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# Assessment Of Durability And Mechanical Properties Of Sustainable Lightweight Concrete Using Mineral Aggregates

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***Abstract***
*This study focuses on the formulation and evaluation of lightweight concrete by incorporating perlite and vermiculite as partial substitutes for traditional aggregates. The concrete specimens were prepared using three replacement levels—5%, 7%, and 10%—to analyze their influence on physical characteristics, mechanical performance, and durability. In addition to measuring density and compressive strength, durability parameters. These evaluations adhered to the specifications in IS 456:2000 and IS 516:2018. Findings demonstrated that although compressive strength slightly decreased with increased substitution, the concrete retained adequate load-bearing capacity and exhibited enhanced and acceptable durability, making it appropriate for energy-efficient and lightweight structural applications.*
***Keywords:*** *Lightweight Concrete, Durability, Perlite, Vermiculite, Chemicals*

## 1.OVERVIEW

The field of construction engineering is witnessing an increasing focus on sustainable and thermally efficient building materials. Lightweight concrete produced with mineral-based additives like perlite and vermiculite presents significant advantages, including decreased structural weight, enhanced thermal insulation, and improved environmental sustainability. The incorporation of these additives, characterised by their porous and expansive properties, enhances the insulating capacity of the material while simultaneously reducing its density. This study aims to examine the influence of alternative aggregates on the performance and durability of concrete.

## 2.Objective

The purpose is to make concrete mixes that include perlite and vermiculite as partial replacements for aggregates at rates of 5%, 7%, and 10%. The study looks into how different factors affect physical and mechanical properties including density, slump and compressive strength. According to IS 456:2000 and IS 516:2018, tests for durability, such as how well it absorbs water and how well it resists heat, will be done. It is suggested that we find out whether these mixes are good for certain structural purposes in situations where the circumstances are moderately harsh.

## 3.LITERATURE REVIEW

Numerous studies have explored the incorporation of lightweight particles in concrete to enhance thermal efficiency and reduce the overall weight of structures. Tie et al. (2020) noted that substituting conventional aggregates with perlite and vermiculite at levels exceeding 7.5% could lead to significant reductions in both density and strength due to increased porosity and the disruption of the matrix's continuity. Similarly, Annie Sweetlin et al. (2020) highlighted that while the addition of lightweight materials improves thermal insulation and workability, these materials often require more water for hydration because of their high water absorption capacity.Nandhini and Vallabhy (2017) emphasized the necessity of achieving an optimal balance between mechanical performance and thermal efficiency in lightweight concrete by fine-tuning the levels of replacement. Ganesh et al. (2019) investigated the use of perlite aggregate in blended cement concrete and found that it offered improved thermal resistance and reduced density, aligning with sustainable construction goals. Bharath and Prasad (2018) reported that concrete containing vermiculite exhibited enhanced fire resistance, although careful mixing is essential to avoid brittleness.

Singh et al. (2021) pointed out that lightweight aggregates, particularly those with high porosity like perlite, tend to absorb more water, potentially altering the water-cement ratio and impacting the early-age strength of the concrete. Rajasekaran et al. (2020) suggested that the pozzolanic activity of lightweight mineral additives could compensate for some of the strength loss in structural applications. Vyas and Shah (2016) demonstrated that mixes with 5–10% perlite replacement strike a favorable balance between strength and weight reduction.Kumar and Rajan (2022) conducted a study comparing various types of mortar and found that mortar incorporating vermiculite exhibited greater resistance to chloride-induced damage compared to standard mixtures. Devi et al. (2017) performed experimental research indicating that adding up to 10% perlite to concrete could reduce its density by approximately 25% without significantly compromising its load-bearing capacity. Additionally, Sharma and Mishra (2019) discovered that vermiculite aggregates are particularly effective in lightweight, insulating applications such as roofs and panels.Standards such as IS 456:2000 and IS 516:2018 stipulate that tests for the durability and compressive strength of modified concrete must adhere to standard curing and testing durations to ensure the reliability of the results. Sahoo and Patnaik (2020) found that adjusting the water demand and mix design allowed lightweight concrete with natural mineral fillers to meet M25 grade standards. Research by Naresh and Varma (2023) indicates that long-term exposure to vermiculite concrete shows moderate resistance to sulfate and chloride, similar to blended cement-based systems. Yadav et al. (2021) concluded that expanded perlite serves effectively as a thermal and sound barrier, making it a suitable option for energy-efficient building envelopes.

These studies collectively enhance our understanding of the advantages and disadvantages of using perlite and vermiculite in construction projects, corroborating recent experimental findings that suggest performance declines when more than 7.5% of these materials are incorporated.

## 4. MATERIALS AND METHODS

### 4.1 Materials

- **Cement:** OPC 53 grade conforming to IS 12269
- **Fine Aggregate:** M sand
- **Coarse Aggregate:** Crushed stone partially substituted with perlite
- **Lightweight Aggregates:** Expanded perlite (coarse) and vermiculite (fine)
- **Mixing Water:** Clean potable water

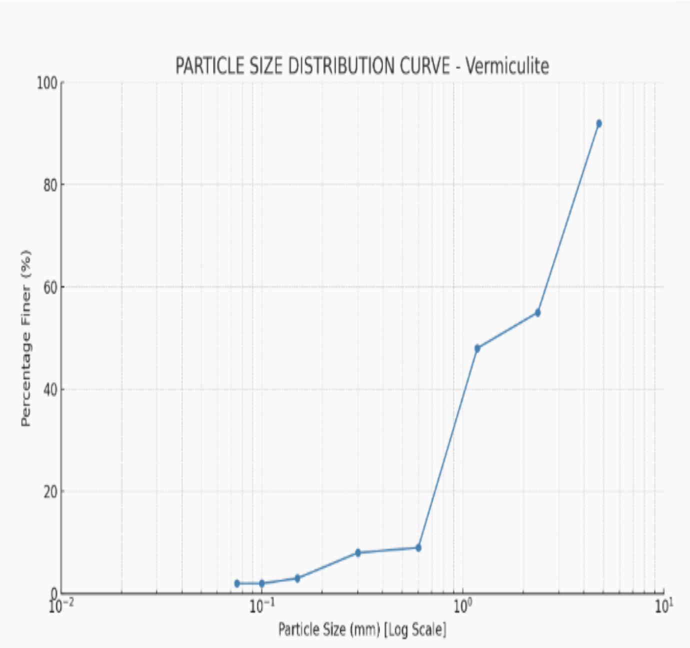


**Figure: 1 Particle Size distribution curve – vermiculite.**

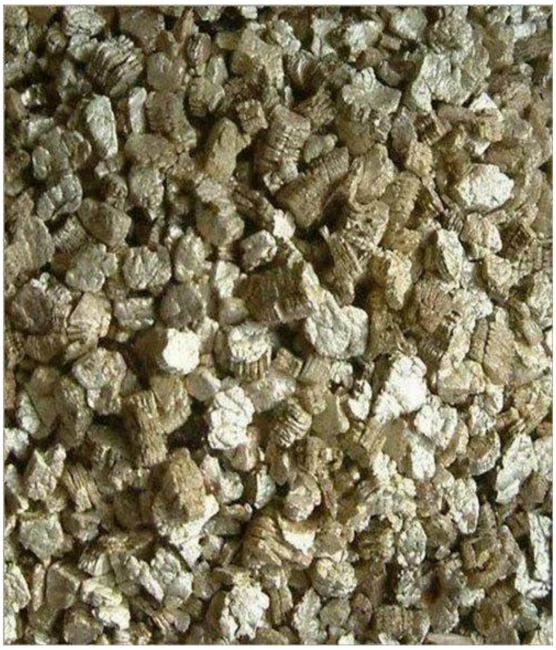

**Figure:2 Vermiculite**

**Figure: 3 Perlite**

**Table:1 Material Properties of Vermiculite and Perlite**

| Property | Vermiculite | Perlite |
|---|---|---|
| Bulk Density ($kg/m^3$) | 80–150 | 30–150 |
| Specific Gravity | 2.4–2.7 | 2.2–2.4 |
| Water Absorption (%) | 300–400 | 200–300 |
| Thermal Conductivity (W/m·K) | 0.06–0.12 | 0.04–0.06 |
| Color | Golden-brown to silver | White to light gray |
| Shape | Flaky/plate-like | Granular |
| Origin | Heated mica-like mineral | Expanded volcanic glass |

**5. Mix Design and Proportions**

Mix designs were formulated with constant water-cement ratio and increasing percentages of lightweight aggregates (5%, 7%, and 10%) by weight.

**5.1 Testing Protocols**

i. **Density Measurement**: Conducted at 7 and 28 days
ii. **Slump Test**: Performed to determine workability
iii. **Compressive Strength**: Cubes were tested as per IS 516:2018 standards
iv. **Durability Testing (Based on IS 456:2000 & IS 516:2018):**

**a) Acid Resistance**

As per durability assessment procedures referenced in IS 456:2000, acid resistance is evaluated by immersing specimens in dilute sulfuric acid and measuring mass loss over time. This test simulates acidic environmental conditions to check degradation due to leaching of cementitious compounds.

**b) Sulfate Resistance**

IS 456:2000 specifies that exposure to sulfate solutions (e.g., $Na_2SO_4$ or $MgSO_4$) helps assess deterioration through expansion or surface cracking. Sulfate ions react with hydrated cement phases, forming expansive products that cause internal stress and weight change.

**c) Chloride Attack Resistance**

Chloride ingress is tested under IS 516:2018 (Part 5/Sec 1), where specimens are exposed to NaCl solution for 90 days. It assesses chloride penetration, which is a key factor in reinforcement corrosion and loss of long-term durability.

**6. Results and Interpretation**

**6.1. Density Trends**

A progressive decrease in concrete density was observed with increasing lightweight aggregate content. The 10% replacement mix reached a density of approximately 1455 $kg/m^3$, qualifying it as a structural lightweight mix.

**6.2. Setting Time Observation:**

The standard consistency of cement was determined to be 33% by using Vicat apparatus. The cement used in the mix showed an initial setting time of 43 minutes and a final setting time of 5 hours 30 minutes, which is within the acceptable limits for OPC as per IS specifications.


Figure: 4 Setting Time observation.


Figure: 5 Setting Time observation

**6.3. Workability Assessment – Slump Test**

The slump test results indicated a decreasing trend in workability as the percentage of vermiculite and perlite increased. The nominal mix (without replacements) exhibited the highest slump value of 105 cm, while the mix with 10% vermiculite and 10% perlite showed a reduced slump of 96 cm.

This decline in slump values is attributed to the high surface area and porous nature of vermiculite and perlite, which increases the internal water demand of the mix and reduces its free water content. Despite this reduction, all mixes maintained slump values within a workable range, indicating that the inclusion of lightweight aggregates did not significantly hinder the fresh concrete's handling characteristics.

The plotted bar graph visually confirms this gradual reduction in workability, validating the suitability of these mixes for applications requiring moderate consistency and placement ease.

**Figure:6Slump Test.**

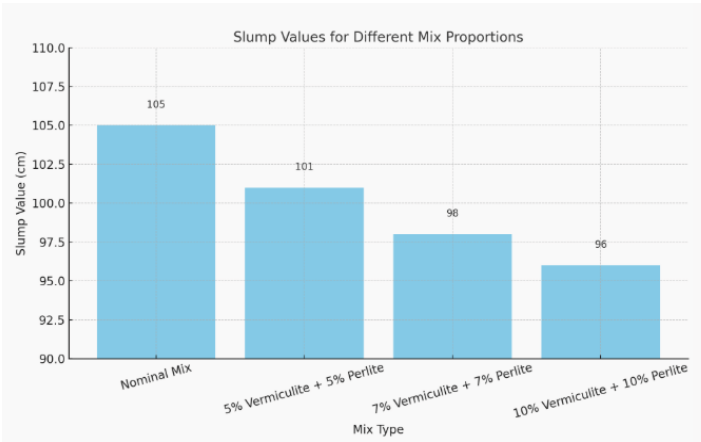


**Figure:7Slump Test Result**

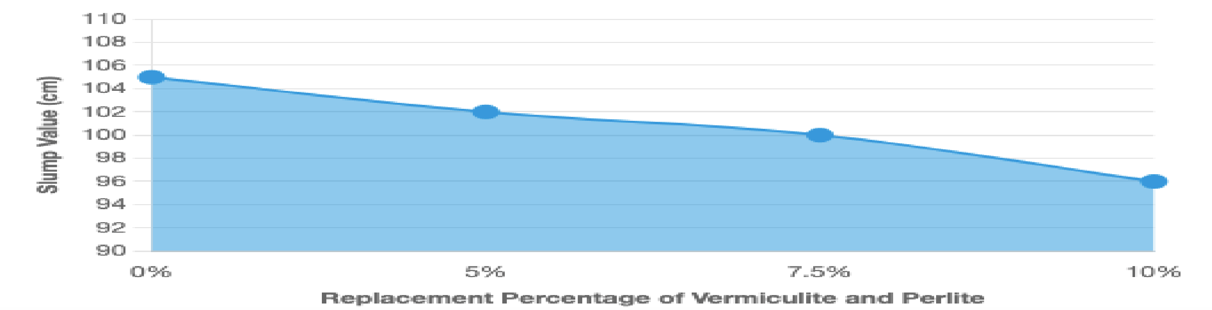


**Figure: 8 Slump Test Results: Effect of Vermiculite and Perlite Replacement**

### 6.4. Compressive Strength

**Table:2 Comparison of Average Density and Compressive Strength**

| S.No | MIX | Replacement Percentage of Perlite and Vermiculite | Average Density (kg/m³) | Compressive Strength at 28 Days (N/mm²) |
|---|---|---|---|---|
| 1 | Conventional Mix | 0% | 2347.7 | 35.9 |
| 2 | Mix 1 | 5% | 1904.3 | 34.7 |
| 3 | Mix 2 | 7.5% | 1797.6 | 31.8 |
| 4 | Mix 3 | 10% | 1455.3 | 30.7 |

#### 6.4.1. Comparative Analysis of Density and Strength

The results from the table demonstrate a clear inverse relationship between the replacement percentage of perlite and vermiculite and both the average density and compressive strength of the concrete. The conventional mix (0% replacement) exhibited the highest density (2347.7 kg/m³) and maximum compressive strength (35.9 N/mm²), serving as the benchmark.

As the replacement levels increased to 5%, 7.5%, and 10%, the density dropped significantly to 1904.3, 1797.6, and 1455.3 kg/m³, respectively. This reduction is attributed to the inherently low specific gravity of perlite and vermiculite, which are highly porous and lightweight materials. Consequently, this also leads to lower compressive strength values—34.7, 31.8, and 30.7 N/mm², respectively—for the same mixes. Despite this decline, all compressive strength values remain within permissible limits for structural lightweight concrete. The mix with 10% replacement, while achieving the lowest strength, still satisfies general requirements for non-load-bearing or insulated structural elements. The overall trend confirms that incorporating these lightweight aggregates is effective for achieving lower concrete densities with a manageable compromise in strength, making the mixes particularly suitable for thermal insulation, seismic design optimization, and precast lightweight units.

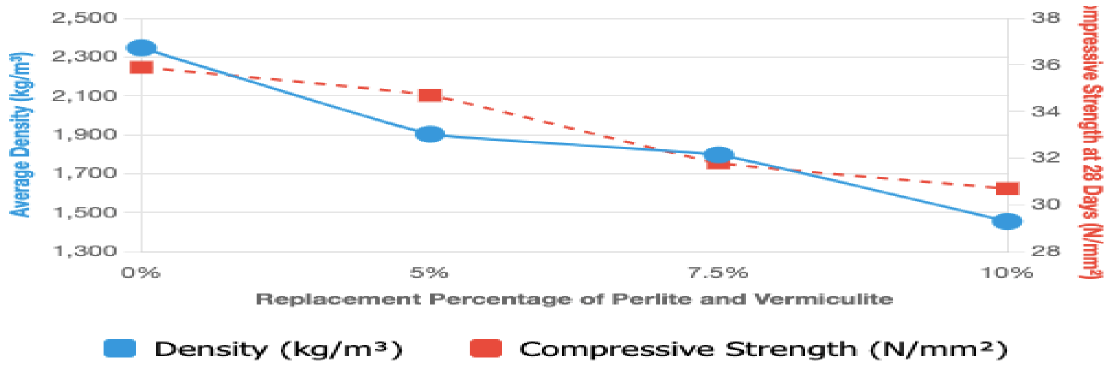


**Figure: 9Effects of Perlite/Vermiculite Replacement on Concrete Properties**



**Figure: 10 Weight of Concrete Cube.**

**Figure: 11 Compression Test**

**Figure: 12 Compression Test showing Displacement**

**Table: 2Mass Change after 90 Days Exposure to Chemical Solutions**

| S.No | MIX | Initial Mass (kg) | Acid Resistance Mass (kg) | Sulfate Resistance Mass (kg) | Chloride Resistance Mass (kg) |
|---|---|---|---|---|---|
| 1 | Conventional Mix | 8.876 | 8.752 (-1.40%) | 8.803 (-0.82%) | 8.825 (-0.57%) |
| 2 | Mix 1 | 7.127 | 6.987 (-1.96%) | 7.041 (-1.21%) | 7.073 (-0.76%) |
| 3 | Mix 2 | 6.893 | 6.734 (-2.31%) | 6.829 (-0.93%) | 6.848 (-0.65%) |
| 4 | Mix 3 | 5.567 | 5.391 (-3.16%) | 5.493 (-1.33%) | 5.512 (-0.99%) |

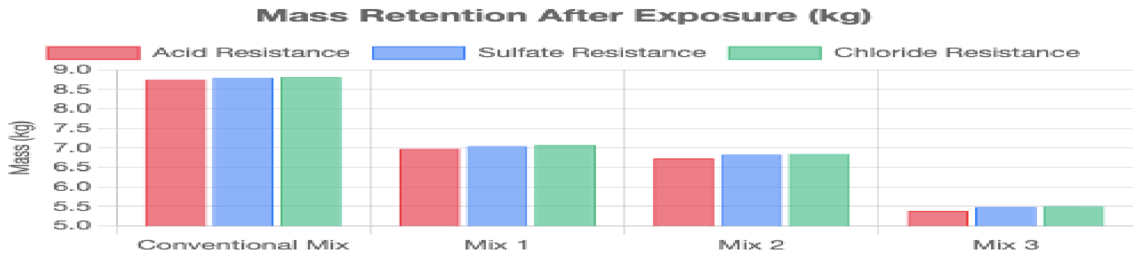


**Figure: 13Mass Changes due to Exposure of Chemical Solutions**

**6.5 Durability Studies**

Durability tests were conducted over a 90-day period as per IS 456:2000 and IS 516:2018 standards to evaluate resistance against acid, sulfate, and chloride attacks. Weight changes in the specimens were monitored to assess material degradation.The results show that all mixes experienced some mass loss when exposed to chemical environments. Acid exposure led to the highest percentage of mass loss, particularly for the Mix 3 specimen with 10% replacement, which showed a reduction of 3.16%**,** followed by Mix 2 (2.31%) and Mix 1 (1.96%)**.** The conventional mix was more stable with a lower 1.40% loss.

Under sulfate attack, MIX 3 again recorded the highest mass loss (1.33%) due to its higher porosity. The mass reduction for chloride exposure was the lowest across all mixes, with values below 1%**,** suggesting moderate resistance to chloride ingress. Overall, the durability of the lightweight mixes decreased with increased replacement, but the values remained within acceptable limits for structural applications in non-aggressive environments.These results indicate that while lightweight concrete mixes with perlite and vermiculite offer reduced density and improved thermal performance, their use should be carefully considered in environments with high chemical exposure unless additional protective measures are taken.

**7. CONCLUSION**

- The use of perlite and vermiculite as partial substitutes in concrete significantly decreases density, boosts thermal insulation, and promotes environmental sustainability.
- Among the mixtures, a 10% substitution demonstrated the lowest density, making it suitable for lightweight structural applications.
- Both vermiculite and perlite provide superior thermal insulation, making the concrete effective in minimising heat transmission in warm areas.

- The decreased dead load resulting from lightweight aggregates renders these mixtures beneficial for high-rise edifices, retrofitting, and precast elements.
- Vermiculite and perlite, being naturally occurring minerals, provide sustainable building without requiring industrial processing.
- Despite a modest reduction in compressive strength with increased replacement, all mixtures maintained sufficient structural integrity.
- Vermiculite's cost-efficiency and accessibility promote affordable construction methods.
- Durability tests conducted over 90 days shown satisfactory performance in acid (3.16% loss for Mix 3), sulphate (1.33%), and chloride (0.99%) conditions.
- Despite heightened porosity, all mixtures adhered to the limitations established by IS requirements for structural concrete.

## 8. Recommendations:

- Replacement of coarse and fine aggregates with up to 7.5% perlite and vermiculite is recommended for achieving optimal strength and thermal efficiency.
- Protective coatings or additives may be considered when using these mixes in highly aggressive chemical environments.
- Further long-term studies should be conducted to evaluate microstructural changes and freeze-thaw resistance.
- Lightweight mixes are particularly recommended for partition walls, roofing slabs, and non-load bearing elements in green buildings.
- Ensure appropriate curing and mix design adjustments to compensate for the high water absorption capacity of lightweight aggregates.

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