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Performance Evaluation Of Hydroceramic Cooling Tile With Hydrogel Clay

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Abstract: The increasing global demand for sustainable cooling solutions has driven research toward innovative building materials that minimize energy consumption while ensuring thermal comfort. This project focuses on the design and performance evaluation of a hydroceramic cooling tile incorporating hydrogel clay for passive indoor thermal regulation. Hydrogel clay, with its superior water retention and evaporative cooling properties, is integrated into ceramic tiles to enhance their thermal performance. The study aims to investigate the tile's ability to reduce indoor temperatures through evaporative cooling, improve thermal comfort, and reduce dependency on active cooling systems such as air conditioners. Experimental evaluation includes material characterization, water absorption tests, thermal conductivity analysis, and real-time monitoring of temperature variations under controlled conditions. Comparative studies with conventional ceramic tiles are conducted to quantify the cooling efficiency and durability of the developed hydroceramic tiles. The expected outcome is a cost-effective, ecofriendly, and energy-efficient building material capable of maintaining comfortable indoor conditions while contributing to sustainable construction practices. This research highlights the potential of hydroceramic cooling tiles as a scalable solution for passive cooling, promoting reduced energy demand, environmental sustainability, and improved indoor living standards.

Keywords: Hydroceramic tile, Hydrogel clay, Passive cooling, Thermal regulation, Sustainable building material, Evaporative cooling.

I. INTRODUCTION

The increasing global temperature and rapid urbanization have led to a significant rise in the demand for cooling in buildings. Conventional cooling systems such as air conditioners and refrigeration units consume large amounts of electrical energy and contribute to environmental issues, including greenhouse gas emissions and global warming. In countries with hot and humid climates like India, this dependence on energy-intensive cooling systems further strains the power infrastructure and increases operational costs. Therefore, the development of sustainable and energy-efficient alternatives has become essential in modern construction practices.

Passive cooling techniques, which utilize natural processes without relying on external energy sources, have emerged as promising solutions to reduce building energy consumption. Among these, evaporative cooling is widely recognized for its effectiveness, as it reduces temperature by absorbing heat during the evaporation of water. Integrating this principle into building materials can significantly enhance thermal comfort while minimizing environmental impact.

Hydroceramic cooling tiles represent an innovative approach in this domain. These tiles are developed by combining traditional clay materials with superabsorbent polymers such as sodium polyacrylate (hydrogel). The clay matrix provides structural strength and porosity, while the hydrogel enhances the

water absorption and retention capacity of the material. When exposed to heat, the absorbed water evaporates gradually, resulting in a cooling effect that reduces the surface temperature of the tiles.
In addition to hydrogel, natural reinforcement materials such as banana fiber (Musa Acuminata) can be incorporated to improve the mechanical properties and crack resistance of the tiles. The inclusion of cement further enhances the binding and durability of the composite material, making it suitable for practical applications such as wall cladding systems.
This study focuses on the performance evaluation of hydroceramic cooling tiles prepared using clay, cement, hydrogel, and banana fiber. The experimental investigation includes the analysis of key parameters such as water absorption, water retention, evaporation rate, temperature reduction, compressive strength, and flexural strength. Different mix proportions with varying hydrogel content are examined to understand their influence on both thermal and mechanical performance.
The results of this study aim to demonstrate that hydroceramic cooling tiles can serve as an effective, eco-friendly, and cost-efficient alternative to conventional cooling methods. By reducing surface temperature and improving thermal comfort without additional energy consumption, these tiles contribute to sustainable building development and help mitigate the effects of climate change.

II. LITERATURE REVIEW

Liu et al. (2025) developed anisotropic hygroscopic hydrogels with directional water absorption and transport properties to enhance evaporative cooling efficiency. Using a layer-by-layer polymerization technique, structured channels were created to enable continuous water movement and sustained evaporation. Experimental results under simulated solar radiation showed temperature reductions of 15–20°C below ambient conditions without external rehydration. This study highlights the potential of integrating advanced hydrogel structures with ceramic materials to achieve efficient and self-sustained passive cooling in building applications.

Xu et al. (2025) investigated the application of hydrogels for photovoltaic (PV) panel cooling in tropical climates. Laboratory and field studies demonstrated that hydrogel coatings reduced panel temperatures by 8–12°C, resulting in a 5–10% improvement in electrical efficiency. The study confirms the effectiveness of hydrogels in real-world conditions and emphasizes their potential for reducing heat gain in buildings, particularly in hot and humid regions.

Cong Lai and Lin Lu (2024) presented a comprehensive review of hydrogel-based passive cooling technologies, including evaporative, radiative, and hybrid cooling systems. The study highlighted key properties such as high water retention and tunable optical characteristics. It also identified challenges such as dehydration and durability, while suggesting strategies for improving long-term performance. This work provides valuable insights for designing efficient hydrogel–ceramic composite materials for building applications.

Zhang et al. (2023) developed hydrogels with optimized optofluidic properties to enhance passive cooling performance. By improving solar reflectivity and evaporation rates, the study achieved temperature reductions of approximately 15°C under direct sunlight. The findings suggest that controlling surface porosity and reflectivity can significantly improve cooling efficiency, which is beneficial for hydroceramic tile development.

Xu et al. (2023) introduced a nanocomposite hydrogel incorporating zro_2 and PTFE nanoparticles to combine radiative and evaporative cooling mechanisms. The material exhibited high solar reflectance (0.924) and infrared emissivity (0.921), achieving temperature reductions of up to 24°C. This dual cooling approach demonstrates the potential for enhanced performance in hydroceramic tiles through hybrid cooling strategies.

Kaya and Deveci (2023) investigated the physicochemical and thermal properties of clay–hydrogel composites. The addition of clay significantly improved water absorption (up to ~10,600%), thermal stability, and mechanical integrity. The study confirms that clay enhances the durability and performance of hydrogel systems, making such composites suitable for long-term passive cooling applications.

Osman et al. (2023) explored the use of natural mucilage-based hydrogels as sustainable alternatives to synthetic polymers. The study demonstrated comparable water retention and cooling performance while offering advantages such as biodegradability and environmental compatibility. This supports the use of eco-friendly materials in hydroceramic tile development.

III. MATERIALS AND METHODOLOGY

A. Material Selection

A. Clay:

Clay was selected as the primary base material due to its high availability, porosity, and favorable thermal characteristics. It provides structural stability and facilitates water absorption, which is essential for evaporative cooling.

B. Cement:

Cement was incorporated as a binding agent to enhance the mechanical strength and durability of the tiles. It improves the cohesion of the composite matrix, making the tiles suitable for structural and cladding applications.

C. Hydrogel (Sodium Polyacrylate):

Hydrogel was used as a superabsorbent material to improve water retention capacity. Its ability to absorb and gradually release water plays a key role in enhancing the cooling performance of the tiles.

D. Banana Fiber (Musa acuminata):

Banana fiber was introduced as a natural reinforcement material to reduce cracking and improve the bonding within the matrix. It contributes to increased durability and sustainability of the composite.

E. Water:

Water was used for mixing, hydration of cement, and activation of hydrogel. Proper control of water content ensures adequate workability and overall performance of the tiles.

B. Mix Proportioning

The mix proportion for the preparation of hydroceramic cooling tiles was designed to achieve an optimum balance between thermal performance and mechanical strength . The proportions of clay , cement , hydrogel , banana fiber and water were selected based on preliminary trials to ensure adequate workability , water retention , capacity , and structural integrity .The details of mix proportions are given in Table 1.

Table 1: Mix Proportion

SAMPLE	CLAY (%)	CEMENT (%)	HYDROEL (%)	FIBER (%)	WATER (%)
S1	70	20	0	2	8
S2	65	20	5	2	8
S3	62	20	8	2	8
S4	58	20	12	2	8

C. Casting and Curing

The steel moulds were thoroughly cleaned and coated with a suitable releasing agent to facilitate easy removal of the specimens. The prepared mix was then placed into the moulds, and mechanical compaction was applied to eliminate entrapped air voids and to ensure proper densification of the material. Unlike conventional casting methods, a waiting period of 24 hours was not required for demoulding. The tiles were demoulded immediately after the application of compaction, as sufficient rigidity was achieved through the process. Following demoulding, the tiles were subjected to air drying for a period of 2–3 days to remove excess moisture. Subsequently, the specimens were dried in a kiln at a temperature range of approximately 600–800°C to enhance strength, stability, and durability.

D. Performance Evaluation Tests

Various tests were conducted to evaluate the thermal and mechanical performance of the developed hydroceramic cooling tiles. The thermal performance was assessed through water absorption , water retention , temperature reduction , and evaporation rate tests . In addition , the mechanical properties of tiles were determined by conducting compressive strength and flexural strength test.

IV. RESULTS AND DISCUSSIONS

1.Flexural strength test result

Table 2 Flexural strength test result

Sample	Strength (MPa)
S1	3.20
S2	3.90
S3	4.50
S4	4.10

Flexural strength vs Sample graph

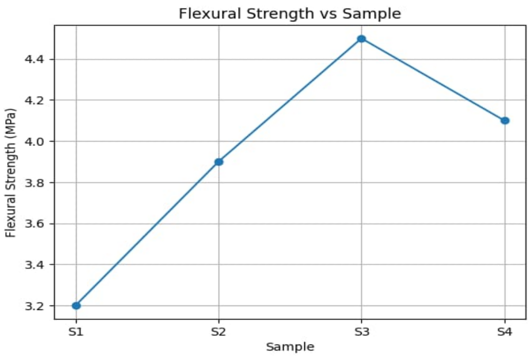

Fig 1 Flexural strength VS sample graph

Flexural strength improves with the addition of hydrogel up to 8%. This is due to better internal structure and the reinforcing effect of banana fibers, which help resist bending and cracking.

After the optimum level, strength may slightly decrease due to increased porosity caused by excess hydrogel.

Observation: Hydrogel and fiber combination enhances bending resistance, making the tiles suitable for practical applications like cladding.

2 Compression test result

Table 3 Compression strength test result

Sample	Strength (MPa)
S1	5.00
S2	5.60
S3	6.10
S4	5.70

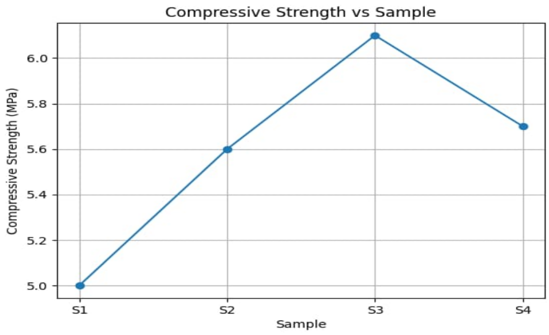

Fig 2 Compression strength VS sample graph

The compressive strength increases with hydrogel addition up to 8%, after which it slightly decreases. The initial increase is due to better bonding and uniform distribution of materials.

Beyond 8%, excess hydrogel creates more voids and increases porosity, which weakens the structure and reduces strength.

Observation : The optimum hydrogel content is 8%, where maximum strength is achieved while maintaining good cooling performance.

3 Water absorption test result

Table 4 Water absorption test result

Time (hrs)	S1 (0%)	S2 (5%)	S3 (8%)	S4 (12%)
0	0%	0%	0%	0%
1	4.0%	7.5%	8.5%	9.5%
3	7.0%	12.5%	13.8%	15.2%
6	9.0%	15.2%	16.0%	17.5%
24	10.0%	16.7%	17.0%	19.4%

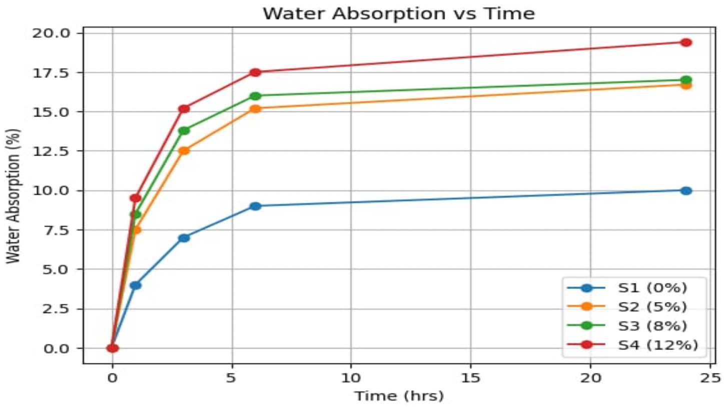

Fig 3 Water absorption VS time graph

The graph shows that water absorption increases rapidly during the initial period and then gradually stabilizes. This behavior occurs because the dry tile has empty pores at the beginning, allowing quick water intake due to capillary action. As time progresses, these pores become saturated, reducing the rate of absorption.

Hydrogel-containing tiles exhibit higher water absorption compared to conventional tiles because sodium polyacrylate can absorb and retain a large amount of water. The stabilization in the graph indicates that the tile has reached its maximum absorption capacity.

Observation: Higher water absorption confirms improved storage capacity, which is essential for effective evaporative cooling.

4 Water retention test result

Table 5 Water Retention test result

Time (hrs)	**S1 (0%)**	**S2 (5%)**	**S3 (8%)**	**S4 (12%)**
0	100%	100%	100%	100%
2	75%	85%	88%	90%
6	55%	70%	75%	78%
12	42%	60%	65%	68%
24	34.6%	56.5%	61.1%	63.2%

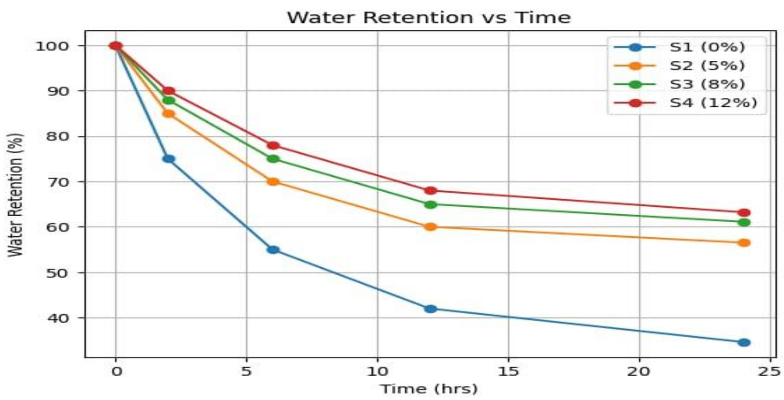

Fig 4 Water retention VS time graph

The graph indicates that water retention decreases gradually with time. Initially, the tile holds maximum water, and then it slowly loses moisture to the environment.

Hydrogel tiles retain water for a longer duration compared to normal tiles due to the presence of hydrogel, which releases stored water slowly. This slow release helps maintain moisture within the tile over an extended period.

Observation: Improved water retention ensures prolonged cooling performance, making hydroceramic tiles more efficient for passive cooling.

5 Evaporation rate test result

Table 6 Evaporation rate test result

Time (hrs)	S1 (0%) (g/hr)	S2 (5%)	S3 (8%)	S4 (12%)
1	2.0	4.0	4.5	5.0
3	1.8	3.8	4.3	4.8
6	1.5	3.5	4.0	4.5
12	1.2	3.0	3.5	4.0
24	1.0	2.5	3.0	3.5

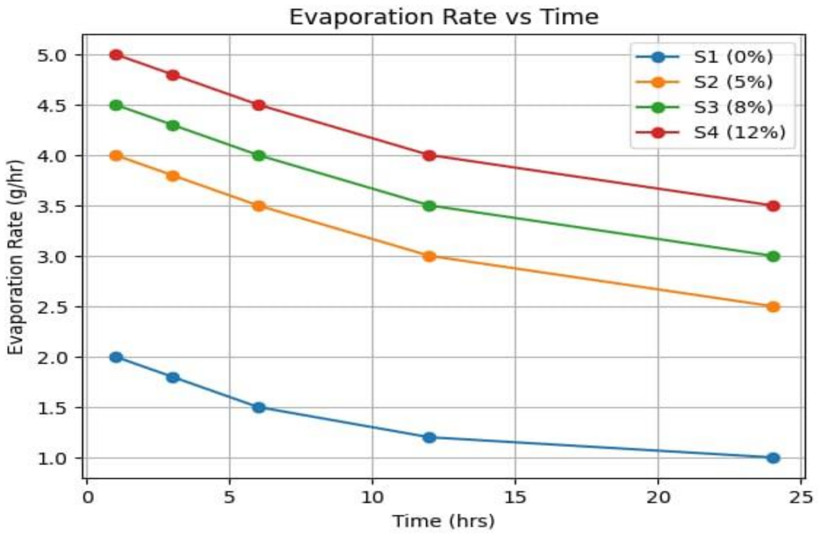

Fig 5 Evaporation rate VS time graph

The evaporation rate is high at the beginning and gradually decreases with time. Initially, excess surface water evaporates quickly, resulting in a high evaporation rate.

As time passes, the available free water reduces, and evaporation occurs mainly from the internal pores, which slows down the rate. However, hydrogel tiles maintain a relatively higher evaporation rate compared to normal tiles because they continuously supply water from within.

Observation : Sustained evaporation supports continuous cooling, which is beneficial for long-term thermal regulation.

6 Temperature reduction test result

Table 7 Temperature reduction test result

Time (hrs)	S1 (0%)	S2 (5%)	S3 (8%)	S4 (12%)
0	0°C	0°C	0°C	0°C
1	1.5°C	3.5°C	4.5°C	5.0°C
3	2.0°C	5.0°C	6.5°C	7.2°C
6	2.3°C	6.0°C	7.5°C	8.0°C
12	2.5°C	6.5°C	8.0°C	8.5°C

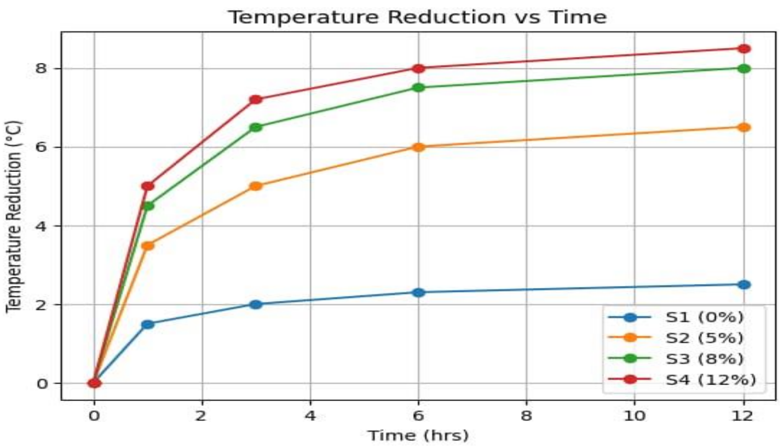

Fig 6 Temperature reduction VS time graph

The temperature reduction graph shows an increasing trend over time. This is due to the evaporation of stored water from the tile surface, which absorbs heat from the surroundings.

Initially, the cooling effect is low because evaporation has just started. As time progresses, evaporation increases, leading to greater heat loss and a noticeable reduction in surface temperature.

Hydrogel tiles show better temperature reduction compared to conventional tiles due to their higher water storage and controlled release.

Observation: The increase in temperature reduction confirms the effectiveness of evaporative cooling in hydroceramic tiles.

V. CONCLUSIONS

The present study successfully investigated the performance of hydroceramic cooling tiles developed using clay, cement, sodium polyacrylate (hydrogel), and banana fiber. The experimental results clearly indicate that the incorporation of hydrogel significantly enhances the thermal performance of conventional clay tiles.

The results of water absorption and water retention tests show a considerable improvement with increasing hydrogel content, demonstrating the enhanced capacity of the tiles to absorb and retain moisture. The water retention behavior confirms that hydrogel-based tiles are capable of holding moisture for longer durations, which directly contributes to sustained evaporative cooling.

The temperature reduction test revealed a noticeable decrease in surface temperature, with the cooling effect increasing over time due to continuous evaporation. This confirms that hydroceramic tiles are effective in reducing surface temperature when compared to conventional tiles. The evaporation rate test further supports this observation, indicating that although evaporation decreases with time, hydrogel tiles maintain a consistent cooling effect over extended periods.

From the mechanical performance perspective, the compressive strength results indicate that optimum strength is achieved at 8% hydrogel content, beyond which a slight reduction occurs due to increased porosity. Similarly, flexural strength shows improvement up to 8% hydrogel addition, indicating enhanced resistance to bending and cracking. The inclusion of banana fiber further improves crack resistance and contributes to the structural integrity of the tiles.

Despite the marginal reduction in strength at higher hydrogel content, all developed samples exhibited adequate mechanical properties suitable for cladding applications. The tiles maintained proper shape, dimensional stability (20 × 7 × 2 cm), and surface finish after demoulding, indicating good manufacturing quality.

Overall, hydroceramic cooling tiles demonstrated superior performance compared to conventional tiles in terms of thermal efficiency and moisture retention. These tiles provide an eco-friendly, cost-effective, and energy-efficient solution for passive cooling in buildings. Their application in wall cladding systems can significantly reduce indoor temperature and energy consumption, particularly in hot climatic conditions.

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