Laboratory Experimental Research on Foamed Warm Mix Asphalt Mixture Road Property

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Abstract. To verify the foamed warm mix asphalt mixture road property, the article formed foaming warm mix asphalt mixture, Sasobi-LM warm mix asphalt mixture, ordinary hot mix asphalt mixture test piece, comparative analysis of different asphalt mixture The resistance of high temperature to rutting, shear resistance, resistance of low temperature crack, water stability and fatigue properties, and comparative economic analysis. The results show that the resistance of low temperature crack, water stability and shear resistance of foamed warm asphalt mixture surpass Sasobi-LM warm asphalt mixture, but slightly lower than ordinary asphalt mixture; The resistance of high temperature rutting and fatigue resistance of the mixture is lower than that of Sasobi-LM warm mix asphalt mixture; through economic analysis, the economical efficiency of foamed warm mix asphalt mixture surpasses the economical efficiency of the Sasobi-LM warm mix asphalt mixture, lower than the ordinary hot mix asphalt mixture, it is recommended to choose construction in special areas.

Keywords: Foaming and warm mixing, road performance, test.

1. Introduction

The traditional hot mix asphalt mixture mixing and construction process needs to be carried out under high temperature conditions [1], which not only consumes a lot [2-3], but also produces a lot of harmful gases and pollutes the environment [4-5]. In order to solve this difficult problem in road engineering construction, warm mix asphalt mixture technology is introduced into road engineering construction. The viscosity of asphalt mixing time can be reduced by the warm mixing asphalt mixture technology, increase the cohesion between aggregate and asphalt, thus reducing the construction temperature of asphalt mixture, thereby reducing the consumption of energy and emission of harmful gas [6-8]. However, the technology of warm mix asphalt mixture mainly achieves temperature drop during mixing construction by adding additives, but because the type and quality of additives can not be guaranteed, the long-term performance of mixtures is difficult to guarantee [6]. The foamed asphalt mixture can make the asphalt foam by adding a certain amount of water in the asphalt under high temperature, so as to reduce the asphalt viscosity and achieve the goal of mixing and construction temperature dropping by 20-30 ℃ [9-10]. No admixtures were added in the whole process to avoid the effect of admixtures on mixture performance. In this paper, foamed warm mix asphalt mixture, Sasobi-LM warm mix asphalt mixture and ordinary hot mix asphalt mixture specimens are formed. The resistance of high temperature rutting, shear resistance, resistance of low temperature cracking, water stability and fatigue performance of different asphalt mixture are compared and analyzed, and their economic performance is also compared and analyzed.
2. Raw Materials and Design for Mix Ratio

2.1. Raw Materials
The asphalt used in this paper is No. 70 heavy-duty road asphalt. The test results are as Table 1. Sasobi-LM is used as an organic viscosity reducer. The test results are as Table 2. The aggregate size specifications are 22-28 mm, 18-22 mm, 12-18 mm, 6-12 mm, 4-6 mm and 0-4 mm. Mineral powder is produced by Hami Nangang Building Materials Co., Ltd. The test results of asphalt and mineral materials conform to the demands of JTGF40-2004 “Construction Technical Specification of Highway Asphalt Pavement”.

### Table 1. Test results and demands of asphalt technical indicators for No. 170 heavy traffic roads.

| Inspection items                                      | Detection result | Prescribed value |
|------------------------------------------------------|------------------|------------------|
| Needle penetration (0.1mm) 100g, 25 C, 5S            | 67               | 60~80            |
| Penetration index                                     | -0.5             | -1.5~+1.0        |
| Softening point (°C)                                  | 50               | ≤45              |
| 10°C Ductility (cm)                                   | 97.0             | ≥25              |
| 60°C Dynamic viscosity (Pa.s)                         | 527.4            | ≤160             |
| Wax content (distillation) (%)                        | 1.8              | ≥22              |
| Flash point (°C)                                      | 335              | ≤260             |
| Solubility (%)                                       | 99.7             | ≤99.5            |
| Quality change after RTFOT (%)                        | -0.5             | ±0.8             |
| Residual penetration ratio after RTFOT (25°C) (%)     | 74.6             | ≤61              |
| Residual Ductility after RTFOT (10°C) (cm)           | 23.6             | ≤6               |
| Density 15°C (g/cm³)                                 | 1.000            | Measured record  |

### Table 2. Sasobi Technical Indicators.

| Index | 25 °C density (g/cm³) | Drop melting point (°C) | Flash point (°C) | Average molecular weight (g/mol) | Aqueous solution pH |
|-------|-----------------------|-------------------------|------------------|----------------------------------|---------------------|
| Data  | 0.9                   | 105                     | 285              | Approximately 1000               | Neutral             |

According to the test method specified in the “Recycling Technical Specification of Highway Asphalt Pavement” (JTG F41-2008), the optimum test conditions of foamed asphalt are determined through experiments, and the test results of foamed asphalt technical indicators are obtained. The best test conditions and test results of foamed asphalt technical indicators are as Table 3.

### Table 3. Best test conditions and test results for technical indicators of foamed asphalt.

| Asphalt type | Air pressure (psi) | Water pressure (psi) | Asphalt foaming temperature (°C) | Foaming water consumption (% of asphalt usage, %) | Half-life (s) | Expansion ratio (times) |
|--------------|--------------------|----------------------|----------------------------------|--------------------------------------------------|--------------|-------------------------|
| 70# asphalt  | 1000               | 1000                 | 155                              | 1.5                                              | 31           | 23                      |

2.2. Design for Mix Ratio
The test selected asphalt mixture AC-25C, according to the “road asphalt pavement construction technical specifications” JTGF40-2004 design method and process for mix design. Finally, the mineral
The high stability of the common hot mix asphalt mixture, the Sasobi LM warm mix asphalt mixture and the foamed warm mix asphalt mixture are improved. However, the high temperature stability of the asphalt mixture: Sasobi-LM warm mix asphalt mixture > foaming warm mix asphalt mixture > ordinary hot mix asphalt mixture. The high stability of the three asphalt mixtures conforms to the demands of the specification. Compared with the high temperature stability of the common hot mix asphalt mixture, the Sasobi-LM warm mix asphalt mixture and the foamed warm mix asphalt mixture are improved. However, the high temperature property of Sasobi-LM warm mix asphalt mixture is improved significantly.

### Table 4. Synthetic Grading of Mineral Materials.

| Screen hole (mm) | 31.5 | 26.5 | 19.0 | 16.0 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|------------------|------|------|------|------|------|-----|------|------|------|-----|-----|------|-------|
| Synthetic grading | 100.0 | 98.6 | 83.0 | 75.7 | 67.7 | 59.2 | 38.4 | 24.6 | 16.9 | 14.0 | 10.2 | 7.4 | 5.6 |
| Grading ceiling | 100 | 100 | 90 | 83 | 76 | 65 | 52 | 42 | 33 | 24 | 17 | 13 | 7 |
| Lower limit of grading | 100 | 90 | 75 | 65 | 57 | 45 | 24 | 16 | 12 | 8 | 5 | 4 | 3 |
| Gradation median | 100 | 95.0 | 82.5 | 74.0 | 66.5 | 55.0 | 38.0 | 29.0 | 22.5 | 16.0 | 11.0 | 8.5 | 5.0 |

### Table 5. Mixing Temperature and Compaction Temperature of Asphalt Mixture.

| Mixture type | Mixing temperature (°C) | Compaction temperature (°C) |
|--------------|--------------------------|-----------------------------|
| Hot mix AC-25C | 155-160                  | 145-150                     |
| Sasobi-LM warm mix AC-25C | 140-145                  | 130-135                     |
| Foaming warm mix AC-25C | 135-140                  | 125-130                     |

### 2.3. Confirm the Best Mixing Temperature and Forming Temperature

The common hot mix asphalt mixture and the organic additive asphalt mixture are confirmed according to the viscosity curve, and according to the mixing temperature of foamed warm mix asphalt mixture, the porosity of the test piece is measured under different mixing temperature and compaction temperature, and the best mixing temperature and compaction temperature are calculated through mathematical statistics and analysis. The best mixing temperature of each asphalt mixture is shown in table 5.

### Table 5. Mixing Temperature and Compaction Temperature of Asphalt Mixture.

| Mixture type | Mixing temperature (°C) | Compaction temperature (°C) |
|--------------|--------------------------|-----------------------------|
| Hot mix AC-25C | 155-160                  | 145-150                     |
| Sasobi-LM warm mix AC-25C | 140-145                  | 130-135                     |
| Foaming warm mix AC-25C | 135-140                  | 125-130                     |

### 3. Road Property Test Study

#### 3.1. Property of High Temperature

In this paper, the foamed warm mix asphalt mixture high temperature property is assessed by adopting the rutting test, and the foamed warm mix asphalt mixture high temperature property is compared with the Sasobi-LM warm mix asphalt mixture and the ordinary hot mix asphalt mixture. The production of the mixture car slab test piece is made according to the operation procedure of the “Test Code for Asphalt and Asphalt mixture of Highway Engineering” (JTJE20-2011). The size of the sill plate is 300mm*300mm*50mm. The test temperature is 60 °C, the applied load on the wheel is 0.7 MPa, and the round-trip speed is 42 times/mm. The dynamic stability was calculated based on the test data, and the test results are as figure 1.

From figure 1, it can be seen that the high temperature stability of the asphalt mixture: Sasobi-LM warm mix asphalt mixture > foaming warm mix asphalt mixture > ordinary hot mix asphalt mixture. The high stability of the three asphalt mixtures conforms to the demands of the specification. Compared with the high temperature stability of the common hot mix asphalt mixture, the Sasobi-LM warm mix asphalt mixture and the foamed warm mix asphalt mixture are improved. However, the high temperature property of Sasobi-LM warm mix asphalt mixture is improved significantly.
3.2. Property of Low Temperature

The property test of asphalt mixture low temperature is assessed by the bend test commonly used in China. The test piece production and test method are carried out according to the operation procedure of “Test Code for Asphalt and Asphalt Mixture of Highway Engineering” (JTJE20-2011). The size of the test piece is 30 mm × 35 mm × 250 mm. The test temperature is -10 °C, the fulcrum spacing is 200 mm, and the single point loading rate is 50 mm/min. The test results are as Table 6.

| Mixture type                  | Maximum load (kN) | Inter-span deflection (mm) | Bending strength (MPa) | Stiffness modulus (MPa) | Destructive strain (µε) | Request (µε) |
|------------------------------|-------------------|----------------------------|------------------------|------------------------|------------------------|------------|
| Hot mix AC-25C               | 0.99              | 0.4635                     | 8.08                   | 3321                   | 2433                   |            |
| Sasobi-LM warm mix AC-25C    | 0.93              | 0.4501                     | 7.59                   | 3213                   | 2363                   | 2000       |
| Foaming warm mix AC-25C      | 0.95              | 0.4532                     | 7.76                   | 3259                   | 2379                   |            |

From Table 5, it can be seen that the low temperature property of the three asphalt mixtures conforms to the specification requirements. The low temperature property of hot mix asphalt mixture surpasses Sasobi-LM warm mix asphalt mixture and foaming warm mix asphalt mixture. The low temperature property of Sasobi-LM warm mix asphalt mixture and foaming warm mix asphalt mixture is almost equal. This is mainly because the asphalt mixture is in the test process, the aggregate is not completely dried, resulting in a small amount of residual moisture in the mixture. The moisture will inevitably have influence on the adhesion of the asphalt and the mineral material, and meanwhile, the high temperature treatment is carried out during the mixing process of the mixture. The asphalt coated on the surface of the mineral material is reduced, thus affecting the low temperature property of the mixture.

3.3. Stability of Water

In this paper, the stability of water of the foamed warm asphalt mixture is assessed by the test of water immersion Marshall and the freeze-thaw split. The test piece fabrication and test methods are made...
according to the “Test Code for Asphalt and Asphalt mixture of Highway Engineering” (JTJE20-2011). The results of the Marshall test for water immersion in the mixture are as table 7. The results of the freeze-thaw split test are as table 8.

### Table 7. Results of Water Immersion Marshall Test.

| Mixture type                  | Marshall Stability (kN) | Water immersion Marshall stability (kN) | Residual stability S₀ (%) | Claim (%) |
|------------------------------|-------------------------|----------------------------------------|---------------------------|-----------|
| Hot mix AC-25C               | 10.76                   | 9.53                                   | 88.6                      | ≥80       |
| Sasobi-LM warm mix AC-25C    | 11.90                   | 10.51                                  | 88.3                      | ≥80       |
| Foaming warm mix AC-25C      | 10.68                   | 9.54                                   | 89.3                      |           |

### Table 8. Freeze-thaw Split Test Results.

| Mixture type                  | Unconditional splitting strength (MPa) | Conditional splitting strength (MPa) | TSR (%) | Claim (%) |
|------------------------------|----------------------------------------|-------------------------------------|---------|-----------|
| Hot mix AC-25C               | 0.672                                  | 0.581                               | 86.5    |           |
| Sasobi-LM warm mix AC-25C    | 0.665                                  | 0.549                               | 82.6    | ≥75       |
| Foaming warm mix AC-25C      | 0.6587                                 | 0.573                               | 87.0    |           |

From table 7, it can be seen that the residual stability of three asphalt mixtures is almost equivalent. From table 8, it can be seen that the water stability of hot mix asphalt mixture and foamed warm mix asphalt mixture surpasses the water stability of Sasobi-LM warm mix asphalt mixture, and the water stability of foamed warm mix asphalt mixture is equivalent to the water stability of hot mix asphalt mixture, indicating that the foamed warm asphalt mixture has good water resistance.

#### 3.4. Fatigue Property

In this study, the fatigue resistance of the foamed warm mix asphalt mixture is assessed by adopting an indirect tensile test. The test piece fabrication and test methods are made according to the “Test Code for Asphalt and Asphalt Mixture of Highway Engineering” (JTJE20-2011). The loading method was controlled by stress and the test temperature was controlled at 15 °C ± 1 °C. The test equipment used MTS-810 material testing machine. The fatigue test results of the three asphalt mixtures areas table 9. Table 9 was obtained by statistical analysis.

From table 9, it can be seen that the three asphalt mixtures’ stress ratio has a good correlation with the fatigue life. The larger the K value, the better the fatigue resistance of the material. The K value of the three asphalt mixtures: ordinary heat Mix asphalt mixture>Sasobi-LM warm mix asphalt mixture>foamed warm mix asphalt mixture. The value of n stands for the sensitivity of the fatigue life of the mixture to the stress level. The larger the value of n, the greater the sensitivity of the mixture to the stress level. The value of n: foaming mixed asphalt mixture>Sasobi-LM mixed asphalt mixture > Ordinary hot mix asphalt mixture. This shows that the anti-fatigue property of ordinary hot mix asphalt mixture surpasses Sasobi-LM warm mix asphalt mixture and foamed warm mix asphalt mixture, compared with ordinary hot mix asphalt mixture and Sasobi-LM warm mix asphalt mixture. Foamed warm asphalt mix is more sensitive to stress changes. As the stress ratio increases, when the stress ratio is 0.6, the fatigue times of the three asphalt mixtures are almost the same, indicating that the fatigue resistance of three asphalt mixtures is basically the same at higher strain levels.
Table 9. Fatigue test results of three kinds of asphalt mixture under different stress ratios.

| Mixture type          | Stress ratio | Number of cycles (times) | Fatigue life logarithm | Regression equation |
|-----------------------|--------------|--------------------------|------------------------|---------------------|
| Hot mix AC-25C        | 0.3          | 12996                    | 4.1138                 | n=4.265 k=5.475 R2=0.950 |
|                       | 0.4          | 6880                     | 3.8376                 |                     |
|                       | 0.5          | 2850                     | 3.4548                 |                     |
|                       | 0.6          | 660                      | 2.8195                 |                     |
| Sasobi-LM warm mix    | 0.3          | 10865                    | 4.0360                 | n=4.289 k=5.451 R2=0.950 |
| AC-25C                | 0.4          | 5790                     | 3.7627                 |                     |
|                       | 0.5          | 2690                     | 3.4298                 |                     |
|                       | 0.6          | 520                      | 2.7160                 |                     |
| Foaming warm mix AC-25C | 0.3     | 11569                    | 4.0633                 | n=4.293 k=5.418 R2=0.945 |
|                       | 0.4          | 6680                     | 3.8248                 |                     |
|                       | 0.5          | 2720                     | 3.4346                 |                     |
|                       | 0.6          | 580                      | 2.7634                 |                     |

3.5. Property of Shear

In this paper, the shear resistance of foam mixed asphalt mixture is assessed by adopting the uniaxial penetration test. The test loading rate is 1 mm/min, the test piece is kept at least for 6h in the temperature control, the test temperature is 20 °C to test the shear resistance of the road surface under normal temperature conditions, and 60 °C is used to simulate the shear resistance of the road surface under high temperature conditions.

From table 10, it can be seen that the shear property of the ordinary hot mix asphalt mixture surpasses the shear property of the Sasobi warm mix asphalt mixture, and the shear property of the foamed warm mix asphalt mixture is almost equivalent to the shear property of the ordinary hot mix asphalt mixture. With the increase of temperature, the shear strength of common hot mix asphalt mixture decreases the most, which indicates that the shear strength of common hot mix asphalt mixture is most sensitive to temperature changes.

Table 10. Test results of shear strength of three kinds of asphalt mixtures under different test temperatures.

| Mixture type          | 60 °C shear strength (MPa) | 20 °C shear strength (MPa) |
|-----------------------|---------------------------|---------------------------|
| Hot mix AC-25C        | 0.3120                    | 0.8814                    |
| Sasobi-LM warm mix AC-25C | 0.2996                | 0.8491                    |
| Foaming warm mix AC-25C | 0.3061                    | 0.8619                    |

4. Economic Analysis

Through the market research and calculation, one ton of foamed warm mix asphalt mixture (see table 11 for details) is produced, which saves 2 yuan compared with the ordinary hot mix asphalt mixture, and the production of Sasobi-LM warm mix asphalt mix increases by 24.6 yuan per ton. This paper refers to the existing construction technical specifications, selects the technical evaluation indicators required by the specifications and the reference market to determine the economic and technical evaluation indicators, and uses the efficacy coefficient method to systematically evaluate the economics of the mixed materials. Through analysis, the comprehensive property of ordinary hot mix asphalt mixture surpasses that of foamed warm mix asphalt mixture and Sasobi-LM warm mix. The paving temperature and rolling temperature of foamed warm mix asphalt mixture are less than ordinary hot mix asphalt mixture and Sasobi-LM warm mix asphalt mixture, effectively reducing fuel
consumption during road paving and rolling process. And reduce the high temperature loss of mechanical equipment. Therefore, in the construction of special areas, it is recommended to use foamed warm mix asphalt mixture.

Table 11. Three Kinds of Asphalt Mixture Road Property Indicators.

| Mixture type                        | Mix unit price (yuan/t) | Cost savings compared to ordinary hot mixes (yuan) |
|------------------------------------|-------------------------|--------------------------------------------------|
| Ordinary hot mix asphalt mixture   | 219.7                   | /                                                |
| AC-25C                             |                         |                                                  |
| Sasobi-LM Warm Mix Asphalt Mix AC-25C | 244.3                 | +24.6                                            |
| Foaming warm asphalt mixture AC-25C | 217.7                  | -2.00                                            |

5. Conclusions

Through the above analysis, the following conclusions are drawn:

1. Comparison of the performance of three types of asphalt mixture, and the results show that Sasobi-LM warm mix asphalt mixture has best high temperature stability, hot mix asphalt mixture has best low temperature performance and foaming warm mix asphalt mixture has best water stability. And foaming warm mix asphalt mixture has better high temperature stability and poorer low temperature performance.

2. Anti-fatigue performance of ordinary hot mix asphalt mixture is best, Sasobi-LM warm mix asphalt mixture less and foaming warm mix asphalt mixture least. The fatigue life of asphalt mixture decreases with the increase of stress ratio, and when the stress ratio is 0.6, the fatigue times of the three asphalt mixtures are almost the same, and the fatigue resistance of the three asphalt mixtures is basically the same.

3. With the increase of temperature, the shear strength of asphalt mixture decreases, and the shear strength of ordinary hot mix asphalt mixture is most sensitive to temperature changes. The shear performance of foaming warm mix asphalt mixture is between that of ordinary hot mix asphalt mixture and Sasobi warm mix asphalt mixture.

4. According to market research and calculation, the comprehensive performance of ordinary hot mix asphalt mixture is better than foaming warm mix asphalt mixture and Sasobi-LM warm mix. For construction in special areas, it is recommended to use foamed warm mix asphalt mixture.

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