Study on Electro-thermal and Electromagnetic Properties of Carbon Fiber Heating Wire in Airport Cement Concrete Pavement

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Abstract. This paper studies the electro-thermal and electromagnetic properties of carbon fiber heating wire (CFHW) buried in airport cement concrete pavement. The temperature of CFHW is analyzed when the input power of CFHW is from 10 W/m to 60 W/m. The magnetic flux density is analyzed when the heat flux is from 100 W/m^2 to 600 W/m^2. It is shown that the temperature of 24k CFHW is higher than that of 48k CFHW, and the magnetic flux density of pavement with 15 cm CFHW spacing is higher than that of 10 cm CFHW spacing. The 24k CFHW is more suitable for melting snow on airport pavement. The magnetic flux density can meet the electromagnetic environment requirements for aeronautical radio navigation stations.

1. Introduction

Snow, ice and slush on airport cement concrete pavement significantly impact aircraft landing, taxiing and takeoff safety in winter because snow, ice and slush reduce the friction coefficient between the tire and the surface of airport pavement, which not only hinders the transportation of people and goods but also threatens people's lives and properties [1]. The traditional method of pavement snow removal with snow-melting chemicals or machine induces flight delay and needs a large number of manpower, chemicals and machine, which is labor intensive and time-consuming. The use of snow-melting chemicals also leads to some adverse effects on the structure, function and environment [2-4].

It is necessary to conduct timely and high-efficient removal of snow and avoid the adverse effects of snow-melting chemicals on airport pavement. Some other pavement snow-melting methods have been researched, such as super-long flexible heat pipes [5], electric heating cables [6], electrically conductive concrete [7-9], hydronic heating system [10-12] and CFHW [1, 13].

In recent years, Zhao et al. conducted a systematic study on bridge deck and pavement snow-melting by embedding CFHW in concrete [1, 13]. 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. However, the snow-melting method with CFHW requires further study on the application of airport pavement [14]. The CFHW generates electromagnetic fields when it is electrified. The Electro-thermal and Electromagnetic Properties of CFHW are the important factors of melting snow on airport pavement. The aeronautical radio navigation stations have some specific

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electromagnetic environment requirements [15]. Therefore, it is proposed that the electro-thermal and electromagnetic properties of CFHW is studied.

2. Experiment

2.1. Materials

The raw materials include cement, fine aggregate, coarse aggregate, water, water reducer 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 2.7. The coarse aggregate gradation is the gravel of 5~40 mm. The mixed water is tap water. The ratio of water to cement is 0.42. The sand ratio is 0.3. The solid content of water reducer is 5.0%. The heating material is 24k and 48k CFHW with Teflon coat, the resistance of which is 18.89 Ω/m and 8.75 Ω/m, respectively.

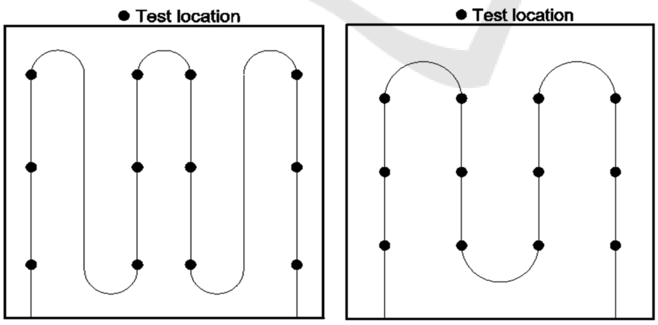
Table1. Mix proportions of concrete.

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		
330	609.4	568.8	853.2	138.6	6.6

2.2. Experiment program

The 24k and 48k CFHW are connected to the AC voltage regulator which is connected with the power supply. The load power of CFHW is 0~60 W/m by adjusting the output voltage. The CFHW hang in the air at ambient temperature of 0°C. The temperature sensor is tied up on the CFHW, and the temperature is measured by the data acquisition device.

The mixture is stirred for 90s according to GB/T 20473-2009. The specimens are prepared in the mold of 60 cm×60 cm×40 cm. The 24k and 48k CFHW are located 5 cm below the pavement surface. The CFHW spacing is 10 cm and 15 cm. The cement concrete pavement is cured for 28 days at 20°C and 60%±5% relative humidity. As shown in Figure 1, the test location of magnetic flux density contains 12 test points. The test location of magnetic flux density that is directly above the CFHW is 0 m, 0.25 m, 0.5 m, 0.75 m and 1 m on the pavement surface, respectively. The test is carried out at the ambient temperature of 0 °C.



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

Figure 1. Test location of magnetic flux density.

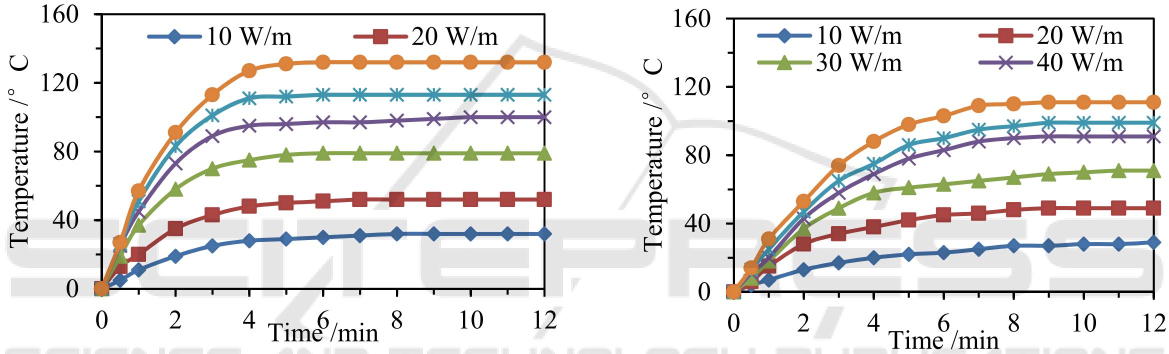
3. Results and discussion

In the experiment, the input power is controlled by an AC voltage regulator. The power of CFHW is 10 W/m, 20 W/m, 30 W/m, 40 W/m, 50 W/m and 60 W/m, respectively. The input heat flux of the airport cement concrete pavement is 100 W/m^2, 200 W/m^2, 300 W/m^2, 400 W/m^2, 500 W/m^2 and 600 W/m^2, respectively.

3.1. Electro-thermal properties

The resistance value of CFHW is invariable after heating, which is considered to be a constant value. The temperature of 24k and 48k CFHW is measured against heating time as shown in Figure 2. After the CFHW is electrified, the temperature of CFHW increases rapidly. The greater the power is, the greater the temperature increases. However, the temperature increase decreases with time and then gradually becomes stable. As shown in Figure 3, when the power per meter is increased from 10 W/m to 60 W/m, the time that the temperature of 24k CFHW is stable is shortened from 8 minutes to 5 minutes, and the time that the temperature of 48k CFHW is stable is shortened from 12 minutes to 7 minutes. The time difference between the temperature of 24k and 48k CFHW reaches a stable value is decreased from 4 minutes to 2 minutes.

As shown in Figure 4, when the power per meter increases from 10 W/m to 60 W/m, the constant temperature of 24k CFHW increases from 32°C to 132°C, the constant temperature of 48k CFHW increases from 29°C to 111°C. The temperature difference between 24k and 48k CFHW increases from 3°C to 21°C. The greater the power is, the shorter the temperature of CFHW tends to be constant, and the higher the temperature is. The CFHW with Teflon coat is intact without damage after heating, indicating that the high temperature performance of CFHW with Teflon coat is better. Based on the thermal effect and the price of CFHW, the 24k CFHW is selected as the following test.



(a) 24k CFHW (b) 48k CFHW

Figure 2. The CFHW temperature variation with heating time.

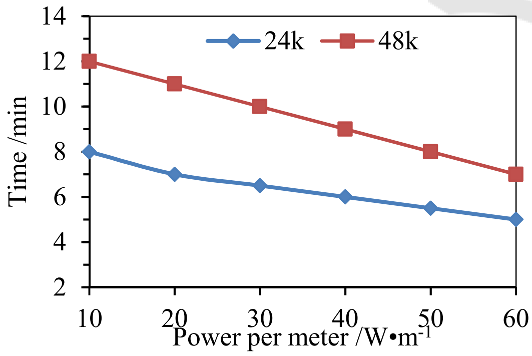


Figure 3. The time variation with power per meter.

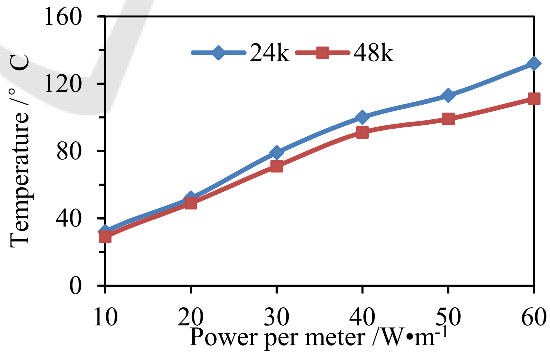
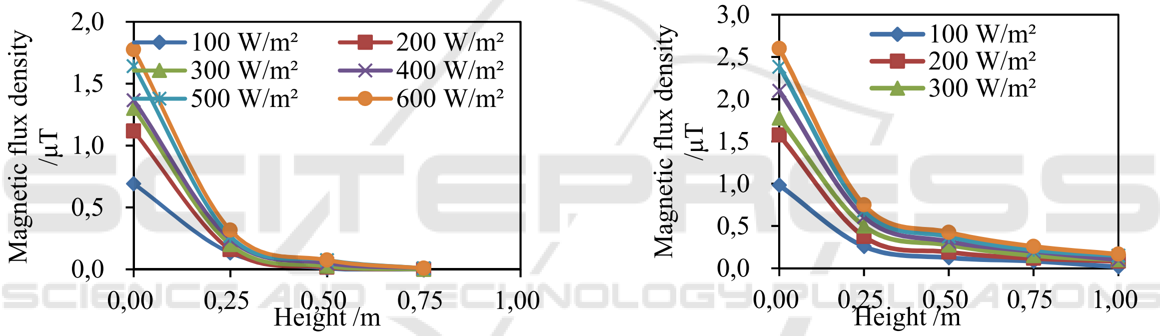


Figure 4. The CFHW temperature variation with power per meter.

3.2. Electromagnetic properties

According to GB 6364-2013, a key requirement of electromagnetic environment is protection rate that is the minimum ratio between signal electric field intensity at receiving point of normal operation of navigation receiving equipment and interference electric field intensity of the same channel. In the test, the electric field intensity measured at any position of concrete pavement is 0 V/m. The magnetic flux density of pavement with 24k CFHW is measured against height as shown in Figure 5. For the same heat flux, the magnetic flux intensity on concrete pavement rapidly decreases when the height increases from 0 m to 0.25 m, and then the magnetic flux intensity decreases slowly with the increase of height. As shown in Figure 5(a), the magnetic flux intensity of pavement with 10 cm CFHW spacing is 0μT when the height is higher than 0.75 m. As shown in Figure 5(b), the magnetic flux intensity of pavement with 15 cm CFHW spacing is close to 0μT when the height is 1 m.

As shown in Figure 6, the magnetic flux density increases with the increase of the heat flux for different height and spacing. When the heat flux increases from 100 W/m^2 to 600 W/m^2, the magnetic flux density of pavement surface with 10 cm CFHW spacing increases from 0.69μT to 1.78μT, and the magnetic flux density of pavement surface with 15cm CFHW spacing increases from 0.98μT to 2.6μT. At the height of 0.5 m above the pavement, when the heat flux increases from 100 W/m^2 to 600 W/m^2, the magnetic flux density with 10cm CFHW spacing increases from 0μT to 0.08μT, and the magnetic flux density with 15 cm CFHW spacing increases from 0.13μT to 0.43μT. The magnetic flux density of pavement with 15 cm CFHW spacing is higher than that of 10 cm CFHW spacing for the same heat flux. This is because the current of CFHW with 15 cm spacing is larger than that of 10 cm CFHW spacing. All the test data show that the electromagnetic performance meets the requirements of the navigation electromagnetic environment.



(a) 10 cm spacing (b) 15 cm spacing

Figure 5. The relationship of magnetic flux density and height.

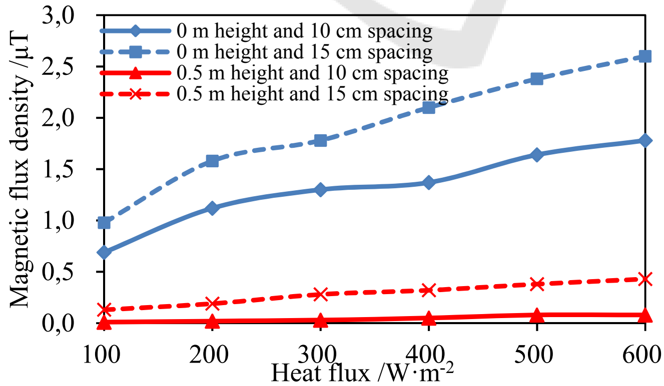


Figure 6. The relationship of magnetic flux density and heat flux.

4. Summary

The CFHW with Teflon coat has the advantages of fast heating speed, good heat resistance and the stable resistance value. It is easy to control when the CFHW is electrified. Compared with the 48k CFHW, the heating rate of the 24k CFHW is faster for the same power, the time to achieve stable temperature is shorter and the temperature is higher; the economic benefit and the heating effect of 24k CFHW are better in snow-melting project. The magnetic flux density of pavement with 10 cm CFHW spacing is less than that of 15 cm CFHW spacing when the heat flux is less than 600 W/m^2. The farther the distance is, the smaller the magnetic flux density is. The magnetic flux density is zero when the height is greater than 1 m. The electromagnetic performance of snow-melting pavement meets the requirements of navigation electromagnetic environment.

Acknowledgments

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