Construction and Building Materials 172 (2018) 422–432

Contents lists available at ScienceDirect

Construction and Building Materials

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

Heat conduction effect of steel bridge deck with conductive gussasphalt concrete pavement

Chaohui Wang [a,*], Qian Chen [a], Hao Fu [a], Jiao Chen [b]

[a] School of Highway, Chang'an University, Xi'an, Shaanxi 710064, China
[b] Zhongjiaotongli Construction Co., Ltd, Xi'an, Shaanxi 710065, China

HIGHLIGHTS

- The heat conduction effect of conductive gussasphalt concrete was evaluated.
- Estimation equations of heat conduction effect were derived and verified.
- The time required to maintain the surface temperature above 0 °C was determined.

ARTICLE INFO

Article history:
Received 18 December 2017
Received in revised form 4 March 2018
Accepted 21 March 2018

Keywords:
Road engineering
Conductive gussasphalt concrete
Estimation of heat conduction effect
Deicing and snow melting

ABSTRACT

The snow- and ice-melting effect and energy usage of steel bridge deck pavement are affected by the heat-transfer rate and temperature change in the middle of the combination structure when using conductive gussasphalt concrete (CGA). To determine the heat conduction effect and the snow melting time of conductive gussasphalt concrete pavement, the heat conduction estimation method and a theoretical equation of the CGA combination structure are derived. A CGA combination structure with spreading carbon fiber in the middle of the CGA layer is prepared. The accuracy of the theoretical equation is checked and verified. Then, the heat conduction effect and the time required to reach and maintain the temperature above 0 °C of different CGA combination structures are evaluated. According to the estimation results and weather conditions, the power will be turned on or shut off ahead of time to improve the deicing efficiency and save energy. The results show that the theoretically obtained estimation values are close to the test values. The theoretical equation can estimate the heat conduction effect of the CGA combination structure. With a decrease in the environmental temperature, the time required for the surface temperature of different CGA combination structures to exceed 0 °C gradually increases, and the time required for the surface temperature to remain above 0 °C decreases. The surface temperatures of the CGA combination structure based on schemes 3 and 4 can be increased to above 0 °C in a short time and remain above 0 °C for a long time.

1. Introduction

Conductive gussasphalt concrete (CGA) is prepared for steel bridge deck pavements to achieve the effect of deicing and snow melting. CGA can protect electrodes from being destroyed during the concrete rolling process, and it can prevent short circuits and other hidden dangers caused by water-electricity contact during deicing and snow melting. However, the deicing and snow-melting technology of conductive asphalt concrete (CA) has not been studied or applied to steel bridge deck pavements using gussasphalt concrete (GA).

Gussasphalt concrete has excellent impermeability, aging resistance and fatigue resistance. It can match well with the steel bridge design system. In recent years, it has been one of the mainstream pavement materials for steel deck pavement and applied widely in long-span steel deck pavement. It originated from Europe and was first used to build a waterproof layer in Germany in 1917 [1,2]. Then, it was successfully applied in bridge deck pavements, municipal engineering and other fields [3], where it demonstrated excellent performance [4,5]. Japan introduced Germany gussasphalt concrete in 1956, and its corresponding technology and material combination were improved [6]. Then, it was applied in the construction of long-span steel bridges and exhibited good performance [7]. Compared with other countries, the study and application of gussasphalt concrete began later in China [8]. Initially,

* Corresponding author.
E-mail address: wchh0205@chd.edu.cn (C. Wang).

https://doi.org/10.1016/j.conbuildmat.2018.03.161
0950-0618/

cracking, bulging, rutting and other issues occurred to different degrees when gussasphalt concrete was introduced into China [9]. In recent years, a large number of studies and applications of the long-span steel bridge pavements had been carried out [10–15]. And a set of bridge deck pavement technology using gussasphalt concrete was formed. Based on the related technical specifications of Germany, Japan and other countries, the *Design and Construction Technology Guidelines of Highway Steel-box Beam Bridge Pavement (China)* was formulated in 2006, and the performance control indices and requirements of gussasphalt concrete were specified.

Conductive asphalt concrete is prepared by adding conductive materials with a suitable proportion into ordinary asphalt concrete. It can timely and efficiently melt snow and ice on bridge decks to ensure unblocked roads and driving safety [16]. Furthermore, it can be used to prevent traffic jams and accidents to reduce the loss of national economy caused by ice and snow disasters [17]. Qi et al. put carbon fiber and glass fiber grating 5 cm below the surface of asphalt concrete pavement, which increased the road surface temperature to above 0 °C in a short time [18]. Wang et al. added a proper amount of steel fiber into conductive asphalt concrete to improve the high- and low-temperature performance compared with ordinary concrete [19]. The heating process of conductive asphalt concrete was simulated by Hai et al. The results showed that graphite and carbon fiber could improve the snow-melting effect of asphalt mixtures and that their combination is more effective than is that of graphite or carbon fiber alone [20,21]. Pan et al. systematically studied the effect of aggregate and conductive filler on the heat-transfer rate of conductive asphalt concrete pavements [22].

Overall, the technologies of gussasphalt concrete and conductive asphalt concrete have been explored worldwide, and a series of results has been obtained, but the study and application of the bridge deck pavement technology using conductive gussasphalt concrete have not been considered.

In this study, the heat conduction estimation method and its theoretical equation of the CGA combination structure are derived. Various CGA combination structures are prepared. The accuracy of the theoretical equation is verified. Then, the heat conduction effects of different CGA combination structures are evaluated. The time required to reach and maintain the temperature above 0 °C is estimated. According to the estimation results and weather conditions, the power is turned on or off ahead of time to improve the deicing efficiency and save energy. This study lays a foundation for the application of steel deck pavement using conductive gussasphalt concrete to deice and melt snow.

2. Test materials and methods

2.1. Raw materials

The CGA combination structure of steel deck pavement includes two layers: GCA (35 mm) as the upper layer, and SMA (40 mm) as the lower layer. The major components of CGA are the compound modified asphalt (SBS:TLA:Sasobit = 75:25:1.5), basalt, limestone, and carbon fibers (0.8%). The optimal asphalt content of CGA is 9.75%, according to the Marshall test. The compound modified asphalt was prepared by stirring for 30 min at 170 °C and 3000 r/min rotating speed. The major components of SMA are SBS (I-D) modified asphalt, basalt, limestone, and lignin fibers (0.3%). The optimal asphalt content of SMA is 6.2% according to Marshall test.

The raw materials and indices of the basic performance in this study are listed in Table 1. The compound gradations of CGA and SMA are shown in Table 2. According to the *Design of Highway Steel-box Beam Bridge Pavement and Construction Technology Guidelines (China)*, the CGA specimens were prepared for the performance testing using the mixing technology and materials. It is shown in Fig. 1.

2.2. Preparation of CGA combination structure

(1) Production of CGA layer
After the mixing process, conductive asphalt concrete was poured into a rutting plate molding to 0.5 mm in height of the molding, and two parallel L aluminum electrodes were placed onto the concrete surface. The height of the aluminum electrode was 2.5 mm, and the distances between the two aluminum electrodes and edge of the rutting plate were both 20 mm. The wires in the electrode side were connected to the power supply, and the final height of the concrete was 35 mm. When carbon fiber was spread in the middle position of the subsurface of the conductive GA concrete, the pouring height of the concrete was 17 mm. The height was 35 mm when the spraying material was 170 g/m thin carbon fiber.

(2) Preparation of the SMA layer
The 5–10-mm premixed macadam (5–8 kg/m^2) was spread after the CGA layer was completed and molded. Treatment was performed between the layers. The SMA concrete was mixed, and the rolling was compacted after the tack coat was spread (SBR-modified emulsified asphalt: 0.3–0.5 kg/m^2).

(3) Embedding temperature sensor
When the CGA combination structure was completed and cooled to room temperature, some holes were drilled in the middle of the CGA layer using an electric drill. Temperature sensors were embedded in the holes to prevent the embedded temperature probe from being destroyed during the

Table 1
Materials and their basic performance indices.

Materials	Basic performance indices
SBS (I-D)	Penetration 49.7 (0.1 mm, 25 °C, 100 g and 5 s), ductility 27 cm (5°C) , softing point 70.6 °C
TLA	Penetration 4.0 (0.1 mm, 25 °C, 100 g and 5 s), softening point 93.1 °C, ash content 36.7%, relative density 1.372 g/cm^3, residual penetration ratio 51.2% (25 °C)
Sasobit	White spherical particles, melting point 103 °C, there were 40–115 carbon atoms in main chain molecules, which can reduce mixing temperature of asphalt concrete about 15–20 °C
The compound modified asphalt	Penetration 21.6 (0.1 mm, 25 °C, 100 g and 5 s), ductility 11.2 cm (10 °C), softening point 90.5 °C, residual penetration ratio after aging 68.9% (25 °C), change of softening point after aging 1.5 °C
Carbon fiber	Tensile strength 1.68 GPa, tensile modulus 753 GPa, fiber diameter 10 μm, length 6 mm, conductivity 5×10^3 S/m
Aggregate	Coarse aggregate density 2.86 g/cm^3, content of flat and elongated particle 3.3%, maximum particle size 13.2 mm, electrical resistivity is more than 10^{12} Ωm, fine aggregate density 2.876 g/cm^3, sturdiness (>0.3 mm) content 0.31%, sand equivalent 93.6%
Lignin fiber	Length ≤ 5 mm, oil absorption 6.6, water content 2.4, asphalt adsorption 5.8 g/g, bulk density 28 ~ 29 g/L
Functional fine aggregate	Apparent relative density 5.243 g/cm^3, methylene blue number 0.36 g/kg, angularity 31.5 s

Table 2
Compound gradation of asphalt concrete (quantity percentage of passing).

Gradation type	Sieve mesh (mm)									
	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
CGA-10	100	100	97.4	71.9	54.0	45.6	39.3	33.0	29.7	25.9
SMA-13	100	96.8	70.9	27.9	21.6	18	14.5	12.8	11.4	10.2