ENHANCING ASPHALT PAVEMENT PERFORMANCE WITH PHASE CHANGE MATERIALS

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Abstract- This study aims to utilize Phase Change Materials (PCM) technology to protect and maintain asphalt pavement from temperature changes, thereby preventing cracks. PCM assists in temperature regulation by exploiting latent heat characteristics, thereby maintaining the workability of asphalt surfaces. Asphalt pavement, often exposed to temperatures up to 60°C in summer, becomes prone to cracking due to sunlight. The issue can be resolved by using PCM, which will extend the life and performance of asphalt pavement. In this investigation, the asphalt mixture had gravel and sand as fine and coarse particles, respectively, and a bitumen penetration grade of 50/60. To implement PCM in asphalt pavement, we took into account the mechanisms for temperature regulation, road efficiency, and mix design techniques. According to the findings, there was a maximum temperature difference of 4.72°C between the top and the bottom, with peak surface and bottom temperatures of 43.41°C and 46.47°C, respectively. This study demonstrates the potential of PCM technology to effectively mitigate temperature fluctuations within asphalt pavement, thereby improving its durability and performance.

Keywords- asphalt pavement, 50/60 grade bitumen, surface and bottom temperature, phase change materials.

1 Introduction

Asphalt pavement can reach temperatures up to 60°C due to its high heat absorption from the sun. To optimize this heat retention, a layer can be installed underneath the pavement to store and utilize the thermal energy effectively [1]. Utilizing the stored heat can mitigate the heat effect and prevent the pavement from becoming excessively soft and prone to rutting. When it comes to using solar energy, we need two main parts: a collector to gather the sunlight and a storage unit to hold onto the collected energy. The collector takes in sunlight and turns it into heat or electricity. To store this solar energy in the pavement, we need materials that can absorb and hold onto heat [2]. The use of phase change materials, or PCMs, in concrete pavement was discovered to have a combined effect of lowering surface temperatures and weakening the pavement [3]. To solve this issue, we suggest investigating microencapsulated PCM particles for asphalt pavement that have stronger outer shells. Before the asphalt mix is rolled out, such particles could be added to help stop the mechanical impacts of compaction on the PCMs. Capsules containing the PCM materials will be used, but they won't be loaded with PCM [4]. This prevents excessive pressure from building up and breaking the capsules while allowing the PCM material within to expand and compress. To simulate sun radiation, the PCM-filled capsules will buried in the pavement's top layer and subjected to infrared heat [3]. They will then be allowed to cool naturally. We can investigate the impact of PCMs by timing temperature variations during this procedure [5]. Phase transitions between solids and liquids, solids and solids, liquids and solids, and solids and gases are examples of latent heat storage. These storage compounds come in a variety of forms, from inorganic to organic, including paraffin and non-paraffin. Organic-organic, organic-inorganic, and inorganic-inorganic are the three primary categories of inorganic PCM and eutectic mixes. Since they possess melting points between 115°C and 897°C, inorganic materials are typically chosen in the setting of solar power generation [6].

1.1 Phase Changing Material (PCM)

Pavement is continuously exposed to the elements, which over time may cause deterioration. Temperature is one of the most important variables affecting pavement performance. Significant temperature variations can put a lot of strain on the pavement, which can result in fractures and damage. It might be less expensive to maintain if these temperature swings are smaller. Phase Change Materials, or PCM, can be added to a pavement mixture to accomplish this. PCMs are materials that can expend or absorb heat, which aids in temperature regulation. The range of temperatures at which the change in phase takes place and how heat is absorbed or released during the phase shift are major determining factors in deciding what kind of PCM to utilize in the mixture. When a car's wheels spin vertically on the pavement, it can cause, [7, 8] which causes adjacent pavement portions to move sideways. As seen in Figure 1, this movement causes channels or ripples to appear on the pavement's surface.

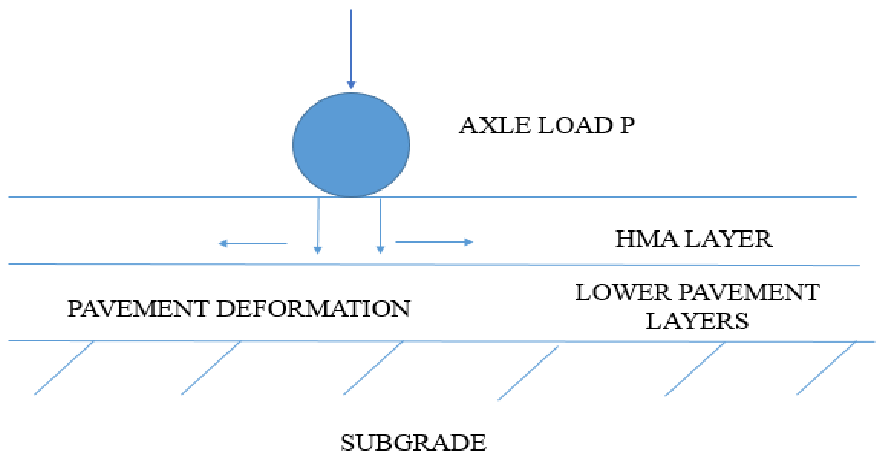

Figure 1: Rutting in hot asphalt mixtures primarily results from the prolonged application of heavy wheel loads

According to the temperature range, different phase-change materials, or PCMs, are employed. Three primary categories are commonly used to classify PCMs: organic, inorganic, and eutectic material (PCM) [9]. There are two primary categories of organic PCM, like paraffin: paraffin hydrocarbons and paraffin waxes. The most popular organic phase change material (PCM) for heat storage among them is paraffin wax. Its volume swells by roughly 10% as it melts. Furthermore, because paraffin is softer, it exerts less force when it expands, making it less likely to cause harm [8]. Because of this, it can be used in applications without phase separation concerns where repeated cycles of melting and solidification are required. The majority of PCMs are classified as non-paraffin compounds, which have a variety of characteristics. These materials are combustible, which presents a major disadvantage that renders them inappropriate for elevated temperature storage purposes. The three main categories of non-paraffin compounds are polyalcohol, fatty acids, and glycols [10]. The challenges posed by temperature-induced strains on asphalt pavement can result in degradation and increased upkeep costs. [11] To tackle this challenge, the study delves into the potential of phase change materials (PCMs) for temperature management in pavement systems. Through the exploration of microencapsulated PCM particles and their incorporation into asphalt mixes, the research seeks to alleviate the negative impacts of temperature variations, thereby enhancing pavement resilience and diminishing maintenance expenditures [12].

2 Research Methodology

Table 1 Bitumen Properties

Property	Result	Limits	Standard
Penetration (0.1mm)	64	60-70	ASTM D5
Softening Point (°C)	48	45-55	ASTM D36

In this investigation, bitumen with a penetration grade of 50/60 was kept for use, with its essential properties, such as penetration (65 at 0.1 mm) and softening point (47 degrees Celsius), determined according to the guidelines of ASTM D5 and ASTM D36, respectively as shown in table 1. The composition of the asphalt mixture comprised gravel as the coarse aggregate and sand as the fine aggregate. Introducing Phase Change Material (PCM) into the mixture at a 5% proportion served as a substitute for filler, enhancing its thermal properties. To facilitate experimentation, asphalt slabs measuring 30 by 30 cm were meticulously prepared. Continuous exposure to heat radiation over 10 days, maintained for 24 hours each day, simulated real-world conditions,[13] allowing for an in-depth assessment of the asphalt's response to thermal stress. Mechanical evaluations of the asphalt samples were then conducted to gauge their performance under varied conditions. Stiffness, rutting resistance, and fatigue life were among the key parameters assessed, employing standardized testing methodologies such as ASTM D6373, ASTM D6925, and ASTM D7460, respectively. Each test was executed with precision, adhering strictly to the protocols outlined by standards, thereby ensuring the accuracy and reliability of the experimental results. This meticulous approach not only facilitated a comprehensive understanding of the asphalt mixture's behaviour but also provided valuable insights into the efficacy of incorporating PCM as a filler substitute to enhance its thermal characteristics and overall performance. The temperature was measured using embedded thermocouples. The optimal temperature range for preventing and healing asphalt cracks is typically between 50°C and 70°C, as this range supports proper compaction and bonding, reducing the likelihood of cracking.[14]

3 Results

This study's experiment concentrated on pavement elements that are exposed to high surface temperatures. The mixture reached its maximum temperature between three and six o'clock in the evening. Figure 2 shows the mean, highest, and lowest temperatures of PCM over 10 days. 37.15°C is the average degree at the PCM's bottom. The PCM's average bottom temperature ranges from 31.41°C to 45.95°C at its maximum and minimum, respectively. The PCM's surface has an average temperature of 36.55°C. The PCM's average surface temperature is 30.45°C at its lowest and 42.41°C at its highest points. The PCM's bottom and surface have an average temperature differential of 0.45°C. While the average lowest temperature difference is 0.30°C, the mean highest temperature variation of the PCM is 4.85°C.

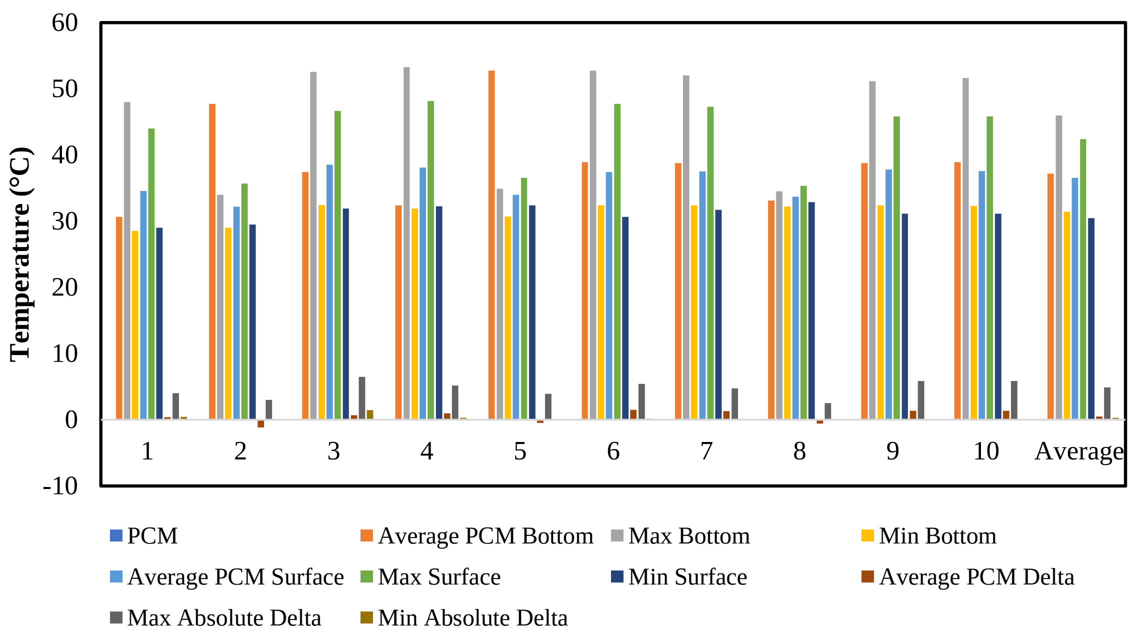

Figure 2 PCM Results

4 Practical Implementation

Observing how the PCM reacts with asphalt and variations in the temperature leads to improving the temperature of the pavement. This research helps in controlling of temperature of the pavement layer and maintaining its span against temperature variations.

5 Conclusion

- In this study, the temperature of the PCM asphalt mixture was measured, and a comparison was made between the temperatures at the top and bottom of the mixture. The highest temperature of the mixture was observed between 3 and 6 p.m. at the bottom layer and between 4 and 7 p.m. at the surface layer.
- The highest temperature measured at the surface was 42.41°C, while the lowest recorded temperature was 45.95°C. Furthermore, we noted that the absolute greatest temperature differential between the bottom and surface was 4.85°C. These encouraging results imply that temperature changes within asphalt pavement can be effectively improved by utilizing organic PCM encapsulated in about 800μm capsules.

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