Research on Climatic Influencing Factors of Low Temperature Cracking Index of Asphalt Pavement in Cold Area

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Abstract. According to the current Chinese standards, the prediction model of asphalt mixture low-temperature cracking index does not consider the influence of climatic factors on the performance of pavement materials and low-temperature stress. This paper analyzes the influence of cooling conditions and long-term aging in cold areas on the low-temperature damage of pavement. It is proposed that the prediction model of asphalt mixture low temperature cracking index is a function model that changes with time. It is necessary to consider parameters such as cooling rate and creep rate attenuation index to correctly predict the low temperature cracking condition of roads within the service life.

Keywords: asphalt pavement, cold regions, low temperature cracking index, climatic factors.

1. Introduction

Cracking of asphalt pavement during service life is a common problem in countries all over the world. The phenomenon of low-temperature cracking of asphalt pavement is more prominent in countries and regions such as Northern Europe, North America, Russia, Japan and Northern China. According to statistics, some roads have different degrees of cracking damage before reaching the designed service life, which is mainly manifested by the increase in the number of cracks in winter, the obvious widening of cracks and the continuous lengthening of cracks. The occurrence of cracks not only affects the performance of the road, but also severely shortens the service life of the road, and at the same time increases the maintenance cost of the road, and finally causes serious economic losses. Asphalt concrete pavement cracks are caused by many and complex factors. However, in high-cold areas, where the temperature difference is large and the cooling rate is faster, it is very important to predict the low-temperature damage of asphalt pavement in a specific climate environment. A large amount of relevant information shows that traditional standards and methods cannot control the damage of asphalt pavement, and many pavements that meet current codes and are designed according to traditional methods have suffered early damage. The important reason is that the impact of the special climate environment on the road performance of asphalt mixture is not considered. Therefore, it is necessary to put forward reasonable factors affecting the low-temperature cracking of asphalt mixture in cold areas, and provide a reference for further revising the low-temperature cracking prediction model of asphalt.
mixture. Correctly predicting the occurrence and development of cracks is very important for road construction and management departments in the cost analysis and maintenance measures of low-temperature crack maintenance for high-grade roads.

2. Haas low temperature crack prediction model
Many international researchers have done a lot of investigation and research on the prediction of low-temperature cracking of asphalt pavement. Through verification, the Hass model can predict the low-temperature cracking of asphalt pavement very well. Its function mode is:

\[ I = f(S, a, m, d, t) \]

In the formula, \( I \) is the crack index; \( S \) is the original stiffness of the asphalt; \( a \) is the road age; \( d \) is the roadbed type parameter, \( m \) is the low-temperature design temperature, \( t \) is the asphalt layer thickness.

Although scholars from different countries have verified the applicability of this model in different regions, the road is in an environment with changing external climatic conditions. In addition to the material properties, pavement structure and other factors that do not change over time, the prediction of cracking conditions should also consider the direct influence of weather conditions on material properties and temperature stress over time.

3. The effect of cooling rate on temperature stress
In North China and Northeast China, the temperature is lower in January and December in winter. The lowest monthly average temperature in January in colder areas in Inner Mongolia and Heilongjiang is \(-27^\circ\text{C} \sim -31^\circ\text{C}\). From November to January in Mohe, Heilongjiang, the average daily maximum temperature and daily average minimum temperature are below zero and the temperature difference is above \(15^\circ\text{C}\). The daily minimum temperature in December is \(-40^\circ\text{C} \sim -35^\circ\text{C}\), and the daily maximum temperature is \(-25^\circ\text{C} \sim -20^\circ\text{C}\). In Yakeshi, Inner Mongolia, the average monthly maximum temperature and monthly minimum temperature in January are both below zero and the temperature difference is above \(12^\circ\text{C}\). The relaxation performance of asphalt mixtures is poor at lower temperatures, which has a greater impact on low temperature stress. As the temperature decreases, the stress relaxation modulus increases, and the stress relaxation performance and low temperature crack resistance of the asphalt mixture worsen. Therefore, in an environment where the temperature of the asphalt pavement drops sharply in areas with large temperature differences, the temperature shrinkage stress generated inside the structure does not have time to relax and slowly accumulates, and finally exceeds the tensile strength and causes cracking.

Fu Guozhi used the Boltzmann superposition principle and considered the relaxation effect of the asphalt mixture to calculate the stress accumulation process of the asphalt mixture at different cooling rates, and calculated the low-temperature cracking temperature from the tensile strength of the material [1]. The accumulation process of temperature stress of asphalt mixture accelerates with the increase of the cooling rate. The faster the cooling rate, the higher the low-temperature cracking temperature, that is, the easier it is for low-temperature cracking to occur. The reason is that the relaxation modulus of the asphalt mixture increases as the temperature decreases, and the relaxation performance and low temperature crack resistance of the asphalt mixture decrease accordingly. In the process of a sudden temperature drop, the faster the temperature drop, the less time the temperature shrinkage stress can relax. It gradually accumulates until it exceeds the tensile strength and cracks.
Tian Xiaoge used the Thermal Stress Restrained Sample Tests (TSRST) to conduct temperature stress tests on different asphalt mixture specimens under different cooling conditions (different cooling initial temperatures, different cooling rates) [2]. The test results show that at the same initial temperature, the greater the temperature drop rate, the greater the temperature stress. When the temperature is higher than 5°C, the temperature stress of the asphalt mixture measured in the test is 0. This is because the asphalt mixture has better relaxation performance at higher temperatures, which just offsets the temperature stress generated during the cooling process. At the same time, it also shows that the influence of cooling conditions on temperature stress should be considered in areas with high cold and large temperature differences.

In summary, considering the influence of relaxation effect on temperature stress under different cooling rates is to accelerate the rate of stress accumulation and increase the low temperature failure temperature. Therefore, in high-cold areas with large temperature differences, the low-temperature cracking index prediction model indirectly corrects the low-temperature design temperature through the cooling rate.

4. The effect of long-term aging on low-temperature cracking
At present, it is unreasonable to use the low temperature test of the original asphalt mixture in the low temperature crack prediction model to evaluate its failure state. Pavement asphalt mixtures in use should be tested for low-temperature cracking resistance after long-term aging to evaluate low-temperature cracking resistance. Research shows that as the degree of aging of road asphalt mixture deepens, its low-
temperature crack resistance decreases, and long-term aging has a more significant impact on low-temperature crack resistance. A large number of survey data show that most road cracks do not appear within a period of time after completion, but after a certain period of natural aging. There is a good correlation between the cracking condition of the aging asphalt mixture pavement and the low-temperature creep characteristics. As the temperature decreases, the creep rate decreases and the creep stiffness becomes larger, the lower the resistance to low-temperature deformation, the worse the low-temperature crack resistance. Considering the practical significance of long-term aging for evaluating low-temperature cracking of asphalt mixtures, the delay oven heating method should be used to obtain the creep rate decay index \[ \eta = \frac{\varepsilon_0 - \varepsilon_a}{\varepsilon_0} \]

In the formula, \(\varepsilon_0\) is the creep rate of the original asphalt mixture; \(\varepsilon_a\) is the creep rate of the asphalt mixture after long-term aging.

5. **Modified low-temperature cracking index function model**

According to survey data, the pavement cracking index of Minnesota, USA (43°N to 49°N) develops rapidly in the early stage of road use and slower in the later stage. The development of pavement cracking index in Illinois (36°58′~42°30′ north latitude) is just opposite to that of Minnesota [5].

![Figure 3. The relationship between Minnesota’s low temperature cracking index and service life](image1)

![Figure 4. The relationship between Illinois low temperature cracking index and service life](image2)

According to the above survey data, first of all, the low-temperature cracking index is a function of time t, and the low-temperature cracking index varies with time in different regions. Secondly, analyzing the climate of Minnesota, the average highest temperature in January is only -10°C, while the lowest temperature can be as low as -22°C. The lowest temperature record is -51°C. Under the climatic conditions of lower temperature and faster cooling rate, the road will produce greater temperature stress and higher cracking temperature. The cracks develop faster in the early stage of use, and the cracks develop mainly due to creep in the later stage. Illinois is a temperate zone with an average minimum temperature of -11°C in winter and a maximum temperature of 2°C. Under the action of the climatic conditions with a small temperature difference and a small cooling rate, the road produces less temperature stress and fewer cracks during use. However, as the road service cycle increases, the more serious the aging, the more severe the pavement performance, the greater the creep stiffness, the lower the creep rate, the worse the low temperature performance, the more serious the cracking. The calculation from the data shows that the crack development speed caused by temperature and cooling rate is greater than the crack development speed after asphalt pavement aging.

Based on the analysis of the above survey data, the low-temperature cracking index in cold areas should consider the impact of cooling conditions and long-term aging on the low-temperature damage.
of the road surface. Therefore, the prediction model of asphalt mixture low-temperature cracking index is a function model that changes with time. It is also necessary to consider parameters such as cooling rate and creep rate attenuation index to correctly estimate the low-temperature cracking condition of roads within the service life. The function model is as follows:

$$I = f(S, a, m, d, t, \eta, v)$$

In the formula, $\eta$ is the attenuation index based on long-term aging, and $v$ is the cooling rate.

6. Conclusions
Different regions have different climatic conditions, and the development model of road low-temperature cracking index over time is different. Correction of existing models by climate parameters to accurately predict low temperature cracking index.

(1) Low temperature cracking index is a function of time (road service life);

(2) The cooling rate speeds up the stress accumulation speed and increases the low temperature failure temperature. In high-cold areas with large temperature differences, the low-temperature design temperature can be corrected indirectly through the cooling rate;

(3) Considering the effect of aging on material properties, the original stiffness is corrected by the decay index based on the creep rate of long-term aging.

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