American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-14, Issue-8, pp-60-69
www.ajer.org
Research Paper Open Access

Study of the Use Phase Changing Materials in the development of Self-Heating Concrete: Qualitative performance study of concrete with evaluation of mechanical ramifications

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ABSTRACT : *The This research investigated the development of a proprietary concrete mix incorporating phase change materials (PCMs), specifically paraffin oil, to introduce self-heating capabilities. The aim was to enhance thermal performance while maintaining the mechanical integrity of the concrete. Two experimental procedures were conducted: the casting of slabs with varying thicknesses and the preparation of specimens with different paraffin-oil infusion percentages. The former allowed for an observational study on the performance of concrete with the latter investigating the effect of paraffin oil on the mechanical properties of concrete. This study aims to explore the potential integration of PCM-enhanced self-heating concrete into construction practices for structures operating in cold climates. It provides insights into structural behavior, material innovation, and practical implementation, contributing to the broader development of sustainable and adaptive infrastructure.*

KEYWORDS: *Self-heating concrete; Phase change materials; Paraffin oil; Concrete durability; Sustainable infrastructure*

Date of Submission: 11-08-2025 Date of acceptance: 24-08-2025

I. INTRODUCTION

Concrete is a widely used material vulnerable to freeze-thaw cycles. Concrete contains water through both its initial mix (as part of the hydration process) and later through absorption and seepage from external sources. The expansion of this water when it freezes creates pressure within the concrete. If the pressure exceeds the material's tensile strength, cracks can form. Over time, these cracks can widen, leading to spalling, where pieces of concrete break off from the surface. This deterioration, known as the freeze-thaw cycle, not only affects the aesthetic quality of concrete structures but over time, freeze-thaw damage can weaken the overall structural capacity of concrete, reducing its load-bearing ability. This poses a safety risk for buildings, bridges, and other infrastructures, especially those that support heavy loads. Freeze-thaw damage to concrete can be observed in Figure 1 below. Researchers studied the effect of adding several materials on the performance of concrete to prolong its life span, such as super absorbent polymer (Al-Nasra 2013, Al-Nasra 2018)

Fig. 1. Freeze-Thaw Damage to Concrete

Road surface condition has been identified as the most critical factor affecting winter driving safety, surpassing weather variables like visibility or wind speed (University of Waterloo,2014),. According to the Federal Highway Administration, about 21% of the total vehicle crashes in the United States each year can be attributed to weather conditions, which include but are not limited to: rain, sleet, snow, fog, wet pavement, snowy/slushy pavement, or icy pavement (Federal Highway Administration, 2024).

Conventional deicing methods are primarily designed to mitigate the formation of ice on roadways, bridges, and other concrete surfaces during winter months. The most common deicing agents used include rock salt (sodium chloride), calcium chloride, magnesium chloride, and other salt-based compounds. These materials are typically spread on roads and surfaces to lower the freezing point of water, thereby preventing the formation of ice. One of the most popular options, sodium chloride is effective at temperatures around 15°F (-9°C), but as temperatures drop further, its effectiveness decreases (Wang, et al, 2019). Studies have shown that the widespread use of sodium chloride can lead to severe environmental problems, including soil and water contamination (Mullaney, et al, 2019).

The application of deicing salts, especially calcium chloride and magnesium chloride, can accelerate the corrosion of metal structures such as bridges and guardrails, as well as reinforcement bars within concrete. Researchers found that chloride-based deicers can penetrate concrete surfaces, leading to the corrosion of steel reinforcements inside the concrete (Shen, et al 2020). This corrosion compromises the structural integrity of the infrastructure, leading to costly repairs and replacements.

Solutions such as the use of phase-changing materials (PCMs) and self-heating concrete emerge as potential alternatives to traditional deicing practices, offering a more environmentally friendly and cost-effective way to mitigate the effects of freeze-thaw cycles. PCMs are materials that can store and release thermal energy by changing their physical state. This change typically happens between solid and liquid phases, but it can also involve changes from gas to liquid, or other combinations.

When a PCM absorbs heat, it starts to warm up. As the temperature rises, the material reaches a point where it starts to melt (if it's solid) or vaporize (if it's liquid). During this phase change, the PCM doesn't increase in temperature significantly but instead stores the heat energy in the form of latent heat. When the PCM melts (or vaporizes), it absorbs a large amount of heat. For example, ice melts into water at 0°C, but it requires a lot of heat to melt despite its temperature staying constant during the melting process. This is because the energy is being used to break the bonds between the molecules in the solid phase so they can move freely in the liquid phase. When the surrounding temperature cools down, the PCM will solidify (or condense from gas to liquid). In doing so, it releases the stored thermal energy back into the environment. For instance, as water freezes into ice, it releases the heat energy it had absorbed during melting. A descriptive graphic of this process is illustrated in Figure 2 below.

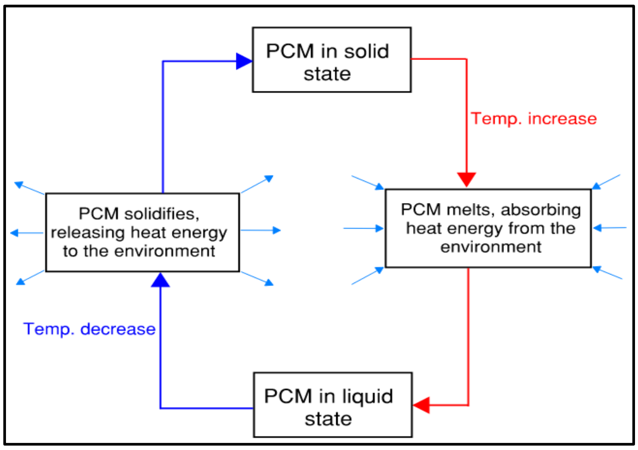

Fig.2. Action of Phase Changing Material with Varying Temperature

When incorporated into concrete, PCMs can effectively create a self-heating concrete system. During the winter, when external temperatures drop, the PCM within the concrete absorbs thermal energy from the surrounding environment and releases it as the temperature falls. This reduces the formation of ice on the concrete surface and minimizes the internal stresses caused by freeze-thaw cycles. As a result, the concrete's durability is significantly improved, reducing the frequency of repairs and extending the overall service life of structures. Moreover, they reduce the need for salt and other chemicals that can cause soil and water contamination. The reduction in the need for road salting lowers the overall environmental footprint of winter maintenance operations.

Despite the higher upfront costs associated with incorporating PCMs into concrete, the long-term benefits, including a longer lifespan, less required upkeep and maintenance, and lower operational costs, make it a cost-effective alternative. The use of self-heating concrete can save money by eliminating the need for frequent repairs, reducing the consumption of deicing materials, and extending the longevity of infrastructure. This innovation not only addresses the environmental and economic drawbacks of conventional methods but also offers a sustainable alternative that benefits both infrastructure and the environment.

II. RESEARCH SIGNIFICANCE

The integration of thermal energy storage (TES) materials into concrete represents a promising advancement in smart infrastructure, particularly in regions subject to freeze-thaw cycles or extreme temperature fluctuations. Among various TES materials, paraffin oil, a type of organic phase change material (PCM), has garnered interest due to its high latent heat storage capacity, chemical stability, affordability, and availability. When incorporated into concrete, paraffin oil has the potential to regulate internal temperature fluctuations, mitigate cracking due to thermal stresses, and improve the durability of concrete structures.

Reviewing existing literature on PCM incorporation in concrete, focusing on its properties, thermoregulatory mechanisms, and integration methods, formed the foundation of this project. Building on prior research, this study advances this work by developing and refining paraffin oil-infused concrete mix designs and further investigating fluctuations in compressive and tensile strength with the incorporation of paraffin oil. .

III. PARAFFIN OIL AS PCM

When reaching phase transitions, PCMs either release or absorb large amounts of energy. Therefore, any PCMs with a phase change temperature range near the freezing point of water, which is 32°F or 0°C, could theoretically melt snow and ice while its energy is being released through the phase change. Paraffin Oil, a PCM with a phase change temperature range of 3°C to 6°C, is an ideal candidate to mix in concrete as it not only has an ideal temperature range, but it is also non-reactive to the cementitious chemicals within concrete (ASCE, 2023).

Paraffin oil, a hydrocarbon-based compound derived from petroleum, has garnered increasing attention as a PCM for thermal energy storage in cementitious systems. Its ability to absorb, store, and gradually release latent heat makes it particularly attractive for integration into self-heating concrete, especially in cold-weather concreting applications, such as bridge decks. The inclusion of paraffin oil into concrete systems addresses a crucial thermal management challenge by mitigating temperature-induced stresses and supporting hydration under suboptimal curing conditions.

Liquid paraffin oil of 99% purity, commonly referred to as white mineral oil, is a highly refined, colorless, and odorless hydrocarbon mixture derived from petroleum distillation. Its composition is predominantly composed of saturated aliphatic hydrocarbons (alkanes), with carbon chain lengths typically ranging from C15 to C30, depending on the grade and refinement method (Reboul, et al, 2013, Wang, et al, 2015). These long-chain alkanes are primarily linear (n-paraffins), although some branched isomers (iso-paraffins) may be present in small amounts. Due to the extensive refining processes - such as hydrotreatment, solvent extraction, and dewaxing - this grade of paraffin oil contains minimal aromatic hydrocarbons, sulfur, nitrogen compounds, or other impurities, making it chemically stable and biologically inert (U.S. Food and Drug Administration (FDA), 2020). The near-total absence of polar compounds and reactive functional groups contributes to its high oxidative stability and compatibility with sensitive matrices, such as biomedical products, pharmaceuticals, and in this case, cementitious systems. The purity level ensures that the paraffin oil does not disrupt cement hydration processes or chemically interact with calcium silicate hydrates (C-S-H), which is critical in preserving the structural integrity of the self-heating concrete matrix (Kim, S., et al, 2020).

Paraffin oil exists in multiple grades and formulations, each designed for specific industrial, pharmaceutical, or technical applications. The main categories include light paraffin oil, heavy paraffin oil, industrial-grade paraffin oil, pharmaceutical (white) paraffin oil, and microencapsulated paraffin oil. Its utility in self-heating concrete is primarily driven by its thermal behavior, inertness, and stability under varying environmental conditions.

Liquid paraffin lamp oil is not a single compound, but a mixture of hydrocarbons, typically in the alkane family (saturated hydrocarbons). It's a highly refined, odorless mineral oil derived from petroleum. It consists primarily of long-chain alkanes (straight or branched chains). These molecules follow the general formula:

$$C_nH_{2n+2} \quad (1)$$

… where *n* typically ranges from 12 to 20 in lamp oil-grade paraffin.

99% pure paraffin oil was chosen for this study self-heating concrete design mix due to its consistent thermal performance, high purity, and chemical stability. Below, Figures 3-6 depict the specific alkane structures present in the paraffin oil used.

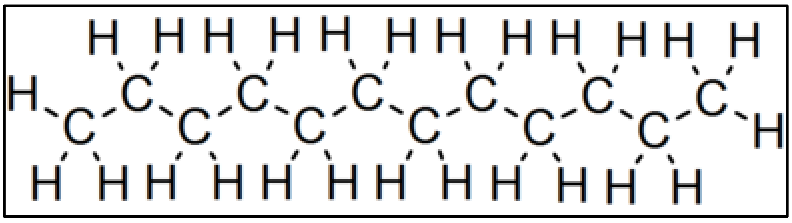

Fig.3. Chemical Structure Dodecane, ($C_{12}H_{26}$)

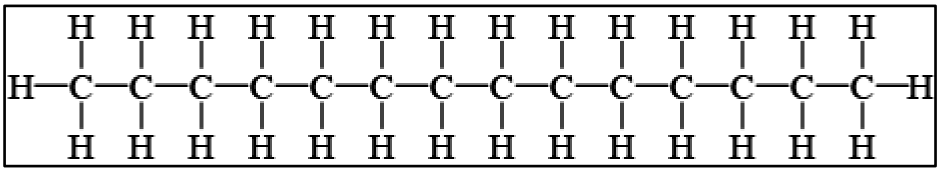

Fig.4. Chemical Structure Tetradecane, ($C_{14}H_{30}$)

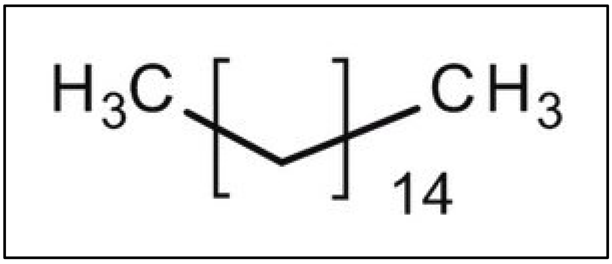

Fig.5. Chemical Structure Hexadecane, ($C_{16}H_{34}$)

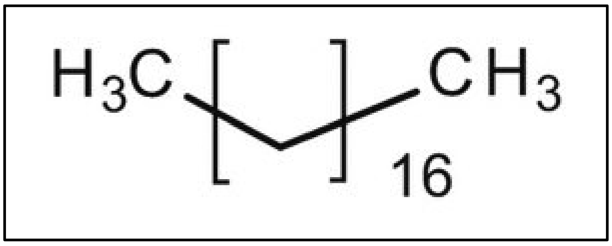

Fig.6. Chemical Structure Octadecane, ($C_{18}H_{38}$)

The high purity ensures a narrow and predictable melting point range - typically between 30°C and 38°C (Wang, Y., et al, 2015) - which is ideal for capturing and releasing heat during the early stages of concrete curing. This level of purity also minimizes the presence of impurities or volatile compounds that could interfere with the cement matrix or degrade over time. Additionally, 99% pure paraffin oil offers a high latent heat of fusion, enabling efficient thermal energy storage and gradual heat release. Its non-reactive, non-toxic, and odorless nature further supports safe handling and long-term durability within the concrete system, making it the optimal choice for the heat-regulating concrete application. When embedded in a concrete matrix - either directly, emulsified, or microencapsulated - paraffin oil can buffer temperature fluctuations during hydration and environmental exposure, improving thermal efficiency and reducing thermal cracking risks (Sharma, A., et al, 2009, Khudhair, A. M., et al, 2004).

Moreover, its high latent heat of fusion (~200–250 kJ/kg) ensures efficient thermal energy storage, while the chemical inertness of pure paraffin ensures compatibility with the alkaline environment of Portland cement. Because it is also non-reactive and stable over multiple thermal cycles, 99% pure paraffin oil can be reliably reused in long-term thermal cycling without degradation, making it an ideal PCM for self-heating concrete design applications.

Economically, 99% pure paraffin oil offers a balanced trade-off between performance and cost. While it is more expensive than lower-grade paraffin oils or blended mineral oils, the long-term thermal efficiency, stability, and reduced risk of degradation justify the initial investment - especially in structural applications where performance consistency is critical.

IV. METHODOLOGY

The methodology used for incorporating the paraffin into the concrete mix was developed using prior researched techniques [8]. The researchers incorporated paraffin oil into their concrete mix in order to measure its effectiveness on melting ice and snow in concrete slabs. Their two methods of incorporation involved a) soaking lightweight aggregate in the oil before adding it to a centrifuge in order to reach saturated-surface dry conditions and b) enclosing the paraffin oil into resin microcapsules, each between 15 and 30 µm in size. These microcapsules were then mixed directly into the cement powder used to create concrete slabs. While this study served as a foundation to this research paper, efforts were made to build upon these initial findings. Calculated modifications were performed, with some modifications based on scale, cost, and availability of different materials and equipment, in order to maximize the concrete's performance while limiting the adverse impact on strength and other mechanical properties. Based on existing literature and the findings out of the experimental tests, it has been deduced that the best practice was to incorporate the paraffin oil into the concrete batch through the coarse aggregate (CA). This was achieved through a soaking procedure.

V. CONCRETE SELF-HEATING PERFORMANCE

For the first part of the research, an observational study was conducted on the performance of this self-heating design. This involved casting three concrete 12” x 12” slab components - one control (traditional mix) and two paraffin oil-infused specimens. The control slab contained no paraffin oil within the mix, while the two paraffin oil-infused slabs contained 100% paraffin oil-soaked aggregate. This allowed for direct comparison of the performance in mitigating snow and ice accumulation on the slab surface between the oil-infused slabs and the traditional concrete control slab. The two oil-infused slabs varied in depth - 3” and 5” thick respectively - in order to investigate the effect of slab depth on performance. The performance of the paraffin oil-infused specimens was tested 4 times during the months of February and March 2025. Out of the four tests, the most successful test occurred on February 11-12th, when 1-2 inches of snow accumulated over the course of 24 hours. Snowfall began on February 11th at 12pm, and continued throughout the afternoon and overnight, resulting in an accumulation of 0.6 in. Snow continued throughout the day on February 12th, stopping at 5pm. Throughout the snowfall event, 5 different photos were taken to monitor the accumulation and melting rates of the snow on the three different slabs. Pictures were taken at 3pm, 5pm, and 7 pm on February 11th, and at 10am and 12pm on February 12th. The first three photos show that the two paraffin oil-infused slabs, located on the center and the right of the photo, were not covered in snow as a result of the snowfall event on February 11th. Unlike the two oil-infused slabs, the control slab, located on the left of the photo, was covered in snow by 7pm on February 11th. This suggested that the paraffin oil had an effect on the melting capabilities of the concrete, preventing the snow from accumulating at low amounts. The next two photos were taken on February 12th. The first photo, taken at 10am, shows all three slabs covered in snow. However, the 3” paraffin slab, located in the center of the photo, was not completely covered in snow, suggesting that the paraffin oil was still working to melt the snow off the concrete. The last picture, taken at 12pm, showcases melting on both the 3” and 5” oil-infused slabs. On both these slabs, it is evident that melting occurred as there is less snow accumulation at 12pm than there was at 10am. Furthermore, the control slab appeared to have an increase in snow accumulation between the two pictures, suggesting that the melting capabilities of the paraffin oil-infused concrete worked not only to melt snow, but to also limit further accumulation on the two slabs. Based on these findings, it was concluded that paraffin oil could be used as a potential method for limiting snow and ice accumulation on concrete surfaces, and that the thickness of the slab had no impact on the melting capabilities of the concrete slabs.

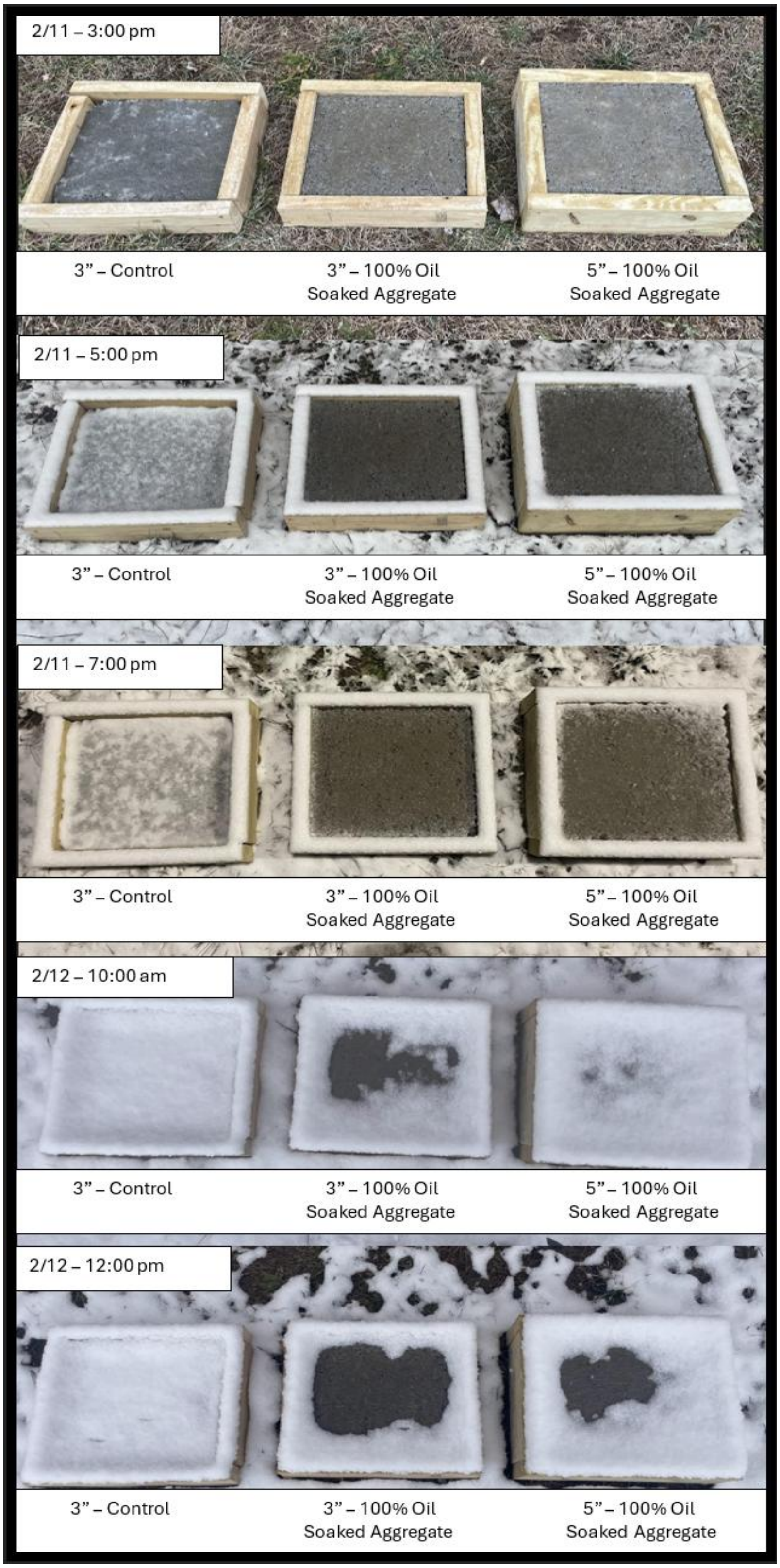

Fig.7. Snow Accumulation Observation Test on February 11-12th, 2025

VI. EFFECT OF PCM ON THE MECHANICAL PROPERTIES OF CONCRETE

For the second part of this research, a quantitative study was performed to investigate the addition of paraffin oil on the mechanical strength of the concrete. For this study, three batches of concrete were made under the same conditions: a traditional (0% oil) mix, a mix utilizing 50% oil-soaked aggregate and 50% regular aggregate as its CA, and a mix utilizing 100% oil-soaked aggregate as its CA. Ratios of water, fine aggregates (FA), and cement were kept constant during mixing to standardize the procedure and maintain control over the case study.

After measuring the required amount of coarse aggregate to be treated with paraffin oil, the CA were emptied into a large basin. Paraffin oil was poured over the aggregate, ensuring complete submersion, at an aggregate to oil ratio of 8. The aggregates were soaked in the oil for at least 72 hours, allowing it to become completely saturated. After 72 hours, the aggregate was removed from the oil using a perforated bucket, and placed onto clean, dry towels, to allow it to air dry. Air drying was chosen due to time and resource constraints as surface drying the aggregate would involve drying each particle individually by hand. While not ideal, air drying allowed for the majority of the aggregate to be dried in a shorter time period. After 48 hours, the aggregates were ready to be incorporated in the mix. This process is shown in Figure 8 and Figure 9.

Fig.8. Soaking the coarse aggregates

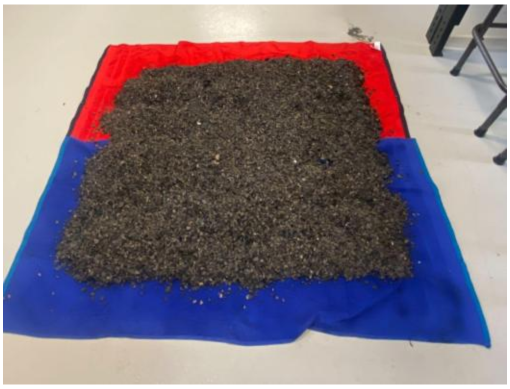

Fig.9. Drying the coarse aggregates

Several concrete cylinders were prepared and tested for compressive strength and splitting strength as shown in Figure 10, and Figure 11. The concrete cylinders were tested for compressive strength and tensile strength over time. Figure 12 and Figure 13 show the effect of adding paraffin-soaked coarse aggregates at different percentages on the compressive strength and tensile strength of concrete. The strength reduces with the increase in the percentage of the paraffin-soaked coarse aggregates in the concrete mix. This reduction in strength appears not to be linearly proportional to the percentage of the treated coarse aggregates.

Fig.10. Concrete compressive strength test

Fig.11. Concrete splitting strength test

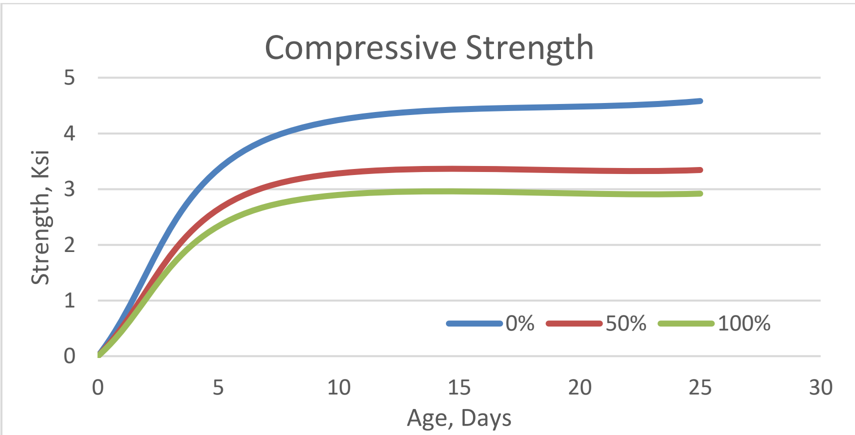

Fig.12. Effect of paraffin oil on the concrete compressive strength

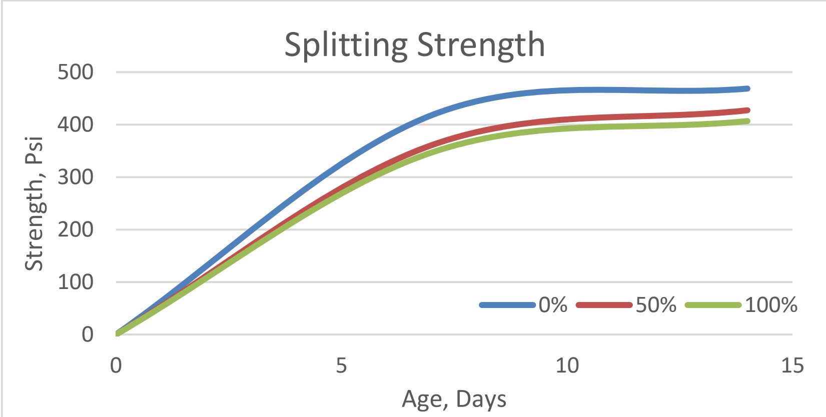

Fig.13. Effect of the paraffin oil on the concrete tensile strength

VII. CONCLUSIONS

Paraffin oil displays promising potential as an affordable and widely available PCM. Its incorporation into everyday concrete structures would produce vast savings in maintenance costs while greatly extending their lifespans. The concrete with PCM enhanced can be used as a coating layer, above structural concrete to enhance performance without compromising strength requirements. The strength of concrete decreases with the increase in the percentage of treated coarse aggregates with paraffin oil in the concrete mix.

REFERENCES

[1]. Al-Nasra, M. (2013). Concrete made for energy conservation mixed with sodium polyacrylates. International Journal of Engineering Research and Application, 3(5), 601–604. https://pdfs.semanticscholar.org/d9af/ 94d1c985d8b22b5090972745a962fed7d43b.pdf
[2]. Al-Nasra, M. (2018). Study of the self-sealing capability of polymer concrete. ARPN Journal of Engineering and Applied Sciences, 13(4), 1297–1303. http://www.arpnjournals.com/jeas/ volume_04_2018.htm
[3]. University of Waterloo. (2014, February 5). Salt + winter roads = safety: New study finds road surface condition biggest safety factor during a winter event [Press release]. https://uwaterloo.ca/news/news/salt-winter-roads-safety
[4]. Federal Highway Administration. (2024). How do weather events impact roads? U.S. Department of Transportation. Retrieved 8 June 2025 from https://ops.fhwa.dot.gov/weather/q1_roadimpact.htm
[5]. Wang, X., Li, Y., Zhang, T., & Chen, L. (2019). *Performance of de-icing salts at low temperatures: A comparative study*. Journal of Cold Regions Engineering, 33(1), 1–10. https://doi.org/10.1061/(ASCE)CR.1943-5495.0000198
[6]. Mullaney, J. R., Lorenz, D. L., & Arntson, A. D. (2019). *Chloride in groundwater and surface water in areas underlain by road salt usage*. U.S. Geological Survey Scientific Investigations Report 2019–5090. https://doi.org/10.3133/sir20195090
[7]. Shen, Y., Li, B., & Xu, J. (2020). *Corrosion mechanisms in concrete structures subjected to deicing salts: A review*. Construction and Building Materials, 245, 118473.
[8]. ASCE. (2023). *Development of self-heating concrete using low-temperature phase change materials: Multiscale and in situ real-time evaluation of snow-melting and freeze–thaw performance*. Journal of Materials in Civil Engineering, 35(3), 04023017. https://doi.org/10.1061/JMCEE7.MTENG-3444
[9]. Reboul, C., Vleminckx, C., & Selderslaghs, I. (2013). Toxicological assessment of mineral oil hydrocarbons in food. Food and Chemical Toxicology, 60, 254–275.
[10]. Wang, Y., Yang, Y., & Hu, Y. (2015). Refining process and compositional analysis of liquid paraffin. Journal of Petroleum Science and Engineering, 133, 109–115
[11]. U.S. Food and Drug Administration (FDA). (2020). White Mineral Oil (21 CFR 172.878). https://www.ecfr.gov
[12]. Kim, S., Park, Y., & Lee, H. (2020). Effects of phase change materials on the hydration and microstructure development of cement-based composites. Construction and Building Materials, 245, 118422
[13]. Sharma, A., Tyagi, V. V., Chen, C. R., & Buddhi, D. (2009). *Review on thermal energy storage with phase change materials and applications*. Renewable and Sustainable Energy Reviews, 13(2), 318–345.
[14]. Khudhair, A. M., & Farid, M. M. (2004). *A review on energy conservation in building applications with thermal storage by latent heat using phase change materials*. Conversion and Management, 45(2), 263–275.