

Numerical Analysis on Temperature Field of Airport Pavement with Phase Change Energy Storage Concrete

Chunzhi DU, Bingfei LIU, Xiangyu HE, and Liangyu RAO

Abstract—The airport has been playing a more important role in national transportation with the rapid developments of the civil aviation industry. However, there are more than one hundred airports cannot work normally in winter due to snow and ice. Here, the phase change energy storage materials (PCESMs) had been added to concrete pavement to melt snow and ice, and the effect of the buried depth of pipes, the distance between buried pipes and the thermal conductivity of surface layer materials on pavement temperature had been analyzed using the FEM(ANSYS). The results show that the temperature transmit decreasing with both the pipe depth and the distance increasing and, the efficiency of the pavement on ice-snow melting increased as the thermal conductivity of the surface layer became bigger, the temperature can be kept longer above 8°C. Therefore, the efficiency can be improved by adding heat conduction material, taking suitable pipe depth and distance.

Keywords—Analysis of temperature field, airport pavement, ANSYS and finite element analysis, phase changes energy storage materials.

I. INTRODUCTION

AIRPORT has been playing a very important role in the transportation system in China, and there are more than one hundred airports located in the snow belt[1], which make the airports cannot work effectively. Therefore, the research on efficiently and eco-friendly ice-snow melting method has become the focus of world aviation [2], [3]. At present, the artificial mechanical method, hot melt method and snow melting agent can be available to melt snow and ice at home and abroad. However, these methods still have some weaknesses, such as, inefficient or polluting environment, cannot make full use of energy and taking a large amount of investment. The phase change energy storage materials(PCESMs), which can make the energy transferred from different space and time by the phase changing, and have no pollution to the environment, have been widely used in aerospace, heating, construction and other fields, for its recyclable and efficient[4]-[9]. Thus, it would be of great

significance both in society and economy if PCESMs would be applied to construct pavements in airports to help ice-snow melting. At present, some researches on the model of pavements or decks ice-snow melting had been carried out [10], [11], and the numerical analysis had been achieved. However, researches on ice-snow melting system in airport pavements using PCESMs are still a few. Therefore, it has practical meanings to analyze the temperature field of pavement system with PCESMs.

II. PCESMs ICE-SNOW MELTING SYSTEM

The structure of airport pavements with ice-snow melting system based on PCESMs is shown in Fig. 1. It can be divided into four layers: the surface layer which can provide sufficient friction, under surface layer, there is the heating layer that can keep the temperature of surface layer above 4°C using the energy provided by the PCESMs, which were full filled in the pipes, then, the bearing bed that can provide sufficient strength to ensure the normal operation of the aircraft, followed at the end by the soil layer, which can hold the concrete structure above, is generally thicker. Above the structure, there is the ice-snow layer. The latent heat of PCESMs had been generally occurred under isothermal or approximate isothermal conditions, which can effectively prevent the waste of energy caused by quick release. When the phase change completed, the PCESMs can absorb energy from other heat resources such as the resistance wire, solar energy, and store it by reverse phase changing, then the energy recycling would be achieved, and the energy can be stored in daytime and released when the temperature decreased below 4°C.

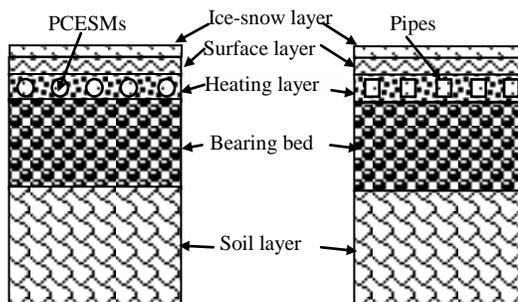


Fig.1 Structure of pavement system with PCESMs

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III. NUMERICAL ANALYSIS ON TEMPERATURE FIELD OF PAVEMENT

A. Modeling with Finite Elements

In fact, the heat transfers process between the pipes and the surrounding concrete, which is actually a complicated and unsteady process. So the model needs to be simplified as 1) the material of each layer is isotropic, and the mechanical characteristics do not change with temperature, 2) the model is symmetric structure, 2) the contact resistance between the layers and the soil layer is not considered. The cloud image of temperature field of pavement is shown in Fig.2. For the more, to analyze the efficiency of the ice-snow melting system, two temperature points had been defined: the point on the surface layer and above the buried pipe, referred to the check point A; the point on the surface layer and in middle of two buried pipes, referred to the check point B, as shown in fig.2.

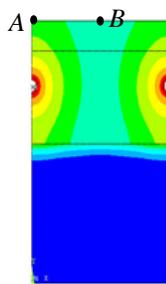


Fig.2 The cloud image of temperature field

For the pavement with PCESMs system, there are many factors that can affect the energy conversion efficiency, and the buried depth of pipes, the distance between pipes and the thermal conductivity of the surface layer had been considered here and numerically analyzed using ANSYS.

The governing differential equation for the thermal analysis is as follow:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(\lambda_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda_z \frac{\partial T}{\partial z} \right) + \ddot{q} \quad (1)$$

Here: ρ is the density, c is the specific heat capacity, λ_x, λ_y , and λ_z is the thermal conductivity in direction x, y , and z respectively, and \ddot{q} is the heat generation rate.

The analysis area is divided into finite elements, and triangle or quadrilateral element can be available in 2-D model, and tetrahedral or hexahedral element can be available in 3-D model. The matrix form of the governing differential equations can be obtained using FEM method as (2):

$$[C]\{\dot{T}\} + [K]\{T\} = \{Q\} \quad (2)$$

Here: $[C] = \sum_{i=1}^n [C]_i$, $[K] = \sum_{i=1}^n [K^{m,d,c}]_i$, $\{Q\} = \sum_{i=1}^n [Q^{f,c,g}]_i + \{Q_0\}$, and n is number of elements, and $\{Q_0\}$ is the rate of heat flow in nodes.

The initial conditions and the boundary conditions:

(1) The initial conditions: the initial temperature can be regarded as the same as 2°C in each layer, and the temperature of pipes and PCESMs are set as 70°C at the beginning.

(2) The boundary conditions: a) the heat transfer coefficient on the outer surface is 100 W/m²/K, and the temperature of air is

-2°C. b) Between the pipes and PCESMs, the heat transfer coefficient is changing with temperature, and the relationship is shown as Fig.3. c) In the two sides of the model, there are no heat transfers, which can be set as adiabatic boundary. The physical parameters of each layer are as table 1.

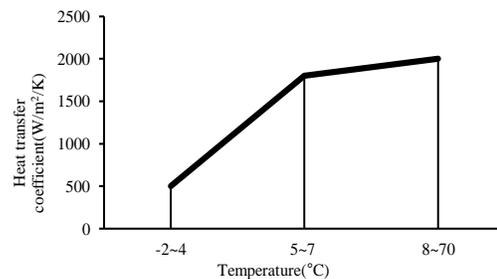


Fig. 3 The heat transfer coefficient between pipes and PCESMs.

TABLE 1
THE PHYSICAL PARAMETERS OF EACH LAYER IN PAVEMENT.

	Surface layer	Heating layer	Bearing bed	Pipes
Thermal conductivity(W/m/K)	70	60	1.2	200
Specific heat capacity(KJ/Kg/K)	920	840	1200	460
Density(Kg/m ³)	2100	3500	1600	7800

B. The Influence of Buried Depth of Pipes on Temperature Field

The progress of the heat energy transferred to the surface layer from the pipes may be affected by the buried depth of the pipes. To consider this affect, the buried depth was taken as $h = 0.23\text{m}$, 0.28m and 0.33m , and other physical parameters were taken as table 1. The distributions of temperature and the temperature curves of check points with different buried depth are shown in Fig.4 and Fig.5.

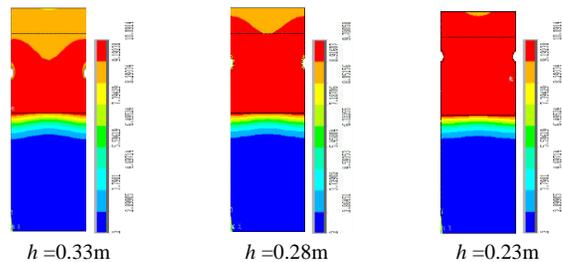


Fig.4 The distributions of temperature with different buried depth

From the Fig.4 and Fig.5, the maximum temperature of check point A and B had decreased with the increase of buried depth, and the decreasing became more stationary when the depth exceeded 0.28m. The difference of the maximum temperature between the two check points is gradually decreased with the increase of buried depth. Under different buried depth, the temperature of the surface layer can be remained above 8°C which can provide enough energy to deice ice and melt snow well. In addition, the maximum temperature can be kept longer above 5°C when the buried depth is 0.23m. For the more, the maximum temperature of check point B had rebounded within a certain range, which indicated that the temperature of the surface layer was greatly influenced by the heat releasing time of phase change energy storage systems, and the recommended buried depth of the pipes was taken as $h = 0.28\text{m}$.

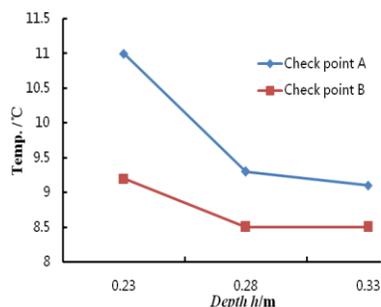


Fig.5 The temperature curves of check points vs. Buried depth

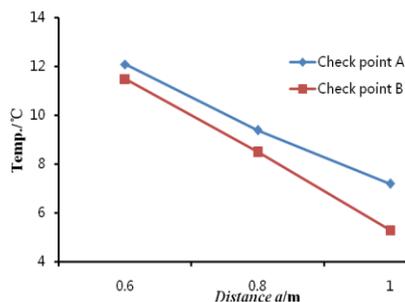


Fig.6 The temperature curves of check points vs. distances

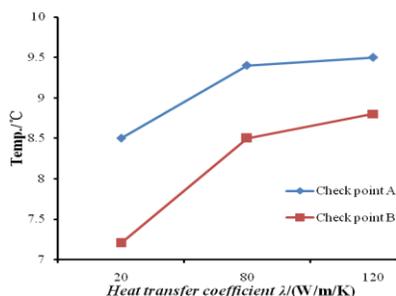


Fig.7 The temperature curves of check points vs. thermal conductivity

C. The Influence of Distance between Pipes on Temperature Field

The distance between buried pipes would produce an effect on the duration of the surface layer temperature and the cost of pavement directly. That is to say, increasing distance would reduce costs, but it would also reduce the duration of the surface layer temperature, which would not be conducive to ice-snow melting. Therefore, it is very important to determine the reasonable distance between buried pipes in the design of the pavement. In this work, the distance between pipes were taken as $a = 1\text{m}$, 0.8m and 0.6m , and the numerical analysis was carried out using ANSYS. The temperature curves of check points were shown as Fig.6. Hereby, with the distance between pipes increasing, the maximum temperature of check points decreased, and the temperature difference between point A and B became more and more large gradually. The efficiency of heat release of the pavement system would be improved and the effect of deicing and snow-melting would become better when the distance small than 0.8m , but which can increase the costs of pavement. Thus, the reasonable distance between pipes would be set as $a = 0.8\text{m}$.

D. The Influence of Thermal Conductivity of Surface Layer Materials on Temperature Field

The thermal conductivity of the surface layer materials

directly affects how much heat had been transferred from the heating layer to surface layer, thereby affecting the airport pavement temperature distribution. In this part, the thermal conductivity of the surface layer materials had been considered, and which would be taken as $\lambda = 20\text{W/m/K}$, 70W/m/K and 120W/m/K , and it was taken as 60W/m/K in heating layer. The temperature curves of check points were shown in Fig.7. With the increase of the thermal conductivity in surface layer, the maximum temperatures of check points would be significantly increased, which would be conducive to the ice-deicing and snow-melting in airport pavement. However, it would be difficult to blindly increasing this coefficient in practice, and which would affect the strength and the anti-friction ability of surface layer. Therefore, the reasonable the thermal conductivity would be suggested as 70W/m/K .

IV. CONCLUSIONS

To research the effect of ice-snow melting on pavement with PCESMs, the numerical analysis on factors that influence the effect of ice-snow melting had been carried out, and which including the buried depth of pipes, the distance between pipes and the thermal conductivity of the surface layer materials. The results shown that, with the decreasing of buried pipe depth, the efficiency of energy conversion will increase; with the decreasing of distance between the buried pipes, the efficiency of energy conversion will increase; with the increasing of the thermal conductivity in surface layer, the efficiency of energy conversion will increase. Finally, the reasonable structure and size of pavement with PCESMs had been given, and which can provide reference for field construction and designing of airport pavement.

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REFERENCES

- [1] XU Yuanjie. The techniques of snow-ice melting in FOREIGN highway and discuss on method of heating [J]. Sichuan Architecture, 2012, 32(3): 281-283. (In Chinese)
- [2] YU Wenbing, YI Xin, GUO Ming, CHEN Lin. State of the art and practice of pavement anti-icing and deicing techniques[J]. Sciences in Cold and Arid Regions, 2014, 6(1): 14-21.
- [3] ZHAO Fangran, LIU Xinchun. Study on airport concrete pavement damage law of hot wind snow removal[J]. Concrete, 2015, (4):74-77. (In Chinese)
- [4] He Xiaofang, Wu Yonghao, Wang Yueming, Huang Lina, Cao Xinxin. Research progress on phase change materials for thermal energy storage[J]. New Chemical Materials, 2014, 42(12):27-29. (In Chinese)
- [5] Hasnain S.M. Review on sustainable thermal energy storage technologies, Part I: heat storage materials and techniques[J]. Energy Conversion and Management, 1998, 39(11): 1127-1138.
- [6] Jennifer Luckas, Daniel Krebs, Stephanie Grothe. Defects in amorphous phase-change materials[J]. Invited Feature Paper Cambridge Journals, 2013, 28(9):1139-1147

- [7] He B, Setteerwall F. Technical grade paraffin waxes as phase change materials for cool thermal storage and cool storage systems capital cost estimation[J]. *Energy Conversion and Management*, 2002, 43(9): 1709-1723.
- [8] Oró E, de Gracia A, Castell A, M.M.Farid, L.F.Cabeza. Review on phase change materials(PCMs) for cold thermal energy storage applications[J]. *Applied Energy*, 2012, 99: 513-533.
- [9] LI Yanshan, WANG Shujun, SHI Quan, LIANG Wenzhang. Recent progress on preparation of energy storage phase change material[J]. *Journal of Functional Materials*, 2015, 46(6): 6008-6014. (In Chinese)
- [10] LI Honglei, GU Qiangkang, CEN Guoping. Application study of self-heating technology in snow-ice melting on airport pavement[J]. *Subgrade Engineering*, 2011, (1):77-80. (In Chinese)
- [11] LI Hongbo, YU Guangyun. Research on mechanical behavior of asphalt pavement with deformation joints based on ANSYS[J]. *Journal of Wuhan University of Technology*, 2011, 33(2): 87-90,104. (In Chinese)