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Quick heating method of asphalt pavement in hot in-place recycling

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HIGHLIGHTS

- A novel heat transfer model of asphalt pavement was established.
- A constant temperature heating method was proposed to improve the heating speed.
- Temperature fields of asphalt pavement with various heating methods were discussed.
- Numerical results from the heat model were validated by the experimental results.

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ABSTRACT

To improve the heating rate of asphalt pavement in Hot In-Place Recycling (HIR), a quick heating method was proposed. Considering input heat flux, the thermal capacity and thermal resistance of asphalt pavement materials, a novel heat transfer model was established based on energy conservation law. Time-dependent heating temperature field distributions of various heating methods were calculated with Euler formulation, and numerical simulation results from the heating transfer model were validated by measured results. The results indicate that one-way continuous heating method (OCHM) leads to an obvious temperature gradient along the depth direction at the upper layer of asphalt pavement, and the heating speed is too slow when the temperature at the bottom of the upper layer reaches 100 °C. However, the heating speed is increased using another reciprocating intermittent heating method (RIHM). The surface temperature is changed periodicity, and the operation is too complex to control all the peak temperatures at 180 °C, which leads to the aging or charring of asphalt binder. Finally, a new constant temperature heating method (CTHM) was proposed and the ideal heat flux curve was obtained. With CTHM, the surface temperature of asphalt pavement is always kept 180 °C to ensure the heating quality by adjusting the input heat flux. Especially, the heating speed with CTHM is the fastest compared with OCHM and RIHM.

1. Introduction

Currently, the focus of pavement construction has been changed from new construction to pavement maintenance and rehabilitation [1]. To save materials and reduce the burden on landfill, asphalt recycling has become more important and popular [2]. Amongst various pavement recycling methods, hot in-place recycling (HIR) is considered as a process for recycling 100% of the existing asphalt pavement on site [3,4] and it has been proved to be one of the most viable and economic rehabilitation techniques and widely used for deteriorated asphalt pavement [5,6].

During the HIR of asphalt pavement, heating procedure is the first especially most important, but it is the slowest one due to heat conduction. Only sufficient heat can the asphalt be melt and its viscosity be reduced [7]. Then, minimal aggregate degradation is taken place before complete scarifying and/or milling process [8]. Therefore, the efficiency of HIR is mainly determined by heating speed. In addition, the heating speed of asphalt pavement is closely related to the heating quality.

Guo et al. [4] proposed that all recycled asphalt materials temperature was more than 100 °C to meet the lower limit temperature warranty for broken aggregate in recycled asphalt pavement. However, Huang et al. [9] reported that the surface temperature of asphalt pavement was less than 180 °C to meet the upper limit temperature warranty for use of recycled asphalt. Therefore, taking the heating quality as the premise for an ideal heating method, the bottom temperature of the upper layer of asphalt pavement should

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reach 100 °C at the end of the heating procedure, and the highest surface temperature of asphalt pavement should be less than 180 °C all the time.

It has been previously reported that the heating speed is mainly influenced by the energy source types and the heating methods. At present, a large number of studies have been reported on performance of the energy sources in HIR. Main energy sources used in HIR are flame, hot-air, infrared, microwave radiation and their combination. Flame heating is a continuous heating method. The heat is conducted directly to asphalt pavement through the burning flame. The surface temperature sharply increases up to more than 180 °C, which not only leads to overheating, aging and carbonization of asphalt binder, but also releases toxic smokes [10,11]. Hot-air heating possesses many advantages in heating uniformity and small temperature gradient. However, the heating rate is low and the time taken in HIR is long [12,13]. Infrared heating has the merits of rapid heating and deep penetration [14], but the temperature gradient is large along the depth direction and the surface asphalt can be charring, which leads to smoke particles [14,15]. Microwave heating is well known for its uniformity, non-pollution and deep penetration over 10 cm [15,16], which allows to reduce heating time and save energy [17–19]. Although the operational and environmental advantages of microwave technology are well known in the field of highway engineering [20–22], real commercial applications have not been developed yet [23]. However, the heating methods for various energy source types can easily be influenced by wind speed, light, environmental temperature, etc. [24]. Therefore, it is difficult to exactly know the internal temperature field and heating effects of asphalt pavement during HIR, which brings adverse effects on heating speed and the construction quality of recycled asphalt pavement [25].

With the advance in computer technology and the development of computational methods, quick heating methods of asphalt pavement are attracting more attention of researchers. Huang et al. [24] proposed that one-way continuous heating method (OCHM) caused an obvious temperature hysteresis at the lower part of heated pavement layer. Li et al. [13] reported that the surface temperature with OCHM reached 455.9 °C for 9 min, which easily leaded to uneven heating effects of asphalt pavement and severe aging or charring of surface asphalt binder. However, reciprocating intermittent heating method (RIHM) can acquire better heating effect [9,26]. Huang et al. [9] further investigated that the surface temperature was lower with RIHM, which facilitated to reduce the aging or charring of surface asphalt binder and improve the construction quality and pavement performance of recycled pavement. Gu et al. [27] presented a multi-stage heating technology, and only 40% of time and 70% of energy were needed compared with the single-stage technology. Dong et al. [28] established a model to discuss the relationship between temperature rising characteristics and heat input during HIR, and found that the heating power should be gradually reduced along the heating process to improve heating speed. However, the heating effects of excessively aged of upper pavement layer are not fully satisfactory using existing heating methods. Furthermore, the heating speed is still not fast enough. Therefore, it is necessary to further develop a better heating method.

In this study, we established a new heat transfer model based on energy conservation law to analyze the temperature field distribution. Then, the temperature field distributions with various heating methods were discussed using the new heat transfer model to simulate the heating process during HIR of asphalt pavement. Further, numerical simulation results were compared with the experimental results to further discuss the model reliability for analyzing the heating effects during HIR. A new promising heating method was developed to predict the quicker heating speed and keep the surface temperature of asphalt pavement within the upper limit nearly all the time, improving the construction quality of recycled asphalt pavement.

2. Heat transfer model and temperature analysis

2.1. Structure of asphalt pavement

A typical asphalt pavement structure [24] is shown in Fig. 1. There are three layers: the upper layer consists of SMA-13 with the thickness of 4 cm (the maximum aggregate diameter is less than 13 mm), the middle layer consists of AC-20 with the thickness of 6 cm (the maximum aggregate diameter is less than 20 mm), and the lower layer consists of AC-25 with the thickness of 8 cm (the maximum aggregate diameter is less than 25 mm).

Below the lower layer, there are still the cement stabilized layer and the ground layer. In HIR, the whole upper layer will be usually recycled, and the recycled depth is 4 cm [28].

2.2. Feature of asphalt pavement heating

Before milled, the asphalt pavement is often referred to as a whole, and the heat flux output from preheater can only input to the upper surface, as shown in Fig. 2. Although many aggregates are random distributed in the asphalt pavement, the changes of temperature field among aggregate particles in asphalt pavement are neglected since the max aggregate diameter is very small (Fig. 1) as compared with the large dimension of preheater (e.g. Length × Width = 4500 mm × 4000 mm). Therefore, materials parameters of asphalt mixture can be got in test section with the average method [24]. Moreover, the asphalt layers can still be assumed as a homogeneous medium. Except for very narrow area near the edge of the preheater, heat transfer module in the most areas under the preheater can be suited to heat transfer law of one-dimension (1D).

2.3. Heat transfer model

Many numerical simulation methods have been used in establishing the 1D heat transfer model of asphalt pavement and calculating the heating temperature field, such as the finite control volume method [29], the finite element (FE) model in software FEMMASSE [30], the FE model in software COMSOL [31], the FE model in software ABAQUS [26], the FE method in MATLAB [32], the Laplace transform and numerical inverse Laplace transform [33], the discrete element method [9], the separation of variables and Duhamel's principle [34], and so on. All these methods are good at solving the temperature field of asphalt pavement. However, differences only occur in the accuracy. A new method is proposed here to deal with the heating procedure of asphalt pavement.

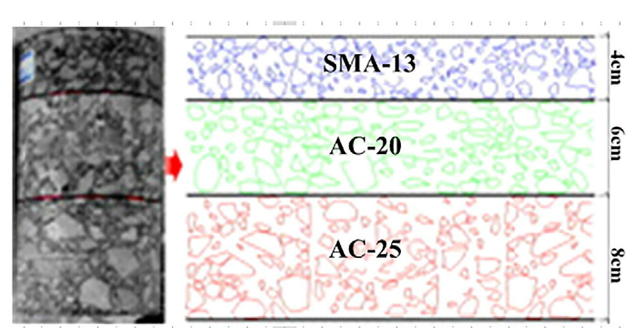

Fig. 1. Asphalt pavement structure and aggregate particle distribution.