Energy and Buildings 85 (2014) 23–31

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Highly oriented heat-induced structure of asphalt pavement for reducing pavement temperature

Du Yinfei, Shi Qin, Wang Shengyue [*]

School of Transportation, Southeast University, Nanjing 210096, PR China

ARTICLE INFO

Article history:
Received 11 September 2014
Accepted 16 September 2014
Available online 28 September 2014

Keywords:
Heat-induced structure
Gradient thermal conductivity
Pavement temperature
Rutting

ABSTRACT

In order to reduce the solar absorption of pavement and inhibit the downward heat conduction rate inside, two highly oriented heat-induced structures were designed, one named G-OHIS (gradient thermal conductivity) and the other named G + R-OHIS (the combination of gradient thermal conductivity and heat reflective structure). Compared with the contrast structure, the total heat absorption was decreased by 12.7% for the G-OHIS and 35.0% for the G + R-OHIS. Meanwhile, the downward heat conduction rates in the middle and bottom layers of the designed structures were also reduced. The coupling effect of less heat absorption and lower downward heat conduction rate decreased the heat accumulation within the pavement as much as 14.2% for the G-OHIS and 34.0% for the G + R-OHIS. The maximum temperature reduction was 2.47 °C for the G-OHIS and 7.07 °C for the G + R-OHIS. The indoor irradiation test showed a good consistency with the simulation results. Rutting simulation results showed that the maximum rutting depth was reduced by 44.3% for the G-OHIS and 65.0% for the G + R-OHIS. The highly oriented heat-induced structure is expected to be used to reduce pavement temperature and alleviate rutting in summer.

1. Introduction

The high pavement temperature, which is generally caused by its high solar absorption, can easily generate rutting disease [1]. Rutting may cause hydroplaning and nonuniform tire-pavement contact stresses [2], which will further accelerate pavement damages and cause traffic accidents [3]. In urban areas, high pavement temperature increases long-wave radiation and convective heat to the atmosphere, intensifying urban heat island effect [4]. The urban heat island requires large expense of energy [5] and accelerates near-surface generation of smog or ozone, seriously endangering people's health [6]. In permafrost regions, the high heat absorption effect of asphalt pavement can also lead to heat accumulation in subgrade, which subsequently causes thawing settlement and rising artificial permafrost table [7,8]. In response of these problems there are some specific measures, including the use of high modulus asphalt mixtures to reduce rutting [9], increasing tree planting to ease the urban heat island [10], and the use of inclined open-ended channel to protect permafrost subgrade [11].

In order to cool the pavement in summer, some technologies, including cool coating [12,13], permeable pavement [14,15] and energy collector of asphalt pavement [16,17], have been employed. As the coating is applied to the pavement surface, the coupling effect of vehicle's wear and tear and the natural environment easily reduces its reflectivity [18]; the high void content of permeable pavement makes it very susceptible to rutting [19]; energy collector changes the stress distribution in the pavement [20], which is conducive to reducing rutting.

For reducing pavement temperature, we designed two gradient thermally conductive structures to induce the heat conduction in asphalt pavement layers [21,22]. The heat-induced structure [21] was proved to be able to reduce the downward heat transfer rate. But, when using high thermal conductivity material in top layer, the structure was found to allow the radiant heat entering the pavement more easily. For decreasing the heat absorption of top layer in the daytime and reducing the heat accumulation in middle and bottom layers, two highly oriented heat-induced structures were designed in this paper, named G-OHIS (gradient thermal conductivity structure) and the other named G + R-OHIS (the combination of gradient thermal conductivity and heat reflective structure). To verity the simulation result, the temperature field of the G-OHIS was measured. Besides this, a numerical simulation method was used to study the impact of the temperature reduction of the new designed structures on rutting.

---

[*] Corresponding author. Tel.: +86 025 83790551.
E-mail address: sywang@seu.edu.cn (W. Shengyue).

http://dx.doi.org/10.1016/j.enbuild.2014.09.035
0378-7788/

Table 1
Aggregate gradation for Sup13 mixture.

Sieve sizes (mm)	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing (% by weight)	100	94.6	69.0	43.8	29.7	20.3	14.3	9.1	7.5	6.0

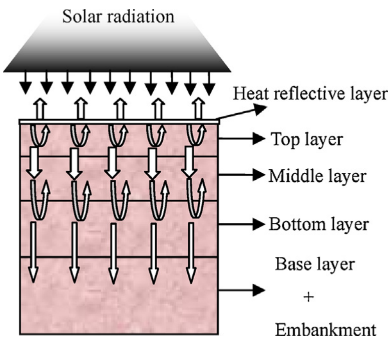

Fig. 1. Design schematic diagram of the highly oriented heat-induced structure.

Table 2
Designed gradient thermally conductive structures.

Structure number	Top layer	Middle layer	Bottom layer
CS	–	–	–
A1	+15% Graphite	–	–
A2	+10% Graphite	–	–
A3	+5% Graphite	–	–
A4	+15% Floating bead	–	–
A5	10% Floating bead	–	–
A6	5% Floating bead	–	–
A7	To be determined	5% Floating bead	10% Floating bead
A8	To be determined	5% Floating bead	15% Floating bead
A9	To be determined	10% Floating bead	15% Floating bead

2. Design principle

Asphalt pavement absorbs up to 90% of solar radiation [23]. For a contrast structure (CS), the thermal parameters of its three layers are almost equal. Heat can smoothly conduct in the pavement, which results in pavement temperature rise and permafrost subgrade's degradation.

To decrease the heat accumulation, in this paper three heat-induced routes were designed (Fig. 1): (1) to improve the reflection on solar radiation, we designed a heat reflective layer on the pavement surface; (2) to prevent heat entering the pavement as much as possible, we designed a heat resistance layer in the top layer by decreasing its thermal conductivity; (3) to inhibit the heat conduction in the middle and bottom layers and form a backward heat flow, we designed a two-layer gradient thermally conductive structure by changing the thermal conductivities of the middle and bottom layers. Through the combination of the three technologies, heat was blocked outside the pavement, and also was prevented from conducting to lower layers. The coupling effect of the heat absorption reduction and the backward heat flow within the pavement can decrease inner heat accumulation and reduce pavement temperature.

3. Materials and method

3.1. Material

According to the literature [24], the thermal properties of asphalt mixture are mainly influenced by its void content. For Superpave asphalt mixture, the designed void percentage is 4% [25]. So only Sup13 mixture was used to design heat induced structures. Here, SBS modified asphalt was used. The asphalt content was 4.9%. The coarse aggregate was basalt and the mineral filler was made of limestone. The gradation for Sup13 used is shown in Table 1.

In this paper, the thermal properties of mixture are changed by adding graphite or floating bead. In consideration of the impacts of powder on mixture's volume indexes and performances, the maximum dosages of floating bead and graphite were both 15 vol% of asphalt.

3.2. Determination method of gradient thermally conductive structure

As the top layer is in direct contact with the atmosphere, the thermal parameters of the top layer are mainly related to the amount of heat entering the pavement. To decrease it, different percentages of graphite or floating bead were added into the top layer mixture, while remaining the thermal parameters of the middle and bottom layers unchanged. The powder's type and dosage were determined by the heat flux on the upper surface of the middle layer.

In order to reduce the downward heat conduction rates in the middle and bottom layers, the thermal conductivities of the two layers needed to be decreased. Meanwhile, the downward heat conduction rates could be further reduced by the structure reported in the literature [21]. Three structures, A7–A9 (Table 2), were therefore designed in order to form a thermal gradient in the middle and bottom layers.

3.3. Model establishment

A 2-D model was established using the finite element software ABAQUS. Pavement layers in this model are shown in Fig. 2. The left, right and bottom boundaries were all thermally insulated. The upper boundary was subjected to solar radiation, heat convection and effective radiation.

Parameters being used for temperature field calculation are shown in Table 3. Among them, the calculation equations of solar

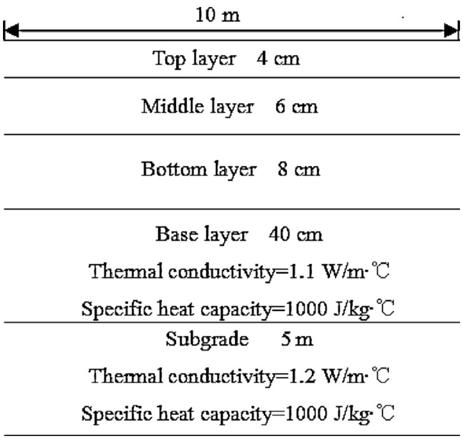

Fig. 2. Layout of pavement layers.