Application of High Stiffness Modulus Asphalt Mixture in Longitudinal Slope of Jiqing Expressway

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Abstract. In this paper, according to the French LCPC asphalt mixture design method, the high modulus asphalt mixture is designed. It is found that the designed high-stiffness modulus mixture has high water stability, high temperature resistance to rutting and fatigue performance. The high-speed and long-slope section was successfully promoted and applied, which solved the problem of the structure and material durability of the long-slope section of the expressway under heavy load conditions and prolonged the service life of the road.

1. Introduction
In recent years, the rutting phenomenon of asphalt pavement has increased greatly, and it has become the most serious and common damage form of asphalt pavement. Traffic conditions causing ruts include large traffic volume, wheel load, high tire pressure, slow driving speed and concentrated wheel tracks. The use of high-strength tyres in overload vehicles, the excessive loading, the impact on the speed of the vehicle, the vehicle travels very slowly, especially in the uphill section, this phenomenon is particularly evident. Field investigation shows that due to the role of channelized traffic, the rutting of the lane is more serious than that of the overpass lane, and the rutting of the uphill section is more serious than that of the downhill section.

With the further improvement of service quality and service life requirements of highway asphalt pavement, higher requirements are put forward for the diversity and durability of asphalt pavement materials. The traditional design method of asphalt mixture in our country is relatively simple. Some asphalt pavement under heavy load, complex climate and special section or pavement conditions can not meet the requirements of the project. In view of the durability of pavement structure and materials in Jinan-Qingdao expressway reconstruction and extension project, a new generation of high-quality durable asphalt mixture was popularized and applied in the long longitudinal slope section of Weilai Expressway Interchange (longitudinal slope up to 2.997%).

2. Pavement Structure
The high quality durable asphalt pavement structure studied in this paper is shown in figure 1. The structure is changed from the original 6 cm middle surface AC-20 and 8 cm AC-25 asphalt mixture to the EME high modulus asphalt mixture with two layers of 7 cm.
3. Asphalt Mixture Design

3.1. Raw Material
This project uses limestone, asphalt is SBS modified asphalt, additive adopts PR (Modulus) high modulus agent imported from France, which can effectively improve the modulus and fatigue resistance of asphalt mixture, and its content is 0.5% of the quality of asphalt mixture.

| 4cm SMA-13 SBS Modified Asphalt |
|----------------------------------|
| 7cm EME SBS Modified Asphalt + PR (Modulus) |
| 7cm EME SBS Modified Asphalt + PR (Modulus) |
| 10cm ATB-25 HMA Asphalt |
| 18 (20) cm +2 Cement Stabilized Macadam |
| 18 (20) cm Low-dose Cement Stabilized Macadam |

Figure 1. Asphalt pavement structure with high stiffness and durability in long longitudinal slope section.

3.2. Proportion Design of Asphalt Mixture

3.2.1 Gradation Design. The EME high modulus asphalt mixture of this project is designed in accordance with the design requirements of French LCPC asphalt mixture. Its gradation design meets the requirements of NFP98. Its gradation design scope and design gradation diagram are shown in table 1 and figure 2.

| Table 1. Requirements for EME2 (0/14) Gradation Design scope in France (NFP98-140) [1]. |
|------------------|-----|-----|-----|-----|-----|-----|
| Gradation       | 16.0| 14.0| 6.3 | 4   | 2   | 0.063 |
| Upper limit     | 100 | 100 | 70  | 60  | 38  | 7.7   |
| Lower limit     | 100 | 90  | 50  | 40  | 25  | 5.4   |
| Target value    | 100 | -   | 53  | 47  | 33  | 6.7   |

Figure 2. EME (0/14) design gradation diagram.

3.2.2. Determination of Asphalt Content. For EME2, the amount of binder is controlled by K value of abundance coefficient [2], which requires

\[ K > 3.4, \text{ as shown in table 2. The } K \text{ value is calculated according to the following formula:} \]

\[ 100 = 0.25G + 2.3S + 12s + 135f \]

In formula, \( TL'' \) - asphalt ratio (ratio of asphalt weight to aggregate weight), unit%

\[ 100 \sum = 0.25G + 2.3S + 12s + 135f \]
G-Aggregate with particle size greater than 6.3 mm is the percentage of aggregate, unit %
S-The percentage of aggregates with particle size ranging from 0.25 mm to 6.3 mm, unit %
s-The percentage of aggregates with particle size ranging from 0.063 mm to 0.25 mm
f-The percentage of aggregates with particle size less than 0.063 mm to total aggregates

\[ \alpha = \frac{2.65}{\rho_e} \]

\( \rho_e \)-The effective density of aggregate, unit \( g/cm^3 \)

**Table 2. Coefficient table.**

|   | G (%) | S (%) | s (%) | f (%) | \( \rho_e \) (g/cm³) |
|---|-------|-------|-------|-------|----------------------|
| 1 | 47    | 43    | 3.3   | 6.7   | 2.760                |

The asphalt content depends on the gradation. For EME2 (0/14), when the asphalt-stone ratio is 5.5%, the abundance coefficient \( K = 3.51 > 3.4 \), that is, 5.5% of the asphalt ratio can meet the requirement of the abundance coefficient \( K \), that is, the asphalt content is 5.2% which can be used as the design asphalt content.

3.2.3 *Rotary Compaction Forming*. The volume index of formed specimens is shown in table 3.

**Table 3. EME2 volume index of high modulus asphalt mixture.**

| Number | 1             | 2             | 3             |
|--------|---------------|---------------|---------------|
| The weight of specimen in air (g) | 4999.48       | 4892.86       | 4917.12       |
| The weight of the specimen in water (g) | 2971.33       | 2921.37       | 2937.16       |
| Dry quality of specimen sheet (g) | 5007.83       | 4898.24       | 4920.66       |
| Gross bulk density \( (g/cm^3) \) | 2.455          | 2.475          | 2.479          |
| Maximum theoretical density \( (g/cm^3) \) (France) | 2.537          |               |               |
| Maximum theoretical density \( (g/cm^3) \) (US) | 2.530          |               |               |
| Minimum height of specimen theory (mm) | 111.5          | 109.1          | 109.7          |
| Specimen height (mm) | 117.3          | 114.2          | 114.4          |
| Air void of US Standard (%) | 2.97           | 2.18           | 2.00           |
| Air void of France Standard (%) | 4.93           | 4.44           | 4.13           |
| VMA (%) | 14.1          | 13.4           | 13.3           |

From the table, it can be concluded that air void calculated by the French method of EME2 high modulus asphalt mixture is 1 time larger than that calculated by the American standard method. Air void calculated by the French method is between 0-6, air void calculated by the American standard is between 0-3 and air void calculated by the American standard is between 13-15%.

4. Verification of Mixture Performance

Based on the research of performance evaluation system of mixture, the performance of EME2 high modulus asphalt mixture was systematically studied, including water damage performance evaluation, rutting resistance performance evaluation, mechanical properties evaluation, fatigue performance evaluation and low temperature performance evaluation.

4.1. Water Stability

AASHTO T283 [3] is used to evaluate the water damage of high modulus EME2 asphalt mixture. The test data are shown in table 4. From the data, it can be seen that it meets the requirements of the code and has good water damage resistance.
Table 4. Test results of freeze-thaw splitting of EME2 asphalt mixture.

| Mixture type | Unconditioned | condition | TSR (%) | Specification (%) |
|--------------|---------------|-----------|---------|-------------------|
|              | AV (MPa)      | Splitting strength (MPa) | AV (%) | Splitting strength (MPa) | |
| EME2(0/14) (5.2%) | 6.4 | 0.4807 | 4.9 | 0.3704 | 82.1 | ≥80 |
|              | 5.9 | 0.4054 | 5.5 | 0.3836 | 7.0 | 0.3531 |
|              | 7.0 | 0.4610 | 7.0 | 0.3692 | | |
| AVG value    | 6.4 | 0.449 | 5.8 | 0.369 |

4.2. High Temperature Stability
This project uses the French rutting tester to carry out the test, according to the French standard NF P 98-252 test method [4], the test temperature is 60℃, before the test, the test specimens should be placed in such an environment for 12h-16h. During the test, the temperature in the specimen should be kept at the specified temperature (+2℃). When the specimens are subjected to a specified number of load cycles of 1000, 3000, 10000, 30000, stop the operation of the equipment and measure the rutting depth.

The proportional rutting depth $P_i$ obtained by calculating a series of measured values $i$ of the specimen is calculated by equation (1) according to the 15 deformation values $m_{ij}$ and the thickness $h$ of the specimen.

$$P_i = 100 \times \frac{\sum_{j=1}^{15} (m_{ij} - m_{0j})}{(15 \times h)}$$  

(1)

where $P_i$ is a proportional rutting depth measured for $i$ cycles, unit %; $m_{ij}$ is the deformation value of $j$ point in $i$ cycles, unit mm; $m_{0j}$ is the initial measurement at point $j$, unit mm; $h$ is the thickness of the specimen, unit mm.

The test results are shown in table 5. The test results meet the relevant technical requirements of EN 12697-22:2003. The designed mixture has good high temperature stability.

Table 5. French rutting test results.

| Number | N1 cycles | N2 cycles | N3 cycles | N4 cycles | Spec requirement N4≤7.5 |
|--------|-----------|-----------|-----------|-----------|------------------------|
| A      | deformation mm | 1.12 | 1.42 | 1.65 | 2.01 | / |
|        | Deformation ratio % | 2.24 | 2.84 | 3.31 | 4.03 | meeting |
| B      | deformation mm | 0.87 | 1.15 | 1.63 | 1.91 | / |
|        | Deformation ratio % | 1.75 | 2.3 | 3.26 | 3.82 | meeting |

4.3. Stiffness
This project uses two-point bending test [5] of European standard to test modulus. The test temperature is 15 ℃ and the frequency is 10 Hz. The test results are shown in table 6. The modulus of stiffness meets the relevant technical requirements of EN 12697-24 and EN 12697-33. It shows that the designed asphalt mixture meets the requirements of modulus of mechanical properties. It has better resistance to deformation.

4.4. Fatigue Test
This project adopts the two-point bending fatigue test [6] of France. The test data are shown in table 7.
### Table 6. French two-point stiffness test results.

| Number | Deformation (mm) | Stress (Kpa) | Micro strain (με) | phase angle (φ) | Stiffness (Mpa) |
|--------|------------------|--------------|-------------------|----------------|----------------|
| 1      | 0.0929           | 715.30       | 72.21             | 19.42          | 14010          |
| 2      | 0.0870           | 710.40       | 68.53             | 18.95          | 14366          |
| 3      | 0.0939           | 698.18       | 72.34             | 18.87          | 15652          |
| 4      | 0.0870           | 726.89       | 66.88             | 19.27          | 15869          |

### Table 7. EME2 Two-point bending fatigue test results.

| Micro strain (με) | Number of spec | Air viod in France (%) | Stiffness (MPa) | Fatigue cycles |
|-------------------|----------------|------------------------|-----------------|----------------|
| 160               | 4              | 3.2                    | 16964           | 370344         |
| 130               | 6              | 3.6                    | 15956           | 1822525        |

The test data show that the fatigue deformation of the designed high modulus asphalt mixture can reach 160 μdef under 1 million times of action at 10 °C and 25 Hz, which meets the requirements of the code not less than 130 μdef. At the same time, at 130 μdef, the fatigue test results are more than 1 million times. It shows that the EME high modulus asphalt mixture meets the requirements of Level 4 proposed by the French Code, and that the EME designed has high fatigue resistance.

#### 4.5. Low Temperature Bending Test

The low temperature bending test [7] of China is used to verify the low temperature performance of this project. The test results are shown in table 8. The low temperature of the test is -10 °C. The test results meet the requirements of “Technical Specifications for Construction of Highway Asphalt Pavements” (JTG F40) that the low temperature bending strain is not less than 2,000 με.

### Table 8. Test results of bending beams at low temperature.

| Mixture type | No. | Air voids | Deflection (mm) | Maximum load p (N) | Flexural tensile strength (MPa) | Flexural strain με | Modulus (MPa) |
|--------------|-----|-----------|-----------------|--------------------|-------------------------------|-------------------|---------------|
| EME2 (0/14)  | 1   | 3.7       | 0.8231          | 920                | 6.246                         | 4529              | 2379          |
|              | 2   | 2.9       | 0.603           | 991                | 6.942                         | 3340              | 2078          |
|              | 3   | 2.6       | 0.3546          | 887                | 6.315                         | 1934              | 3266          |
|              | 4   | 2.5       | 0.2782          | 1070               | 7.878                         | 1514              | 3205          |
|              | 5   | 2.4       | 0.8719          | 911                | 6.834                         | 4685              | 2459          |
|              | AVG | 2.8       | 0.5867          | 956                | 6.843                         | 3200              | 2677          |

### 5. Test Road

Jinan-Qingdao Expressway Reconstruction and Expansion Project started at Zhujiaguanzhuang New Main Toll Station in Jimo City, Qingdao. From east to west, it passed through Weifang, Zibo and Binzhou in turn. It was connected with G35 (Jiguang Expressway) by Tangwang Junction Interchange. Finally, Jinan Zero-Point Interchange was completed with a total length of 309.2 km. The existing expressway is a two-way four-lane expressway, and the standard of two-way eight-lane expressway is adopted after reconstruction and expansion. The high modulus asphalt mixture designed by this project is applied to the long longitudinal slope section of Weilai Expressway interchange project, with the longitudinal slope as high as 2.997%. The field situation of the test road is shown in figures 3 and 4.
Hamburg test [8] was carried out to verify the high temperature water stability and rutting resistance. The test results are shown in table 9.

![Figure 3. Paving of test road.](image1)

![Figure 4. Pavement completed and coring.](image2)

**Table 9. Field coring Hamburg test results.**

| No.  | Data acquisition point | Maximum Def. of 15,000 rolling compaction (mm) | Maximum Def. of 20,000 rolling compaction (mm) | Are there any inflection point |
|------|------------------------|-----------------------------------------------|-----------------------------------------------|------------------------------|
| Spec 3 | Third point        | 3.05                                          | 3.88                                          | No                           |
|       | Ninth point          | 3.32                                          | 4.39                                          |                              |
| Spec 4 | Third point        | 2.66                                          | 3.32                                          | No                           |
|       | Ninth point          | 3.60                                          | 5.46                                          |                              |

**6. Conclusion**

(1) The voidage of EME2 high modulus asphalt mixture calculated by French method is 1 time larger than that calculated by American standard method. The voidage of EME2 high modulus asphalt mixture calculated by French method is between 0-6. The voidage of EME2 high modulus asphalt mixture calculated by American standard is between 0-3 and VMA is between 13-15%.

(2) High modulus asphalt mixture has good water damage resistance, high-temperature rutting resistance, but also has high fatigue resistance and low-temperature performance.

(3) Through the design method of asphalt mixture based on performance index, the designed high modulus asphalt mixture has not only good high temperature rutting resistance, but also good fatigue and low temperature performance. It has been successfully popularized and applied in Jiqing long longitudinal slope section.

**Reference**

[1] AFNOR. Couches d'assises: enrobés à module élevé (EME) (In French), NF P98-140, 1999

[2] LPC Bituminous Mixtures Design Guide, CEN Bituminous Mixture Specification for hot mixture asphalt

[3] AASHTO T283-07, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

[4] EN 12697-22 Bituminous mixtures — Test methods for hot mix asphalt — Part 22: Wheel tracking

[5] EN 12697-26 Bituminous mixtures – Test methods for hot mix asphalt – Part 26: Stiffness

[6] EN 12697-24 Test methods for hot mix asphalt – Part 24: Resistance to fatigue

[7] Industry Standards of the People’s Republic of China, Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTJ E20-2011), Beijing: China Communications Press, 2011

[8] AASHTO T 324-04, Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)