Study on Preparation and Performance Evaluation of Environment-Friendly Asphalt Mixture

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Abstract. In this paper, the environmental characteristics of foaming asphalt mixture are analyzed and the benchmark ratio is determined by Marshall test. Through the research on the production control parameters of mineral foaming and mechanical foaming, on the one hand, the optimal content of ZQ mineral foaming agent was determined to be 7%. On the other hand, the water consumption for mechanical foaming of SBS modified asphalt was set as 3.0 ± 0.2%, the asphalt temperature was set as 165 ± 2 °C, and the water temperature was set as 30 ± 2 °C. At the same time, a method for determining the optimal content of mineral foaming agent based on asphalt modulus evaluation is proposed, and the influence degree of each factor of mechanical foaming based on grey correlation method. During the mixing test, the actual production was simulated, the samples were formed after the mixture aged for 2 hours in a short time, and the cooling range and performance of the foamed asphalt mixture were studied. The results show that the foamed asphalt mixture can reduce about 25 °C compared with the hot-mixed asphalt mixture, and the performance of the mixture can meet the requirements of the current specification.

1. Introduction
Since 1990s, the application of foamed asphalt technology in engineering shows a trend of continuous growth [1-3]. On the one hand, the technology of cold and hot regeneration and warm mixing of foamed asphalt can not only solve the high cost and waste of resources of traditional road maintenance. On the other hand, the foam warm mixing technology has greatly reduced carbon emissions and environmental pollution [4].

Due to the limited time of application and development, many technical problems such as asphalt foaming characteristics, material design and construction process have not been completely solved, and systematic research results are lacking. At the same time, there are objective differences in material properties, climatic conditions and geological environment in different countries and regions. Scholars have different opinions on key technical issues such as foaming effect standards and material design methods [5-6].

Different asphalt temperature, foaming water consumption, foaming water temperature and foaming agent dosage were determined to study the influence of various factors on foaming effect.
Through grey correlation analysis, the optimal implementation scheme of mineral foaming and mechanical foaming was determined. Through compaction test, the mixing ratio of foamed asphalt mixture was designed and the compaction temperature of the mixture was studied. The road performance of the mixture was evaluated by high temperature, low temperature, water damage resistance and fatigue test. The research results provide reference for the application of foaming asphalt mixture.

2. Base mix design of asphalt mixture

2.1. The materials
SBS modified asphalt was used in this test. Mineral foaming agent is ZQ additive, and the aggregate used in the experiment is limestone aggregate. Test according to JTG e42-2005, The test results are shown in Table 1.

| material | Apparent density (kg/cm³) | Bulk density (kg/cm³) | Water absorption (%) | Bulk density (kg/cm³) | Loose porosity (%) | Compacted density (g/cm³) | Ramming voidage (%) |
|----------|---------------------------|-----------------------|----------------------|-----------------------|-------------------|--------------------------|-------------------|
| 10~20mm  | 2.743                     | 2.710                 | 0.45                 | 1483                  | 45.29             | 1616                     | 40.38             |
| 5~10mm   | 2.733                     | 2.700                 | 0.44                 | 1392                  | 48.46             | 1576                     | 41.62             |
| 0~3mm    | 2.714                     | 2.670                 | 0.604                | 1606                  | 39.86             | 1782                     | 33.27             |

2.2. Mix design
Ac-20 asphalt mixture was used in this test. The gradation design of the mixture refers to JTG f40-2004. The synthesis grading results are shown in Table 2. This subject considers the actual situation, the mixture aged for 2 hours after mixing. The Marshall results are shown in Table 3.

| project                      | The pass rate of each mesh % | The pass rate of each mesh % |
|------------------------------|------------------------------|------------------------------|
|                              | 26.5 19 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |                              |
| The maximum                  | 100 90.0 83.0 73.0 56.0 35.0 22.0 15.0 10.0 6.0 5.0 4.0 |                              |
| The minimum value            | 100 100 95.0 86.0 70.0 48.0 33.0 23.0 16.0 11.0 9.0 6.0 |                              |
| The median value             | 100 95.0 89.0 79.5 63.0 41.5 27.5 19.0 13.0 8.5 7.0 5.0 |                              |
| Design value                 | 100 98.1 90.7 80.8 62.0 38.6 26.5 19.2 12.4 8.3 6.8 4.8 |                              |

3. Determination of foam asphalt production parameters

3.1. Determination of production parameters of mineral foamed asphalt
A mineral foaming agent ZQ was used in this paper. Four different dosages (0%, 6%, 7%, 8%) were prepared according to the manufacturer's recommendation. The influence of ZQ on asphalt properties was studied.
Table 4. The results of conventional indexes of asphalt under different ZQ content

| Parameter                          | ZQ dosage | maximum fluctuation |
|------------------------------------|-----------|---------------------|
| Needle penetration, 25°C, (0.1mm)  | 48 49 49 48 | 2.1%                |
|                                    | 6% 7% 8%  |                     |
| Softening point, (°C)              | 84 83.5 83 81 | 3.6%                |
|                                    | 6% 7% 8%  |                     |
| Ductility, 5°C, (cm)               | 31 33 32 33 | 6.5%                |
|                                    | 6% 7% 8%  |                     |
| Viscosity of 135°C, Pa.s           | 3.00 3.15 3.05 3.19 | 6.3%                |
|                                    | 6% 7% 8%  |                     |

Through the test of the conventional index of asphalt with different ZQ content, the results show that the effect of ZQ content on the conventional index of asphalt is small.

According to AASHTO T315, the high temperature performance test of asphalt mortar was carried out at 30°C, 40°C, 50°C and 60°C, and the dynamic modulus data was collected. The test conditions were: the rotor diameter was 25mm, the rotor clearance was 1mm, the speed was 10rad/s, the stress level was 100Pa. The curve of modulus change of asphalt with different foaming agent dosage is shown in the Figure1.

Figure 1. The influence of ZQ content on asphalt modulus

The experimental results show that there is an extreme value of its modulus. When the content of ZQ is 7%, the modulus of asphalt is the largest and the high temperature performance is the best. The phase Angle is basically stable at various temperatures and does not fluctuate significantly with the change of mixing amount. It shows that the admixture has no effect on the structure of asphalt.
3.2. Determination of Production Parameters of Mechanical Foamed Asphalt

3.2.1. Determine the optimum foaming conditions. The test results show that the modified asphalt temperature is lower than 140°C, which is easy to cause the blockage of the foaming machine, and the asphalt is difficult to foam. At the same time, too high heating temperature of asphalt is easy to cause asphalt aging, so the test temperature of modified asphalt is determined to be 150-180°C.

Based on all factors, 4 different asphalt heating temperatures (150°C、160°C、170°C、180°C), 7 different foaming water consumption (1%、1.5%、2%、2.5%、3%、3.5%、4%) and 7 different foaming water temperatures (10°C、20°C、30°C、40°C、50°C、60°C、70°C) were selected. Study the influence of various factors on the foaming effect of asphalt. The specific test results are shown in the Table 5

| Asphalt temperature(°C) | Water ratio(%) | Asphalt water temperature(°C) | Asphalt pressure(Mpa) | The water pressure(Mpa) | Air pressure(Mpa) | Maximum expansion rate(%) | The half-life(s) |
|--------------------------|----------------|-------------------------------|-----------------------|------------------------|------------------|--------------------------|------------------|
| 150                      | 2              | 23                            | 1.5                   | 0.5                    | 0                | 6                        | 40.5             |
| 160                      | 2              | 23                            | 1.5                   | 0.5                    | 0                | 6.2                      | 37.1             |
| 170                      | 2              | 23                            | 1.5                   | 0.5                    | 0                | 6.6                      | 35.5             |
| 180                      | 2              | 23                            | 1.5                   | 0.5                    | 0                | 6.4                      | 36.7             |
| 170                      | 1              | 23                            | 1.5                   | 0.5                    | 0                | 4.3                      | 40               |
| 170                      | 1.5            | 23                            | 1.5                   | 0.5                    | 0                | 5.0                      | 37.7             |
| 170                      | 2.5            | 23                            | 1.5                   | 0.5                    | 0                | 8.9                      | 32.1             |
| 170                      | 3.5            | 23                            | 1.5                   | 0.5                    | 0                | 9.4                      | 30.6             |
| 170                      | 4              | 23                            | 1.5                   | 0.5                    | 0                | 8.0                      | 33.1             |
| 170                      | 3              | 10                            | 1.5                   | 0.5                    | 0                | 9.6                      | 30.9             |
| 170                      | 3              | 20                            | 1.5                   | 0.5                    | 0                | 10.0                     | 30.7             |
| 170                      | 3              | 23                            | 1.5                   | 0.5                    | 0                | 10.2                     | 30.2             |
| 170                      | 3              | 40                            | 1.5                   | 0.5                    | 0                | 10.0                     | 30.8             |
| 170                      | 3              | 60                            | 1.5                   | 0.5                    | 0                | 9.8                      | 30.1             |
| 170                      | 3              | 70                            | 1.5                   | 0.5                    | 0                | 9.6                      | 31.1             |

According to the test data in Table 5, the maximum expansion rate and half-life of asphalt after foaming are plotted in the figure, and the results are shown in the Figure2, Figure3 and Figure4.

![Figure 2. Effect of asphalt temperature on foaming](image-url)
Figure 3. The effect of water content on the foaming of asphalt

Figure 4. Effect of water temperature on foaming

(1) Effect of asphalt temperature on foaming

Figure 2 shows that under other conditions unchanged, the maximum expansion rate and half-life of modified asphalt will both have an extreme value when the asphalt temperature reaches 170°C. Through the above experiments, it can be seen that increasing the temperature of asphalt is conducive to foaming, and the maximum expansion rate will increase with the increase of temperature, but it is not that the higher the temperature of asphalt, the better the foaming effect. The temperature of modified asphalt was set at 170°C based on the test results of maximum expansion rate and half-life.

(2) The effect of water content on the foaming of asphalt

Figure 3 shows that the water content has a great influence on the foaming effect. The amount of water used for foaming can increase the size of foam and increase the expansion rate, but the stability of foam asphalt decreases with the increase of water use. When the water consumption increases to a certain degree, the stability of the system changes gradually, and the maximum expansion rate and half-life both appear an extreme value when the water consumption increases to 3%.

(3) Effect of water temperature on foaming

Figure 4 shows that the foaming expansion rate of asphalt will increase with the increase of water temperature. However, it does not mean that the higher the temperature, the better. On the premise that other conditions remain unchanged, combined with the maximum expansion rate, half-life and
economic factors, the final foaming water temperature is set as room temperature, and the test room temperature water is about 30°C.

Based on the above research results, the water consumption for mechanical foaming of SBS modified asphalt was set as 3.0±0.2%, the asphalt temperature was set as 165±2°C, and the water temperature was set as 30±2°C.

3.2.2. Significance analysis of each factor. According to the preliminary results of the asphalt foaming test, the grey correlation coefficient of each influencing factor is analyzed[7], and the calculated results are shown in the Table 6.

| Test index       | Calculation results based on foam expansion ratio | Calculation results based on foam half-life |
|------------------|--------------------------------------------------|------------------------------------------|
| Asphalt temperature | 0.748                                           | 0.784                                    |
| Water consumption | 0.762                                           | 0.830                                    |
| Water temperature | 0.414                                           | 0.652                                    |

According to the results in table 6, the foaming effects of each factor from large to small are as follows: water consumption, asphalt temperature and water temperature.

4. Study on the cooling amplitude of environment-friendly asphalt mixture

Aggregates and gradations of the same ratio as the reference were used. For hot mix asphalt, the voidage is mainly determined by gradation when the temperature is very high and very low. Under normal operating temperature, the compaction effect depends on the asphalt viscosity, which is closely related to the temperature. Therefore, the compaction temperature affects the pavement performance of asphalt mixture, so it is necessary to determine the optimum forming temperature of foamed asphalt mixture.

4.1. Study on cooling amplitude of mineral foaming asphalt mixture

The content of ZQ was 7% of the asphalt quality. Four different mixing temperatures (120°C, 130°C, 140°C and 150°C) were proposed for compaction test. The cooling amplitude of the mineral foaming asphalt mixture was determined according to "volume equivalence principle" of shaped test pieces. The mixing sequence of mineral foam asphalt mixture is different from that of hot mixing. The mixing sequence is as follows: aggregate → asphalt →ZQ additive → mineral powder. The voidity-temperature curve of mineral foaming mixture is shown in the Figure5.

![Figure 5. Voidity-temperature curve of mineral foaming mixture](image-url)
Through the compaction test, the optimal molding temperature of ZQ mineral foam asphalt mixture was determined to be 145°C, and the temperature could be reduced by about 20°C compared with the hot-mixed mixture.

4.2. Study on the optimum molding temperature of mechanical foaming asphalt mixture

The foamed asphalt mixture was compacted at different temperatures. The optimum compaction temperature of foamed asphalt mixture was obtained by volume equivalence. Figure 6 shows the change curve of void fraction under different compaction temperatures.

![Figure 6. Curve of relation between compaction temperature and voidage of asphalt mixture](image)

It can be seen from the figure that the void ratio of foamed asphalt mixture increases with the decrease of compaction temperature. When the compaction temperature is between 130°C and 140°C, the voidage of the mixture can meet the requirements, and the voidage is about 4%. Therefore, the compaction temperature can be reduced by about 25°C compared with the hot mix asphalt mixture.

5. Study on road performance and mechanical properties of environmental-friendly asphalt mixture

5.1. Study on road performance of mineral and mechanical foamed asphalt mixture

The high temperature stability, low temperature crack resistance and water stability of foamed asphalt mixture were studied by using the benchmark ratio. The comprehensive performance was further evaluated by Hamburg test. The comparison of test data is shown in the Table 7.
Table 7. Comparison of pavement performance of foamed asphalt mixture

| Project                           | Mineral foam asphalt mixture (ZQ content: 7%) | Mechanical foam asphalt mixture | SBS asphalt mixture | Specification的要求 | Test method |
|-----------------------------------|------------------------------------------------|---------------------------------|---------------------|-----------------------|-------------|
| Batch process                     | Aggregate→asphalt→foaming agent→mineral powder | Foamed asphalt preparation; Aggregate→asphalt→mineral powder | Aggregate→asphalt→mineral powder | / /                    | / T07 02-2011 |
| Molding method                    | Short aging 2h, Marshall compaction or rotary compaction | Short aging 2h, Marshall compaction or rotary compaction | Marshall compaction or rotary compaction | / /                    | / T07 02-2011 |
| Mold temperature                  | 145°C                                          | 140°C                           | 165°C               | / /                    | / T07 05-2011 |
| Void, %                           | 4.1                                            | 4.0                             | 4.5                 | 3-6                    | / / T07 05-2011 |
| Dynamic stability, second/mm      | 4300                                           | 4247                            | 4865                | ≤2800                  | / / T07 15-201 |
| Freeze-thaw splitting strength ratio, % | 80.3                                           | 89.0                            | 91.5                | <80                    | / / T07 05-2011 |
| Trabecular bending test, μm        | 2527                                           | 2509                            | 2657                | <2500                  | / / T07 05-2011 |
| Hamburger test                    | 3.68                                           | 4.15                            | 3.2                 | 20,000 times of rolling, deformation <12.7mm | / / USA |

Compared with the hot-mix mixture, the rutting stability of foamed asphalt mixture is reduced by about 12%, the low-temperature failure strain is reduced by about 5%, the splitting strength ratio is reduced by about 8%, and the reduction is not high. Therefore, the foam asphalt mixture design and production attention to mix ratio control, when necessary, can be taken anti-stripping measures.
5.2. Study on dynamic mechanical properties of mineral foam and mechanical foam asphalt mixture

At present, the design and application of warm mix asphalt have been widely studied, but the related mechanical properties are still few. The dynamic modulus of foamed asphalt mixture obtained by SHRP simple performance tester SPT was tested. The test results at 15°C and at different loading frequencies (25 Hz, 10 Hz, 5 Hz, 1.0 Hz, 0.5 Hz, 0.1 Hz, 0.01 Hz) are shown in Figure 7, and are compared with the dynamic modulus of SBS asphalt mixture. The test methods refer to AASHTO tp62-03.

![Figure 7. Dynamic modulus numerical comparison diagram](image)

6. Conclusion

Through the test of the conventional index of asphalt with different ZQ content, the results show that the effect of ZQ content on the conventional index of asphalt is small.

The method for determining the optimal content of mineral foaming agent based on asphalt modulus evaluation is proposed, and the optimal content of ZQ mineral foaming agent was determined to be 7%.

The foaming effects of each factor from large to small are as follows: water consumption, asphalt temperature and water temperature. Based on the above research results, the water consumption for mechanical foaming of SBS modified asphalt was set as 3.0±0.2%, the asphalt temperature was set as 165±2°C, and the water temperature was set as 30±2°C.

During the mixing test, the actual production was simulated, the samples were formed after the mixture aged for 2 hours in a short time.

The cooling amplitude of foamed asphalt mixture was determined by the method of equivalent volume index. The experimental results show that, the introduction of foam can effectively improve the construction workability of asphalt mixture, and the control requirements of the target porosity can be achieved when the compaction temperature is reduced by about 25°C.

Compared with the hot-mix mixture, the rutting stability of foamed asphalt mixture is reduced by about 12%, the low-temperature failure strain is reduced by about 5%, the splitting strength ratio is reduced by about 8%, and the reduction is not high. Therefore, the foam asphalt mixture design and production attention to mix ratio control, when necessary, can be taken anti-stripping measures.

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