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Thermal and Mechanical Performance of Natural Additive Organic Mortar Sheets for Cold Rooms

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Abstract - **Post-harvest losses of agricultural produce caused by inadequate storage infrastructure remain a significant challenge in developing countries. Conventional cold storage insulation materials such as polyurethane foam and polystyrene-based panels present environmental, durability, and disposal concerns. This study reports the development and experimental evaluation of eco-friendly insulation sheets fabricated using lime mortar incorporated with natural organic additives.**

A pilot cold storage room with a volume of 1200 ft³ (≈ 34 m³) was considered for performance evaluation. The lime mortar composites were prepared using jaggery, aloe vera gel, fenugreek powder, neem oil, kikkar gum, plaster of Paris, and glass fibre reinforcement. Mechanical properties were evaluated through compressive and transverse strength tests following relevant Indian Standards, while thermal conductivity was measured using the Guarded Heat Flow Meter method (ASTM C518).

The developed sheets exhibited compressive strength values ranging from 20 to 30 N/mm² and a transverse bending strength of 289.7 N/mm². Thermal conductivity values were observed between 0.06 and 0.09 W/m·K. Field application demonstrated an indoor temperature reduction of 8–12°C, with relative humidity maintained within 15–65%. The results confirm that organic additive-based lime mortar sheets offer a sustainable, low-cost alternative for cold room insulation in agro-based industries.

Keywords - Lime mortar · Organic additives · Cold storage · Thermal conductivity · Sustainable insulation

1 INTRODUCTION

Post-harvest losses account for nearly 30–40% of total agricultural production worldwide, primarily due to inadequate storage and preservation facilities. In tropical and semi-arid regions, high ambient temperatures and fluctuating humidity significantly accelerate deterioration of agro-based products. Effective cold storage systems are therefore essential to preserve quality, extend shelf life, and stabilize market supply.

Conventional insulation materials used in cold rooms—such as polyurethane foam (PUF), expanded polystyrene (EPS), and extruded polystyrene (XPS)—provide excellent thermal resistance but are associated with high embodied energy, environmental toxicity, flammability, aging degradation, and disposal challenges. These limitations necessitate the development of eco-friendly, durable, and locally available insulation alternatives.

Lime-based mortars modified with organic additives have been traditionally used to enhance strength, durability, and moisture resistance. Recent research highlights their potential for thermal insulation applications. The present study focuses on developing natural additive-based lime mortar sheets reinforced with glass fibre and evaluating their mechanical and thermal performance for cold room applications.

2 PROBLEM STATEMENT

Agro-based industries and small-scale farmers face significant challenges due to the lack of affordable and reliable cold storage systems. Improper post-harvest storage leads to insect infestation, microbial growth, discoloration, and oxidation of stored products, resulting in economic losses and reduced food quality. Existing cold storage solutions remain expensive and environmentally unsustainable, limiting their adoption in rural areas.

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3 STORAGE LOSSES IN AGRO-BASED PRODUCTS

Poor storage conditions cause both quantitative and qualitative losses, including mold growth, insect damage, mycotoxin formation, discoloration, cracked or sprouted seeds, odour development, and heat damage. Pulses and grains are particularly susceptible, and these losses adversely affect farmers, traders, and food processors.

4 SAFE STORAGE REQUIREMENTS

Safe storage refers to the long-term preservation of agricultural produce without spoilage or quality degradation. The two most critical parameters governing safe storage are temperature and moisture content. The storage temperature should remain below 25°C but above freezing, while grain moisture content must be controlled to suppress microbial activity and biochemical degradation. Maintaining these conditions using eco-friendly insulation materials can significantly improve storage performance.

5 MATERIALS AND METHODS

5.1 Materials

Hydrated lime conforming to IS 712:1984 was used as the primary binder. Organic additives included jaggery, aloe vera gel, fenugreek seed powder, kikkar (Acacia) gum, neem oil, and plaster of Paris. Glass fibre reinforcement was incorporated to enhance tensile and flexural performance.

Hydrated lime improves mortar strength through carbonation, pozzolanic reactions with siliceous components, and maintenance of high pH levels, which enhance chemical reactivity.

5.2 Preparation of lime mortar sheets

The lime was hydrated and matured for 30 days prior to mixing. The materials were mixed in specified proportions using a homogeneous mixer. Sheets of dimensions 450 × 450 × 12 mm were cast using iron moulds coated with neem oil to prevent adhesion. Glass fibre fabric was embedded between layers of plaster, and the sheets were air-cured for 28 days before testing.

Method of preparation of lime mortar

Table -1

Material	Hydrated Lime	Gypsum	Jaggery	Kikkar gum	Fenugreek plant	Alovera	Glass fibre	Neem oil
Percentage	%	%	%	%	%	%	%	%
100	20	44	10	4	4	12	4	2
100	38	26	10	4	5	10	5	2

5.3 Mechanical testing

5.3.1 Compressive strength

Compressive strength tests were conducted on 12 mm thick sheet specimens using a Universal Testing Machine. Aloe vera gel at 12% concentration resulted in a compressive strength of 24.32 N/mm² after 28 days, while jaggery at 10% concentration achieved a maximum strength of 30.34 N/mm².

The average compressive strength obtained from full-scale sheet testing was 23.94 N/mm².

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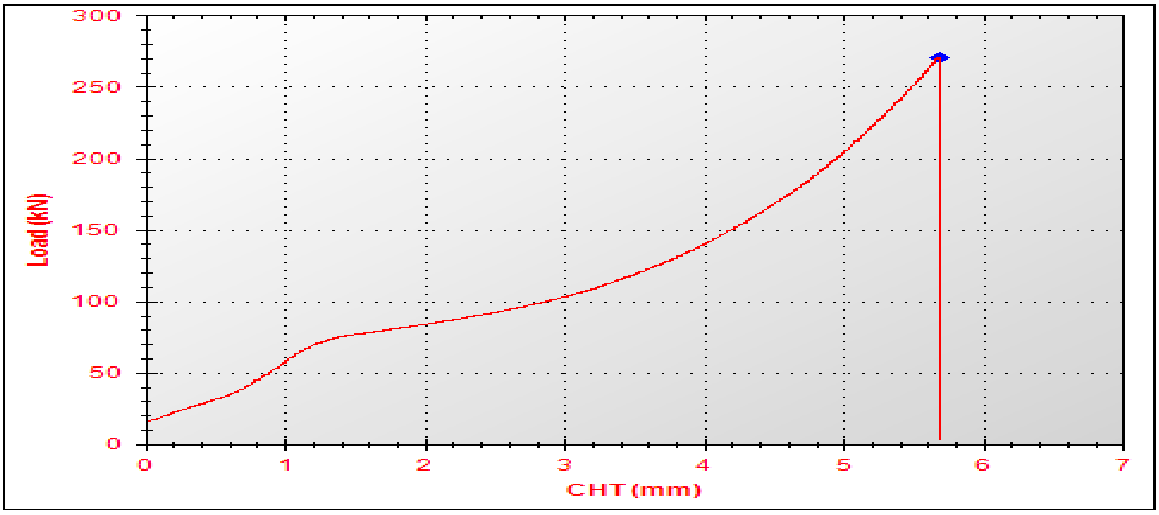
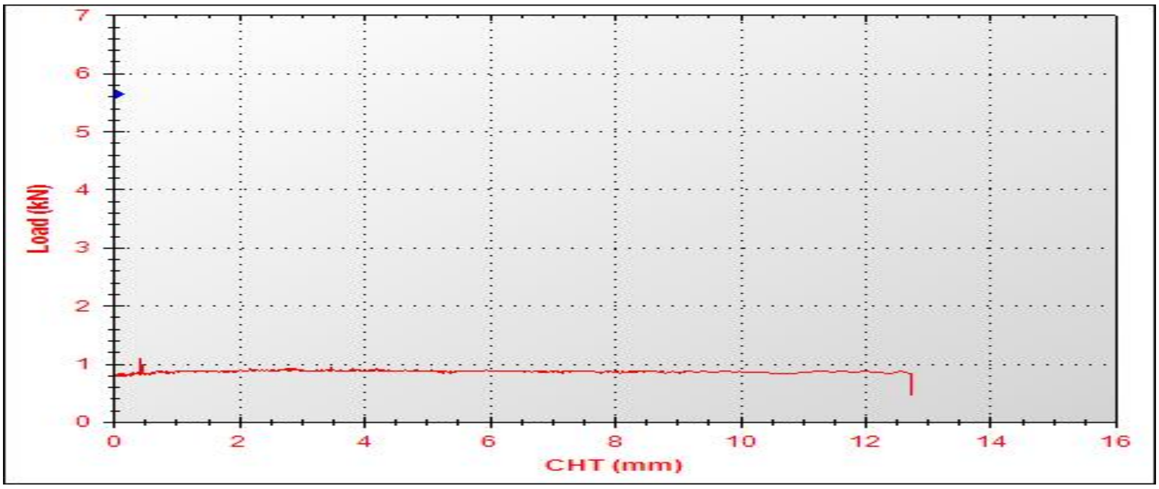


5.3.2 Transverse bending strength

Transverse bending tests were performed as per IS 2542 (Part II). The developed composite sheets exhibited a transverse strength of 289.726 N/mm², indicating adequate flexural resistance and structural integrity.



6.1 Thermal Conductivity Analysis

Thermal conductivity of the developed material was measured using a **Thermtest GHFM-01 guarded heat flow meter apparatus** in accordance with **ASTM C518** standards. The measured thermal conductivity values were found to vary between **0.06 and 0.09 W/m·K** over the tested conditions. These values are comparable to those of conventional insulation materials such as expanded polystyrene and polyurethane foam, indicating the suitability of the material for cold room insulation applications.

The low thermal conductivity demonstrates effective resistance to heat transfer, which contributes to reduced cooling load and improved energy efficiency of the cold storage system. Such performance is particularly advantageous for agro-based cold rooms operating in hot and semi-arid climatic regions.

6.2 The graphs presented below illustrate:

- The reduction in **internal temperature** compared to ambient conditions
- The ability of the cold room to maintain **controlled relative humidity**, essential for preserving agricultural produce
- Stable thermal behaviour despite fluctuations in external temperature and humidity.

The observed results confirm that the cold room maintains a favourable microclimate for storage, minimizing moisture loss, spoilage, and microbial growth.

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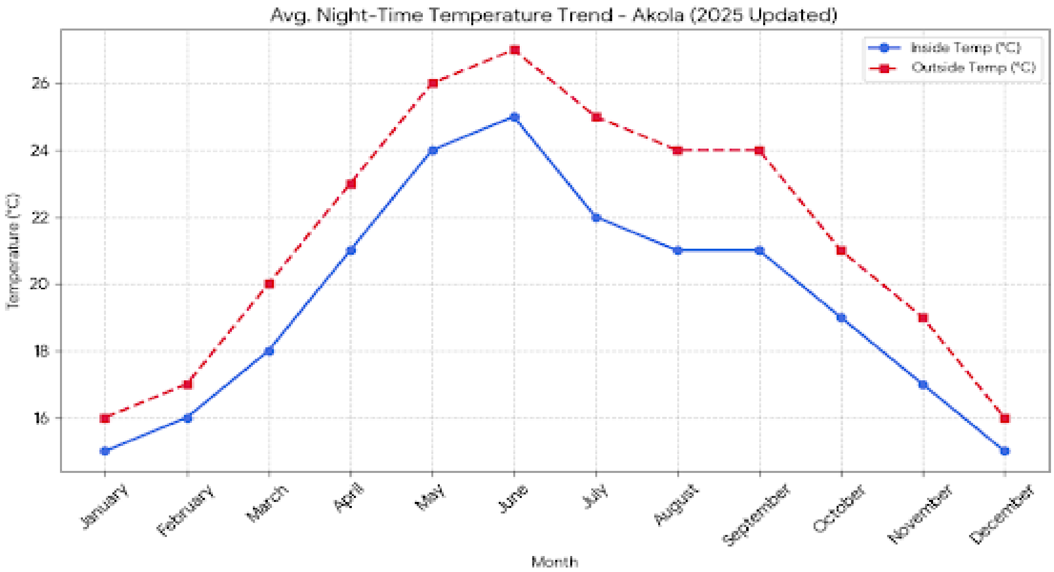
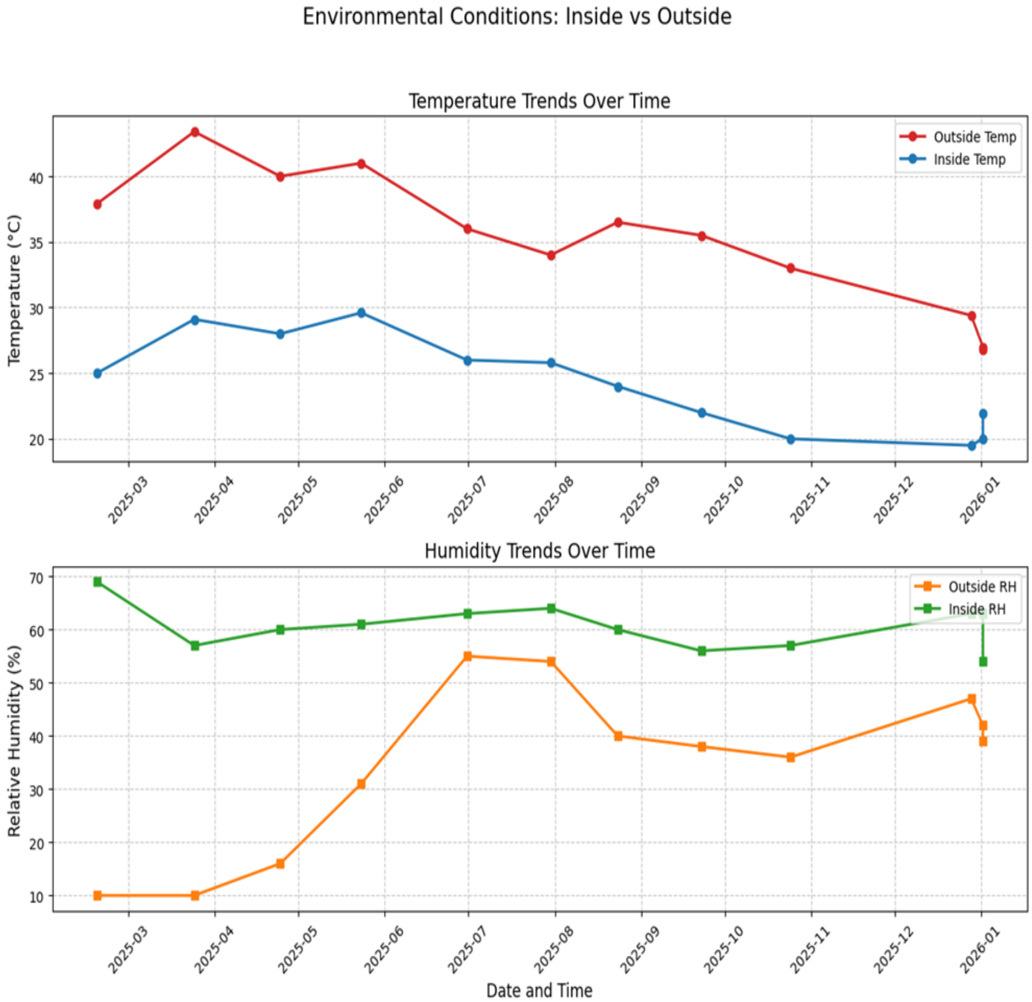
Graph 1: Variation of inside and outside temperature with time for the cold room.



Graph 2: Comparison of inside and outside relative humidity under varying ambient conditions.



Graph 3: Effect of ambient temperature on cold room internal temperature stability.

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7 RESULTS AND DISCUSSION

The mechanical and thermal performance of the developed lime mortar composites highlights the effectiveness of natural organic additives in tailoring both strength and insulation behaviour. Aloe vera gel improved inter particle bonding and reduced capillary porosity, resulting in optimum compressive strength at a dosage of **12%**. Jaggery addition promoted controlled hydration and calcium saccharate formation, with a peak strength observed at **10%**, beyond which excessive retardation adversely affected matrix continuity. The gypsum–lime interaction governed setting kinetics and brittleness; an optimal gypsum content of approximately **44%** achieved a balanced combination of strength, workability, and dimensional stability.

The fabricated sheets demonstrated an average compressive strength of **23.94 N/mm²** and a transverse bending strength of **289.726 N/mm²**, confirming their suitability for load-bearing insulation panels. Thermal conductivity values in the range of **0.06–0.09 W/m·K** enabled effective resistance to heat transfer, resulting in a measurable indoor temperature reduction of **8–12°C** under field conditions. The controlled relative humidity further indicates the material's capability to maintain a stable microclimate essential for agro-product preservation.

8 CONCLUSIONS

This study presents an eco-friendly approach for developing lime mortar insulation sheets using natural organic additives and fibre reinforcement. The developed composites exhibit satisfactory mechanical strength, low thermal conductivity, and effective temperature–humidity regulation. The use of locally available organic materials reduces energy consumption, operational costs, and environmental impact, supporting sustainable cold storage infrastructure for agro-based industries. The findings contribute to the advancement of green construction materials and circular economy practices.

Keywords: Eco-friendly materials; Organic cold sheets; Thermal insulation; Agro-based industries; Sustainable construction; Energy efficiency; Circular economy

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