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Effect mechanism of mixing on improving conductivity of asphalt solar collector

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ABSTRACT

This paper investigates the influence of different mixing parameters of 1 forced mixing on the conductivity of asphalt solar collector (ASC). Graphite powder and carbon fibers were used to improve the conductivity of asphalt concrete. The conductivity of ASC was measured with the same mix gradation, mixing procedure but different mixing parameters. The rational vibrating mixing parameters are obtained according to orthogonal experiments of the conductivity. A laboratory test of volume index and conductivity was performed after determining the rational mixing parameters. The effects of common forced mixing the on microstructure of ASC were investigated using scanning electron microscopy (SEM) and computed tomography (CT). The results obtained show that the mixing parameters have a major impact on the conductivity of asphalt concrete, among which the temperature have the strongest influence, while the revolutionary speed has less influence. The rational mixing parameters include: Bitumen temperature T_1 160 °C, aggregate temperature T_2 180 °C, mixing time t 90 s and mixing revolution speed v 45 r/min. ASC can obtain good conductivity and volume index with rational mixing parameters. The resistivity drops from insulation to 39.8 ohm m and the thermal conductivity increases from 1.531 W/m K to 2.120 W/m K. The microstructure of ASC showed that the conductive fillers have uniform distributions in the sample. Conductive particles and carbon fibers promote the formation of conductive networks, because fibers may bridge up several isolated conductive particles.

1. Introduction

Snow and ice on the pavement surface will seriously affect the traffic smooth and driving safety. It is of great importance that how to keep highway and runway from the influence of snow and ice. It is a concerned issue to improve the transportation safety during the periods of snow, sleet, and freezing rain. Generally, conventional snow melting methods have some certain disadvantages, such as low efficiency, corrosion and soil pollution [1–3]. These problems have drawn much attention of the International Energy Agency (IEA) and the World Health Organization (WHO) [4,5]. Hence, it is very meaningful to exploit some eco-friendly method to keep the pavement clear of snow and ice. To avoid these problems, using a heating system to melt snow has been proposed in the past decades. Recent researches indicated that asphalt concrete is connected to the power and the heat generated can transfer to the surface during the snow event [6,7]. Popular snow melting systems use electrically heating wire embedded in the pavement. However, snow melting systems consume much bigger amount of energy than most people think due to a large amount of energy loss to the ambient. For example, in the application experiences of West Virginia and Oregon, the electric energy consumption for snow-melting covered from 500 to 750 W/m^2 [8].

Asphalt solar collector (ASC) is one kind of conductive asphalt concrete (CSC). A fluid is circulated through a series of pipe circuits lay below a pavement surface. The irradiation from the sun and atmosphere is absorbed by ASC and then the fluid through the pipes brings the solar energy out and stored in the ground over summer time. Hence, the energy is used for the heating of adjacent buildings as well as for keeping the pavement ice-free directly in the winter [9]. However, asphalt concrete is a typical kind of insulation material and has low heat transfer efficiency [10–14]. Obviously, the higher the heating thermal efficiency, the less the energy consumed is. The conductivity of asphalt concrete is closely related to the bitumen binder, the air voids, the conductive materials and the aggregate.

In order to improve the conductivity, conductive materials are added to asphalt concrete. Thus, the conductivity of asphalt concrete is influenced by its raw materials, gradation and other factors

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Table 1
Mix proportion of ASC.

Sieve mm	16	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC-13 Passing %	100.0	95.4	79.3	57.6	36.3	24.0	15.7	11.3	8.9	7.5

such as mixing and compaction. However, researchers always neglected the mixing parameters for conductive researches. Hence, this paper focused on the influence of different mixing parameters of forced mixing on the conductivity of asphalt concrete, the mechanism of mixing on improving conductivity of ASC was explored through resistivity, thermal conductivity, volume index, computed tomography (CT) and Scanning electron microscopy (SEM).

2. Materials and methods

2.1. Raw materials

ASC is composed of bitumen, aggregate and conductive fillers such as graphite, carbon fibers. Graphite was supplied from Qingdao (China) with particle size of 150 μm, carbon content 98.9%, bulk density 0.96 g/cm^3, thermal conductivity 110 W/m K and electrical resistivity 10^{-6} ohm m. Carbon fiber is supplied from Wuhan (China) with the tensile strength 1.68 GPa, the tensile modulus 752 GPa, bulk density 0.42 g/cm^3, Thermal conductivity 20 W/m K and electrical resistivity 10^{-5} ohm m.

A SBS (styrene–butadiene–styrene) modified asphalt was provided by Panjin (China) with a penetration of 71.8 (0.1 mm at 25 °C, 100 g and 5 s), ductility of 47.6 cm (15 °C) and the softening point of 48.9 °C. Basalt with particle size below 16 mm was supplied from Jingshan (China). Limestone powder with size smaller than 0.075 mm was used as the mineral filler.

2.2. Methods

The test measured the conductivity of ASC under the condition of equivalent mix proportion, mixing procedure but with different mixing parameters and time.

The AC-13 mixture was used. Graphite content was 2 wt% of mineral weight. Carbon fiber content was 3 wt‰ of mixture weight. The mix proportion was shown in Table 1. The samples were prepared by Marshall test of ASTM D-1559. Marshall tests were carried out to find the optimum asphalt binder content of the mixture, which was 5.6% by weight of the mineral weight.

The test mixer made in Jiangsu, China. The main performance parameters of the mixer can be seen in Table 2. The mixing procedure was shown in Fig. 1: first, add aggregate at temperature T_2 and mixed; second, add asphalt at temperature T_1 and mixed; last, added mineral powder and conductive materials and mixed. In this study, all the asphalt mixture samples used for the following research were prepared by standard Marshall method.

Table 2
Main performance parameters of mixer.

Performance parameters	Value	Remarks
Nominal volume/L	20	–
Number of mixing blades/pc.	2	–
Temperature/°C	180	room temperature ~ 220, Adjustable
Mixing Time/s	90	0–270, Adjustable
Autorotation speed/r/min	80	–
Revolution speed/r/min	45	40–50, Adjustable

The conductivity of asphalt mixture is measured through Keithley2700 data collector (resistivity, Keithley Instrument Inc, USA) and Hot Disk (Analysing Thermal Properties, Hot Disk Inc. Sweden). Then all the data were calculated the average value $\bar{f}$ and standard deviation σ by Eqs. (1) and (2).

$$\bar{f} = \frac{1}{n}\sum_{i=1}^{n} f_i \qquad (1)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(f_i - \bar{f}\right)^2}{n-1}} \qquad (2)$$

where, n is the number of the samples; f_i is the value of i-th sample, ohm m or W/m K. The higher the f_i of thermal conductivity, the lower the f_i of resistivity and the σ, the better of the conductivity is.

A Keithley 2700 digital multimeter was employed to measure the electrical resistance. The electrical contact areas on the specimens were first painted with graphite powders to fill the voids at the surface. A stainless steel cylinder (Φ150 mm × 20 mm) was pressed on the top of the graphite powders to ensure the conductivity of the contact areas.

The resistivity was calculated as follows (Eq. (3)):

$$\rho = \frac{RS}{H} \qquad (3)$$

where, ρ = the resistivity of ASC; R = the resistance of ASC; S = the cross section area of the specimen; H = the height of the specimen.

The thermal properties were measured based on the transient plane heat source (TPS) hot disk method (Gustafsson, 1991) following the standard ISO 22007-2: 2008(E) [15,16]. TPS 2500 S Thermal Conductivity System associated with the software Hot Disk Thermal Constant Analyser V.5.9.5 was employed (solids, liquids, powders and paste). TPS, utilizing a plane sensor and a special mathematical model describing the heat conductivity, combined with electronics, enables the method to be used to measure the thermal transport properties. The TPS typically employs two samples halves, in-between which the sensor (design number: C5501) is sandwiched as shown in Fig. 2. The relaxation time of the probe is less than 10 ms, and the required time to reach a constant temperature difference is kept as 15 min.

Asphalt concrete is not a homogeneous medium in micro-scale, such as aggregate, mineral powder, bitumen and conductive materials. But in macro-scale, these materials are distributed homogeneously, randomly and non-directionaly in the ASC. Therefore, it is assumed that asphalt concrete is a continuous and isotropic material. The density of ASC is about 2.432 g/cm^3 and the specific heat capacity is 1.63 kJ/kg K, which allows the measurement of the conductivity of the specimen by TPS method.

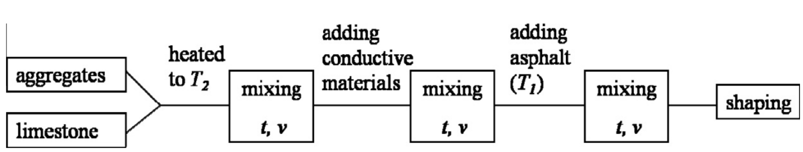

Fig. 1. Experimental procedure of conductive asphalt concrete.