High-temperature Hazards and Prevention Measurements for Asphalt Pavement

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***Abstract*—As a black material, asphalt has a strong heat-absorbing capacity which may cause pavement high temperature especially in summer. With the global climatic warming and the widely application of asphalt pavement, the problem of pavement high-temperature will be more serious. In this paper, the effect of the pavement high-temperature on road durability, traffic safety and ecological environment was analyzed, and the technical methods of lowering the pavement temperature at home and aboard were reviewed. On the basis of introducing phase change materials (PCMs) and its temperature-controlling principle, a new method was proposed to lowering the pavement temperature through preparing a kind of bionic asphalt concrete with PCMs, and the corresponding key technique was analyzed.**

Keywords-asphalt pavement; high-temperature rutting; traffic safety; urban heat island effect; phase change materials;

I. INTRODUCTION

Asphalt pavements form an integral part of any transportation system. In China, the total length of expressway is more than 60,000 kilometers, of which about 90 percent is asphalt pavement. However, as a black material, asphalt has a strong heat-absorbing capacity which easily causes pavement high temperature, especially in summer. Temperature is a significant factor that affects the performance and service life of asphalt pavement. For example, the high temperature of pavement makes the asphalt softer, thus the risk is high that heavy vehicles cause rutting due to the plastic deformation, which will decrease the pavement evenness and consequently affect the traffic safety. Meanwhile, the high temperature of pavement will increase the urban heat island effect. With the global warming, the problem of pavement high-temperature will be more serious. Therefore, it's of vital importance to control the temperature of asphalt pavement.

II. ASPHALT PAVEMENT HIGH TEMPERATURE HAZARDS

Pavement temperatures caused by solar radiation and automotive exhaust emission are undesirable. Usually, the pavement temperature is much higher than that of the ambient air, and sometimes may reach 70°C or more. It's well known that asphalt is a heat-absorbing material with an absorption rate of 0.80–0.95, meanwhile asphalt is an insulating material, absorbing heat easily but cooling slowly. Based on the surveys, the surface temperature of asphalt pavement is 24°C higher than the air temperature. In recent years, with the global warming, air temperature is generally on the rise, and most parts of China have experienced the high-temperature weather which may even last for a long time. For example, Fig. 1 shows the summer temperature in Wuhan in recent 20 years [1].

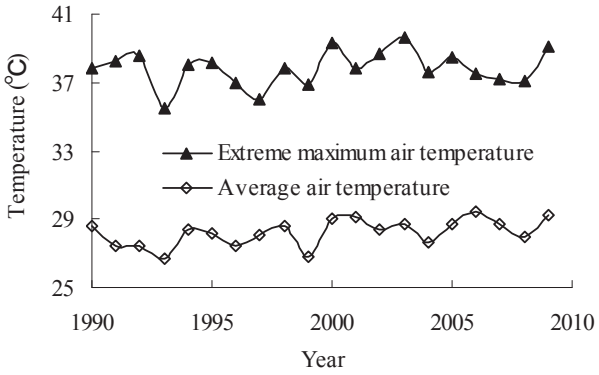

Figure 1 . Air temperature during summer in Wuhan

A. Effect of High- temperature on Road Durability

Temperature is an important factor that influences the performance of asphalt concrete. Fig. 2 shows the effect of temperature on the complex modulus of asphalt binder (AH-70). It can be seen in Fig. 2 that the complex modulus of asphalt binder decreases with the increasing of the temperature. In fact, there is a sharp decline of the stability and the structural strength of asphalt concrete with the temperature increasing. The higher the temperature is, the lower the stiffness modulus and rutting resistance of the asphalt concrete are. Asphalt pavement has been exposed to greater distress due to the softening, volume expansion and aging of asphalt under the effect of continuous high temperature [2,3]. High-temperature rutting is more acute among the asphalt pavement problems, which mainly occurs in summer, especially during the hottest days. Based on the surveys, when the air temperature is lower than 30°C, that is, the surface temperature of pavement is lower than 55°C, rutting will not occur or may be limited to several millimeters. However, it will increase rapidly when the air temperature is higher than 38°C, and serious rutting of pavement will happen in several days if the air temperature is continually higher than 40°C [4].

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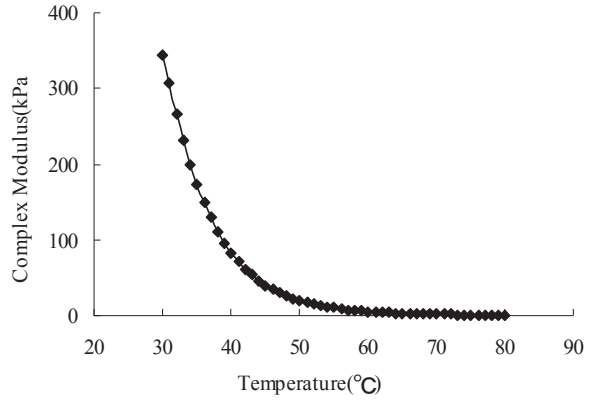

Figure 2 . Influence of temperature on complex modulus of asphalt binder

B. Effect of High-temperature on Traffic Safety

Rutting, caused by the pavement high-temperature, seriously affects the pavement performance and service life. And it decreases the road evenness, reduces driving comfort, and makes the vehicle out of control when it is overtaking or changing lanes, which affects the stability of vehicle handling. The water and ice in rutting will reduce the anti-slide performance of the road, so the rutting affects the traffic safety and induces traffic accidents.

Moreover, it's said that the pavement high-temperature is one of the reasons that cause the tire burst and vehicle self-ignition, especially when the pavement temperature reaches 40^{o}C [5]. In the summer of 2007 in Wuhan, there were 12 vehicles combusting spontaneously due to the road high-temperature during only a week [6]. Besides, the hot pavement in summer may also cause the scald of the pedestrians, especially for the old and children. For instance, there are 24 cases of second-degree scalded pedestrians in the United States during only six years. In addition, the pavement high-temperature affects the physical, mental and spiritual state of the drivers, and increases the traffic accidents due to the illusion of the drivers to the pavement situation. For example, exposed to the strong sunlight, asphalt pavement becomes shiny and seems to give off "false light", because of the oxidation and volatilization caused by softening and volume expansion of asphalt binder. Therefore, the meteorological services and traffic control departments in many provinces and cities of China have strengthened the monitoring and forecasting of the pavement surface temperature.

C. Effect of High-temperature on Ecological Environment

Asphalt pavement in high temperature would release a lot of poisonous compounds, which may deteriorate the ecological environment. It's reported that asphalt's oxidation and evaporation rate increases nearly doubles for each additional 10^{o}C temperature [7]. According to the related information, the long-wave radiation intensity of the asphalt pavement with 63^{o}C reaches 672w/m^{2}, and in summer the direct radiation intensity of the sun is between 700–l000w/m^{2}. With the development of city road nets, the asphalt pavement has become a major factor for the urban heat island effect, which is more obvious at night [8]. Besides bringing high-temperature weather which results in the reduction of industrial output and the increase of water and electricity consumption, heat island effect also leads to warmer winters, hurricane, heavy rains and other extraordinary weather, and impacts the physical and mental health of the residents. Medical researches have shown that, when the air temperature is above 28^{o}C, people will feel uncomfortable, while the temperature surpasses 34^{o}C, a series of diseases occur due to the heat waves.

III. EXISTING COOLING TECHNIQUES OF ASPHALT PAVEMENT

The pavement surface temperature may be affected by both environmental factors (e.g. solar radiation, cloud, relative humidity, wind speed, and rainfall) and road surface features (e.g. albedo, humidity and density) [9]. The possibility of human intervention on the environment is very small except for planting trees to improve the ventilation of the road. At present, the main techniques to lower the pavement surface temperature are showed as followings.

- **Water-spray cooling**. Spraying water at noon in the city can wash the road and reduce the pavement temperature, but it's not very effective. If the surface temperature is too high, the water changes to fog as soon as it is sprinkled, then watering can only act as a "dedusting" effect [10]. Moreover, the asphalt pavement in a state of moisture is prone to produce more rutting [11].
- **Cool pavement technique**. As one of the three major strategies put forward by U.S. Environmental Protection Agency to improve the urban heat island effect, cool pavement techniques focus on the material structures (e.g. porous materials) and pavement surface characteristics (e.g. high reflectance). Surface temperature of porous permeable asphalt pavement can be reduced by the evaporation and permeability of water in the pavement voids [12], which increase the construction quality variability, water damage and asphalt aging. Other methods of improving the pavement reflectivity, such as using light-colored aggregates or solar heat-reflective coating, will affect the driver vision and the high-reflective environment on human health is also unfavorable. What's worse, the high-reflective coating may affect the road anti-slide performance [13,14].
- **Heat-collecting technology**. Asphalt pavement can be heated up to 70^{o}C by the solar irradiation during the summer season because its excellent heat-absorbing property. Meanwhile after sunset the heat retained in the asphalt pavement can still provide energy. So, asphalt pavement, which serves as a solar collector for the heating and cooling of adjacent buildings as well as to reduce the pavement temperature, has gained more and more attention in recent years as an interesting and new renewable energy source [15]. However, the heat-exchange equipments in the pavement will cause a lot of stress concentration, resulting in pavement damage.

IV. APPLICATION OF PCMS IN ASPHALT PAVEMENT

A. Tempeartue-controlling Theory of PCMs in Pavement

Compared with asphalt pavement, green plants also absorb solar energy but its temperature doesn't rise due to the photosynthesis of chlorophylls. So, the pavements with some components like chlorophylls will also self-control the temperature. PCMs have the temperature-controlling function mentioned above. As seen in Fig. 3, heat energy can be stored in the form of latent heat, and the system temperature may keep relatively constant [16]. Based on the principles mentioned above, we proposed preparing a bionic asphalt concrete with PCMs. The pavement temperature rises with the absorption of solar energy, and reaches its phase transition point, then keeps nearly unchanged (seen in Fig. 4) because phase change process begins to take place, and the solar energy is stored as latent heat. Therefore, the temperature of pavement with PCMs is lower than that of one without PCMs.

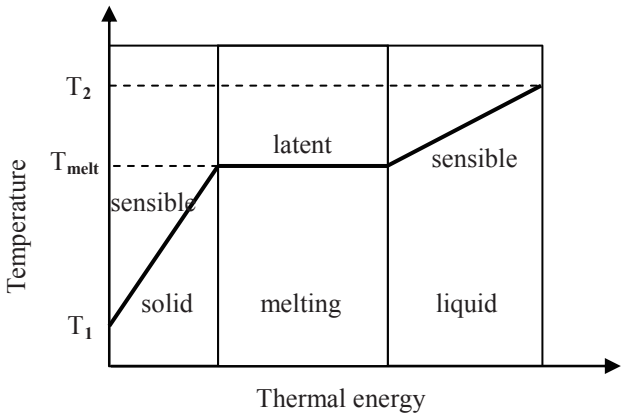

Figure 3 . Temperature –controlling principle of PCMs

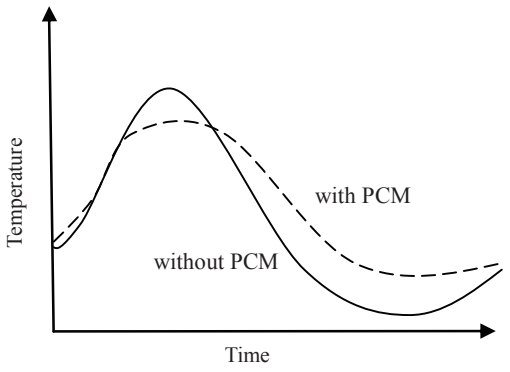

Figure 4 . Temperature cooling model of asphalt pavement with PCMs

B. Application Status of PCMs in Asphalt Pavement

Researches on PCMs in building materials at home and abroad have been studied for over 20 years, mainly concentrating on the cement concrete structures, gypsum board and other building envelope for thermal energy storage. At present there are practical applications [17]. The authors have proposed adding PCMs in large volume concrete to prevent temperature cracks during hydration periods [18,19], and in recent years there are many researches in this area [20,21].

At present, many related references have mentioned that asphalt pavement with PCMs can keep roads and bridges ice-free. In recent years, some relative patents in China have been put forward. For example, Wang B. and Dai L.P. [22] have proposed a method for preparing phase-change energy storage materials of emulsified asphalt, mainly applied in the wall materials or indoor floors. Xu H.L. [23] has proposed a method of using PCMs to prevent the road safety due to frost and cracks. Hu S.G. and Ding Q.J. [24] have proposed to prepare the phase-change asphalt using sol-gel method. However, there are no reported theoretical researches or practical application currently.

C. Key Techniques of Asphalt Pavement with PCMs

Presently, technical difficulties exist in the application of PCMs on asphalt pavement. The first one is the material cost, mainly for the currently high price of PCMs which cannot be accepted as road material. With the development of PCMs preparation technology, PCMs should have the possibility to be widely applied to road engineering. Therefore, we must pay more attention to the key techniques as followings.

- **Selection of melting temperature of PCMs**. It depends on the temperature-controlling requirements of asphalt pavement, which is a key parameter for selecting PCMs. And an ideal PCMs candidate should fulfill a number of criteria such as high heat of fusion and thermal conductivity, high specific heat capacity, small volume change, non-corrosive, non-toxic. Asphalt concrete, which is a thermo-sensitive material with strong regional character, should be selected according to weather conditions. It has been put forward in China that the climatic zoning of asphalt pavement based on the air temperature in various regions. And the relationship between pavement and air temperature has also been built in America. Therefore, it's the key that how to determine the temperature-controlling range of asphalt pavement according to the existed achievements.
- **Integration of PCMs in asphalt concrete**. Numerous studies suggest the compatibility, stability and durability of PCMs in matrix materials are of vital importance. The development of shaped-stabled PCM (SSPCM) provides the technology for the integration of PCMs in asphalt concrete. In addition, the requirements are the following. First, the better adhesivity of SSPCM and asphalt is necessary to ensure the mechanical property of asphalt concrete structure. Second, good chemical durability of SSPCM is important to prohibit the leakage of liquid during the phase change process. Third, the production of conventional asphalt concrete generally bears high-temperature of 160–180°C, which is a thermal shock to the phase change's energy-storing and temperature-controlling performance of PCMs, so the mixing technology of PCMs in asphalt mixture is worth to investigate.
- **Temperature-controlling effect and durability of asphalt pavement with PCMs**. The mixing technique

and latent heat, the dosage of PCMs in asphalt concrete are all directly related to the effect of pavement temperature controlling and durability of road engineering properties. The phase change temperature-controlling function should normally work under the coupling effect of vehicle and temperature load. Further investigation should be performed on the durability of asphalt concrete with PCMs, such as high-temperature deformation, anti-fatigue and aging resistant performance.

V. CONCLUSIONS

With the global warming and the widely application of the black asphalt pavement, the problem of pavement high-temperature becomes more serious. The pavement high-temperature has a serious influence on road durability, traffic safety and ecological environment. Taking appropriate measures to reduce the pavement temperature is of great significance for controlling high-temperature rutting and improving living environment and traffic safety. A new method is proposed to prepare a temperature-controlling asphalt concrete using phase-change materials as the functional constituents in the asphalt mixture. Compared with the existing technical methods to reduce pavement temperature, the phase-change temperature-controlling asphalt concrete is a bionic smart material. Many more researches are yet to be carried out.

ACKNOWLEDGMENT

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