The Influence of Carbon Fiber Heating Wire Spacing on Concrete Pavement Temperature

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Abstract. In this paper, the method of melting snow with carbon fiber heating wire (CFHW) buried in concrete pavement is presented to avoid the adverse effects of snow-melting chemicals. The pavement temperature, heating rate and temperature difference are analyzed. It is shown that, with an input power of 500W/m^2, the average temperature on pavement surface with 10cm CFHW spacing is higher than that of 15cm CFHW spacing when the air temperature is -5°C and the wind speed is 1.0m/s. The temperature different on pavement surface with 10cm CFHW spacing can meet the requirement of the snow-melting temperature uniformity.

Introduction

Snow, ice and slush on concrete pavement significantly impact aircraft landing and vehicle running in winter because snow, ice and slush reduce the friction coefficient between the tire and the pavement surface. The traditional method of pavement snow removal with snow-melting chemicals or machine induces traffic delay and needs a large number of manpower, chemicals and machine, which is labor intensive and time-consuming.

It is necessary to conduct timely and high-efficient removal of snow and avoid the adverse effects of snow-melting chemicals on concrete pavement. Some other pavement snow-melting methods have been researched, such as hydronic heating system[1-4], electrically conductive concrete[5-7] and CFHW[8-11].

The current research of melting snow mainly focuses on CFHW. Zhao et al. conducted a systematic study on bridge deck and pavement snow-melting by embedding CFHW in concrete[9, 10]. In different climatic conditions, the results showed that the method can meet the requirement of bridge deck and pavement snow-melting with different input powers. The CFHW spacing is an important factor of snow-melting project. However, the snow-melting method with CFHW requires further study on the application of pavement. Therefore, the influence of CFHW spacing on concrete pavement temperature is studied.

Experiment

Materials

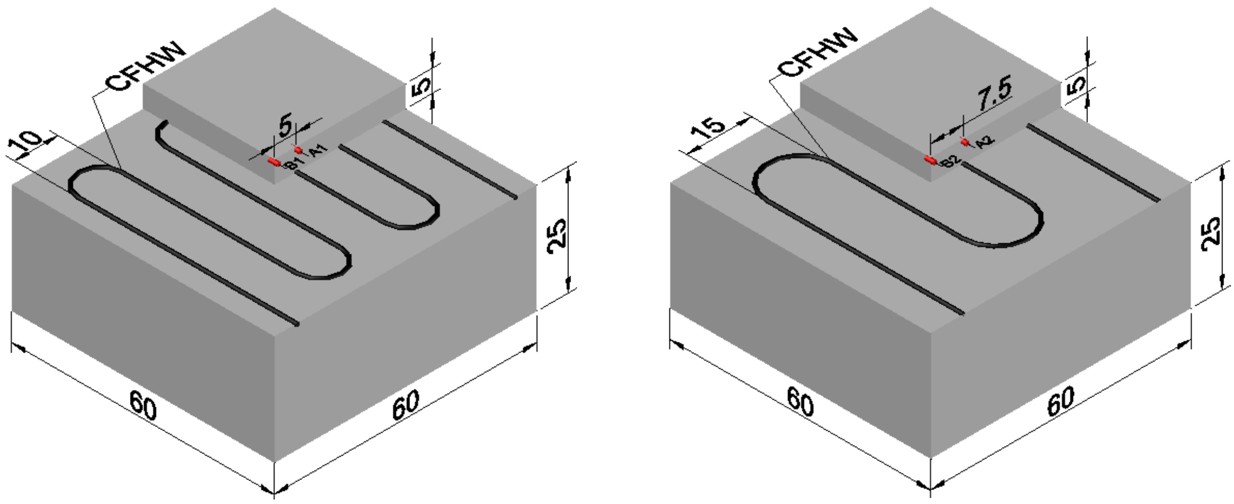
The raw materials include cement, fine aggregate, coarse aggregate, water and CFHW. The mix proportions of concrete are given in Table 1. The cement is Ordinary Portland Cement 42.5. The fine aggregate is natural sand with fineness modulus of 2.85. The coarse aggregate gradation is the gravel of 5~40mm. The mixed water is tap water. The solid content of water reducer is 6.0%. The ratio of water to cement is 0.42. The heating material is 24k CFHW, the resistance of which is 18.5Ω/m.

Tab.1 Mix Proportions of Concrete

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)		Water (kg/m^3)	Water reducer (kg/m^3)
		5-20 mm	20-40 mm		
325	579.9	567.9	851.8	136.5	6.5

Experiment Program

The mixture is stirred for 90s according to GB/T 20473-2009. The specimens are prepared in the mould of 60 cm×60 cm×30 cm. The 24k CFHW is located 5 cm below the pavement surface, which is bundled in steel mesh like snake. As shown in Fig.1(a), the A1 temperature sensor that is in the pavement surface is directly above the CFHW, and the CFHW spacing is 10 cm; the B1 temperature sensor is in the center of pavement surface. As shown in Fig.1(b), the A2 temperature sensor that is in the pavement surface is directly above the CFHW, and the CFHW spacing is 15cm; the B2 temperature sensor is in the center of pavement surface. The cement concrete pavement is cured for 28 days at 20°C and 60% ±5% relative humidity. The 5cm polystyrene insulation board is pasted at the bottom of and around pavement. The test carried out in the freezer that can be used to simulate outdoor weather in winter.



(a) 10cm CFHW Spacing (b) 15cm CFHW Spacing

Fig.1 Concrete Pavement Model

Results and Discussion

In the experiment, the input power was controlled by an AC booster. The heat flux of concrete pavement was 500W/m^2. The average air temperature was -5°C; the wind speed was 1.0m/s; the relative humidity was 90%; the solar radiation intensity was 0W/m^2. The pavements were placed to constant temperature in the freezer.

Pavement Temperature and Heating Rate

The concrete pavement surface temperature is measured against time as shown in Fig.2. The pavement heating experiment is stopped after 90 minutes heating, and then the pavement temperature data are collected to 180min. All pavement surface temperature curves are very smooth because of no radiation and stable convection. In the process of heating, the A1 and B1 point surface temperatures are in the range of A2 and B2 point surface temperatures. The A1 and B1 point temperatures rise above 0°C in 50 minutes; the A2 and B2 point temperatures rise above 0°C in 60 minutes. It is found that the pavement surface temperature of CFHW spacing of 10cm is in the range of that of 15cm for the same heat flux. The B1 and B2 point temperatures still rise within a short time when the electric power is turned off. The pavement surface temperature of 10cm and 15cm CFHW spacing begin to become consistent after stopping heating. The pavement surface temperatures decrease to 0°C at 180 minutes. The pavement heating rate variation with time is shown in Fig.3. The pavement heating rates of 10 cm and 15cm CFHW spacing are almost the same except that the time is 0~20 and 90~120 minutes. The pavement heating rate decreases steadily during 20~90 minutes. The pavement heating rate increases slowly during 120~180 minutes.

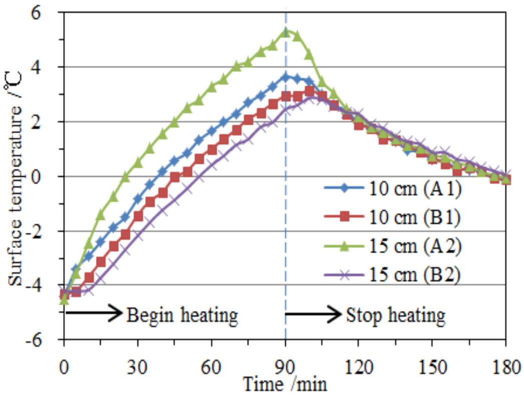


Fig.2 Pavement Surface Temperture Variation with Time

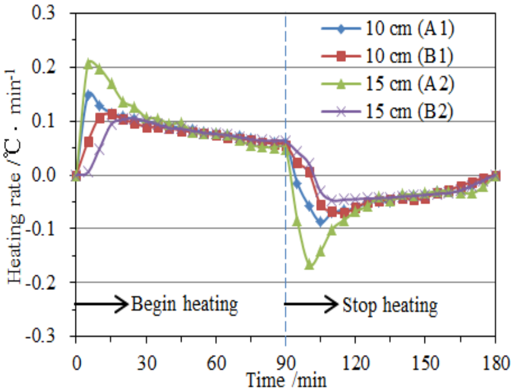


Fig.3 Heating Rate Variation with Time

The average temperature distributions along the depth of pavement at the initial time, power-off moment and 3h are shown in Fig.4. The average temperature is the average value of the same depth of pavement. At the same depth of pavement, the average temperature of CFHW spacing of 10cm and is almost equal to that of 15cm at the initial time and 3h. For the pavement surface, the average temperature of CFHW spacing of 10cm is slightly higher than that of 15cm at 1.5h. The average temperature of CFHW spacing of 10cm is the same as that of 15cm when the depth of pavement is more than 0.1m.

Pavement Temperature Difference

It can be seen from Fig.5 that the maximum temperature difference on pavement surface is 0.8°C and 2.9°C for the CFHW spacing of 10cm and 15cm, respectively. At the heating stage, the surface temperature difference curves of pavement with CFHW spacing of 10cm and 15cm increase to stable in 5min and 20min, respectively. The surface temperature difference of pavement with CFHW spacing of 10cm and 15cm quickly reduce to 0°C after power-off, which indicates that the pavement surface temperature becomes consistent.

The three-dimensional infrared ray (3D-IR) temperature is obtained from the surface of concrete pavement. Fig.6 shows the 3D-IR temperature of pavement with CFHW spacing of 10cm and 15cm at initial time. The 3D-IR temperature of pavement with 10 cm CFHW spacing is from -6.8°C to -5.8°C at initial time, and the average temperature is -6.2°C. The 3D-IR temperature of pavement with 15 cm CFHW spacing is from -6.5°C to -5.6°C at initial time, and the average temperature is -6.1°C. Fig.7 shows the 3D-IR temperature of pavement for 1h heating. The 3D-IR temperature difference of pavement with CFHW spacing of 10cm and 15cm is 1.0°C and 3.1°C, respectively. Their average temperature is -0.4°C and -0.6°C. The maximum 3D-IR temperature difference is large relatively because of the uneven pavement surface and the different distance between the pavement and the infrared thermal imager.

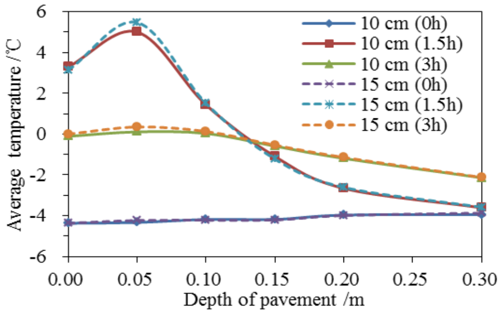


Fig.4 Average Temperture along the Depth of Pavement

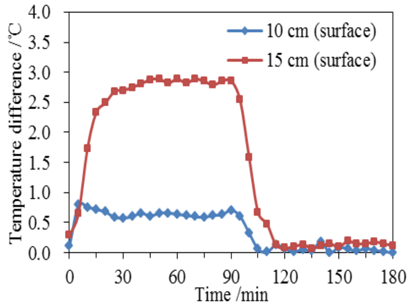
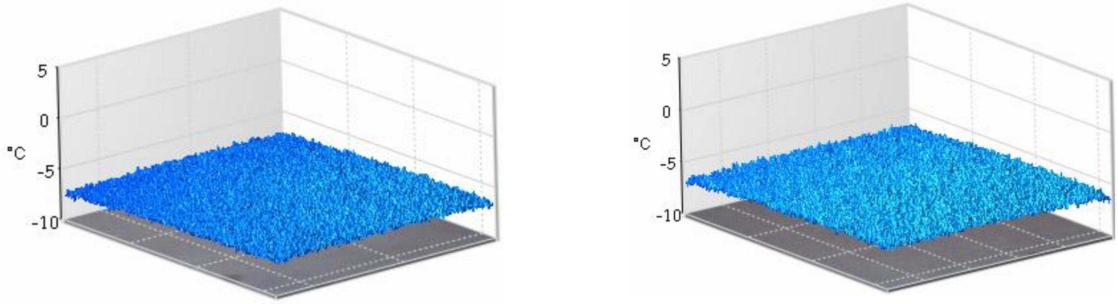
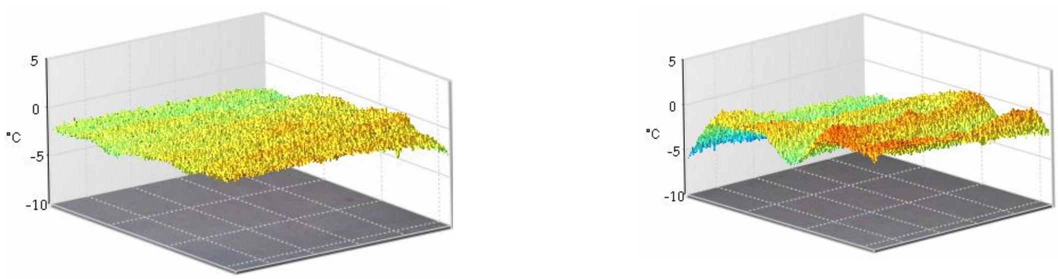


Fig.5 Pavement Surface Temperture Difference



(a) 10cm (b) 15cm

Fig.6 3D-IR Temperture of Pavement at Initial Time



(a) 10cm (b) 15cm

Fig.7 3D-IR Temperture of Pavement for 1 Hour Heating

Summary

In this paper, the method of melting snow with carbon fiber heating wire (CFHW) buried in concrete pavement is presented to avoid the adverse effects of snow-melting chemicals. It is shown that, with an input power of 500W/m^2, the average temperature on pavement surface with 10cm CFHW spacing is higher than that of 15cm CFHW spacing when the air temperature is -5°C and the wind speed is 1.0m/s. The pavement heating rates of 10cm and 15cm CFHW spacing is almost the same in most of the heating time. The temperature different on pavement surface with 10cm CFHW spacing is less than 1°C, which can meet the requirement of the snow-melting temperature uniformity.

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