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Temperature responses of asphalt mixture physical and finite element models constructed with phase change material

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HIGHLIGHTS

- Outdoor asphalt mixture models constructed with and without PCM are established.
- Finite element model is established, and the regulation ability of PCM is studied.
- Finite element numerical simulation analysis agreed with the laboratory test.

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ABSTRACT

Temperature changes of pavement structure have significant influence on the internal stress, strain, and deformation characteristics of the pavement structure. For example, rutting occurs in high temperature range and pavement cracks when its temperature is low. This yields failure and reduces the service life of the pavement structure. Phase change material, PCM, which is a new type of additive for pavement engineering, has been studied for regulating the working temperature of pavement structure. By storing or releasing thermal energy via phase change process, the PCM is able to maintain the temperature of pavement structure in a relatively narrow range. In the present study, outdoor asphalt mixture model constructed with and without PCM were established. The outdoor model was directly exposed to the environment and the temperature distribution inside the outdoor model was measured by using temperature sensors. The specific heat capacities of asphalt mixture mixed with and without PCM were determined by calorimetric method, which is simple and reliable. Based on the outdoor asphalt mixture model, the corresponding finite element model was established by using ANSYS, and the temperature distribution inside the finite element model was determined according to the measured specific heat capacity, density, thermal conductivity of the asphalt mixture, and the meteorological data which were used for determining the boundary conditions. Comparison between the calculated and actual measured temperature values was made. The results show that the calculated temperature values had good agreement with the measure ones, based on which the accuracy of material parameters and boundary conditions were validated. The results of the present study can lay the foundation for calculating the temperature field of pavement structure constructed with PCM and investigating the application of PCM in road engineering.

1. Introduction

Further researches on road materials and structures go along with these large scales of roadway construction, such as physical and mechanical properties of pavement material, subgrade stability, development and application of new materials, mechanical response of pavement structure under environment and traffic load and so on.

Temperature field of pavement structure is also one research hotspot since precise pavement temperature distribution prediction is helpful for better understanding of the mechanical properties of pavement material. Besides, it is also the precondition for determination of internal stress, strain, and deformation of

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pavement structure and for back calculation of modulus of different layers [1]. Generally, hot-mix asphalt mixture (HMA) is adopted as the surface layer of asphalt pavement, the mechanical performance of which is prone to temperature changes [2]. For instance, asphalt mixture is one of the time and temperature sensitive mixtures, which presents strong elasticity under low temperature and shows viscosity in high temperature. However, the deformation accumulated in high temperature under traffic load cannot totally recover in limited time after unloading [3,4]. The selection of raw materials can be optimized based on the precise temperature distribution prediction in various HMA layers, as well as the calculation of mechanical response under traffic load and environmental factors. Phase Change Material (PCM), which is a new kind of materials available for road engineering, is capable of storing or releasing thermal energy when undergoing phase change. For instance, it absorbs heat when it changes phase from solid to liquid, liquid to gas or solid to gas [5–8]. Due to heat absorption and release, PCM is able to regulate the temperature of constructions. PCM has the ability of providing high-energy storage density and relatively stable phase change temperature. Thus, after mixed into pavement mixtures, PCM is capable of mitigating excessive thermal energy absorption and release to ensure the suitable working temperature of pavement.

Ma and Wang analyzed and evaluated the PCM's temperature regulation effect on asphalt pavement by heat transfer theory and simulation test [9]. Zhang et al. tested and analyzed the energy storage capacities of various PCMs and the effect of these PCMs on asphalt pavement performance [10]. Ma and Li have carried out numerous studies about mixing organic solid–liquid PCM into asphalt mixture, the results showed that organic solid–liquid PCM had positive influence on asphalt pavement temperature in a way, but it had gone against pavement service performance [11]. PCMs that added in asphalt mixture could regulate its working temperature with damping effect, which would enhance the temperature resistance ability of asphalt mixture and improve asphalt mixture's adaptability to the changing environment actively [4]. Therefore, PCM can be used in an asphalt mixture to proactively regulate the temperature of asphalt pavement and improve the temperature performance of pavement.

In this paper, outdoor asphalt mixture model constructed with and without PCM were established. The temperature distribution inside the outdoor model was measured by using temperature sensors. The specific heat capacities of asphalt mixture mixed with and without PCM were determined by calorimetric method. Based on the outdoor asphalt mixture model, the corresponding finite element model was established by using ANSYS, and the temperature distribution inside the finite element model was determined according to the measured specific heat capacity and the meteorological data. Comparison between the calculated and actual measured temperature values was made. The results are useful for validating the accuracy of material parameters and boundary conditions, which can lay the foundation for calculating the temperature field of pavement structure constructed with PCM and investigating the application of PCM in road engineering.

2. Materials

The shape-stabilized PCM is made up of, in certain proportions, PCM and silica as a carrier material [12]. Ethyl Cellulose (EC) works as the membrane material and Ethyl alcohol (CH_3CH_2OH) as an organic solvent for EC to cover the PCM material. Plasticizer was used to improve the flexibility of the membrane material. The initial phase change temperature of PCM used in this study was 5 °C, which is 5 °C PCM for short. The DSC curves of 5 °C PCM are shown in Fig. 1 [12]. During the exothermic process, the initial phase change temperature and final phase change temperature were 2 °C and −31 °C, respectively, and the compensation power peak appeared at −5 °C or so. The exothermic enthalpy was 80.31 J/g.

The selected asphalt was SK 90# A petroleum asphalt, which was further modified by SBS (I-C) modifier (dosage of 4.5%). Dioritic crushed stone and sand were selected as the coarse and fine aggregates respectively. Grinded filler was obtained from limestone, which was dry, clean and without blocking. All technical indices of the above materials were in accordance with the requirements of Technical Specification for Construction of Highway Asphalt Pavement. AC-13 fine-grained asphalt mixture was prepared, the gradation of which was determined based on the upper

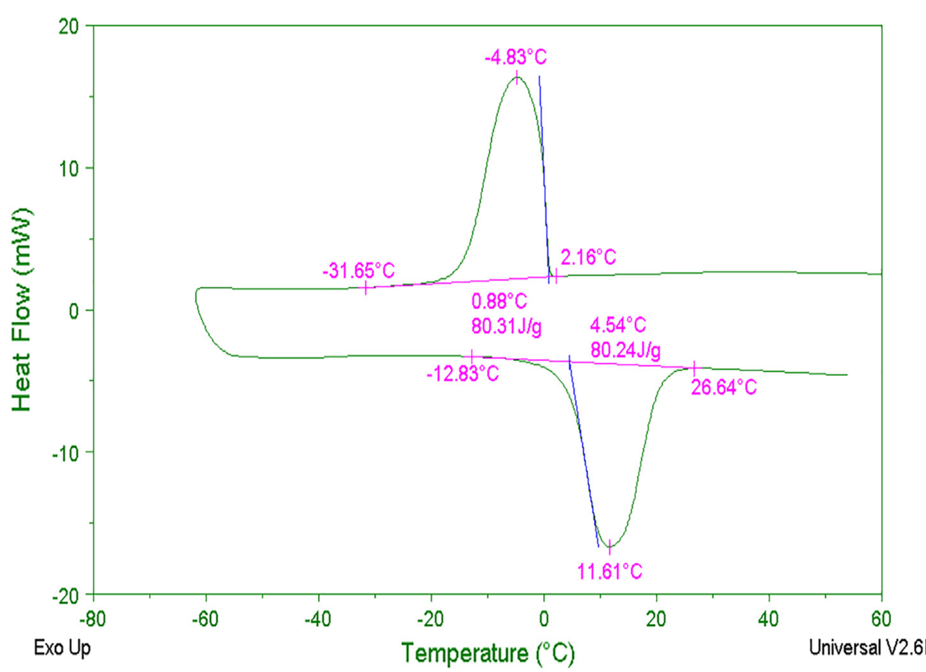

Fig. 1. Differential Scanning Calorimetry (DSC) test results of 5 °C PCM.