Joint Transportation Research Program

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Environmentally Tuning Asphalt Pavements Using Phase Change Materials

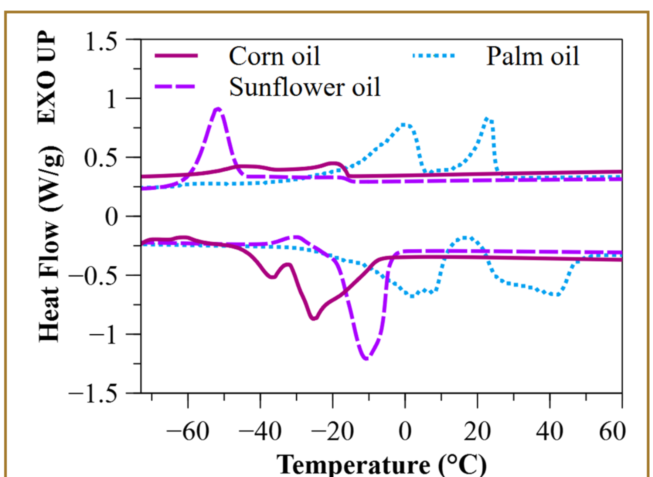
Introduction

Asphalt pavements experience many different diurnal and seasonal temperature fluctuations, which cause the development of thermal stresses in their structures throughout their life cycles. Thus, to maximize pavement performance in such unpredictable environments, asphalt materials must balance the need for thermal management with the need for mechanical resistance. The ability to endow asphalt pavements with thermal energy storage capacities that are based on environmental conditions will enhance their life cycle performance. Phase Change Materials (PCMs) have demonstrated ideal characteristics as thermoregulating agents for various engineering applications. Accordingly, this study aimed to investigate the environmental tuning of asphalt pavements using PCMs. The research objectives of this study were fourfold: (1) investigate the synthesis and characterization of biobased Fatty Acid Amides (FAAms) obtained by direct amidation of different vegetable oils with primary alkyl amines, (2) evaluate the capability of Microencapsulated PCM (μPCM) to withstand the mixing and compression stages of the asphalt mixture processing, (3) identify testing techniques that characterize the thermomechanical performance of μPCM-modified asphalt binders and mixtures, and (4) redesign an asphalt mixture with μPCM and determine the mechanical performance implications of incorporating a significant portion of μPCM in the mixture.

Findings

Overall, this study strengthens the concept that modifying asphalt materials with PCMs makes it possible to "tune" the resulting asphalt pavement to the environment, thereby mitigating or eliminating pavement damage due to the exposure of asphalt pavement surfaces to temperature fluctuations. Moreover, although this study focuses on paving applications, the findings may well influence the general synthesis and characterization of PCMs. The following are key findings drawn from this investigation.

- The synthesis of FAAms from different commercial vegetable oils and primary alkyl-amines is feasible, and their chemical and thermal properties are of interest for asphalt paving purposes. Based on green chemistry metrics focused on maximizing resources, the synthesized materials have the potential to be used as PCMs.
- Experimental results suggest that nearly 90% of μPCM particles can survive abrasive forces at room temperature. Additionally, thermal stability tests and image analysis indicate that μPCM particles are stable at asphalt production temperatures (between 135°C–162°C, or 275°F–325°F).



Synthesis of FAAMs from different vegetable oils.

However, the combined effects of mixing temperatures and abrasive forces are still a concern and are subject to future investigations.

- Rheological measurements can help identify the latent heat effect of μPCM particles in asphalt binders. This study proposes a novel parameter to determine the temperatures at which the μPCM effect occurs. This approach can also provide insights into the intensity of the μPCM impact on asphalt mixtures.
- The experimental results confirm that μPCM modified asphalt mixture specimens can experience temperature differences between 1.8°C and 10.3°C lower than non-μPCM modified asphalt mixture specimens subjected to the same ambient temperatures.
- The asphalt binder and mixture mechanical test results suggest ambivalent performance outcomes caused by the incorporation of μPCM in asphalt paving materials. However, taken together, the mechanical analysis indicates that the μPCM particles could behave like a conventional mineral filler if they suffer no damage during mixing and compaction

Implementation

This research demonstrates that the environmental tuning of asphalt materials using PCM could potentially mitigate the appearance of intense surface and inner temperatures on asphalt pavements. This PCM effect promises to improve pavement performance and help alleviate the urban heat island effect. However, the findings of this study suggest that the implementation of PCM modified asphalt pavements in Indiana is currently impractical. The following aspects of this study that could lead to implementing this technology are highlighted below.

- Future work is needed to ensure that PCM modified materials could be readily implemented in the field. More research is required to evaluate the survivability of μPCM during the production, placement, and compaction of asphalt materials. In addition, the long-term performance of the μPCM particles under repetitive vehicle loading and temperature fluctuations must be assessed.
- The technical and environmental improvements generated by the production of biobased PCMs warrant further investigations. Continued efforts will be vital for the large-scale production of biobased PCMs, such as FAAms.
- Chemical, thermal, and visual techniques could be deployed for the characterization of PCMs. These testing techniques show promise at instilling confidence in quality requirements for the production and placement of PCM modified asphalt pavements.
- A proper mixture design procedure that facilitates the incorporation of μPCM in asphalt mixtures has to be established. The framework provided by this study must be refined to modify asphalt mixtures with PCM microparticles.
- This research adds to the modification of asphalt pavements with PCMs and recommends close monitoring of emerging technologies that could help with the temperature management of pavements or any other highway infrastructures asset.

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