EXPLORING INTEGRATION AND EFFECTS OF ADVANCED MICROENCAPSULATED PHASE CHANGE MATERIALS (AMIC-PCMS) IN CONSTRUCTION FOR ENHANCED THERMAL PERFORMANCE AND ENERGY EFFICIENCY

Abstract

Phase Change Materials (PCMs) are a transformative technology revolutionizing construction, enhancing energy efficiency and thermal performance. PCMs, functioning as "thermal batteries" by absorbing and releasing thermal energy during phase transitions, store heat during warmth and release it as temperatures drop. This paper investigates PCM applications, selection criteria, integration methods, and classifications in construction.

Integrated into materials like concrete and insulation, PCMs offer benefits such as enhanced energy efficiency, thermal comfort, passive cooling/heating, and reduced peak energy demand. Addressing construction's high energy consumption and environmental impact, PCM integration curtails energy use, fostering sustainability. Diverse integration approaches, including PCM-enhanced insulation and HVAC systems, cater to varied designs, climates, and energy requirements.

PCM selection hinges on thermodynamics, chemical properties, accessibility, affordability, and kinetics. Categorized as organic, inorganic, and eutectic based on phase transitions, PCM selection is vital for optimal performance. Investigating the influence of Advanced Microencapsulated Phase Change Material (AMIC-PCM) on mortar, this study examines its effects on workability, density, and mechanical properties. AMIC-PCM's

Author

Aditya Pratap Singh
B. Tech Student
Department of Civil Engineering
Manav Rachna International Institute of Research and Studies
Faridabad, Haryana, India.
singh.aditya1221@gmail.com

fine nature reduces workability, necessitating superplasticizers. It diminishes density and weakens compressive/flexural strength due to lower intrinsic strength.

AMIC-PCM-incorporated mortar's thermal properties reveal intriguing trends in thermal conductivity and heat capacity. Small AMIC-PCM doses enhance properties through void filling, while larger doses lower thermal conductivity due to ingredient replacement. AMIC-PCM's thermal stability and characterization highlight its potential in construction materials.

PCM integration in construction provides energy-efficient, sustainable solutions. PCM selection, integration, and material effects are vital for optimization. Study results underscore the significance of meticulous dosing and balance to achieve desired thermal attributes while preserving structural integrity.

Keywords: Phase Change Materials (PCMs), thermal batteries, energy efficiency, thermal performance, construction, Advanced Microencapsulated Phase Change Material (AMIC-PCM), workability, density, mechanical properties, thermal conductivity, heat capacity, energy-efficient solutions, structural integrity.

I. BACKGROUND OF PHASE CHANGE MATERIAL'S (PCM)

Phase Change Materials (PCMs) have emerged as a revolutionary technology in the construction industry, offering significant benefits in enhancing the energy efficiency and thermal performance of buildings. PCMs are materials that can absorb and release thermal energy during the process of phase transition, typically from solid to liquid and vice versa, at a specific temperature known as the phase change temperature. This unique property allows PCMs to act as "thermal batteries," effectively storing excess heat during warmer periods and releasing it when the surrounding temperature drops, thereby reducing the need for active heating and cooling systems.

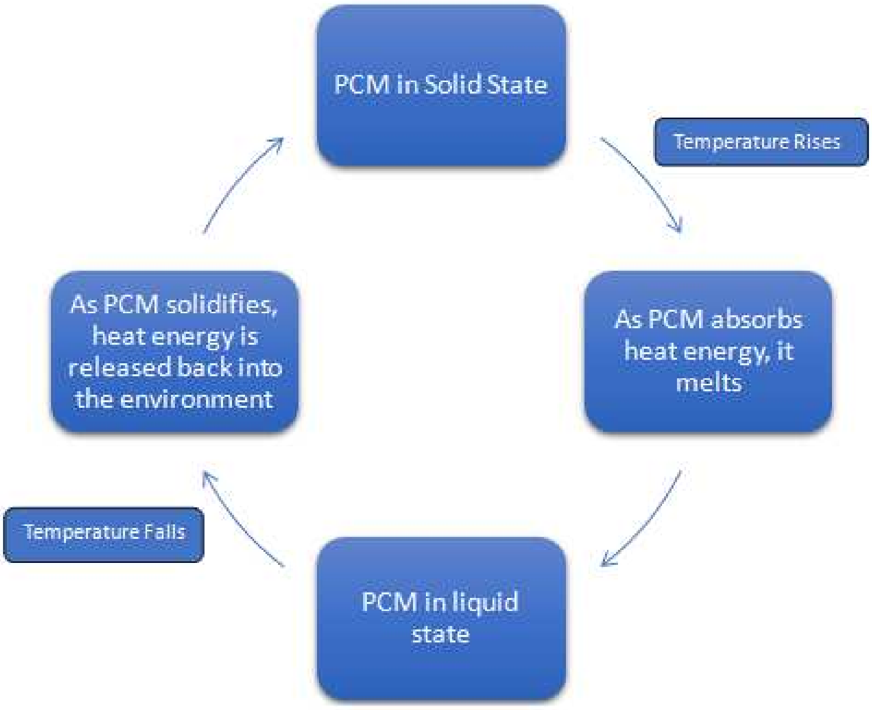


Figure 1: PCM Working

In the construction industry, PCMs are primarily used in building materials such as concrete, mortar, insulation, and wallboards. Here are some key aspects of PCM applications in the construction sector:

- **Energy Efficiency:** By incorporating PCMs into building materials, the thermal fluctuations within the building are reduced, creating a more stable indoor environment. This helps to reduce the overall energy consumption for heating and cooling, leading to significant energy savings and lower utility bills.

- **Thermal Comfort:** PCMs enhance thermal comfort within buildings by maintaining a more constant temperature. This eliminates the discomfort of rapid temperature changes and reduces the need for air conditioning and heating, leading to increased occupant satisfaction.

- **Passive Cooling and Heating:** PCMs facilitate passive cooling and heating strategies. During the day, when the indoor temperature rises above the phase change temperature, the PCM absorbs and stores excess heat. At night or during colder periods, the PCM releases the stored heat, providing passive heating. This passive approach reduces the reliance on active HVAC systems, resulting in reduced carbon emissions.

- **Building Envelope Improvements:** PCM-enhanced building materials can be incorporated into walls, roofs, and floors, improving the thermal performance of the building envelope. This helps to create a more energy-efficient and sustainable structure.

- **Retrofitting:** PCMs can be retrofitted into existing buildings, offering an eco-friendly and cost-effective solution to upgrade thermal performance without major structural changes.

- **Reduced Peak Loads:** The use of PCMs can reduce peak energy demands, which is particularly beneficial for large buildings and densely populated urban areas where peak loads can strain the power grid.

- **Renewable Energy Integration:** PCMs can help in integrating renewable energy sources such as solar and wind by storing excess energy during peak generation times and releasing it when needed, thus improving overall energy utilization.

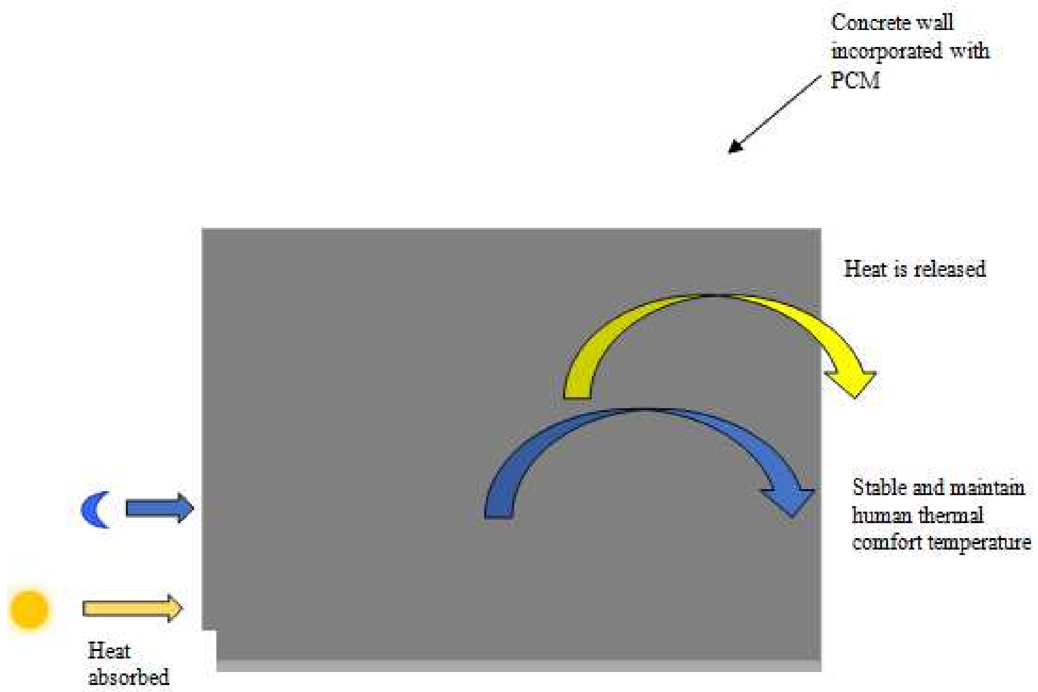


Figure 2: Concept of PCM Utilised in Buildings

1. **Need of PCM:** The global building sector is a significant contributor to energy consumption, accounting for approximately 30% to 40% of total energy usage and leading to considerable greenhouse gas emissions [1,2]. To combat the energy crisis and environmental impact, researchers have been exploring innovative techniques to reduce energy consumption in buildings. One promising solution that has gained attention is the incorporation of phase change materials (PCMs) into building materials, which enhances the thermal mass of structures [3-5].

   In the construction industry, the integration of PCMs into building materials has shown great potential in optimizing energy consumption and improving building performance. By incorporating PCMs into concrete, mortar, or other construction elements, buildings can effectively store and release thermal energy, reducing the reliance on active heating and cooling systems. This, in turn, leads to significant energy savings and a reduction in greenhouse gas emissions, contributing to a more sustainable and environmentally friendly built environment.

   One of the significant advantages of using PCMs in construction is their ability to regulate indoor temperatures, particularly in buildings located in regions with extreme climates. For example, in hot climates, PCMs can absorb excess heat during the day, keeping the interior cooler, and then release the stored heat at night when the outside temperature drops. Similarly, in colder climates, PCMs can absorb heat during the day and release it at night, helping to maintain a comfortable indoor temperature without relying heavily on heating or cooling systems.

2. **Integration Techniques of PCM:** Phase Change Materials (PCMs) play a crucial role in enhancing energy efficiency and thermal performance in construction. There are various ways to integrate PCMs into buildings, each offering unique benefits:

   - **PCM-Enhanced Insulation:** PCM microcapsules or particles are embedded within traditional insulation materials like fiberglass, cellulose, or foam. This PCM-enhanced insulation effectively stores and releases thermal energy, reducing heat transfer through walls, ceilings, and floors.

   - **PCM-Enhanced Plaster and Paint:** Plaster or paint formulations are infused with PCMs, creating surfaces that regulate indoor temperatures by absorbing and releasing heat during phase change. These PCM-enhanced surfaces are applied to interior walls and ceilings, contributing to improved thermal comfort.

   - **PCM-Enhanced Concrete:** PCMs are mixed with concrete during manufacturing. PCM-enhanced concrete stores and releases thermal energy, stabilizing indoor temperatures and reducing energy consumption. It finds application in walls, floors, and roofs to create a thermally efficient building envelope.

   - **PCM-Enhanced Gypsum Board:** Gypsum board, commonly used for interior walls and ceilings, can incorporate PCMs. PCM-enhanced gypsum board provides additional thermal mass and regulates temperature fluctuations within the building.

- **PCM-Enhanced Roofing Materials:** Roofing materials like tiles, shingles, or membranes can integrate PCMs. PCM-enhanced roofing materials reduce heat gain in buildings by absorbing and releasing heat during day-night cycles.

- **PCM-Enhanced Windows and Glazing:** PCM integration into window frames or glazing materials results in PCM-enhanced windows. These windows store and release thermal energy, improving energy efficiency and reducing heat transfer.

- **PCM-Enhanced HVAC Systems:** PCMs can be integrated into heating, ventilation, and air conditioning (HVAC) systems. PCM-enhanced HVAC systems store excess heat during peak hours and release it during off-peak periods, reducing energy consumption.

- **PCM-Enhanced Building Components:** PCMs can be incorporated into various building components like floors, ceilings, or partitions to enhance their thermal properties. These PCM-enhanced components help maintain stable indoor temperatures and reduce energy usage.

The choice of PCM integration depends on the building's design, climate, and energy requirements. PCM integration in construction offers a promising approach towards achieving sustainable and energy-efficient buildings, reducing environmental impact and enhancing occupants' comfort.

3. **Methods of Incorporation of Phase Change Material’s:** Phase Change Materials (PCMs) can be incorporated into various applications using both direct and indirect methods. These methods enable the utilization of PCM's thermal energy storage capabilities to enhance energy efficiency and thermal performance in different systems. Here's an overview of both direct and indirect methods of PCM incorporation:

Direct Methods of PCM Incorporation: Direct methods involve the physical integration of PCMs into the material or system that requires thermal energy storage. This direct incorporation ensures close contact between the PCM and the surrounding environment, facilitating efficient heat transfer. Direct methods include:

- **Wet Mixing Technique:** This method involves directly mixing PCM particles into a base material during its manufacturing process. The PCM particles are evenly distributed within the material matrix, creating a homogeneous mixture. Common base materials include concrete, plaster, and gypsum. Wet mixing can be accomplished using mechanical mixers that ensure uniform dispersion of PCM particles. Once the material sets or solidifies, the PCM particles become an integral part of the structure. This method is often used in building materials like PCM-enhanced concrete, where the PCM enhances the material's thermal storage capacity.

- **Immersion Technique:** In this method, the base material is immersed in a liquid PCM, allowing the material to absorb the PCM by capillary action. The base material, typically porous, absorbs the PCM until saturation is achieved.

Afterward, the material is allowed to solidify or dry. This technique is commonly used in textiles and fabrics to create PCM-enhanced clothing and bedding products. The immersion technique ensures that the PCM is distributed throughout the material, providing efficient heat storage and release capabilities.

Indirect Methods of PCM Incorporation: Indirect methods involve utilizing PCMs as a separate component that indirectly influences the thermal behavior of the system. These methods often involve the transfer of heat between the PCM and the system through a heat exchanger or other intermediary components. Indirect methods include:

- **Encapsulation:** Encapsulation involves enclosing PCM within containers or capsules, preventing direct contact with other materials. These capsules can be made from various materials, such as polymers or metals. The encapsulated PCM can be dispersed within a material or placed in strategic locations within a system. Heat exchange occurs through the capsule walls, allowing controlled thermal energy transfer. Encapsulation offers flexibility and versatility, making it suitable for retrofitting existing systems or incorporating PCMs into materials like textiles.

- **Vacuum Impregnation:** Vacuum impregnation is a method in which porous materials, such as porous ceramics or fibrous structures, are impregnated with PCM. The porous material acts as a scaffold, holding the PCM in place. The porous structure ensures a high surface area for efficient heat exchange. Vacuum impregnation can enhance the thermal storage capacity of materials like lightweight insulation panels. This method is particularly useful in applications where direct mixing is not feasible.

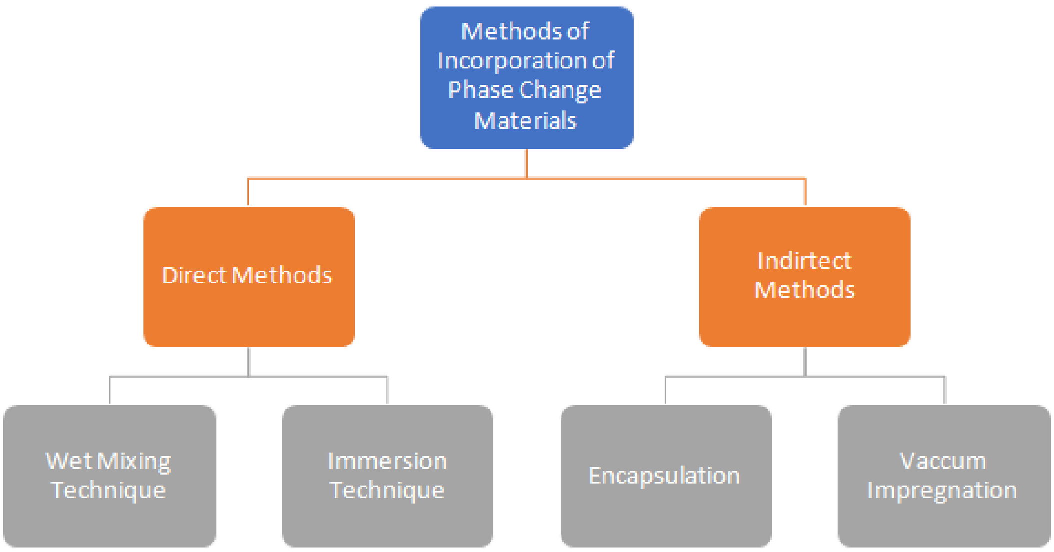


Figure 3: Incorporation Methods of PCM

4. **PCM Selection Criteria:** PCM selection is a crucial step in effectively incorporating phase change materials into building materials and systems, and it involves considering various key criteria. The following are the important PCM selection principles:

- **Thermodynamic Characteristics and Climate Impact:** One of the primary considerations is the thermodynamic behavior of the PCM and its compatibility with the prevailing outdoor thermal conditions in a specific climate. The PCM should have a satisfactory melting temperature suitable for the desired application within the thermal comfort range. High specific fusion heat, latent heat capacity, and energy storage capacity are essential to ensure that the PCM can store and release a significant amount of thermal energy during phase transition.

  Moreover, the thermal conductivity of the PCM plays a crucial role in how efficiently it can distribute the stored thermal energy within the building material. A high energy storage density per volume and congruent melting temperatures are desirable attributes to maximize the PCM's thermal performance.

  When integrated into the building envelope, phase change temperatures are typically chosen to align with the preferred temperature ranges of building occupants. Climate exposure also influences the selection of PCM, ensuring that it performs optimally in specific weather conditions.

- **Chemical Characteristics:** PCM materials must be nontoxic, non-flammable, and non-hazardous to ensure safe energy storage and release. Chemical stability is vital, as any leakage or instability could lead to potential problems. Organic PCMs are preferred over inorganic ones due to their better chemical characteristics and safety profile.

- **Accessibility and Affordability Characteristics:** PCM adoption can be facilitated by the availability of mature manufacturing processes, ensuring that PCMs are easily accessible in the building construction market. The existence of a wide range of PCM building components and technologies, along with cost-based strategies, enriches the technological variety and enhances the affordability of efficient PCM-envelope integrations.

- **Kinetic Characteristics:** The crystallization rate and nucleation rate of the PCM directly impact its thermal performance. To achieve satisfactory thermal performance, it is essential to have high crystallization and nucleation rates. This helps avoid supercooling and ensures efficient heat recovery during the phase change process.

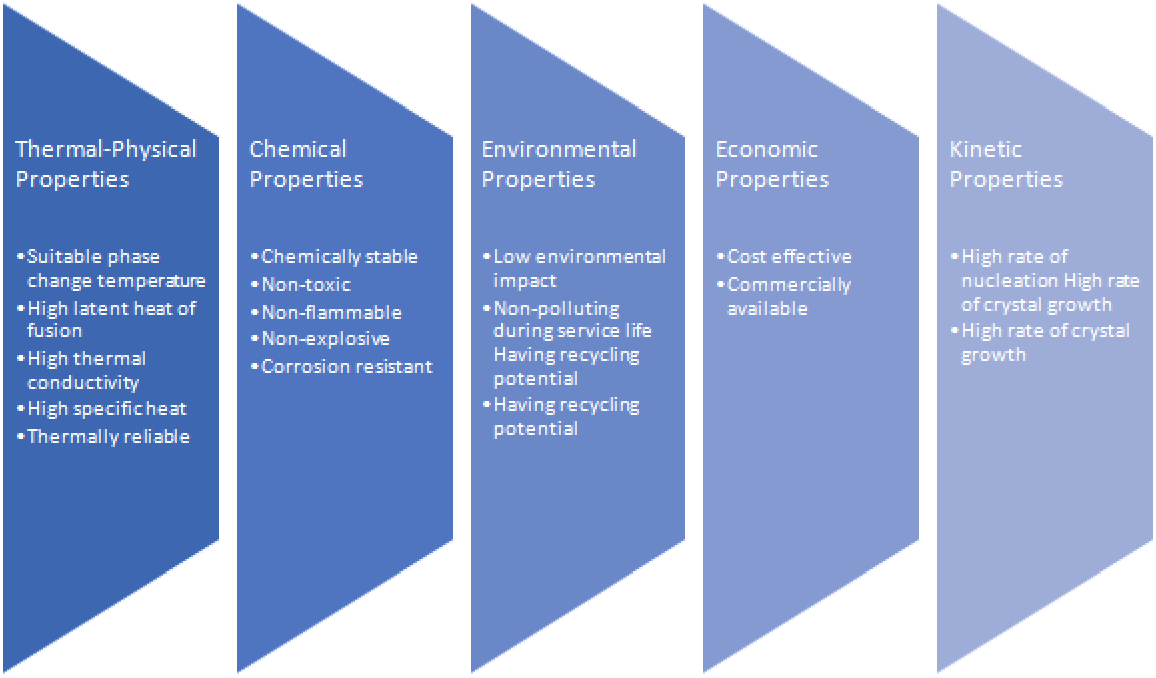


Figure 4: Advantages of PCM

Considering these criteria, engineers and architects can select the most suitable PCM for a specific building project. By integrating high-quality PCMs into construction materials, buildings can achieve improved thermal comfort, reduced energy consumption, and a reduced environmental impact. As the technology advances, PCM applications are expected to play an increasingly significant role in achieving sustainable and energy-efficient buildings worldwide.

5. **PCM Classification:** Phase change materials (PCMs) can exist in four different states: solid–solid, solid–liquid, liquid–gas, and liquid–liquid. However, employing solid–gas and liquid–gas PCMs with building materials is impractical due to the significant volume changes in the gas phase and the high pressures present during phase transitions. As a result, solid–solid and solid–liquid PCMs are preferred for common building applications.

Among the various PCM categories, solid–liquid PCMs are particularly popular and are divided into three main types: organic, inorganic, and eutectic PCMs. These solid–liquid PCMs offer a wide range of possibilities and complexities for various building applications.

When integrating PCMs into building materials, the choice between solid–solid and solid–liquid PCMs depends on the specific requirements of the project. Each type of PCM has unique properties and applications, making them suitable for different thermal energy storage and management needs.

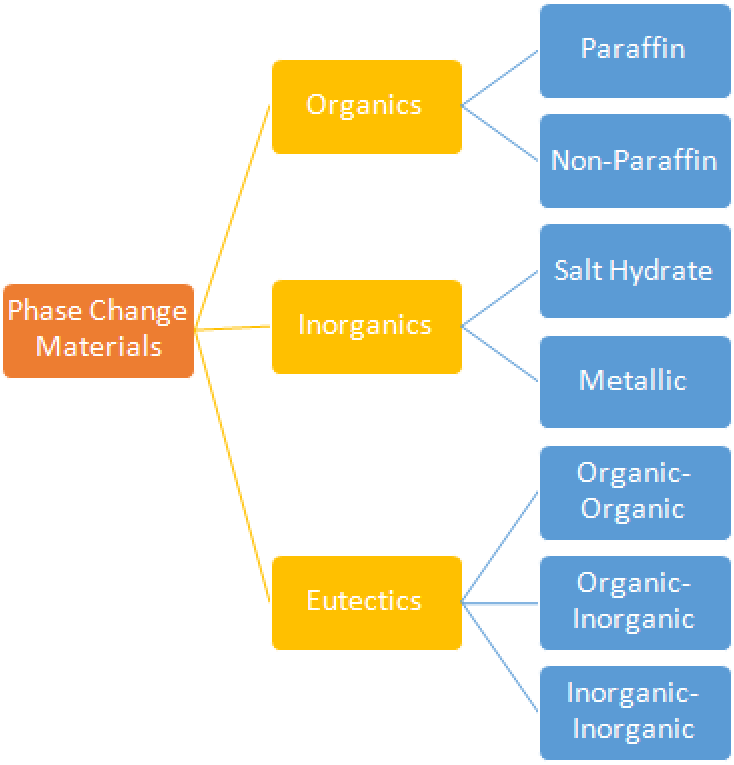


Figure 5: Types of PCM

- **Organic PCM's:** Organic PCMs, primarily consisting of C_nH_{2n+2} and $CH_3 (CH_2)_{2n}\cdot COOH$, are widely used in the construction industry due to their durable chemical characteristics. These PCMs offer consistent thermal energy of fusion and are free from super-cooling, toxic substances, corrosion, and other harmful elements. They can be further classified into paraffin-like substances and non-paraffin-like substances, which include fatty acids, alcohols, glycols, and other compounds. Sustainable plant oils, such as palm and coconut oils, have also shown promising potential as organic PCMs for thermal energy storage (TES) applications. The abundance of such raw materials in Southeast Asia has contributed to the increasing commercial use of these PCMs.

  When integrating organic PCMs into buildings, certain advantages and disadvantages should be considered. On the positive side, they are highly effective in thermal energy storage, with phase change temperatures ranging from 12 to 38□, which aligns with the thermal comfort needs of occupants. These PCMs exhibit good chemical stability over the long term, making them suitable for extended use. Additionally, they are environmentally friendly, reusable, and recyclable, contributing to sustainable building practices.

  However, there are some limitations to using organic PCMs. They are combustible, so they must be protected from high temperatures, flames, or oxidizing chemicals. Moreover, they are not compatible with plastic containers and require metallic ones for storage. Although they have relatively good thermal conductivity around 0.2 W/(mK), they may not be as efficient as other materials with higher conductivity. Cost can also be a consideration, as organic PCMs can be relatively expensive compared to traditional building materials. Additionally, their phase change often involves a minor volumetric shift.

Despite these challenges, organic PCMs have demonstrated their compatibility and adaptability with various building applications. Their thermal performance can be significantly enhanced, depending on factors such as the length of the molecular chain and the high latent heat of fusion. As commercial manufacturing of organic PCMs continues to grow, their availability and popularity in the construction industry are increasing, paving the way for more energy-efficient and sustainable buildings.

- **Inorganic PCM's:** Inorganic PCMs, represented by MxNy nH2O, encompass steel and hydrated salts. Historically, hydrated salts were among the earliest PCMs investigated and prioritized due to their non-corrosive nature, compatibility with plastics, and cost-effectiveness. Typically, this PCM alloy consists of inorganic salts and water as its main components. However, they do have some drawbacks, such as irregular organization and reduced nucleation rates [107]. Metallic PCMs, on the other hand, gradually lose their effectiveness due to severe weight penalties and unfavorable temperature ranges when integrated into buildings.

  Salt hydrate PCMs offer advantages over organic PCMs, particularly in terms of superior thermal conductivity and high latent heat of fusion per unit volume. The table presented illustrates correctly described inorganic PCMs for reference (Table 3). In conclusion, the overall assessment of PCMs includes both their benefits and drawbacks.

  Some challenges with inorganic PCMs include incongruent melting and phase separation during cycling, leading to significant enthalpy loss. They are also susceptible to super-cooling and segregation. Additionally, some inorganic PCMs exhibit high-volume changes, sharp melting points, and high thermal conductivity. However, they have a high capacity for volumetric stored latent heat, making them effective for energy storage applications.

  On the positive side, inorganic PCMs are non-flammable and sustainable, contributing to eco-friendly building practices. They are easily accessible and relatively inexpensive, making them viable options for widespread adoption. Furthermore, their high density allows for efficient storage and usage.

- **Eutectic PCM's:** Eutectic PCMs are mixtures of at least two phase-change materials, which together exhibit a precise temperature range suitable for specific applications. These mixtures can consist of organic, inorganic, or a combination of both types of PCM. The main advantage of eutectic PCMs lies in their ability to provide a tailored phase transition temperature range. However, their higher cost compared to other phase-change materials has limited their widespread use beyond building applications. Despite this drawback, eutectic PCMs have shown promise in various settings.

There are three types of eutectic PCMs described in the literature: inorganic-inorganic, organic-inorganic, and organic-organic. Each of these mixtures exhibits specific phase transition temperatures, ranging from 5 to 47 ◦C for crystallization or melting.

The advantages of eutectic PCMs include their ability to undergo crystallization and melting without segregation, resulting in consistent thermal performance. They also offer high thermal conductivity and latent heat of fusion per volume, making them efficient in storing and releasing thermal energy.

On the other hand, the main weaknesses of eutectic PCMs include their higher cost, primarily due to the involvement of at least two different compounds, making them triple the price of other PCMs. Additionally, their heat of fusion per unit mass is relatively unsatisfactory compared to other PCM options.

Despite these drawbacks, eutectic PCMs have the potential to play a significant role in achieving energy efficiency and thermal comfort in buildings and other applications. As research and development continue, efforts to reduce the cost and enhance the performance of eutectic PCMs will likely lead to broader utilization in various industries, contributing to a greener and more sustainable future.

II. RESULTS

This book chapter delves into an in-depth analysis of the properties exhibited by AMIC (Advanced Microencapsulated Phase Change Material) Phase Change Materials (PCMs). This investigation is particularly significant due to the predominant focus of prior research endeavors on PCMs of this specific nature.

1. **Workability:** The incorporation of AMIC-PCM in mortar has a significant impact on its workability. It is observed that the addition of AMIC-PCM drastically reduces the workability of the mortar mix. The reason behind this decrease in workability can be attributed to the fine nature of AMIC-PCM particles compared to the fine aggregate, which results in an increase in the surface area of the mortar mix and subsequently leads to higher water demand. Furthermore, the formaldehyde-based polymer shell of AMIC-PCM exhibits higher water absorption characteristics than sand, further contributing to the increased water demand in the mortar mixture. These findings align with scientific literature that reported a similar trend in the decrease of workability with an increase in MIC-PCM dosage.

   To maintain the desired workability and ensure a constant flow diameter of 200 ± 5 mm, specific superplasticizers (SP) are used in the mortar mixes containing 5% and 10% dosage of AMIC-PCM. Specifically, 0.6% and 1.1% PCE-based SP are employed for these respective mixes. This use of superplasticizers helps to mitigate the reduction in workability caused by the addition of AMIC-PCM.

   In summary, the addition of AMIC-PCM in mortar adversely affects its workability due to the fine nature of AMIC-PCM particles and their higher water absorption properties. However, by carefully selecting the appropriate superplasticizers, it is possible to maintain the desired workability levels and ensure smooth construction processes. These observations have been echoed by numerous researchers in the field, further emphasizing the importance of managing the workability of mortar mixes when incorporating PCM additives.

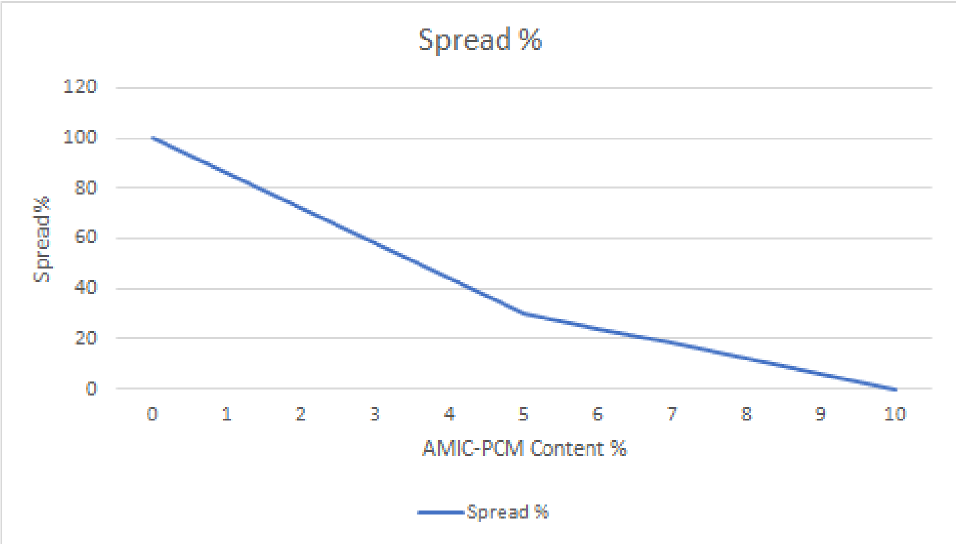


Figure 6: Workability Trend in PCM

2. **Density:** Incorporating AMIC-PCM in mortar has a significant impact on the fresh density of the mix, as shown in the study. The lower density of AMIC-PCM compared to the fine aggregate results in a reduction in the overall density of the mortar mix. This reduction becomes more pronounced with higher dosages of AMIC-PCM. For instance, adding 5% AMIC-PCM to the mortar mix leads to a density decrease of 1.5%, while at 10% dosage, the density decreases even further, by 4.3%.

   The higher decrease in density at the 10% AMIC-PCM dosage can be attributed to the presence of air voids within the mortar. This phenomenon, known as air binding, occurs due to the microencapsulated phase change material (MIC-PCM) within the AMIC-PCM.

   It is crucial to consider the density reduction when incorporating AMIC-PCM in construction applications. The presence of air voids can influence the compressive strength and other mechanical properties of the mortar, impacting its overall performance and structural integrity. Therefore, careful adjustments in the AMIC-PCM formulation and dosage are necessary to strike a balance between enhancing thermal properties and maintaining the required structural strength of the mortar. A thorough understanding of the effects of AMIC-PCM on mortar density and properties is essential for optimizing its integration into building materials and achieving energy-efficient and high-performance constructions.

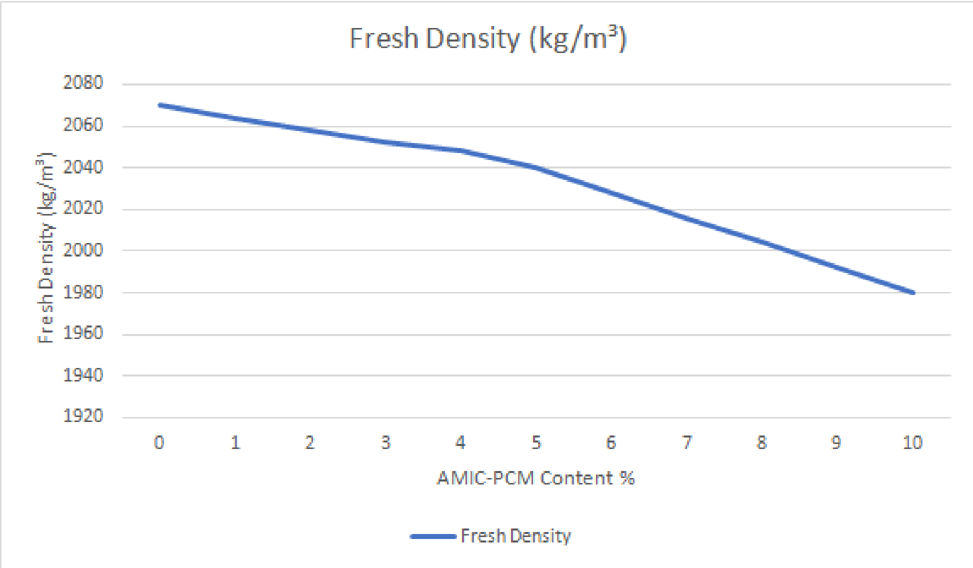


Figure 7: Density Trend in PCM

3. Mechanical Properties of Mortar

- **Compressive Strength:** The findings indicate that the addition of AMIC-PCM at 5% and 10% replacement levels leads to reductions in compressive strength by 15% and 54%, respectively. These reductions in compressive strength can be attributed to several factors.

  Firstly, the intrinsic strength of AMIC-PCM is lower compared to the fine aggregate used in the mortar. As a result, when AMIC-PCM is introduced into the mix, it weakens the overall strength of the mortar.

  Secondly, the fine nature of AMIC-PCM particles, with their associated greater surface area, further contributes to the reduction in strength. This increased surface area affects the mortar's bonding and cohesion, leading to lower strength values.

  At the 5% dosage of AMIC-PCM, the reduction in compressive strength is relatively lesser. This could be due to the void filling effect of AMIC-PCM, where the particles fill the gaps in the mortar, resulting in a less drastic impact on strength.

  However, as the AMIC-PCM dosage increases to 10%, it starts to replace a significant portion of the main ingredients in the mortar mix. This substantial replacement leads to a significant drop in compressive strength, as the AMIC-PCM cannot provide the same structural integrity as the original ingredients.

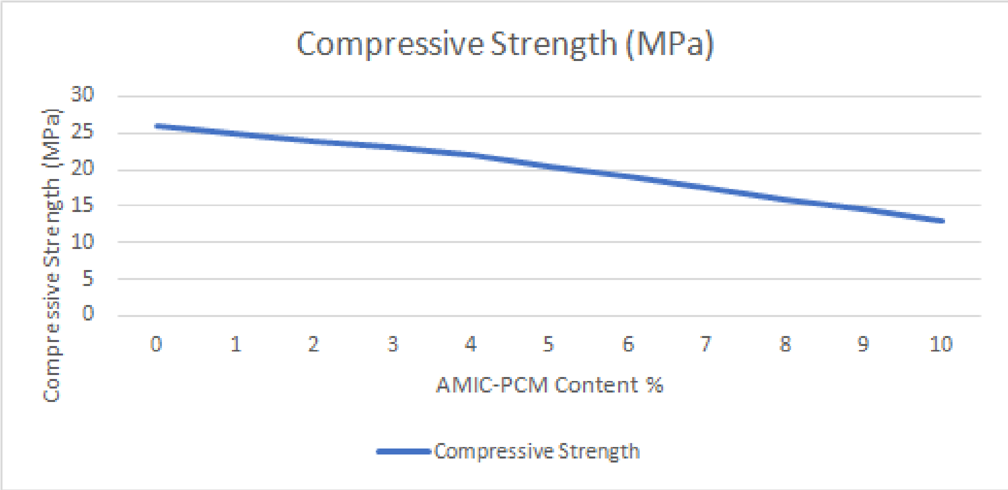


Figure 8: Compressive Strength Trend in PCM

- **Flexural Strength:** The incorporation of AMIC-PCM in mortar also has a notable impact on the flexural strength of the material. The study reveals a substantial reduction in the flexural strength when AMIC-PCM is added to the mix. Several factors contribute to this decrease in flexural strength, which are similar to those affecting compressive strength.

  One of the primary reasons for the reduced flexural strength is the lower intrinsic strength of AMIC-PCM compared to the fine aggregate used in the mortar. As AMIC-PCM is introduced into the mix, it weakens the overall bonding and cohesion of the mortar, leading to a decrease in flexural strength.

  Moreover, the finer particle size of AMIC-PCM results in a larger surface area, which further compromises the mortar's structural integrity. The increased surface area of AMIC-PCM particles hinders the effective bonding between the components of the mortar, leading to a decrease in flexural strength.

  Additionally, similar to the effect on compressive strength, the higher dosage of AMIC-PCM in the mortar mix has a more pronounced impact on flexural strength. As the AMIC-PCM content increases, it replaces a larger portion of the original ingredients, resulting in a more significant reduction in flexural strength.

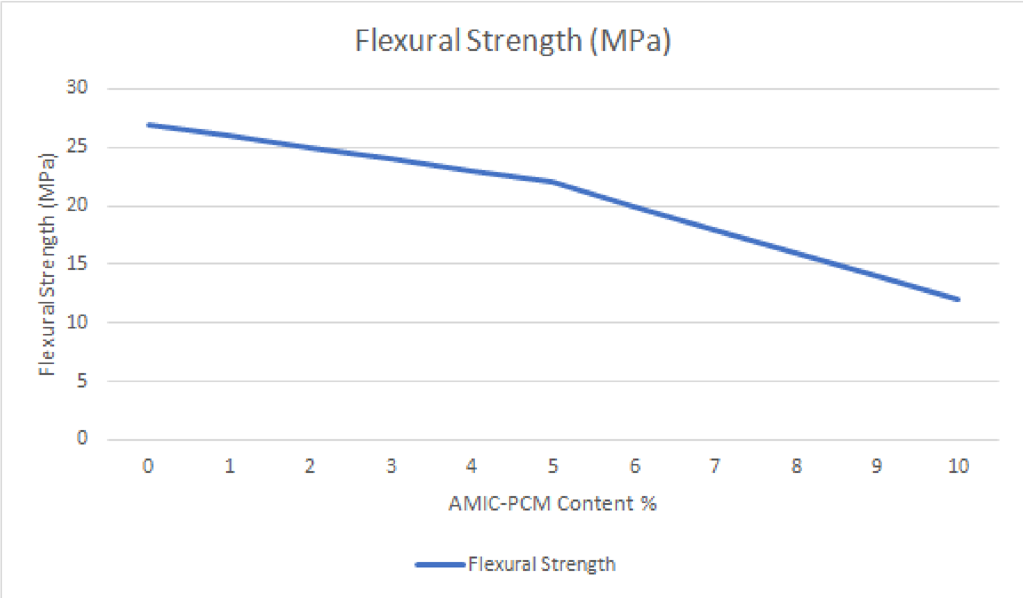


Figure 9: Flexural Strength Trend in PCM

4. **Thermal Properties of Mortar:** The thermal conductivity of AMIC-PCM incorporated mortar exhibits an interesting trend with varying AMIC-PCM content. When 5% of AMIC-PCM is added to the mortar mix, there is an increase in thermal conductivity. This enhancement can be attributed to the void-filling effect of the small AMIC-PCM particles. As these particles are dispersed throughout the mortar, they fill the empty spaces, improving the heat transfer pathways and consequently increasing thermal conductivity.

    However, as the AMIC-PCM content exceeds 5%, the thermal conductivity of the mortar starts to decrease. This reduction can be explained by the fact that at higher AMIC-PCM dosages, the mortar's original ingredients are increasingly replaced by the low thermal conductive AMIC-PCM. As a result, the overall thermal conductivity of the mortar decreases due to the presence of the less conductive material.

    The trend of specific heat capacity in the mortar at 5% AMIC-PCM dosage follows a similar pattern as that of thermal conductivity. The specific heat capacity increases along with the thermal conductivity, indicating that the heat storage capacity of the mortar is improved when a small amount of AMIC-PCM is incorporated.

    Interestingly, at higher AMIC-PCM dosages, the specific heat capacity of the mortar shows a marginal increase. This can be attributed to the high specific heat capacity of AMIC-PCM compared to the mortar's original components. The additional heat storage capacity provided by AMIC-PCM contributes to the slight rise in specific heat capacity at higher AMIC-PCM dosages.

    Overall, the thermal properties of the AMIC-PCM incorporated mortar are influenced by the AMIC-PCM content. While a small dosage enhances thermal conductivity and specific heat capacity due to void filling effects, higher dosages result in reduced thermal conductivity. The trade-off between thermal benefits and the increasing replacement of mortar ingredients must be carefully considered to optimize the thermal performance of the mortar for specific applications.

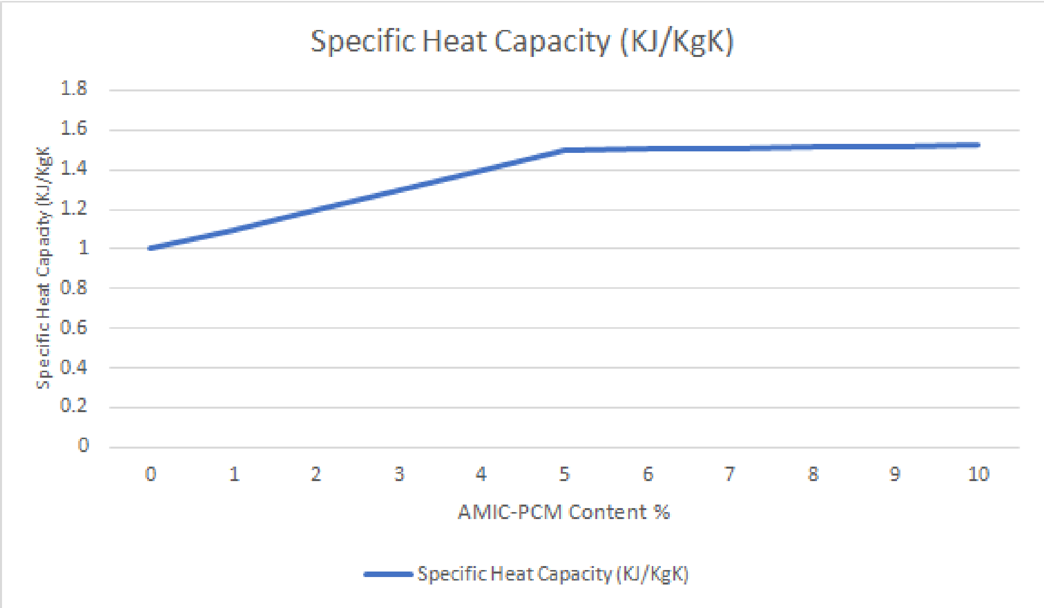


Figure 10: Specific Heat Capacity Trend in PCM

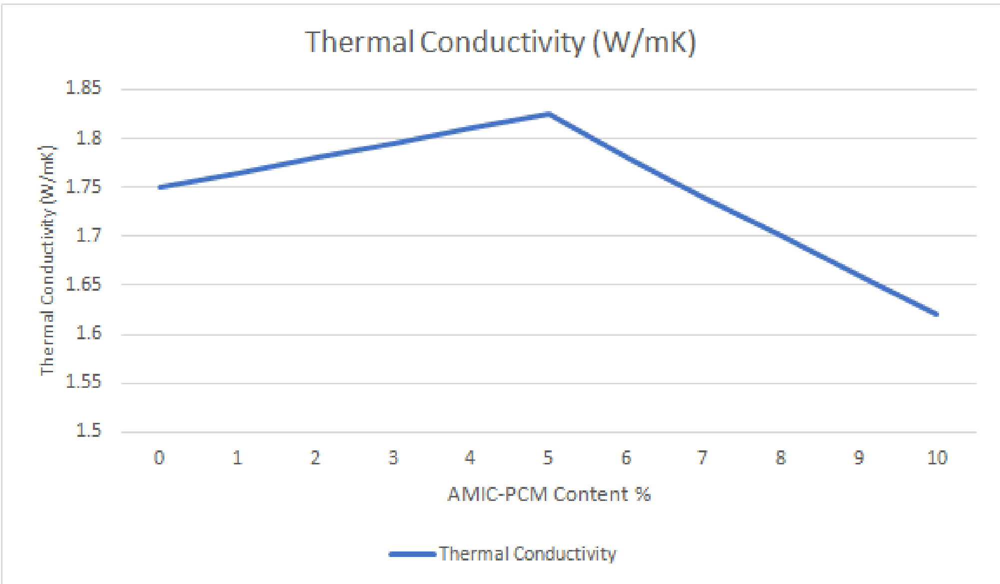


Figure 11: Thermal Conductivity Trend in PCM

5. **Characterization of AMIC-PCM:** The morphology of AMIC-PCM obtained through microscopic analysis reveals that the individual MIC-PCM produced from polymerization is spherical in nature. However, the AMIC-PCM particles are inconsistent in shape. The

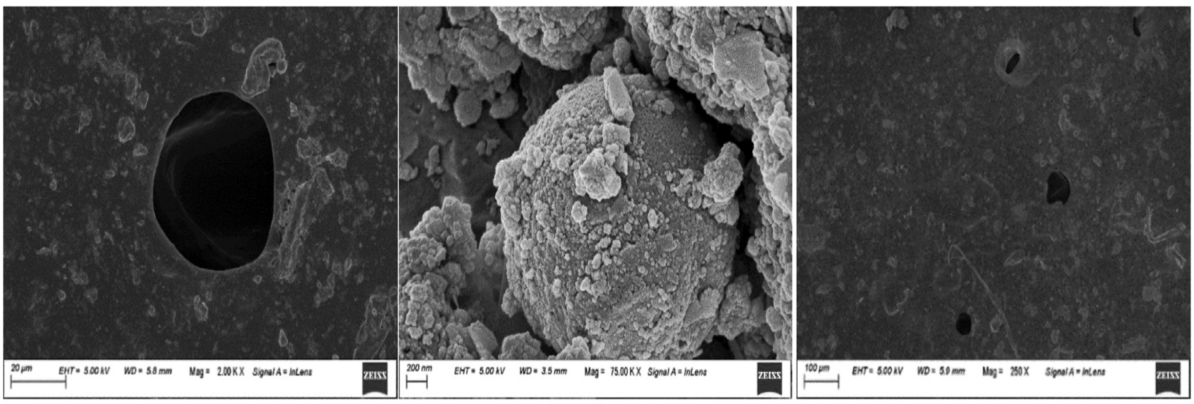
particle size of AMIC-PCM varies approximately from 45 mm to 2 mm. The DSC test results show that the AMIC-PCM has a peak melting temperature of 42 °C and a latent heat capacity of 144 kJ/kg.

Thermal stability analysis through TGA indicates that AMIC-PCM remains stable up to a temperature of 230 °C. Beyond this temperature, AMIC-PCM becomes unstable and loses its weight. At 400 °C, AMIC-PCM is completely unstable with maximum weight loss. However, at operational room temperature, the PCM exhibits satisfactory stability, indicating that it will not create internal vapor pressure within the mortar. This suggests that AMIC-PCM has the potential to be incorporated into building materials.

The specific heat capacity of AMIC-PCM, based on latent heat, is determined from the DSC test. Additionally, the specific heat capacity measured by the TPS method provides insight into the sensible heat capacity of AMIC-PCM. The results reveal that the sensible heat capacity of AMIC-PCM is 1.2 kJ/kgK, which is higher than that of mortar. The high latent heat capacity and sensible heat capacity of AMIC-PCM contribute to an increased heat storage capacity of the mortar.

However, it is worth noting that the latent heat capacity of AMIC-PCM is significantly higher than its sensible heat capacity and that of the mortar. Moreover, the thermal conductivity of AMIC-PCM is 0.16 W/mK, which is lower than that of mortar. Consequently, the addition of AMIC-PCM is expected to reduce the thermal conductivity of mortar, thereby improving its insulation properties.

Nevertheless, the reduction in thermal conductivity of AMIC-PCM incorporated mortar may eventually impact the thermal response of the microencapsulated phase change material (MIC-PCM). Thus, it becomes essential to carefully balance the amount of AMIC-PCM integrated into the mortar mix to maintain its desired thermal properties effectively.



(a) (b) (c)

Figure 12: SEM Images of AMIC-PCM

REFERENCES

[1] W. Su, J.o. Darkwa, G. Kokogiannakis, Review of solid – liquid phase change materials and their encapsulation technologies, Renew. Sustain. Energy Rev. 48 (2015) 373–391.
[2] S.M. Ali, H. Cui, T.Y. Lo, Q. Li, Development of structural – functional integrated concrete with macro-encapsulated PCM for thermal energy storage, Appl. Energy 150 (2015) 245–257.
[3] P. Rathore, S. Rathore, S. Kumar, N. Kumar, Potential of microencapsulated PCM for energy savings in buildings: a critical review, Sustainable Cities and Society. 53 (2020) 101884.
[4] A. Figueiredo, J. Lapa, R. Vicente, C. Cardoso, Mechanical and thermal characterization of concrete with incorporation of microencapsulated PCM for applications in thermally activated slabs, Constr. Build. Mater. 112 (2016) 639–647.
[5] M. Ren, X. Wen, X. Gao, Y. Liu, Thermal and mechanical properties of ultra-high performance concrete incorporated with microencapsulated phase change material, Constr. Build. Mater. 273 (2021) 121714.

