Using Phase Change Material to Improve Asphalt Pavement Behavior

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Abstract. This research is an attempt to use PCM technology in order to protect and treat the asphalt pavement from the influence of temperatures and thus not to crack the road pavements. Applying the phase change materials in roadway traffic domain is becoming an exploration research, although the PCM have been used in many fields. Depending on the properties of latent heat, we can apply the phase change materials to control and regulate temperature of asphalt pavement and keeping mix feasibility. Asphalt pavement is a material that can heat up to 60°C due to solar irradiation in summertime because of their excellent heat-absorbing properties. Using the PCM can treat the asphalt mixture pavement cracks related to temperature, enhance the performance of asphalt concrete pavement, and prolong the service life of asphalt concrete pavement. We address the procedure bitumen penetration grade 50/60 was used in this test. In this study, gravel and sand are used as coarse and fine aggregate respectively in hot mixture asphalt. In order to apply PCM in asphalt concrete pavement, mechanism of controlling temperature, road performance and mixture design method of asphalt mixture have been considered. Results show that maximum temperature of surface and bottom respectively is (43.41°C, 46.47°C), and the maximum absolute Delta (difference between surface and bottom) reached to 4.72°C.

1. Introduction
Asphalt pavement is material that can be heated up to 60°C due to solar irradiation in summertime because of their heat absorbing properties [15]. The energy of solar irradiation absorbed by surface of pavement could be collected by installing heat storage under the layer of pavement. Heat collected from the pavement could also reduce the Urban Heat Island (UHI) effect and the potential rutting of asphalt pavement [9]. According to the nature of solar energy, two components are required to have a functional system of solar energy; collector and a storage unit. The collector collects the radiation that falls at surface and converts it to other forms of energy such as heat and electricity. This requires latent heat storage in pavement materials to collect and store solar energy. A study carried out by Keikhai Dehdezi [6]; show that the use of phase change material (PCM) in concrete pavement is effective for reducing the surface temperature. However, it shows a large reduction in strength. Therefore, we suggest studying the use of microencapsulated PCM particles with stronger external shells in asphalt pavement. This can be performed by adding the PCM with rolled pavement to prevent the mechanical effect of compaction on the PCMs. The PCM materials will be
used in capsules and these are not filled with the PCM completely to allow the volume change of the material which is based on study made by Blaney et al [2], to minimize the pressure inside and to maintain structural integrity of the encapsulated PCM. These encapsulated PCM will be placed in the surface layer and subjected to an infrared heat to simulate the solar radiation and then allow cooling down, to measure the temperature rate of change in order to study the effect of PCMs. This will be performed in tow conditions (dry and wet) [5].

2. System of latent heat storage (SLHS)
In recent years, researchers show interest in the latent heat storage for load leveling and waste heat recovery for power generation [10]. There are many transformations of storage of latent heat; some of these are solid-solid, solid-liquid, liquid-gas and solid-gas phase. These materials include; Organic materials, paraffin and non-paraffin. There are three types of inorganic PCM and Eutectic mixtures; organic–organic, organic–inorganic, and inorganic–inorganic. For solar power generation, mostly inorganic materials are used thanks to their melting point range of 115–897°C [15].

2.1 Phase Changing Materials (PCM)
Pavement is always exposed to environmental factors; to prevent it from damage, it must be improved. The most important environmental factor affects the performance of pavement is the temperature, due to the large potential change causes to the pavement [12]. An improvement in the costs of maintenance could be possible if the size of these changes in temperature decreased. This can be accomplished by using PCMs in a pavement mixture [4], regulate temperature substances that have the ability to either release or absorb heat [1]. The appropriate PCM used in mixture is largely depending on the temperature at which the phase change occurs, heat release or absorption occurs during the phase change [13].

![Figure 1. Theoretical temperature of asphalt control and with PCM](image)

Theoretically, Phase change material can be applied to mitigate cracking and thermal rutting in hot mixture asphalt assuming a proper mixture design with enough strength [14]. The Rutting in hot mixture asphalt accrue because of the deformations results from the density increasing when the large loads move on the pavement when the surface temperature is hot [5]. In case of pavements exposed to loads and high temperature over time, the pavements lose the strength of binding and deform plastically appears [16].
Distortions caused by wheel vehicle path effected vertically on the pavement, which in turn causes nearby sections of the pavement to move laterally, producing ripples or channels in the pavement surface such in Figure 2 [11].

![Figure 2](image)

Figure 2. Rutting in hot asphalt mixture because of wheel loads action repeated over time

### 2.2 Types of Phase Changing Materials (PCM)

Many varieties of phase change materials are used based on the range of temperature. PCMs are generally classified into three types: Organic, Inorganic and Eutectics [8]:

#### 2.2.1 Organic PCM

Organic PCM as paraffin, there are two kinds of paraffin; paraffin hydrocarbons and paraffin waxes. Paraffin wax is the most commonly used organic heat storage PCM, their volume increase upon melting is in the order of 10%. Also, it is less critical because paraffin build up smaller forces upon expansion as they are softer. Paraffin is insoluble in water. They do not react with most common chemical reagents. For that it uses to solve problem of under repeated melting or solidification cycles, that's not has phase segregation [8,14].

#### 2.2.2 Non-paraffin compounds PCM

The non-paraffin compounds are the most numerous of the PCMs with a wide variety of properties. They are flammable in nature hence they are not applicable for high temperature storage. Non-paraffin compounds are further distinguished as Fatty acids, Glycols, and Polyalcohol's [1].

#### 2.2.3 Eutectics PCM

A eutectic mixture is a material composed of two components or more. It is solidifying without segregation and congruently at a temperature that is lower than the one at which one component solidifies, called 'eutectic temperature'. Relatively, their thermal application is new and not much amount information is known. So, it's has sharp melting points similar to pure substances and a higher volumetric storage density than organic compounds [7,8].
3. Experiment and Material
This section addresses the bitumen penetration grade 50/60 used during the test. In this study, Table 1 presents the properties of bitumen. Gravel used as coarse aggregate, and sand used as fine aggregate in hot mixture asphalt.

| Tests                | ASTM Specification | Results | Limit of specification |
|----------------------|--------------------|---------|------------------------|
| Penetration (0.1 mm) | ASTM D 5-06        | 65      | 60-70                  |
| Softening Point (Celsius) | ASTM D 36-06      | 47      | 45-55                  |
| Ductility (cm)       | ASTM D 113-99      | 100     | > 95                   |

The design of aggregate gradation and specification is shown in Table 2 according to Iraq specification. Organic Paraffin was used as PCM in this experiment. Paraffin has been encapsulated in very small size, and capsules are divided by size into three groups; Nanocapsules (sizes between 1 and 1000 nm), Microcapsules (sizes between 1 and 1000 μm) and Macro capsules (sizes greater than 1mm). In this experiment, Paraffin encapsulated size used approximately (800 μm). The phase change material in wearing mixture treated like filler substitution [3]. Wearing mixture was produced based on Iraq specification. The proportion of PCM in asphalt mixture used is 5% considered as filler.

| Sieve Size (mm) | Design Gradation | Add Filler PCM % | Specification Limit |
|-----------------|------------------|------------------|---------------------|
|                 |                  |                  | Lowe | Upper |
| 25              | 92               | 4.6              | 90   | 100   |
| 19              | 80               | 4                | 76   | 90    |
| 12.5            | 60               | 3                | 56   | 80    |
| 9.5             | 51               | 2.55             | 48   | 74    |
| 4.75            | 34               | 1.7              | 29   | 59    |
| 2.36            | 21               | 1.05             | 19   | 24    |
| 0.3             | 12               | 0.6              | 6    | 17    |
| 0.075           | 4                | 0.2              | 2    | 8     |

In this study, slab with size (30 by 30 cm) of asphalt was used and subjected to heat radiation 24 hours for 10 days. Data collected from Resistance Temperature Detector (DTR) which placed on surface and bottom of the slabs for measuring temperature in every 10 minutes. Temperature measurements were taken in direct heat.

4. Results from experiment and Discussion
The experiment of this study is limited to material of pavement that has high surface temperature. Figure 3 shows the profile of temperature at bottom of the sample PCM mixture. The max temperature of mixture coincided, around 3 pm to 6 pm.
Figure 3. The bottom of the PCM mixture
Figure 4 shows the profile of temperature at surface of the sample PCM mixture. The max temperature of mixture coincided, around 4 pm to 7 pm.

Figure 4. The surface of the PCM mixture
Figure 5 shows the profile of difference temperature between surface and bottom of the sample PCM mixture. The max temperature of mixture coincided, around 4 pm to 7 pm.
Figure 5. Difference of PCM between surface and bottom

| Days | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10 | Average over all |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|-----------------|
| PCM  |     |     |     |     |     |     |     |     |     |    |                 |
| average PCM bottom | 34.93 | 31.02 | 39.15 | 39.02 | 33.50 | 38.90 | 38.78 | 33.12 | 38.78 | 38.89 | 36.61 |
| max bottom | 48.00 | 33.96 | 52.56 | 53.28 | 34.90 | 52.74 | 52.01 | 34.53 | 51.13 | 51.63 | 46.47 |
| min bottom | 28.50 | 29.00 | 32.41 | 31.91 | 30.69 | 32.40 | 32.37 | 32.17 | 32.38 | 32.26 | 31.41 |
| average PCM surface | 34.54 | 32.20 | 38.51 | 38.07 | 33.98 | 37.40 | 37.49 | 33.70 | 37.78 | 37.54 | 36.12 |
| max surface | 44.00 | 35.69 | 46.65 | 48.13 | 36.54 | 47.71 | 47.26 | 35.31 | 46.99 | 45.81 | 43.41 |
| min surface | 29.00 | 29.50 | 31.92 | 32.25 | 32.39 | 30.64 | 31.70 | 32.87 | 32.82 | 31.13 | 31.42 |
| average PCM Delta | 0.39 | -1.18 | 0.65 | 0.94 | -0.48 | 1.50 | 1.30 | -0.57 | 1.00 | 1.35 | 0.49 |
| max absolute Delta | 4.00 | 3.00 | 6.47 | 5.15 | 3.89 | 5.38 | 4.75 | 2.52 | 6.17 | 5.83 | 4.72 |
| min absolute Delta | 0.40 | 0.06 | 1.46 | 0.30 | 0.04 | 0.12 | 0.04 | 0.01 | 0.44 | 0.06 | 0.29 |
- The results from Table 3 shows average, maximum and minimum of PCM temperatures for 10 days, the average over all for PCM bottom is 36.61°C, average over all for maximum bottom of PCM is 46.47°C, and the average over all for minimum bottom of PCM is 31.41°C.
- The results from Table 3 shows average over all for PCM surface is 36.12°C, average over all for maximum surface of PCM is 43.41°C, and average over all for minimum surface of PCM is 31.42°C.
- The results from Table 3 shows average over all for PCM difference between surface and bottom, the average over all for PCM for delta is 0.49°C, average over all for maximum delta of PCM is 4.72°C, and average over all for minimum delta of PCM is 0.29°C.

5. Conclusion
In this research, the temperature of PCM asphalt mixture was tested and comparison between surface and bottom of the asphalt mixture was detected. The maximum temperature of mixture coincided around 3 pm to 6 pm at the bottom of asphalt mixture. The maximum temperature of mixture coincided, around 4 pm to 7 pm at the surface of asphalt mixture. From results we see that maximum temperature of surface and bottom respectively is (43.41°C, 46.47°C). And we note that the maximum absolute Delta (difference between surface and bottom) reached to 4.72°C, and this considered as promising results for organic PCM encapsulated by approximately (800 μm) used in asphalt pavement to improve pavement temperature changes.

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