Application of Mid-surface Layer in Asphalt Pavement Tunnel Paving Based on Foam Warm Mix Technology

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Abstract. With the deepening of the national green transportation policy, the construction of environmental protection and energy-saving highway has become the focus of the industry. Based on the problem of flue gas emission from asphalt pavement tunnel pavement, the mechanical foaming warm mixing technology is introduced. The foaming characteristics of modified asphalt, the performance of foam warm mix mixture, and the evaluation of energy consumption and emission reduction of foam warm mix mixture are studied and analyzed. The results show that the energy consumption of foam asphalt production is significantly reduced, which has positive demonstration significance for energy saving and emission reduction in highway construction.

1. Introduction
At present, China is in the period of rapid development of highway construction, the mileage of asphalt pavement is increasing year by year, and the demand for asphalt mixture is very large. With the deepening of the national green traffic policy, the local traffic authorities actively advocate the construction of environmental protection highway, the purpose is to achieve the unity of environmental benefits, social benefits and economic benefits [1-3]. The application of foamed asphalt mixture is a breakthrough in this area and will become a trend of development in the future. Foamed asphalt is not a new asphalt binder. Instead, it controls the physical properties of bituminous materials to make the asphalt foam. When water meets the high temperature asphalt binder, the water will vaporize quickly to form water vapor, and there will be many tiny bubbles from the interface between water and asphalt. In this process, it is because of the foaming expansion of asphalt that the viscosity of asphalt decreases and the mixing performance is improved, but at the same time, the adhesion at lower temperature is improved. After decades of development, scholars have improved the mechanical foaming process, using normal temperature water instead of steam, and in the case of low pressure, injecting cold water into heated asphalt can also produce good foaming and viscosity reduction effect, so this technology becomes more simple and applicable. Due to the high construction temperature of modified asphalt mixture, the amount of flue gas is large, and the emission carries a lot of greenhouse gases. Tunnel pavement construction space is narrow, the smoke in production cannot be discharged immediately, which will not only increase the construction difficulty, reduce the project quality, but also affect the health of construction personnel [4].

Therefore, in view of the problem of asphalt pavement tunnel pavement, the mechanical foaming foam warm mixing technology is introduced. The foaming characteristics of modified asphalt, the
performance of foam warm mix mixture, and the evaluation of energy consumption and emission reduction of foam warm mix mixture are studied and analyzed.

2. Study on foaming characteristics of asphalt
At present, the main technical indexes to evaluate the foaming effect of asphalt are expansion rate and half-life. The expansion rate is the ratio of the maximum volume and the original volume of asphalt that can be reached when asphalt foams. The greater the volume expansion ratio of asphalt, the better the workability and the higher the dispersion uniformity of the foamed asphalt in the final mixture. The half-life is the time required to reach the maximum volume of the asphalt in the foaming state until the foam dissipates to half the maximum volume \([5, 6]\). The longer the half-life, the slower the attenuation of asphalt foam, and the longer the effective mixing time can be provided during construction.

Therefore, when evaluating the effect of asphalt foaming, the expansion rate and half-life are two inseparable indicators. In order to make the asphalt and aggregate fully contacted, the specific surface area of the foamed asphalt needs to be as large as possible, that is to say, the larger the expansion rate is, the better. If foamed asphalt does not have enough time to maintain its foam so that it is too late to mix with aggregate, it will lead to no good adhesion between foamed asphalt and aggregate. Therefore, it is necessary to have enough time to mix the foam asphalt with the aggregate, so that the longer the half-life is, the better.

The best foaming conditions need to make the change curve of expansion rate and half-life according to the data of foaming test, find the upper and lower limits according to the lowest acceptable expansion rate and half-life, and take the middle point of the range as the best foaming condition at this temperature. Finally, compare the best foaming conditions under various temperatures, select the optimal foaming effect, and comprehensively determine the optimal foaming conditions of the asphalt.

The temperature of field modified asphalt is 170℃ and the water temperature is 25℃. Through the control of water consumption, the relationship between expansion rate, half-life and water content is shown in the figure below.

![Figure 1: Relationship curve of water consumption, expansion rate and half-life.](image)

As shown above, when the site water consumption is 1.5%~2.0%, the foamed asphalt can have both expansive rate and half-life condition. Therefore, the site water consumption is 1.8% for paving.

3. Warm mix foam application and study of performance
In order to verify the performance of the mixture, the research group adopted Marshall test mix design method to optimize the mineral aggregate gradation, determine the optimal asphalt content, determine the site paving temperature, and carry out rutting test and freeze-thaw splitting test of specified test
conditions after the raw materials are tested to be qualified, confirmed that the design results meet the technical standards of mix proportion design and the inspection requirements of mix proportion design.

In this test, the target mix proportion design, production mix proportion debugging and field application test section are used to determine the grading, and the passing rate of each sieve hole is shown in Table 1.

| Table 1. Passing rate of each mesh of design target gradation (%) |
|---------------------------------------------------------------|
| Mesh size (mm)       | 26.5 | 19  | 16  | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
| Upper limit          | 100.0 | 90.0 | 78.0 | 62.0 | 50.0 | 26.0 | 16.0 | 12.0 | 8.0 | 5.0 | 4.0  | 3.0  |
| Lower limit          | 100.0 | 100.0 | 92.0 | 80.0 | 72.0 | 56.0 | 44.0 | 33.0 | 24.0 | 17.0 | 13.0 | 7.0  |
| Pass rate            | 100.0 | 95.5 | 84.1 | 73.4 | 61.0 | 34.3 | 25.2 | 19.8 | 13.3 | 10.4 | 9.1  | 5.6  |

From the above table, it can be seen that the passing rate of each sieve hole of the grading is within the scope of the specification. The asphalt content of the determined graded mixture is determined by the test, and the final asphalt content is 4.3%. The Marshall Test results are shown in Table 2

| Table 2. Marshall Test results for determining gradation. |
|---------------------------------------------------------|
| Test results                                           | bulk density | Air voids (%) | Marshall stability (kN) | Flow value (mm) | VMA (%) | VFA (%) |
|---------------------------------------------------------|---------------|---------------|-------------------------|-----------------|---------|---------|
| average                                                 | 2.478         | 4.1           | 15.8                    | 3.7             | 13.7    | 70.2    |
| standard                                                | /             | 3~5           | ≥8                      | 2~4             | ≥13     | 65~75   |

It can be seen from the above table that the Marshall Test results of graded mixture all meet the requirements of the standard. On this basis, the research group carried out Marshall Test of cooling mixture under four kinds of temperature compaction conditions.

| Table 3. Compaction temperature and corresponding porosity. |
|-------------------------------------------------------------|
| temperature                                           | 120℃ | 130℃ | 140℃ | 150℃ |
| air voids (%)                                           | 5.2   | 4.3   | 4.0  | 3.5  |

The test results in the table above show that the volume index of mixture is good when the temperature drop range is 20 ~ 30 ℃, and the volume index reaches the best state when the cooling range is 25 ℃. Therefore, the paving temperature is determined to be 25 ℃ for construction.

According to the requirements of the specification, the dynamic stability of the asphalt mixture is measured by forming the test piece according to the optimal asphalt content, so as to test the anti-rutting ability of the asphalt mixture. The water stability of the mixture is tested by freeze-thaw splitting test. The test results are shown in Table 4

| Table 4. Anti-rutting performance and water stability test. |
|------------------------------------------------------------|
| Type of mixture                                           | dynamic stability (times / mm) | TSR (%) |
| Foamed asphalt mixture                                    | 3088                          | 89      |
| Modified asphalt mixture                                  | 3539                          | 82      |
| Specification requirements                                | ≥2800                         | ≥80     |

From the above table, it is known that the dynamic stability of foam asphalt mixture is lower than that of modified asphalt, and the freeze-thaw splitting strength ratio is higher than that of modified
asphalt mixture. It is proved that the foamed asphalt has higher water stability for the production mix, and the dynamic stability and freeze-thaw splitting strength of the foamed asphalt mixture meet the existing specification requirements.

4. Energy consumption evaluation of foam warm mix mixture
Because the warm mixing technology reduces the mixing temperature of asphalt mixture, it has obvious energy saving and emission reduction effect in the mixing process of asphalt mixture. The use of warm mixing technology of asphalt mixture can effectively reduce the construction temperature, and reduce the construction temperature can reduce the energy consumption.

The production process of asphalt mixing plant mixture will inevitably emit toxic gas. Warm mixing technology can not only reduce the consumption of natural gas and other energy from the source, but also effectively curb the emission of pollution gas and asphalt smoke by reducing the temperature during construction mixing. The significance of foam warm mixing is that the temperature must be controlled within a certain range, and there is not a large amount of asphalt dust in this range.

In the process of asphalt mixture production, the energy saving and emission reduction effect of foamed asphalt is mainly achieved by reducing the heating temperature of aggregates and saving natural gas consumption. In this paper, through the statistics of the use of natural gas in the mixing station before and after the use of foamed asphalt, the proportion of gas saving is determined as follows:

Table 5. Gas saving ratio.

| Production conditions | modified asphalt | foam warm mix |
|-----------------------|------------------|---------------|
| Gas consumption (m³/t) | 6.25             | 5.16          |
| Gas saving ratio      |                  | 17.5%         |

Using foam warm mix asphalt, the heating temperature of the aggregate is reduced from 190 to 160 degrees, which greatly improves the heating efficiency of the aggregate, reduces the energy consumption and the construction temperature drops 25 degrees. The research group has conducted an investigation on the consumption of gas at the mixing station, and the survey result has dropped by about 17.5% compared with the normal production.

5. Summary
(1) The expansion rate and half-life are the key indicators affecting the performance of foamed asphalt. The two indicators are directly related to the water consumption. In this experiment, when the water consumption is 1.5%~2.0%, the foamed asphalt has a balanced expansion rate and half-life, and the final water consumption is 1.8%.

(2) Through the Marshall compaction test of four temperatures, it is found that the volume index of mixture can reach good when the cooling range is 20 ~ 30 ℃, and the volume index reaches the best state when the cooling range is 25 ℃;

(3) Tests on rutting resistance and water stability showed that the dynamic stability of foam asphalt mixture was lower than that of modified asphalt, and the splitting strength of freeze-thaw was higher than that of modified asphalt mixture. It was proved that foamed asphalt had higher water stability and slightly lower rutting resistance.

(4) The research group carried out the investigation of natural gas consumption at the mixing station, and the results showed that the foam asphalt decreased by about 17.5% compared with the normal production. It has a demonstration significance for energy conservation and emission reduction in highway engineering construction.

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