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MECHANICAL AND THERMAL PROPERTIES OF BEEF TALLOW/RICE HUSK CHARCOAL-BASED PLASTER FOR BUILDING APPLICATIONS

I Made Astika
Department of Mechanical Engineering[1]
Doctoral Study Program of Engineering Science[2]

I Nyoman Suprapta Winaya✉
Department of Mechanical Engineering[1]
ins.winaya@unud.ac.id

I Dewa Gede Ary Subagia
Department of Mechanical Engineering[1]

I Ketut Gede Wirawan
Department of Mechanical Engineering[1]

[1]*Udayana University*
Bukit Jimbaran str., Badung, Bali, Indonesia, 80361

[2]*Udayana University*
P. B. Sudirman str., Denpasar, Bali, Indonesia, 80234

✉**Corresponding author**

Abstract

The construction industry represents the largest energy-consuming sector globally, primarily due to its substantial operational processes power demand. To address this, there has been an increased emphasis on using materials capable of absorbing and storing heat as alternative energy storage in buildings. Phase Change Materials (PCMs) demonstrate this capability, harnessing the latent heat principle to absorb surplus heat energy and subsequently release it in times of deficiency. This study examines the mechanical and thermal properties of wall cladding materials integrated with PCMs, specifically beef tallow and rice husk charcoal. These composites were produced via direct incorporation, with rice husk charcoal weight fractions of 8, 10, and 12 %. This approach resulted in weight fractions of 28, 30, and 32 % in the plaster layer material. Fourier Transform Infrared Spectroscopy (FTIR) tests confirmed the PCM composite's chemical compatibility across all its components, with the composite morphology appearing as microcapsules. In terms of thermal conductivity, the addition of rice husk charcoal to beef tallow enhanced the PCM composite's performance. This enhancement indicated that approximately 10 % of rice husk charcoal weight fraction could be successfully incorporated into the plaster layer material without leakage. At an ambient temperature of 45 °C, a plaster composite with 30 wt. % PCM met the standard compressive strength for plaster coating. Furthermore, it was found that this composite could reduce the temperature by 2.4 °C. The results concluded that beef-tallow PCM exhibits promising potential as a heat storage system for buildings, contributing to energy conservation in the construction industry.

Keywords: phase change material, beef tallow, rice husk charcoal, chemical compatibility, thermal properties, compressive strength, thermal performance.

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1. Introduction

The building sector represents the most significant energy consumer, contributing to approximately 40 % of the global total energy consumption [1, 2]. Similar trends are observed in Indonesia, where the residential or construction phase accounts for about 35 % of the country's total energy usage [3]. The integration of technological solutions like Thermal Energy Storage (TES) systems can lead to substantial reductions in building energy utilization [4–6]. Furthermore, the selection of appropriate materials and the implementation of efficient heat storage systems can also significantly decrease energy consumption [7].

One of the promising materials in this context is PCM, capable of absorbing and releasing heat energy during periods of surplus and deficit, respectively. This material operates on the Latent Heat Thermal Energy Storage (LHTES) principle, demonstrating significant potential as a safe and cost-effective energy reserve for future systems [8, 9]. PCM has found applications in building construction for energy consumption reduction and is commonly used in roofs, ceilings, windows, walls, and floors [10]. Owing to their larger heat exchange area and ease of implementation, wall-integrated PCMs have been widely studied [11]. When applied to the plaster layer, these materials absorb and store most of the solar radiation, mitigating temperature fluctuations inside the building and effectively reducing peak energy consumption [12].

Beef tallow, an organic material with PCM properties and a melting temperature range of 36–40 °C, is often employed to enhance thermal comfort due to its phase change temperature closely aligning with normal human body temperature [13, 14]. However, PCMs generally exhibit low thermal conductivity, limiting the kinetics of heat absorption and release [15–17]. Certain high-heat-conductivity materials, such as graphite [18], metal and copper foam [19, 20], perlite [21], and materials processed via encapsulation [22], can enhance these thermal properties. Other carbon-based materials, such as rice husk charcoal, have also been reported to improve the conductivity and other thermal properties of PCM [23].

This study explores the use of beef tallow, a phase change material (PCM) with low thermal conductivity, for its potential in heat absorption and release. To enhance its thermal properties, rice husk charcoal was incorporated as an additive, and its performance was evaluated using the T-history method. The chemical compatibility between the beef tallow and rice husk charcoal, once integrated into the plaster coating material, was examined through Fourier Transform Infra Red (FTIR) spectroscopy. The results showed that the combination created a composite where the beef tallow maintained its PCM characteristics. The study further evaluated how the quantity of PCM integrated into the plaster influences the material's thermal and mechanical properties. The plaster-PCM composite's compressive strength was analyzed at two different ages (7 and 28 days) and at two different temperatures (27 and 45 °C). This was done to ensure it meets the regulatory standards. In addition, the thermal performance of the plaster-PCM composite, specifically its ability to absorb and store heat, was assessed through a dedicated test.

The overarching goal of the research was to develop a plaster-PCM composite that exhibits optimal thermal and mechanical properties, thereby making it suitable for application on building walls. By incorporating PCM into the plaster layer, the material can serve as a heat storage system, potentially reducing temperature fluctuations within the room. This innovative approach may ultimately decrease the reliance on electrical energy, particularly for room heating and cooling systems.

2. Materials and Methods

2. 1. Materials

Beef tallow, procured from PT Utama Jakarta, exhibited characteristics of melting temperature (36–40 °C), latent heat (112 kJ/kg), and thermal conductivity (0.181 W/m K). Rice husks were obtained from the «Mulya Sejahtera» cooperative rice mill in Tabanan, Bali, Indonesia, and were converted into rice husk charcoal through carbonization at 400 °C for 2 hours, resulting in a carbon content of 41.10 %. The fundamental ingredients for the finishing plaster layer, including polyvinyl acetate (PVAc), limestone, and cement, were sourced from a building shop in the Tabanan region of Bali.

2. 2. Plaster PCM composite preparation

The PCM composites were produced using the direct incorporation method, in which beef tallow was melted in a thermostatic water bath. Rice husk charcoal was then added to the melted tallow in concentrations of 8, 10, and 12 wt %, with continual stirring until a slurry was formed. Around 5 % PVAc was further integrated into the slurry and stirred to achieve homogeneity. The PCM composite, with weight fractions of 28, 30, and 32 %, was subsequently blended with the plaster layer material. Here, limestone was added in variations of 48, 50, and 52 wt %, and cement was included in a 20 % weight fraction. Upon reaching homogeneity, the mixture was poured into a preselected mould for analytical performance assessment.

2. 3. Characterization

An FTIR spectrometer (ASTM E1252) was utilized to analyze the interactions and chemical compatibility of the composite constituents, using a wavenumber range of 400–500 cm^{-1}. The morphology of the PCM composites was assessed through a Scanning Electron Microscope (SEM) (ASTM E1508). The phase change temperature, as well as the specific and latent heat of the composites, were determined using the T-history method, depicted in **Fig. 1**.

The quantity of PCM to be incorporated into the plaster coating material was ascertained through a leakage test conducted prior to any observed leakages. For this, the specimen was heated to 45 °C for 90 minutes. The mechanical properties were evaluated by pouring a set of mixtures into a plastic mould as per ASTM D695, with tests conducted at 7 and 28 days of age, at 27 °C and 45 °C, respectively. Thermal performance was examined utilizing equipment supported by ASTM C1363-19, containing a 60-watt infrared lamp mounted atop the test box. The thermal performance of the samples was measured using a multichannel temperature measurement system equipped with thermocouples. The schematic for testing the thermal performance of the plaster PCM composite is illustrated in **Fig. 2.**

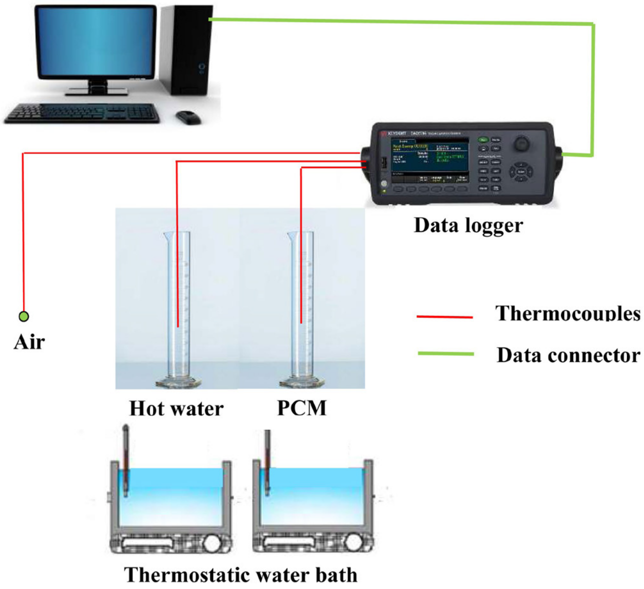


Fig. 1. T-history method schematic

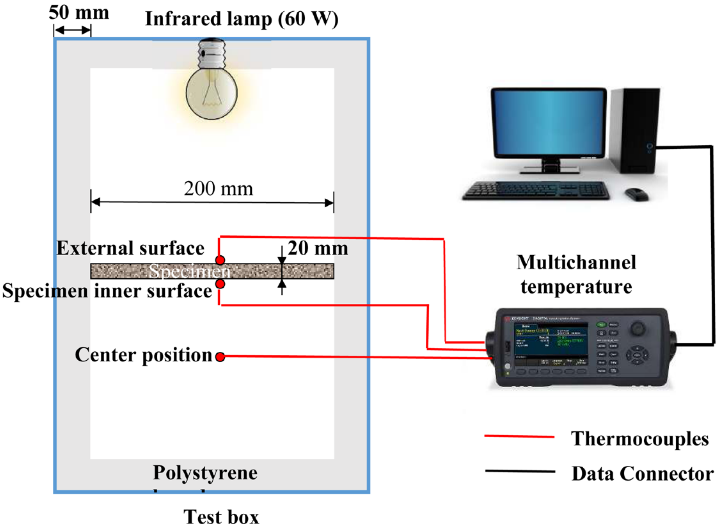


Fig. 2. Schematic of the thermal performance test

In this experimental setup, specimens measuring 200×150×20 mm were centrally positioned within the test box, while the remaining five surfaces were insulated with polystyrene boards. Three thermocouples were strategically installed within the test box for accurate temperature monitoring during heating and cooling cycles. One thermocouple was positioned centrally to record temperature fluctuations throughout the experiment, while the other two were placed on the inner and outer surfaces of the test object to measure surface-specific thermal behavior. An infrared lamp served as the heat source for the experiment, engineered to raise the temperature of the specimen's outer surface to 45 °C. This method ensured a controlled and consistent heat supply to investigate the thermal performance of the specimens accurately.

3. Result and Discussions

3. 1. FTIR analysis

FTIR analysis is instrumental in detecting potential chemical or physical interactions between disparate components within a composite material. **Fig. 3** illustrates the FTIR transmission spectrum of beef tallow, rice husk charcoal, polyvinyl acetate, plaster coating materials, and their composites.

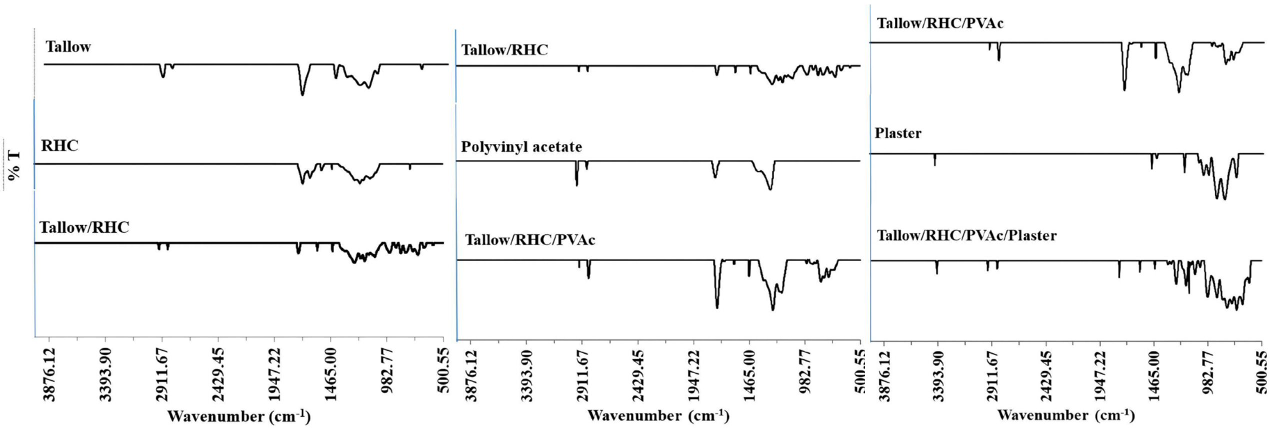
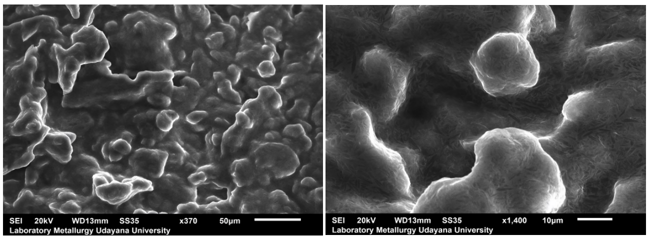


Fig. 3. The infrared spectrum of PCM composite

As per **Fig. 3**, the spectrum of the plaster PCM composite didn't reveal any new peaks beyond those present in the constituent materials. The bonds were neither broken nor modified during the integration of beef tallow, rice husk charcoal, and PVAc into the plaster coating material. This aligns with findings reported by [24], where the assembly of paraffin, expanded pearlite, and waterproof materials into the plaster coating material to create PCM composites resulted in no observable chemical bonds between the materials. FTIR tests affirmed that the amalgamation of materials used had no chemical consequences or bonds, affirming the presence of a composite product.

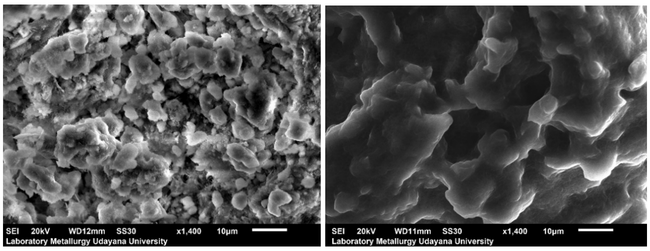
3. 2. Morphology of the PCM Composite

Fig. 4, 5, *a* showcase the microcapsule morphology of the material formed through the direct union of beef tallow, rice husk charcoal, and polyvinyl acetate.



a *b*

Fig. 4. SEM images of combined beef tallow and rice husk charcoal:
a – 370 × magnification; *b* – 1400 × magnification



a *b*

Fig. 5. SEM images: *a* – tallow + rice husk charcoal + polyvinyl acetate;
b – tallow + rice husk charcoal + polyvinyl acetate + plaster

Conversely, **Fig. 5, *b*** depicts the microcapsules of the PCM cloaked by the plaster layer material and distributed uniformly.

This mirrors the findings of [25], where equivalent results were accomplished by integrating PCM into cement-based construction materials. The eutectic PCM was also reported to be evenly dispersed among the cement particles.

3. 3. Leakage assessment

In **Fig. 6**, a weight loss of 14.18 % was noticed in the sample containing 8 wt. % rice husk charcoal, signaling a decrease in the sample PCM attributed to leakage. The weight of the plaster layer material without PCM saw a reduction of 9.67 %. Simultaneously, the material's weight decreased by 6.93 % and 6.66 % with rice husk charcoal contents of 10 % and 12 %, respectively. This primarily signifies the evaporation of the material's water content.

Fig. 7 reveals that there was no seepage observed for the composite samples containing 10 and 12 wt. % rice husk charcoal. However, leakage traces were visible in the 8 wt. % samples.

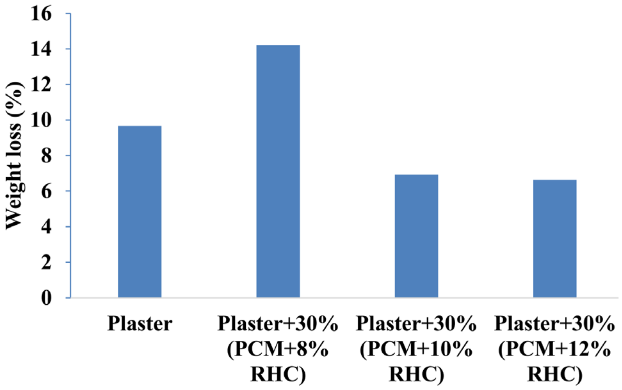


Fig. 6. Percentage of sample weight loss

Plaster+30% (PCM+10% RHC) **Plaster+30% (PCM+12% RHC)** **Plaster+30% (PCM+8% RHC)**

Fig. 7. PCM composite plaster leak test results

This suggests that a 30 wt. % (PCM + 10 and 12 % RHC) was successfully integrated into the plaster layer, resulting in a sTable and usable material, in agreement [25], where leakage occurred at the integration of 30 wt. % PCM into the plaster layer material. The results indicate that the PCM amount that can be safely incorporated into the plaster coating material without any leakage is approximately 28 wt. %.

3. 4. Thermal properties of the PCM composite

The thermal property analysis using the T-History method was effective, demonstrating supercooling in the temperature profile. **Fig. 8** illustrates the equipment used to test the thermal properties of the mixture.

Fig. 9 presents the temperature vs. time profile for the parameters (1) 100 % beef tallow, and (2) beef tallow + (8 %, 10 %, and 12 %) rice husk charcoal samples. The examination was carried out over 200 minutes, allowing all test temperatures to stabilize.

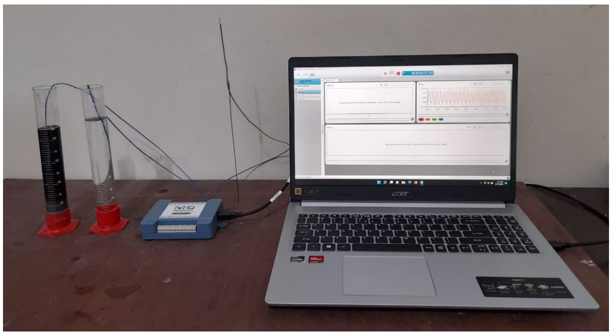
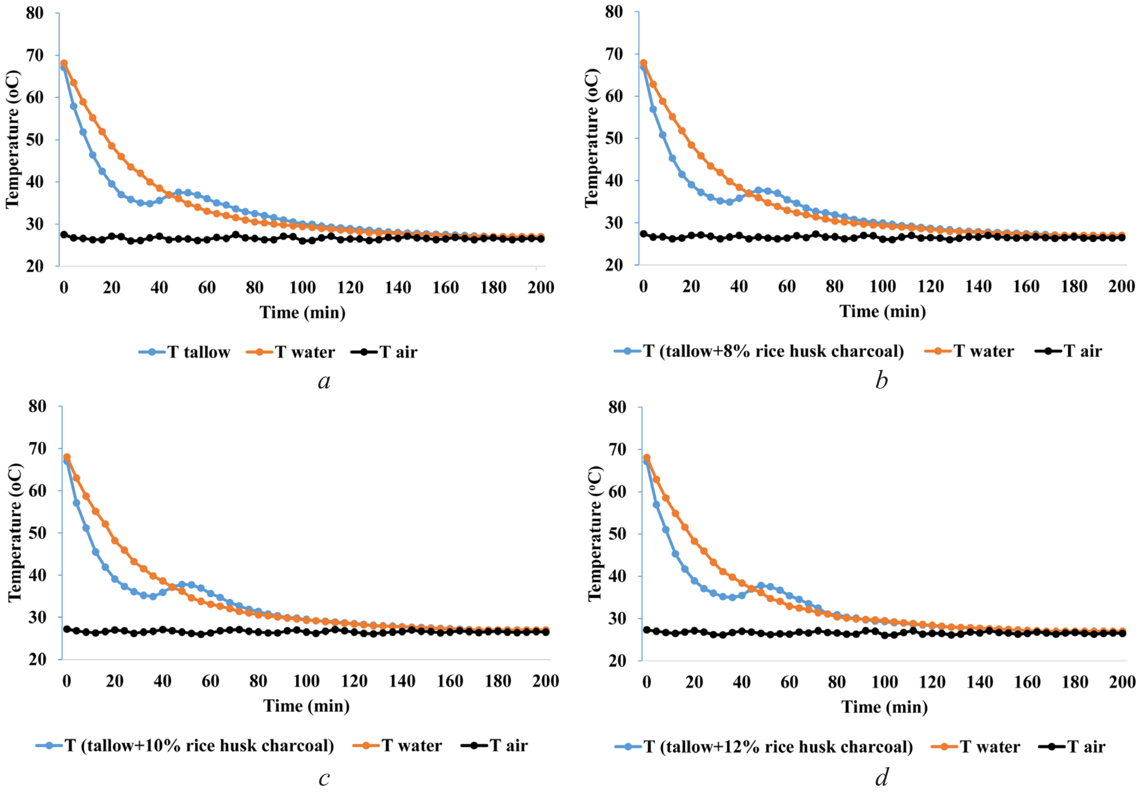


Fig. 8. Equipment to test the thermal properties of PCM composite



a *b*

c *d*

Fig. 9. The temperature profile of PCM ingredients:
a – 100 % beef tallow; *b* – beef tallow + 8 % rice husk charcoal;
c – beef tallow + 10 % rice husk charcoal; *d* – beef tallow + 12 % rice husk charcoal

Based on **Fig. 9**, the PCM composite and the reference sample in the test tube experienced a decrease in temperature during the cooling/freezing processes. In this case, the composites underwent a supercooling process during solidification, while the process did not occur for water (reference). From the graphs, the supercooling temperatures and their degrees, as well as liquid heat were obtained. This indicated that the addition of rice husk charcoal to beef tallow had no effect to supercooling and liquid temperatures, respectively.

Fig. 10 shows the degrees of supercooling for each sample were 2.70 °C, 2.71 °C, 2.72 °C, and 2.72 °C. The specific (solid and liquid) and latent heat of the PCM composite was calculated using the Yinping equation [26] as shown in **Table 2**.

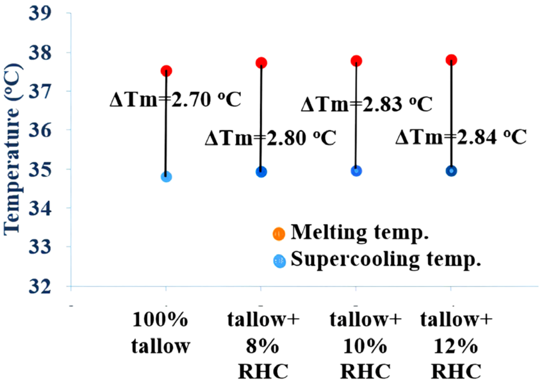


Fig. 10. Degree of supercooling of PCM material

Table 1 shows the obtained melting temperature was 37.50–37.51 °C, a suitable range for wall applications (0–65 °C as per [27, 28]). The addition of rice husk charcoal didn't affect the reduction of the PCM beef tallow's melting temperature. This reduction is beneficial for wall applications due to the decreased load on the cooling system and increased electricity consumption efficiency. **Table 2** reveals that adding rice husk charcoal to beef tallow decreased latent heat from 101.02 to 87.08 kJ/kg. Rice husk charcoal, being a non-phase changing additive, naturally reduces the latent heat of the composite phase change material relative to the pure phase change material (beef tallow). Adding rice husk charcoal increased the thermal conductivity from 0.181 to 0.836 W/mK for tallow and tallow + 12 % RHC, respectively. This increase in thermal conductivity influences heat transfer mechanisms, but optimum thermal conductivity must be maintained to ensure efficient heat absorption and release.

Table 1

Supercooling temperature and liquid temperature of PCM composites

Materials	Supercooling temperature (°C)	Melting temperature (°C)
100 % beef tallow	34.81	37.51
Beef tallow + 8 % rice husk charcoal	34.80	37.51
Beef tallow + 10 % rice husk charcoal	34.78	37.50
Beef tallow + 12 % rice husk charcoal	34.79	37.51

Table 2

Specific heat, latent heat and thermal conductivity of PCM materials

Materials	$cp_{.s}$ (kJ/kg. °C)	$cp_{.l}$ (kJ/kg. °C)	Hm (kJ/kg)	k (W/mK)
100 % beef tallow	2.64	2.94	101.02	0.181
Beef tallow + 8 % rice husk charcoal	2.73	2.97	97.52	0.409
Beef tallow + 10 % rice husk charcoal	2.82	2.98	95.16	0.594
Beef tallow + 12 % rice husk charcoal	2.68	2.95	87.08	0.836

3. 5. Compressive strength

The compressive strength of PCM composite plaster intensified with age, from 7 to 28 days (**Table 3**). The strength intensified by 3.27–4.94 % and 4.31–8.20 % with PCM at 27 °C and 45 °C.

Table 3

Increasing compressive strength with increasing age of PCM composites

Materials	27 °C			45 °C		
	7 days	28 days	Increase (%)	7 days	28 days	Increase (%)
	Compressive Strength (MPa)			Compressive Strength (MPa)		
Plaster	3.656	4.009	8.80	3.418	3.841	11.00
Plaster + 28 % PCM	3.390	3.566	4.94	2.992	3.259	8.20
Plaster + 30 % PCM	3.190	3.330	4.19	2.839	3.024	6.13
Plaster + 32 % PCM	2.599	2.687	3.27	2.325	2.430	4.31

Meanwhile, the compressive strength of plaster without PCM increased by 8.80 % and 11.00 % at 27 °C and 45 °C, respectively. These increases highlighted the rise in the compressive strength of the plaster base material due to a decrease in the water content of the PCM-composite with age.

Table 4 shows that the addition of PCM to the plaster coating material led to a reduction in compressive strength, as the PCM material does not act as a composite reinforcement. The compressive strength of the composite plaster decreases with increased PCM content in the coating material. Compared to plaster without PCM, the reduction in compressive strength ranged from 7.29 % to 36.74 %.

Table 4

Decrease in compressive strength with increasing PCM in plaster

Materials	7 days				28 days			
	27 °C		45 °C		27 °C		45 °C	
	Compressive Strength (MPa)	Decrease (%)	Compressive Strength (MPa)	Decrease (%)	Compressive Strength (MPa)	Decrease (%)	Compressive Strength (MPa)	Decrease (%)
Plaster	3.656	–	3.418	–	4.009	–	3.841	–
Plaster + 28 % PCM	3.390	7.29	2.992	12.48	3.566	11.06	3.259	15.15
Plaster + 30 % PCM	3.190	12.74	2.839	16.96	3.330	16.94	3.024	21.27
Plaster + 32 % PCM	2.599	28.92	2.325	31.98	2.687	32.98	2.430	36.74

Table 5 denotes that the compressive strength analysis demonstrated lower values at 45 °C compared to 27 °C. This reduction can be attributed to a phase change in the PCM at 45 °C, leading to weakened bonds among the composite constituents and subsequently diminishing its strength. The compressive strength decreased by approximately 8.60–10.54 %.

Table 5

Decrease in compressive strength at various test temperatures

Materials	7 days			28 days		
	27 °C	45 °C	Decrease (%)	27 °C	45 °C	Decrease (%)
	Compressive strength (MPa)			Compressive strength (MPa)		
Plaster	3.656	3.418	6.50	4.009	3.841	4.20
Plaster + 28 % PCM	3.390	2.992	11.73	3.566	3.259	8.60
Plaster + 30 % PCM	3.190	2.839	11.02	3.330	3.024	9.19
Plaster + 32 % PCM	2.599	2.325	10.54	2.687	2.430	9.57

This observation aligns with the study presented in [29], which reported analogous patterns when assessing the compressive strength of concrete integrated with beeswax/dammar gum. The study indicated that the inclusion of 10 %, 20 %, and 30 % PCM containing beeswax led to a corresponding reduction in concrete's compressive strength. As evident from the findings, an increase in the PCM concentration resulted in a continuous decrease in the concrete's compressive strength by 10.7–19.10 %.

Interestingly, the age of the sample was found to inversely affect the strength, causing an increase of 11.91–20.71 %. The compressive strength of gypsum, when evaluated with paraffin and expanded graphite as PCM [18], demonstrated that the addition of the PCM to 10 % and 20 % of gypsum caused a significant reduction in compressive strength by 61.2 % and 72.8 %, respectively. The compressive strength of EGPG was found to decrease with an increasing EG/P content. This established that the inclusion of EG/P resulted in an increase in total porosity, thus leading to a notable reduction in mechanical strength. The use of 10 %, 20 %, and 30 % volume fractions of butyl stearate in limestone powder resulted in a compressive strength reduction by 3.7–30.4 % [30].

The elasticity modulus in plaster coating materials and PCM composite plasters were presented in **Table 6**.

Table 6
Modulus of elasticity for PMC composites

Materials	**Modulus of elasticity (MPa)**			
	7 days		**28 days**	
	27 °C	**45 °C**	**27 °C**	**45 °C**
Plaster	3.192	2.808	4.103	2.980
Plaster + 28 % PCM	1.667	1.434	1.976	1.524
Plaster + 30 % PCM	0.752	0.659	0.874	0.704
Plaster + 32 % PCM	1.093	0.961	1.322	0.921

The modulus of elasticity for the composite plaster was found to be lower than the plaster layer without PCM. As confirmed by the data in **Table 6**, the 30 % PCM plaster exhibited the lowest modulus of elasticity at 0.704 MPa. **Fig. 11** illustrates the stress-strain curve of the tested specimen.

Fig. 11 also reveals that incorporating 30 % PCM into the plaster layer resulted in a material exhibiting a broader range of elasticity and strain. Despite possessing the highest compressive strength, the plaster layer material exhibited brittleness. However, the addition of PCM led to a more ductile material, albeit with a reduced compressive strength. Nonetheless, these materials met the requirements for plaster coating in building applications.

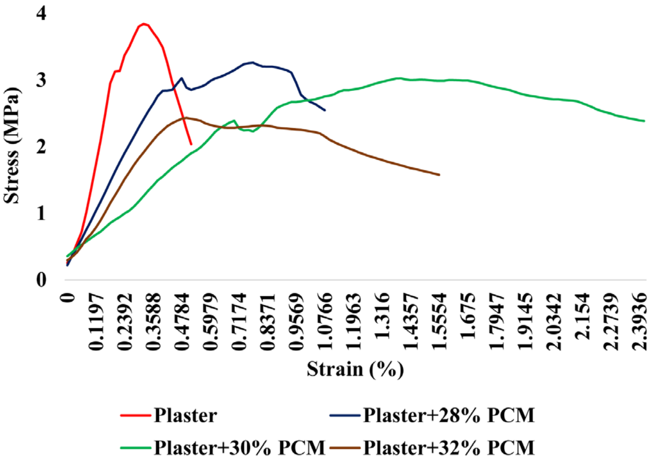


Fig. 11. Stress-strain curve for PCM composites at a test temperature of 45 °C, aged 28 days

The compressive strength of the PCM composite plaster was found to range from 2.430 to 3.849 MPa. This aligns with the standard requirements for plaster layers, which stipulate a minimum of 3 MPa [31]. A 30 % PCM composite plaster satisfied these requirements, showcasing a compressive strength of 3.024 MPa at 45 °C. This indicates the suitability of this material as a plaster layer on building walls, even when the ambient temperature rises to 45 °C, while still meeting the compressive strength requirements.

3. 6. Performance of thermal plaster PCM composite

The thermal performance of the plaster coating material, with and without PCM, was evaluated to ascertain the temperatures at the inner surface and the center of the test box. **Fig. 12** presents the process of measuring the thermal performance of the plaster PCM composite.

Fig. 12. Equipment to test the thermal performance of PCM composite

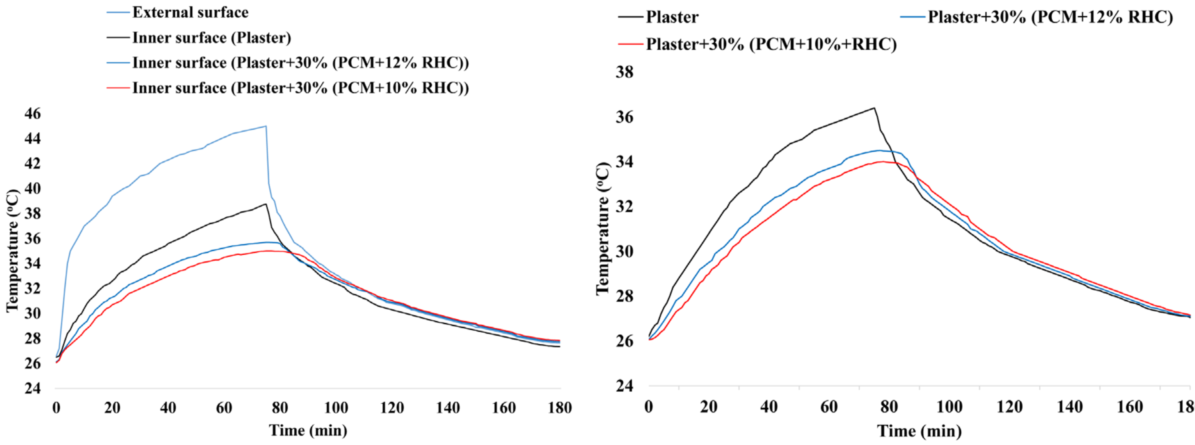
Table 7 and **Fig. 13, *a*** display a comparative analysis of the thermal performance for plaster + 0 wt. % PCM, plaster + 30 wt. % (PCM + 10 % RHC), and plaster + 30 wt. % (PCM + 12 % RHC). These results highlight the inner surface temperature of the layers both with and without PCM. In this evaluation, the peak temperature on the external surface of the test box reached 45 °C. However, the highest temperatures on the inner surface were 35.7 °C and 35.0 °C for plaster + 30 wt. % (PCM + 12 % RHC) and plaster + 30 wt. % (PCM + 10 % RHC), respectively.

Table 7
The temperature of the external and inner surfaces of the specimen, and the center of the box

Materials	**External surface temperature (°C)**	**Inner surface temperature (°C)**	**Centre of the box temperature (°C)**
Plaster	45.00	38.75	36.40
Plaster + 30 % (PCM + 12 % RHC)		35.70	34.50
Plaster + 30 % (PCM + 10 % RHC)		35.00	34.00

These recorded values proved to be less than the maximum temperature of the control layer (without PCM), which registered at 38.75 °C. Throughout the heating and cooling cycles, the energy absorption and release dynamics of the PCM plaster coating were also observed.

Fig. 13, *b* visualizes the temperature at the center of the test box, validating that the plaster layer devoid of PCM experienced an indoor temperature of 36.4 °C. In contrast, the temperatures for plaster + 30 wt. % (PCM + 12 % RHC) and plaster + 30 wt % (PCM + 10 % RHC) were 34.5 °C and 34.0 °C, respectively, reflecting a reduction of 1.9 °C and 2.4 °C. This outcome underlines the role of rice husk charcoal in PCM in mitigating temperature variations within the test box. **Table 7** and **Fig. 13**, ***a*** indicate that the temperature escalation on the inner surface of the PCM plaster is more gradual than that on the outer surface without PCM. Nonetheless, during the cooling phase, the temperature descent was more gradual, in contrast to the abrupt drop in the plaster lacking PCM. This observation is attributable to the heat absorption and storage capabilities of the plaster coating material influenced by the presence of PCM. For the center of the test box, temperatures were found to be lower with the use of a PCM layer. These shifts were steadier at the highest temperature, unlike the thermal transformation in plaster without PCM.



a *b*

Fig. 13. Thermal performance comparison between plaster and plaster PCM composite: *a* – sample external and inner surface temperature; *b* – the center position temperature of the test box

3. 6. 1. Comparison of the thermal performance of various PCM composites

Several studies have employed a laboratory-scale test box to evaluate the thermal performance of PCM composites. In these case studies, the majority of analyses underscored a decrease in indoor temperature fluctuations. Based on [32], cement mortar was incorporated with expanded graphite (EG)/paraffin to formulate PCM composites, indicating a maximum temperature disparity of 2.2 °C at the test box center between ordinary and PCM-based mortar boards.

Furthermore, [33] reported a temperature differential of 3.1 °C using cement panels and PCM types CA-LA/Kc. The thermoregulatory performance of test boxes fabricated from BNT clay and BNT/HE was evaluated [34], revealing that the average temperature differences during heating and cooling cycles were 2.09 °C and 0.96 °C, respectively. Similarly, [5] prepared cement-based panels with lauryl alcohol/kaolin PCM type, portraying a temperature decline of 4 °C compared to the control test room.

The thermal performance of a test chamber constructed with diatomite/PEG-containing siding boards was also scrutinized, showing an indoor temperature decrease of 1.1 °C [35]. Additional studies discovered that the employment of gypsum/PEG600 and natural clay/capric-palmitic acid [36] resulted in a 2.08 °C and 0.96 °C decreases in indoor temperature, respectively.

An investigation into the eutectic mixture of 28 wt % capric (CA)-myristic (MA) acids, vacuum impregnated into the cement material, was documented [25]. This revealed a temperature difference of 0.78 °C between the inner and outer surfaces of the test box during the heating period. Additionally, [16] integrated cement mortar, hydrate salt/expanded graphite oxide, and acrylamide-co-acrylic acid, recording temperature reductions on the inner surface of the tested panel by 5.0 °C and 6.7 °C, respectively. **Fig. 14** offers a comparative view of the thermal performance of various PCM composites.

The obtained results, showcasing notable temperature reductions, are well-suited for use as building wall coatings to diminish indoor thermal fluctuations. As per various literature reviews, the thermoregulatory performance of PCM composites amalgamated into distinct building materials relies on several factors. These include the phase change temperature, amount of PCM infused, composite LHTES capacity, thermal conductivity, the specific heat capacity of the building material, and the test procedure heating rate. Consequently, the PCM plaster layer exhibited a relatively high thermoregulation potential.

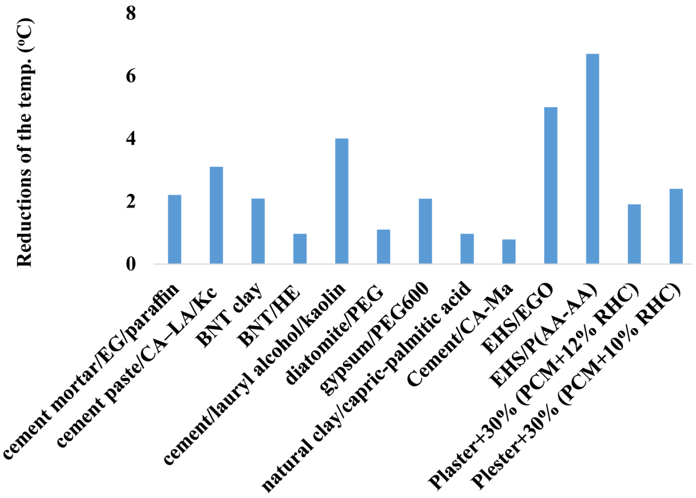


Fig. 14. Thermal performance of some PCM composite

3. 7. Limitations of the study and future directions

The inclusion of rice husk charcoal in beef tallow, as presented in this study, led to a decrease in the thermal properties (latent heat) of the PCM composite. The latent heat of this PCM composite remains a field requiring further enhancement. Generally, materials with higher latent heat exhibit superior heat storage capabilities.

The maximum amount of PCM that can be integrated into the plaster material in this study was 30 wt. %, satisfying the mechanical requirements of plaster in buildings. However, this value still warrants an increase. As a rule of thumb, the more PCM a material contains, the higher its heat absorption and storage capabilities.

Aside from its application in building construction materials, beef tallow can be developed as an absorber and heat storage unit integrated into clothing materials. Given that the phase change temperature of beef tallow closely aligns with the normal human body temperature, integrating PCM into the clothing material could enhance wearer comfort. The recommended method is to form microcapsules such that they can be incorporated into the fabric of the garment.

4. Conclusions

The results of this study confirm the successful preparation of a PCM composite, constituted by a mixture of beef tallow, rice husk charcoal, and polyvinyl acetate, with a commendable chemical compatibility among all components. The obtained morphology was in the form of a microcapsule, preventing leakage during the phase change of the PCM.

Upon analysis, it was noted that the integration of 10 % rice husk charcoal into beef tallow enhanced the thermal conductivity of the PCM composite. This increment in thermal conductivity significantly impacts the heat transfer mechanism in PCM composites. Approximately 10 wt. % of rice husk charcoal was effectively incorporated into the plaster layer without any leakage, qualifying it as a formable and utilizable material.

Regarding the mechanical properties analysis, an inverse relationship was observed between the compressive strength and increasing PCM content in the plaster layer material. Nevertheless, the strength demonstrated an increase with the aging of the PCM composite.

Aside from its application as a plaster coating material for building walls, the 30 wt. % also satisfied the compressive strength requirements when the ambient temperature reached 45 °C. The thermal performance analysis revealed that the PCM plaster layer showcased admirable heat absorption and storage characteristics, along with the ability to decrease indoor temperature fluctuations.

Despite the use of a 30 wt. % PCM composite on the plaster coating material, the temperature reduction and material integration were still not at their optimum. Therefore, alternative combination methods should be explored to improve the thermal and mechanical properties of PCM composites. The compound developed from beef tallow and rice husk charcoal exhibited a relatively high thermoregulation potential, implying its suitability as a plaster layer on building walls. This emphasizes its potential to reduce indoor temperature fluctuations and electricity consumption.

Conflict of interest

The authors hereby declare no conflict of interest associated with this research, including financial, personal, authorship, or other interests that could potentially influence the outcomes and interpretations of the research findings presented in this paper.

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Data availability

Data associated with this study will be made available upon reasonable request.

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