, ensuring the concrete meets the M25 grade requirements. The perlite aggregate is used to replace the coarse aggregate, resulting in a lightweight concrete mix with the desired properties. The detailed mix proportions ensure consistency and reliability in achieving the specified concrete strength and performance.

V. EXPERIMENTAL PROCEDURE

5.1. COLLECTION OF MATERIALS

The materials required for this experimental work include cement, fine aggregate, coarse aggregate (for conventional concrete), and perlite aggregate (for perlite concrete). Each of these materials is collected from reliable sources to ensure the quality and consistency needed for the experimental work.

- Cement: Ordinary Portland Cement (OPC) 53 Grade from Coromandel is collected.
- Fine Aggregate: Crusher Sand is procured and sieved as per Indian standards.
- Coarse Aggregate: 12mm aggregate is procured for conventional concrete.
- Perlite Aggregate: Expanded Perlite is sourced for use as the coarse aggregate replacement in perlite concrete

5.2. MATERIAL PROPERTIES

5.2.1. *Cement*

- Type: Ordinary Portland Cement (OPC) 53 Grade
- Specific Gravity: 3.15
- Fineness: Measured using standard sieve.
- Consistency: Determined by Vicat apparatus.

5.2.2. *Fine Aggregate*

- Type: Natural sand or crushed stone particles
- Specific Gravity: 2.65
- Fineness Modulus: Calculated.
- Sieve Analysis: Conducted for Particle size distribution.

5.2.3. *Coarse Aggregate*

- Type: Crushed stone (12mm size)
- Specific Gravity: 2.70
- Fineness Modulus: Measured.
- Water Absorption: Determined.

5.2.4. *Perlite Aggregate:*

- Type: Expanded Perlite
- Specific Gravity: 0.30-0.45
- Bulk Density: 30-150 kg/m³
- Water Absorption: High due to porous nature.

5.3. CASTING OF SPECIMENS

5.3.1. *Mixing*

Prepare concrete according to the mix design proportions for conventional and perlite concrete.

5.3.2. *Casting*

Pour mixed concrete into Molds (e.g., cubes for compressive strength, cylinders for tensile strength). Ensure proper compaction to eliminate air bubbles.

Casting of Prism & Cylinder

Casting of Prism

5.3.3. *Curing*

Cure specimens under standard conditions (e.g., moist curing) for the required duration (e.g., 7 days, 28 days).

5.4. TESTING OF SPECIMENS

5.4.1. *Compressive Strength Test*

Evaluate the compressive strength of concrete specimens at specified intervals (e.g., 7 days, 28 days).

5.4.2. *Tensile Strength Test*

Measure split tensile strength of concrete cylinders.

5.5. ANALYSIS OF TEST RESULTS & CONCLUSION

5.5.1. *Data Analysis*

- Compare performance of conventional and perlite concrete based on test results.

5.5.2. *Conclusion*

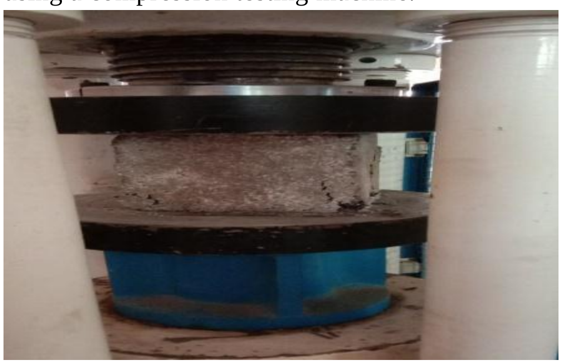
- Draw conclusions regarding the feasibility and benefits of using perlite in concrete.
- Provide recommendations for future applications and improvements.

VI. TESTING OF CONCRETE

6.1. COMPRESSIVE STRENGTH

6.1.1. *Procedure*

- After 7 and 28 days of curing, cube specimens are removed from the curing tank and cleaned to remove surface water.
- The cubes are then tested for compressive strength using a compression testing machine.



- The maximum load at which the specimen fails and the pointer starts moving back is recorded.
- The test is repeated for three specimens, and the average value is taken as the mean strength.

6.1.2. *Testing Details*

- Conventional Concrete: Tested to establish baseline compressive strength.
- Structurally Lightweight Aggregate Concrete: Includes:
- Series 1: Perlite concrete with a water-cement ratio of 0.4.
- Series 2: Perlite concrete with a water-cement ratio of 0.5.
- Tests for Series 1 and Series 2 are conducted after 7 days of curing.

6.2. SPLIT TENSILE STRENGTH

6.2.1. *Procedure*

- Split tensile strength tests are performed on continuously moist-cured and dried lightweight concrete specimens.
- The tensile strength of lightweight concrete is correlated with its compressive strength and is generally considered comparable to that of normal-weight concrete with equal compressive strength.

6.2.2. *Considerations*

- For continuously moist-cured lightweight concrete, tensile strength closely matches that of normal-weight concrete.
- For dried lightweight concrete, moisture loss can lead to tensile stresses on the exterior faces, reducing tensile resistance compared to continuously moist-cured specimens.
- The splitting tensile strength of lightweight concrete is typically 70-100% of that of normal-weight concrete, depending on the compressive strength of the cylinder specimens.
- This section outlines the methods for evaluating the strength of concrete through compressive and split tensile tests, providing insight into the performance of both conventional and lightweight perlite concrete.

VII. RESULT AND DISCUSSIONS

7.1. COMPRESSIVE STRENGTH TEST RESULTS

Table-5**:** Load at Failure in Compression

Trial No	7 days Compressive load (KN)		28 days Compressive load (KN)	
	CC	PC	CC	PC
1	418.50	179.55	612.31	282.00
2	331.42	185.63	659.43	311.85
3	352.57	197.10	752.51	338.85
Average	367.50	187.42	674.75	310.90

Table-6: Compressive Stress Results

rial No.	7 days Compressive load (KN)	28 days Compressive load (KN)

	CC	PC	CC	PC
1	18.60	7.98	27.30	12.54
2	14.73	8.25	29.29	13.86
3	15.67	8.76	33.42	15.06
Average	16.33	8.33	30.00	13.82

7.2. SPLIT TENSILE TEST RESULTS

Table-7: Load at Failure in Tension

rial No.	7 days Compressive load (KN)		28 days Compressive load (KN)	
	CC	PC	CC	PC
1	60.08	25.44	76.16	44.89
2	37.11	17.85	70.33	40.82
3	30.04	20.85	66.09	35.87
Average	42.41	21.38	70.86	40.52

Table-8: Tensile Stress Results

Trial No.	7 days Compressive load (KN)		28 days Compressive load (KN)	
	CC	PC	CC	PC
1	3.40	1.44	4.31	2.54
2	2.10	1.01	3.98	2.31
3	1.70	1.18	3.74	2.03
Average	2.40	1.21	4.01	2.29

7.3. COMPARISON OF COMPRESSIVE STRENGTH

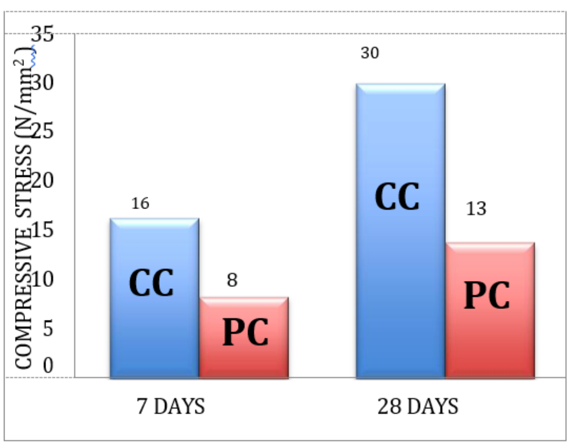


Chart-1: Comparison of Compressive Strength of Structurally Lightweight Perlite Concrete and Conventional Concrete

Chart-1: illustrates the comparison between structurally lightweight perlite concrete and conventional concrete in terms of compressive strength at 7 and 28 days of curing.

7.3.1. *Perlite Concrete*

- 7 Days: 8.33 MPa
- 28 Days: 13.82 MPa
- Increase: 65.9%

7.3.2. *Conventional Concrete*

- 7 Days: 16.33 MPa
- 28 Days: 30.00 MPa
- Increase: 83.71%

7.4. ANALYSIS

7.4.1. *Perlite Concrete*

Shows a significant increase in compressive strength over time, with a 65.9% increase from 7 to 28 days.

7.4.2. *Conventional Concrete*

Exhibits a higher percentage increase of 83.71% in compressive strength over the same period.

This comparison indicates that while both types of concrete exhibit growth in compressive strength with time, conventional concrete demonstrates a higher overall increase in strength compared to perlite concrete.

VIII. CONCLUSION

8.1. REDUCTION IN SELF-WEIGHT

The use of perlite as a coarse aggregate significantly reduces the self-weight of concrete blocks compared to conventional concrete. This reduction in weight can be substantial, making perlite concrete an advantageous option where weight reduction is important.

8.2. SEISMIC RESISTANCE

Lightweight perlite concrete is particularly beneficial in earthquake-prone areas due to its ability to resist seismic forces more effectively. Its lower density contributes to reducing the overall structural load, which can enhance the building's performance during seismic events.

8.3. STRENGTH COMPARISON

- The compressive strength of perlite concrete is approximately 46.06% lower than that of conventional concrete.
- The tensile strength of perlite concrete is about 57.10% lower compared to conventional concrete.

- These differences highlight that while perlite concrete offers lower strength, it provides other benefits like reduced weight.

8.4. APPLICATIONS AND STRUCTURAL BENEFITS

- Although the compressive and tensile strengths of perlite concrete are lower than those of conventional concrete, its significantly lower density makes it suitable for various non-load bearing applications.
- Perlite concrete can be effectively used in non-load bearing walls, lightweight roof decks, floor fills, and in-fill walls. By using perlite concrete in these applications, the structural dead load of buildings can be substantially reduced, which can lead to cost savings in structural support and improved overall building performance.
- These conclusions underline the potential of perlite concrete as a viable alternative to conventional concrete in specific applications where weight reduction and seismic resistance are prioritized over strength.

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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