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Automatically melting snow on airport cement concrete pavement with carbon fiber grille

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ABSTRACT

In this paper, the method of melting snow with carbon fiber grille buried in airport pavement is presented to avoid the adverse effects of snow-melting chemicals on the structure, function, environment and safety. The outdoor snow-melting experiment of airport cement concrete pavement is conducted when the snow is heavy and the air temperature is from −3 °C to −1 °C. Electrical power is supplied to the airport pavement through the use of carbon fiber grille. It is shown that, with an input power of 350 W/m^2, the temperature of pavement surface can achieve an increment of 4.63 °C and the 2.7 cm thick snow can be melted within 2 h, which is just for melting snow at this condition. After the heating stopped, the residual heat can melt snow on the pavement in real time when the temperature of pavement surface is kept above 0 °C. The temperature and energy distribution along the depth of pavement are analyzed at different times. The findings indicate that the method of melting snow on airport pavement with carbon fiber grille is feasible in the snowy weather condition.

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 (Zhao et al., 2010). 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 (Wang et al., 2006): damage to concrete pavement (e.g., steer bar corrosion and surface scaling), corrosion of drainage system and destruction of the soil ecological environment (Kayama et al., 2003; Thunqvist, 2004).

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 infrared heat lamps (Zenewitz, 1977), electric heating cables (Henderson, 1963), electrically conductive concrete (Tuan and Yehia, 2004; Xie and Beaudoin, 1995; Zhang et al., 2011), hydronic heating system (Lee et al., 1984; Liu and Spitler, 2004a, 2004b; Liu et al., 2006a, 2006b; Miró, 2012) and carbon fiber heating wires (Zhao et al., 2010, 2011).

The current research of melting snow mainly focuses on electrically conductive concrete. To attain high electrical conductivity, concrete must contain a certain amount of electrically conductive components, such as steel shaving, steel fibers, graphite product, carbon fibers and nickel particle (Hou et al., 2002; Tuan, 2004, 2008; Tuan and Yehia, 2004; Xie and Beaudoin, 1995; Yehia and Tuan, 1998, 1999; Yehia et al., 2000; Zhang et al., 2011). However, the research and application of electrically conductive concrete mainly focus on bridge deck and highway pavement, which can't meet the requirements of airport pavement. In addition, the electric resistivity of the conductive concrete varies with time, which is inconvenient for the control.

Some studies have demonstrated the experimental tests, design and numerical simulations for snow-melting using hydronic heating system (Liu and Spitler, 2004a, 2004b; Liu et al., 2006a, 2006b). The use of embedding hydronic heating system in airport pavement has been limited to relatively small surface area comprising aircraft parking slots and has not been applied to larger area such as runway. This study has identified three international airports in Scandinavia that use heating sections of outdoor pavement: Oslo-Gardermoen, Stockholm-Arlanda and Helsinki-Vantaa (Miró, 2012). In all three cases, the heat is applied to the pavement by means of hydronic system connected to the district heating system. Although the hydronic heating system is capable of melting snow on airport pavement to some extent, its construction is complex and the snow-melting performance is delayed to heat the circulating liquid.

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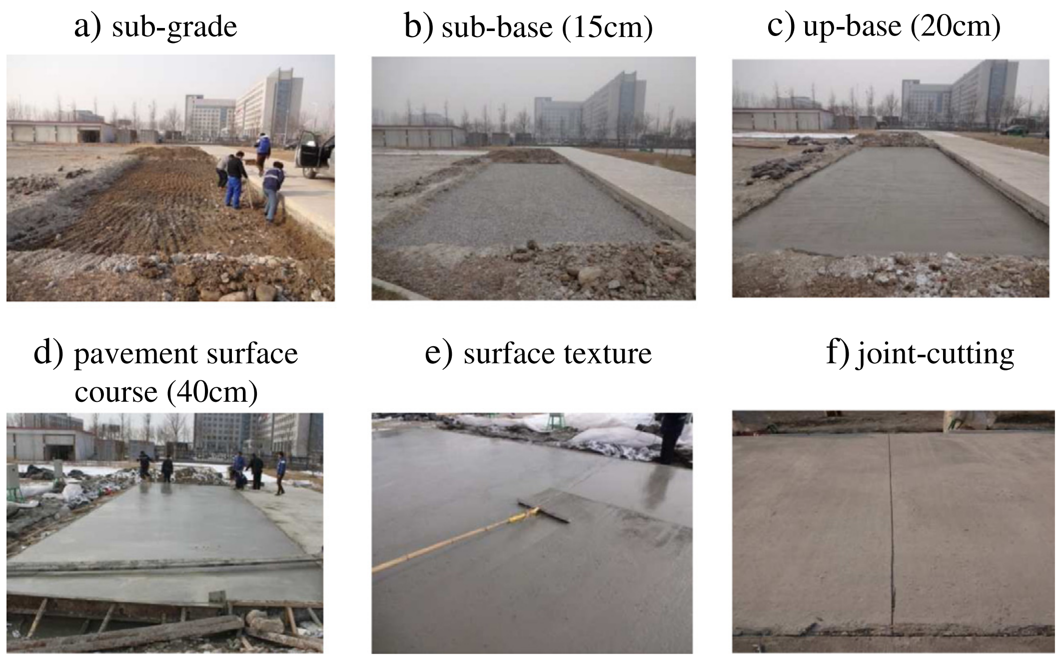

Fig. 1. Airport cement concrete pavement construction.

In recent years, Zhao et al. (2010, 2011) conducted a systematic study on bridge deck and pavement snow-melting by embedding carbon fiber heating wires in concrete. 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 carbon fiber heating wires requires further study on the application of airport pavement. The selection of snow-melting method and technologies depends highly on the geographic, economical, environmental and safe factors of practical projects. Therefore, melting snow on airport cement concrete pavement with carbon fiber grille is proposed.

This paper studies the method of melting snow on airport pavement in which carbon fiber grille is buried. Carbon fiber grille is made of steel mesh and carbon fiber heating wires which have high tensile strength and good electric-thermal properties. In addition, steel mesh can reinforce the airport pavement. In the case of input power, the temperature of airport pavement surface maintains above the freezing temperature in order to prevent snow accumulation. Finally, the full-scale snow-melting experiments are performed in outdoor environment.

2. Experiment

2.1. Airport pavement design and construction

The design and construction of airport cement concrete pavement was conducted according to specifications for Cement Concrete Pavement Design for Civil Airports and technical specifications for Construction of Cement Concrete Pavement for Airfield Area of Civil Airports. The airport pavement was cast by using commercial concrete whose flexural strength is more than 5.75 MPa at an age of 28 days. Fig. 1 has shown that the structural layer combination includes subgrade, sub-base, up-base and cement concrete pavement surface course. The surface texture and joint-cutting are also shown in Fig. 1. The size of each pavement is 4.6 m × 4.6 m × 0.4 m. The resistance thermometer sensors were placed along the concrete pavement depth at 0 m, 0.5 m, 0.1 m, 0.2 m, 0.3 m and 0.4 m, respectively. The carbon fiber grille was located 5 cm below the pavement surface. The carbon fiber grille was made of steel mesh and 48 k carbon fiber heating wires that were a given spacing at 10 cm.

2.2. Experimental equipment

The required experimental equipment mainly includes AC voltage regulator, resistance thermometer sensor, field data acquisition, data adapter and infrared thermal imager. The measurement range of the resistance thermometer sensor is −50–153 °C; the accuracy of the resistance thermometer sensor is 0.1 °C. The field data acquisition was used to collect temperature signal, which was connected to the data adapter. The temperature data obtained by monitoring system could automatically store in the computer system.

3. Results and discussion

The heating requirement for snow-melting depends on rate of snowfall, air temperature, wind velocity and relative humidity. The snow-melting system must first melt the snow and then evaporate the resulting water film. The rate of snowfall determines the heat required to warm the snow to 0 °C and to melt it. The evaporation rate

Table 1
Climatic data, input power, snow-melting time and power consumption.

Precipitation (mm)	Wind scale	Air temperature (°C)	Heat flux (W/m^2)	Snow melting time (h)	Power consumption (kWh/m^2)	Pavement surface temperature before heating (°C)	Pavement surface temperature after heating (°C)	Date
2.06	1–2	−1.8–−1.2	350	2.0	0.70	−1.2	3.4	3 Feb.
1.10	1	−3.8–−3.4	300	1.5	0.45	−1.0	2.3	20 Jan.
1.00	2–3	−2.5–−1.0	250	2.0	0.50	−2.1	2.6	1 Feb.
0.40	1	−3.5–−3.1	200	1.75	0.35	−0.6	2.9	30 Jan.