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A Review on Phase Change Materials Incorporation in Asphalt Pavement

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ABSTRACT

Phase Change Material (later to be referred as PCM) has been successfully utilized in some areas. PCM has emerged as one of the materials for pavement temperature reducing due to its latent heat. Some research has been done regarding this topic. The objective of this paper is to review the development of PCM in asphalt pavement. The review has shown that organic PCM appears as the favourite PCM in asphalt concrete studies. Choice of porous material depends on method of incorporation. Reduction of temperature in PCM-asphalt mixture compared to conventional one is undoubtable. However, the mechanical performance of PCM-asphalt mixture need to be explored.

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1. INTRODUCTION

Asphalt pavement tends to have high surface temperatures because of its characteristic that has low albedo (reflection). Some studies have reported the surface temperature of asphalt pavement (Harrington *et al.*, 1995; Benrazavi *et al.*, 2016; "Reducing Urban Heat Islands" 2012). It can reach 700C in summer peak. The high surface temperature of pavement can cause problems, not only aggravating Urban Heat Island (UHI) but also degrading the performance of pavement. Another issue is harmful matter to human due to emissions of toxic volatile from overheating pavement.

Phase Change Temperature (PCM) can be utilized in asphalt to adjust temperature of asphalt pavement and alleviate the changing temperature effect on pavement structure. Actually asphalt is also a kind of PCM but its phase change enthalpy is too low (low melting heat value) (Ryms *et al.*, 2017). Phase change material (PCM) is a substance that can change their phase during absorb or release heat. PCM has four types in terms of its phase change, which are solid/solid, solid/liquid, solid/gas and liquid/gas.

Technical requirement of PCM utilized in asphalt mixture are ; suitable phase change temperatures , suitable thermal conductivity, phase transition process completely reversible, resistance to high temperature, no wastage when it is mixed up in high temperature , pollution free, low cost and simple incorporation process (Ma *et al*., 2011)

The objective of this paper is to review the development of PCM in asphalt pavement. This paper summarizes the type of PCM and its incorporation methods in asphalt mixture. Thermal and mechanical performance of PCM-asphalt mixture are investigated.

2. TYPES OF PHASE CHANGE TEMPERATURE (PCM)

PCM can be classified into organic, inorganic, and eutectic. Organic can be divided into paraffin and non-paraffin. Most study of PCM in asphalt pavement used paraffin (Chen *et al*., 2011; Kheradmand *et al*., 2015; Biao *et al*., 2013; "Development and Testing of PCM Doped Cool Colored Coatings to Mitigate Urban Heat Island and Cool Buildings - ScienceDirect" n.d.; Manning *et al*., 2015; Ryms *et al*., 2015). **Figure 1** can explain why paraffin is studied mostly in asphalt pavement. Paraffin have quite range of melting temperature and lie in the temperature range of pavement. The advantages of paraffin are safe, reliable, cheap, a high latent heat, non-corrosive, non-sub cooling, their volume does not change considerably when changing phase, and congruent melting (Akeiber *et al*., 2016).

Phase change temperature is one of the parameters to choose PCM. Depending on the phase change temperature, PCM could be devide into three groups (Agyenim *et al*. 2010). First group is PCM with phase change temperature within (0-65)^{0}C. This range is suitable for heating/ cooling application. PCM of melting (80-120)^{0}C could be used in absorption cooling system consider as second group. The third group, those types of melting temperature above 150^{0}C could be applied in solar power plant systems.

The other reason is related to the characteristic of paraffin based PCM, which are noncorrosive and nontoxic (Sharma *et al*., 2009)

The purpose of PCM application in asphalt pavement is for heating or cooling. It is related to two distresses of pavement, rutting and low temperature cracking, because of environment temperature. Low melting temperature (0-20)^{0}C is suitable to prevent low temperature cracking and (21-65)^{0}C melting temperature is appropriate for rutting resistant.

Biao Ma (Biao *et al*., 2013) used Tetradecane which has melting point 5.8^{0}C to prevent pavement damage due to low temperatures. A mixture of paraffin which is called ceresin has proposed as PCM in asphalt mixture (Ryms *et al*., 2015).

One of the fatty acid, linolenic acid, is utilized to reduce negative influence of temperature variation on asphalt mixture (Ma *et al*., 2011). Less temperature variation means extending the operating life of asphalt pavement. Using a similar PCM, Guan (Guan *et al*., 2011) investigated thermal conductivity and specific heat of asphalt mixture doped PCM. Both thermophysical characteristic increased because of PCM ; however, it depends on the temperature of phase-changing. Bian (Bian *et al*., 2012) evaluated 3 items of fatty acid PCM, which are Myristic Acid, Palmitic Acid and PEG 4000. This choice is based on some of consideration. Phase change temperature is

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around 45⁰C - 65⁰C, latent heat and thermal conductivity coefficient are as much as possible and volumetric change rate is as small as possible. Chen (Chen *et al.*, 2012) utilized organic acid with phase change temperature 45⁰C and 50⁰C. Another study (Biao *et al.*, 2014) utilized organic acid but with different phase change temperature , which is 22.1⁰C

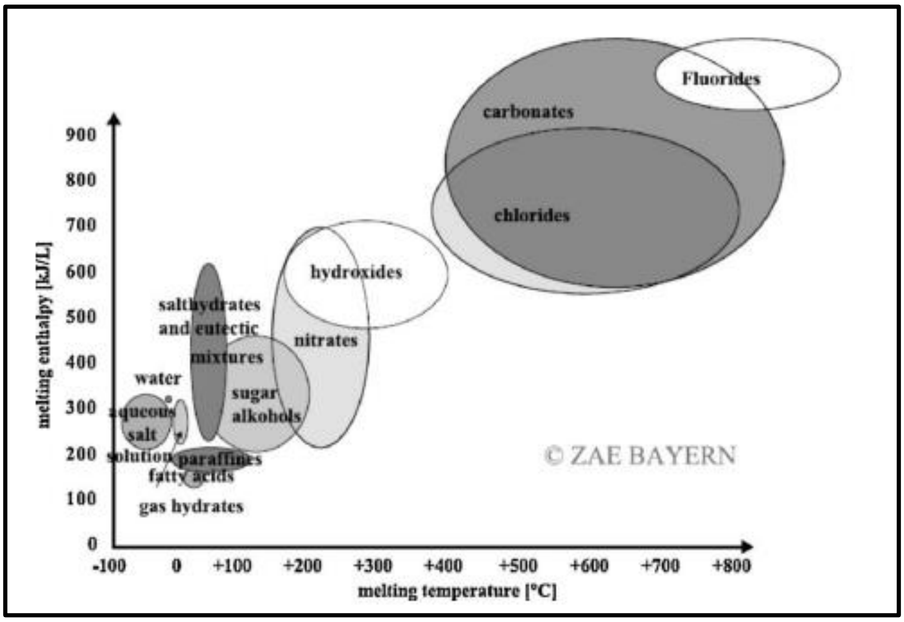

Figure 1. Classes of materials that can be used as PCM with regard to their typical range of melting temperature & melting enthalpy (Ma *et al.*, 2011)

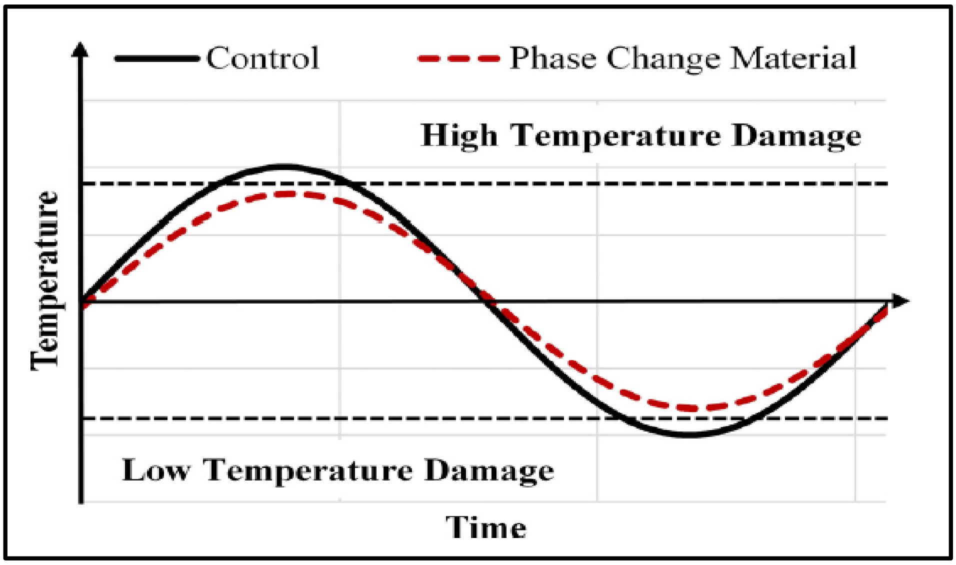

Figure 2. Theoretical temperature profile of asphalt with and without PCM (Guan *et al.*, 2011)

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3. PCM INCORPORATION METHOD

There are generally three PCM incorporation methods in asphalt pavement. These including direct incorporation, shape-stabilized and encapsulation PCM.

3.1. Direct incorporation.

A study has proven that the direct incorporation of PCM can affect the asphalt properties, in-term of Penetration, Softening point and Ductility (Bian *et al.*, 2012).

3.2. Shape-stabilized PCM.

Shape-stabilized PCM utilized porous material to absorb PCM. This prevent leakage because of the capillary and surface tension forces (Chen *et al.*, 2012). Porous materials that have been used as PCM incorporation are polymer (Biao *et al.*, 2014), diatomite powder (Bian *et al.*, 2012), silica powder (Ma & Li, 2011; Guan *et al.*, 2011) and Light Weight Aggregate (LWA) (Kheradmand *et al.*, 2015; Ryms *et al.*, 2015; Manning *et al.*, 2015). The drawback of this method is low dosage of PCM. The low dosage PCM gives a little influence on the specific heat capacity of asphalt mixture and the delay in the rise in temperature is insignificant (Ma *et al.*, 2016).

Bian (Bian *et al.*, 2012) prepared PCM asphalt mixture using palmitic acid as PCM and two porous materials which are diatomite powder and granular pottery sand. Granular pottery sand palmitic acid was substitute for fine aggregate and diatomic powder palmitic acid replaced filler. Import mode is very simple, porous material shields PCM to some extent and reduce the impact of contact on asphalt. One form of active carbon, graphite, was used as porous material at another study (Chen *et al.*, 2011; Chen *et al.*, 2012). However this stabilized PCM experienced leakage.

Ren (Ren *et al.*, 2014) & Biao Ma *(Ma et al.*, 2011) compared similar three porous materials which are silica powder, drift beads and active carbon . However the result is not in line each other. Silica powder is suitable for shape stabilized method whereas active carbon is good for encapsulation method. Silica powder has ideal porous that can hold small amount PCM although it has poor adsorption capacity based on SEM test. Meanwhile active carbon is open hole material but good for adsorbing PCM, thus it needs encapsulation.

3.3. PCM Encapsulation.

To increase the content of PCM, the porosity of aggregate should be increased or the PCM should be introduced in a different form i.e. encapsulation (Ryms *et al.*, 2015). Encapsulation divided into: Macro encapsulation (D>1 micrometer), Micro encapsulation (D = 1 micrometer), Nano encapsulation (D<1 micrometer)

Functions of encapsulation (Akeiber *et al.*, 2016) are to prevent the low viscous liquids from diffusing throughout the material (leaking during changing of PCM phase to liquid), increase the thermal conductivity (increase the heat transfer between the PCM and surrounding environment by enlarging the surface area), isolate harmful environment factors, compatibility between PCM and surrounding material, decline in corrosion and managing volume variation during state change.

Biao Ma (Biao *et al.*, 2013) developed composite shape-stabilized phase change material (CPCM). CPCM is other name of encapsulation. This study compared carbon & silica as carrier materials, silica performed better than carbon. It is not in line with (Ren *et al.*, 2014). The difference between shape-stabilized and encapsulation is that the encapsulation has a shell material to cover the shape-stabilized. In this study, they used ethyl cellulose as a shell.

Kheradmand confirmed (Kheradmand *et al.*, 2015) that the encapsulation method is

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effective for incorporating PCM into asphalt road pavements. Encapsulation can prevent PCM leakage.

4. THERMAL PERFORMANCE

Thermal performance in this paper is refer to temperature of asphalt pavement. Theoretically, the main purpose of PCM incorporation is to reduce the extreem temperature during service life of pavement. **Figure 2** showed that there are two extreem temperatures, low and high temperature damage.

The temperature of sample with PCM is about 20^{0}C lower than the sample without PCM in average (Chen *et al.*, 2011). However, this result was based an indoor experimental apparatus which consisted solar simulator (produced by 300W metal halide lamp).

The 20^{0}C difference between mixture with and without PCM is also presented in another research (Biao *et al.*, 2014). This study was held at indoor experiment and field simulation.

Another study (Bian *et al.*, 2012) proved that PCM asphalt pavement could reduce temperature (8-10)^{0}C (laboratory simulation) and (3-4)^0 C (field simulation). This study replaced filler and fine aggregate with CPCM (Composite Phase Change Material). It was in direct agreement with (Ryms *et al.*, 2015).

PCM with phase change temperature 1.5 above softening point of asphalt gave a better result to reduce temperature than PCM with phase change temperature 3.5 below softening point of asphalt. It is due to the fact that that PCM has lower thermal conductivity and higher volumetric heat capacity (Chen *et al.*, 2012).

During the heating process, PCM mixture with phase change temperature around softening point of asphalt exhibited a lower temperature increasing rate than mixture without PCM (Chen *et al.*, 2012).

PCM can slow down the heating and cooling rate, decrease temperature amplitudes of asphalt mixtures and postpone the occurrence of extreme temperature.

5. MECHANICAL PERFORMANCE

Good performance of flexible pavement is needed during service life of pavement. Two of pavement failures, rutting and fatigue are often used to measure pavement life. These failures are related to temperature because flexible pavement has thermoplastic material in it.

It is well established in the literature that the rutting is one of the most important factors in determining the pavement life. Mallick (Mallick *et al.*, 2009) simulated pavement structures under different traffic and climate condition employing Mechanistic-Empirical Pavement Design (MEPD) Software. They concluded that, for the same traffic and same materials, the life of the pavement can be extended by 5 years for drop in temperature of 5^{0}C. They considered a range of maximum pavement temperatures from 52^{0}C to 70^{0}C. Mills Brian (Mills *et al.*, 2009) provided further evidence for rutting issue. This issue will be exacerbated by climate change. The evidence is from 6 sites in Canada.

Good mechanical performance is a key to accept that PCM-asphalt mixture is a solution to decrease pavement temperature. Some of research studies have been done **Table 1**. The choice of melting temperature is depend on the purpose of study.

The incorporation of PCM decreased the indirect tensile strength & rutting resistance of asphalt mixture (Chen *et al.*, 2012). This study explained that there was leakage of PCM.

Phase change temperature of PCM used in asphalt pavement should be (3-5)^{0}C less than the softening point of the asphalt used in practical (Chen *et al.*, 2011). Rutting more

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likely occur when the temperature of pavement higher than softening point of asphalt.

A study (Ma *et al*., 2011) analyzed the impact of different PCM dosage (which are 0%, 5%, 10% and 20% of the asphalt content) on rutting test. Rutting test under the condition of 60^{0}C was done to evaluate PCM-asphalt mixture. The result showed that PCM reduced the high temperature stability. When amount of PCM is more than 10 %, it will give the same effect in terms of rutting. The graph can be seen in **Figure 3.** Unfortunately, this study did not compare it with control mixture. Thus, there is no information which mixture is better, with or without PCM, in terms of rutting.

Tabel 1. Purpose of incorporation PCM in asphalt mixture

Ref.	PCM Name	Phase Change Temp (0C)	Latent Heat (kJ/kg)	Purpose
(Biao et al. 2013)	Tetradecane	5.8	231	Low temperature cracking
(Ma, Wang, and Li 2011)	Linolenic acid	8-25	n.a	Low temperature cracking
(Bian et al. 2012)	Myristic Acid	49-51	141.48	rutting
(Bian et al. 2012)	Palmitic Acid	61-64	164.79	rutting
(Bian et al. 2012)	PEG 4000	51-54	143.56	rutting
(M. Chen, Wan, and Lin 2012)	Organic Acid	45	110	rutting
[16]	Organic Acid	50	100	rutting
(Biao et al. 2014)	Organic Acid	22.1	46.97	Thermal performance

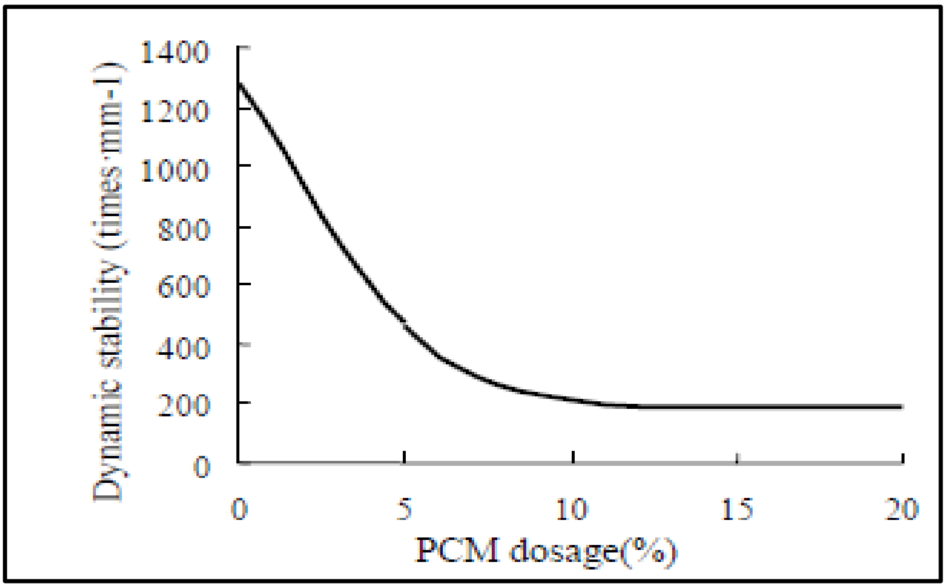

Figure 3. PCM dosages on the impact of dynamic stability

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6. CONCLUSION

Athough there are three type PCM, the organic PCM has been studied in asphalt pavement. Paraffin and organic acid with different phase change temperature has been incorporated in asphalt mixture. The characteristic organic PCM is more relevant with asphalt mixture than other PCM. Shape stabilized and encapsulation are PCM incorporation method that used porous material. The choice of porous material can be various. PCM has been proven as material to adjust temperature of asphalt mixture. However, there needs to be further elaboration to study their effects in mechanical performance of asphalt mixture.

7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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