# Research on Joint Displacement of Airport Cement Pavement and Structural Stress of Caulking Material based on Phase Change Temperature Control Material

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## Abstract

**The main failure forms of the cement pavement caulking materials are that the adhesion between the airport pavement caulking materials and the side wall of the slot is lost, the caulking materials are squeezed out and the adhesiveness is destroyed. Based on phase change energy storage materials and functional gradient design idea, the field track is designed into three layers according to functional requirements. The calculation shows that the horizontal displacement of the joint slot of airport cement pavement is basically the same as that of highway cement pavement. When the content of shape memory polyurethane is 8%, the performance of asphalt-based caulking compound is far better than other formulations, and the modification effect on road performance and mechanical performance of caulking compound is the best. Therefore, it is recommended to use 8% shape memory polyurethane asphalt as caulking material for cement pavement, which is of great significance to improve the durability of cement pavement.**

## Keywords

**Phase Change Temperature Control Material, Airport, Cement Pavement, Sealing Material, Seam Displacement; Structural Stress.**

## 1. Introduction

Civil airport construction, as the main investment field of China's infrastructure, is in full swing all over China. The construction of cement concrete airport runway project is undoubtedly one of the hot spots concerned by all parties. How to solve the disadvantage of "thermal expansion and cold contraction", among which the cement concrete pavement joint caulking material plays an important role. In recent years, phase change temperature control materials have been gradually used in building insulation and pavement deicing systems, which have the advantages of energy saving and environmental protection, and become the research focus of people. In this paper, the displacement of airport cement pavement joints and the structural stress of caulking materials are studied based on phase change temperature control materials.

## 2. Phase Change Temperature Control Material and its Application

Phase change temperature control materials can absorb and store the heat (cold) of the environment during the phase change, and release the heat (cold) to the environment when needed, so as to control the ambient temperature. Using this feature, we can not only manufacture various facilities to improve the energy utilization rate, but also reuse them for many times to solve the contradiction between the supply and demand of energy in time and space, that is, we can store energy when there is a lot of energy and release it when needed, so as to improve the energy utilization rate.

According to chemical composition, phase change temperature control materials can be divided into: organic and inorganic; According to the phase change temperature, it can be divided into low temperature, medium temperature and high temperature phase change temperature control materials [2-3]. At present, the most widely used organic energy storage material is paraffin wax, but its phase transition temperature is high, which is not suitable for melting snow and ice. Therefore, it is necessary to mix organic polyol phase change materials to control the phase change temperature at 5~7℃ to meet the temperature requirements of melting snow and ice.

Within the phase change temperature range, the energy absorbed or released when the phase state changes is called latent heat of phase change. Compared with the heat absorbed and released when the material temperature changes, the latent heat of phase change is much larger. For example, the latent heat of phase change of ice-water is 335J/g, while the sensible heat absorption of water is only 4 J/g [4]. By use that heat storage and heat release function of phase change materials, the temperature of the environment around the object can be adjust and controlled, so that a microclimate with basically constant temperature can be formed around the object.

This endothermic and exothermic process of phase change materials is automatic, reversible and infinite. In the process of phase transformation, there are usually endothermic and exothermic phenomena, which can be used to realize the functions of thermal energy storage and temperature control.

## 3. Displacement of Airport Cement Pavement Joint

### 3.1 Horizontal Displacement of Pavement Joint

The horizontal displacement of cement pavement joints and slots is mainly related to the volume change of plates caused by the change of ambient temperature and humidity, including the joint displacement caused by plate warping under the action of temperature gradient, the joint displacement caused by the overall change of plate temperature, and the joint displacement caused by dry and wet changes.

Airport pavement is a complex layered structure. By introducing the idea of functional gradient, the concrete pavement is divided into three layers according to functions: surface layer, heating layer and base layer. The function of surface layer is to maintain the smoothness of pavement and provide enough friction. The function of the heating layer is to provide a heat source through the latent heat of phase change of phase change temperature control materials, and to keep the surface layer temperature from falling to freezing point. The pipeline for packaging phase change materials in the heating layer can be a circular section pipe or a square pipe. Provide sufficient strength and rigidity for the entire pavement structure at the grass-roots level to ensure the smooth operation of the aircraft [5].

On the airport cement pavement, because the pavement itself has a certain heat capacity, the change of ambient temperature will not make the pavement temperature change immediately. This temperature lag effect will be reflected in the temperature gradient between the surface and the bottom of the slab, which will easily cause the slab warping of cement slab.

With the increase of plate thickness, the pavement temperature gradient will decrease. Therefore, we introduce the thickness correction coefficient $a_b$ to correct the pavement temperature gradient. The introduced exponential regression formula is as follows [6]:

$$a_b = 1.829e^{-0.02H}, r^2 = 0.999 \tag{1}$$

Where $a_b$ is the thickness correction coefficient of the temperature gradient; $H$ is the plate thickness; $r$ is the regression coefficient.

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The correction coefficient of pavement temperature gradient with different thickness is calculated by exponential regression formula. Based on the comprehensive consideration of the elastic modulus of the base and the geometric size of the plate, a three-dimensional finite element model of joint deformation is established, and the influence of each element on the joint is systematically analyzed.

Environmental changes will cause the cement slab to expand with heat and contract with cold, and then cause the horizontal displacement of joints and slots. The horizontal displacement of joints and grooves and the temperature change of cement slab can be expressed by the following formula:

$$\Delta L = \xi\alpha\left(T_0 - T\right)\times L \tag{2}$$

Where $T$ is the annual average temperature of cement plate; $T_0$ is the actual temperature of the cement slab when filling the caulking material; $\alpha$ is the coefficient of thermal expansion of cement plate; $\xi$ is the friction coefficient between cement plate and base; $L$ is the length of cement slab.

The volume of cement plate will be deformed by the increase or decrease of water in the plate. In general, the drying shrinkage phenomenon caused by moisture evaporation inside cement slab is the most common. We will change the plate humidity caused by plate joint deformation and opening:

$$\Delta L' = \varepsilon \times L \tag{3}$$

Where $\varepsilon$ is the drying shrinkage coefficient of cement slab.

### 3.2 Elastic Displacement Analysis of Joints

There are many methods to solve the elastic body. Except for a few cases, it is hard to find a solution that fully satisfies the equilibrium equation, compatibility equation and boundary conditions. Therefore, some secondary conditions are often sacrificed according to the nature of the problem. Because the purpose of this paper is to find the displacement, the accuracy of the displacement must be ensured, and the stress can be relaxed. Therefore, this paper adopts the direct method when the joint is free and the displacement variational method when the joint bottom is consolidated [7-8].

At this time, there are the following displacement conditions:

$$U\big|_{x=0} = 0, U\big|_{y=0} = 0, V\big|_{y=0} = 0 \tag{4}$$

Therefore, in the displacement variational method, the following displacement modes satisfying the displacement conditions can be made:

$$U = A_1xy + A_2x^3y^2 \tag{5}$$

$$V = B_1y^2 + B_2x^2y^3 \tag{6}$$

According to elasticity, the deformation potential energy $P$ of plane strain problem is:

$$P = \frac{E}{2(1+\mu)}\iint_{\Omega}\left[\frac{\mu}{1-2\mu}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)^2 + \left(\frac{\partial U}{\partial x}\right)^2 + \left(\frac{\partial V}{\partial y}\right)^2 + \frac{1}{2}\left(\frac{\partial V}{\partial x}+\frac{\partial U}{\partial y}\right)^2\right]dxdy \tag{7}$$

 

Where $\Omega$ is the integral domain.

Figure 1 shows the temperature curve of observation points with time under different heat transfer coefficients of the surface layer.

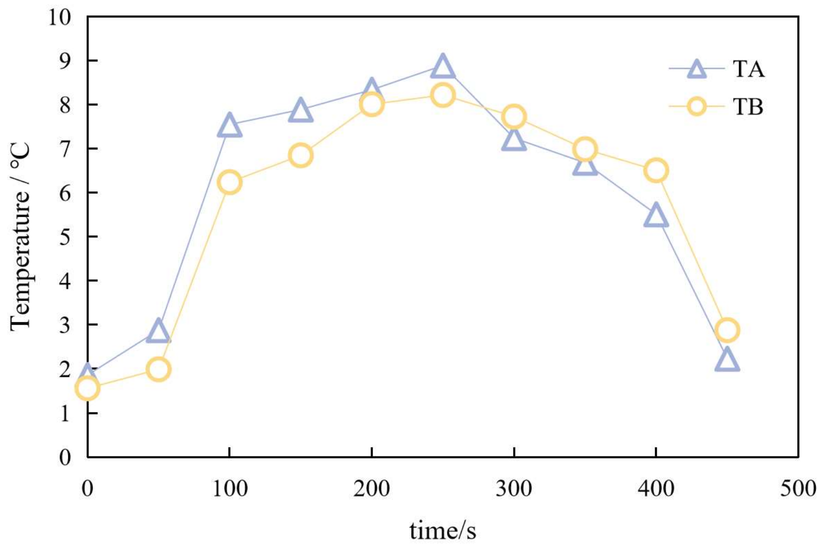


**Figure 1.** Temperature-time variation diagram of observation point under the influence of surface heat transfer coefficient

As can be seen from Figure 1, with the increase of the heat transfer coefficient of the surface layer, the maximum temperature of the nearest point and the farthest point gradually increases, which indicates that the heat energy released by the phase change material is transferred to the surface layer to the greatest extent and can be kept for a long time, so as to better melt snow and ice.

In addition, the gap between the curves of the nearest point and the farthest point becomes smaller and tends to coincide, which indicates that the overall temperature of the system tends to be balanced, which is conducive to the heat released by the system for melting snow and ice and increasing the heat release efficiency of the system. Therefore, the greater the heat transfer coefficient of the material, the better the effect of melting snow and ice. In practice, metal materials with higher thermal conductivity can be appropriately added to the surface layer to improve the heat transfer coefficient of the surface layer, thus improving the system efficiency.

# 4. Structural Stress of Caulking Material

## 4.1 Parsing Process

The joint material is also affected by shear, which is mainly due to the fact that the driving load does not act on the concrete slab statically, but passes through the joint of the pavement slab at a certain driving speed. The vertical displacement difference occurs between the loaded plate and the adjacent unloaded plate, and under the load, the pavement slab produces a slight shear vibration effect in the vertical direction, so that the caulking material is also subjected to the corresponding vibration shear effect.

Cement pavement is often subjected to various complex stresses, including vehicle loads caused by driving conditions and temperature loads caused by temperature changes. In recent years, the mechanical-thermal coupling problem at the joint of cement pavement has become a hot research topic, so the research on the mechanical properties of cement pavement sealant has always been a very important process.

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The mechanical properties of the same material are completely different because of the difference of loading time. Therefore, it is necessary to evaluate the load-carrying capacity of joints under dynamic load and identify the void slab for cement pavement, and analyze the interaction mechanism between them. In this way, we can not only know the service status of the existing cement pavement structure, but also provide the basis for taking economic and reasonable measures to repair and rebuild the old road.

Determine the material limit standard, that is, determine the ultimate tensile strain, elastic modulus and cohesive strength of the joint filler. Generally, the ultimate tensile strain $[\varepsilon_x]$ and the elastic modulus $d$ of the joint filler can be determined according to the measured stress-strain curve in the room, and the cohesive strength $[\sigma]=E[\varepsilon_x]$ can be obtained.

The joint displacement and joint width determine the strain of joint filler. If the width of pavement joint filling is $l$, the horizontal strain of joint filler is $\varepsilon_x=\frac{d}{l}$ due to thermal tensile deformation $d$.

Determine whether the horizontal strain caused by joint displacement is greater than the ultimate tensile strain. $\varepsilon_x<[\varepsilon_x]$, if the deformation is still in the elastic range, then the horizontal tensile stress $\sigma=E\varepsilon_x$ at the lowest part of the concave surface; If $\varepsilon_x>[\varepsilon_x]$, it means that the displacement of the joint opening is too large, which has exceeded the ultimate tensile strain of the material, and the joint filler is invalid and must be replaced.

Determine the vertical deformation $h$ and radian angle $\theta$ of joint filler according to the deformation coordination. The width and depth of the seam are $l,H$ respectively. According to the assumption of the deformed arc, the geometric triangle relation can be listed as follows:

$$\left(\frac{l+d}{2}\right)^2+(R-h)^2=R^2 \tag{8}$$

$$tg\theta=\frac{l+d}{2(R-h)} \tag{9}$$

After $h$ is determined, the calculation parameters such as $R,\theta$ can be obtained by substituting formula (8) and formula (9):

$$R=\frac{(l+d)^2+4h^2}{8h} \tag{10}$$

$$\theta=arctg\frac{l+d}{2(R-h)} \tag{11}$$

Silicone modified asphalt with 6%, 8% and 10% silicone modifier was selected for shear performance test, and the test results are shown in Figure 2.

From Figure 2, it can be seen that when silicone modifier is added into asphalt, the shear performance of modified asphalt is better improved, and with the change of silicone modifier content, the shear performance of silicone modified asphalt will also change. Because of the low bond strength of silicone material, it is often debonded under the action of small shear force, so its shear strength is small, but it can still meet the requirements of road performance.

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When the content of silicone modifier is 8%, the peak force of silicone modified asphalt reaches the maximum, which is obviously higher than the peak shear force when the content of silicone modifier is 6% and 10%. The results show that when the content of silicone modifier is 8%, the shear performance of silicone modified asphalt is the best. When the content of silicone modifier is 10%, its shear force is slightly larger than that of 6%.

Therefore, when silicone modifier is added into asphalt, the shear performance of modified asphalt can be improved, and the mechanical index requirements of caulking materials proposed in finite element analysis can be met. When the content of silicone modifier is 8%, the shear performance of silicone modified asphalt is the best.

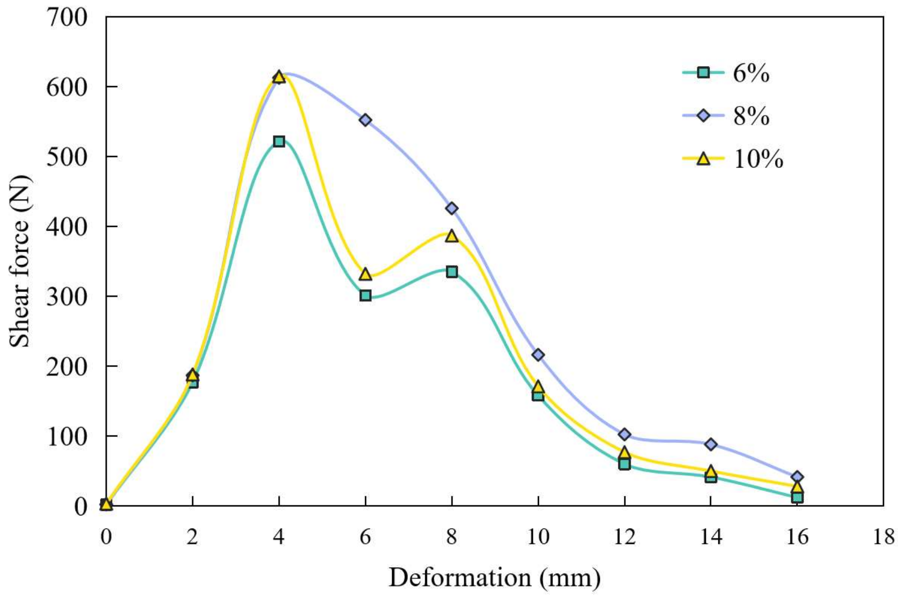


**Figure 2.** Silicone modified asphalt shear stress-strain curve

## 5. Conclusion

Based on the design idea of phase change temperature control materials and functional gradient, this paper studies the influence of factors such as the buried depth of heating layer and the heat transfer coefficient of surface layer on the strength and temperature field of the structure by numerical analysis. The horizontal displacement of airport cement pavement joints under the influence of environmental temperature and humidity changes is basically the same as that of highway cement pavement. After adding modifier into asphalt, its mechanical properties and shear strength can be greatly enhanced, and it can meet the requirements of determining the mechanical indexes of caulking materials. And when the content of modifier is 8%, the modification effect on the shear performance of modified asphalt is the best. Therefore, choosing 8% polyurethane modified asphalt-based caulking compound has the best modification effect on its shear performance.

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