With the increase in traffic volume and axle load, the requirement of road quality is continuously improving, and high modulus asphalt has attracted the attention of researchers due to its excellent road service performance and economic benefits. In order to further improve the durability and use quality of Chinese roads, realize the scientific evaluation of the performance of high modulus asphalt and its mixture, and further promote the development of high modulus asphalt technology in China, the performance indexes of high modulus asphalt and its mixture were comprehensively investigated. The differences in high- and low-temperature performance of matrix asphalt, basic modified high modulus asphalt, and composite modified high modulus asphalt were compared and evaluated. Based on the results of mathematical statistics and the relevant specifications of high modulus asphalt in China, the performance grades of high modulus asphalt and its mixture were proposed. The results showed that compared with the basic asphalt, the softening points of the basic modified high modulus asphalt and the composite modified high modulus asphalt were increased by 18.76% and 82.89%, respectively, and the rutting factors were increased by 2 and 9 times, respectively, but the improvement effect of the low-temperature performance of the high modulus asphalt was not obvious. Based on the data statistics node and relevant Chinese regulations, high modulus asphalt and its mixtures were divided into four grades: excellent, good, fair, and poor, aiming to provide scientific suggestions for the wide application of high modulus asphalt.

1. Introduction

In recent years, China’s transportation industry has developed vigorously, and the highway mileage has ranked first in the world by 2021. However, the increase in traffic volume and vehicle axle load has led to the increase in road rutting, congestion, and other diseases, which has seriously damaged the service performance and service life of China’s highway [1]. It is the transportation industry current that promotes the application of new technologies to improve the quality, durability, and environmental protection of asphalt roads [2–4]. On one hand, high modulus asphalt has excellent mechanical properties, high-temperature properties, and fatigue resistance. The application of high modulus asphalt to the middle and lower layers of the pavement can effectively prevent rutting and improve the durability and use quality of the pavement. On the other hand, high modulus asphalt mixtures can significantly reduce the thickness of the pavement structural layer, which effectively saves construction costs and promotes the green economic development of the transportation industry [5]. Therefore, high modulus asphalt has been widely favored by Chinese researchers in recent years.

At present, the research on high modulus asphalt in China mainly focuses on high modulus modification mechanism and asphalt performance indexes improvement. Xu et al. studied the modification mechanism of high modulus asphalt by means of rheology and microscopic
methods and found that high modulus agent particles could expand into polymer chains in asphalt, which improved the viscoelasticity of asphalt [6]. Wang et al. studied the microscopic molecular structure of high-molecular-weight polyethylene high modulus asphalt, modified polyethylene molecular, and asphalt combined uniformly and densely, which showed good compatibility [7]. Yuan and Li divided high modulus asphalt into three categories: adding modifier high modulus asphalt, adding natural rock asphalt high modulus asphalt, and adding hard asphalt high modulus asphalt. It was found that high-modulus modification could effectively reduce the asphalt grade and improve the high-temperature performance of asphalt significantly [8]. Wang et al. compared and evaluated the high-temperature performance law of hard asphalt, antirutting agent modified asphalt, and matrix asphalt before and after aging and found that hard asphalt had obvious performance advantages [9]. Fang et al. evaluated the high-temperature rheological properties of high modulus asphalt based on rheological tests such as the dynamic shear rheometer test and multiple stress creep recovery test, and recommended nonrecoverable creep compliance as the evaluation index for high modulus asphalt high-temperature performance [10].

At present, the research on high modulus asphalt mixture in China mainly focuses on the improvement of the dynamic modulus of the mixture and the evaluation of road performance. Ma et al. compared the dynamic modulus of different high modulus asphalt mixtures and considered that the simplified frequency of dynamic modulus obeyed the sigmoidal model [11]. Si et al. studied the stress and deformation distribution of asphalt pavement based on asphalt viscoelasticity theory and found that the strain of high modulus asphalt pavement under moving load was less than that of conventional asphalt pavement, and the deformation of surface asphalt material could be reduced by adopting high modulus pavement under changing temperature [12]. Wang et al. predicted the dynamic modulus of high modulus asphalt based on multiple regression, general regression neural network, and support vector machine (SVM), respectively, and recommended adopting SVM model to predict the dynamic modulus of high modulus asphalt [13]. Ning et al. studied the antirutting and anti-fatigue performance of high modulus asphalt pavement with different gradations. The antirutting ability of AC-20C asphalt mixture was better than that of AC-13C, but the fatigue life of AC-13C asphalt mixture was longer than that of AC-20C under low-temperature and low-stress conditions [14]. Li systematically analyzed the influencing factors of low-temperature performance of high modulus asphalt mixture and found that mineral aggregate gradation had no significant influence on its low-temperature crack resistance. Increasing asphalt content and adding ethylene-ethyl acetate could improve its low-temperature crack resistance [15]. Wang studied the water stability of high modulus asphalt and determined that the optimal dosage of admixture was 0.6%, and the water stability of high modulus asphalt was increased by 13–43% [16]. Zheng et al. proposed a method to characterize the fatigue characteristics of high modulus asphalt mixture based on the strain fatigue life equation of the uniaxial tensile test. The fatigue characteristics of high modulus asphalt mixture and conventional asphalt mixture were compared and found that the strain threshold and ultimate tensile strain of high modulus asphalt mixture were smaller than that of matrix asphalt mixture [17].

Chinese scholars have carried out a large number of studies on the comparison and selection of service performance indexes of high modulus asphalt and its mixture and the improvement of dynamic modulus of the mixture and have achieved certain results. However, the research results are complex and scattered and lacked systematic review. The performance classification system of high modulus asphalt and its mixture has not been established, and it is difficult to realize the scientific evaluation of the performance index of high modulus asphalt and its mixture. In view of this, the main purpose of this paper is to sort out and analyze the performance indexes of high modulus asphalt and propose the classification standard of high modulus asphalt and its mixture. The overall structure of this paper is shown in Figure 1. Firstly, the research status of high modulus asphalt in China is systematically investigated. Secondly, the high-/low-temperature performance of different types of high modulus asphalt is compared and analyzed by the mathematical statistics analysis method. Finally, combined with the investigation results of road performance of high modulus asphalt mixture and relevant specifications [18–21], the grading standards of performance evaluation of high modulus asphalt and its mixture are proposed respectively, which is of great significance to promote the scientific evaluation of high modulus asphalt and its mixture performance and promote its further application in China.

2. High Modulus Asphalt

At present, the methods for preparing high modulus asphalt in China are divided into three categories [22]: preparing high modulus asphalt with low-grade hard asphalt, preparing high modulus asphalt with self-blending asphalt, and preparing high modulus asphalt with admixture. Asphalt blending is generally to add high melting point natural asphalt, such as lake asphalt and rock asphalt in the matrix asphalt, and the admixtures are mainly polyolefins, such as French PRS, PRM high modulus agents, and high modulus agents independently developed in China. In addition, in order to further improve the performance of high modulus asphalt, some researchers will also choose to add SBS and crumb rubber into high modulus asphalt. For the convenience of discussion, the high modulus asphalt prepared by the above three basic methods is called the basic modified high modulus asphalt, and the high modulus asphalt prepared by adding SBS and crumb rubber is called the composite modified high modulus asphalt.

2.1. Test Methods

2.1.1. Softening Point of High Modulus Asphalt. According to the Chinese test specification JTG E20-2011, the softening point of high modulus asphalt is tested by the ring and ball method to evaluate the high-temperature
stability of high modulus asphalt. Firstly, the asphalt is poured into the ring test mold, and after the asphalt was cooled, excess asphalt is scraped off with a hot scraper, as shown in Figure 2(a); secondly, the test mold with asphalt and steel ball are placed in water at 5°C ± 0.5°C for at least 15 min; finally, the container is heated to make the water rise by 5°C ± 0.5°C per minute. The softening point of asphalt is obtained by reading the temperature when the asphalt falls into contact with the bottom plate, as shown in Figure 2(b).

2.1.2. Dynamic Shear Rheometer (DSR) Test of High Modulus Asphalt. According to the Chinese test specification JTG E20-2011, parameters such as shear stress, shear strain, complex shear modulus, and phase angle of asphalt are determined by DSR test. The test pictures are shown in Figure 3. The phase angle $\delta$ can measure the time lag between stress and strain of asphalt under load conditions, which reflects the proportion of viscoelastic components of the material. The complex shear modulus $G^*$ characterizes the resistance characteristics of the material during repeated shear deformation. The rutting factor $G^*/\sin\delta$, which characterizes the rutting resistance of asphalt, can be obtained by calculating the phase angle and the complex shear modulus.

2.1.3. Bending Beam Rheometer (BBR) Test of High Modulus Asphalt. According to the Chinese test specification JTG E20-2011, BBR test was used to evaluate the low-temperature performance of high modulus asphalt. The test instrument is shown in Figure 4(a). Firstly, the asphalt beam specimens with a length of 127 mm, a thickness of 6.4 mm, and a width of 12.7 mm are prepared, as shown in Figure 4(b). Then, under the conditions of setting temperature and time, the beam specimens are placed on the two fulcrums of the low-temperature oil bath tester, and a pressure load is applied to the middle of the specimen, and the asphalt is gradually deformed. The low-temperature stiffness modulus ($S$) and creep rate ($m$) can be calculated by the following equations:

$$S(t) = \frac{p l^3}{4 b h^3 v(t)}$$

$$m = \frac{\Delta \log S(t)}{\Delta \log t}$$

In the formula, $S$ is the creep stiffness modulus, MPa; $p$ is the creep load, N; $l$ is the beam span, mm; $b$ is the beam width, mm; $h$ is the beam height, mm; $v$ is the vertical deformation of the middle point of the beam, mm; $t$ is the test time; $m$ is the creep stiffness change rate.

2.2. Investigation of Performance of High Modulus Asphalt

2.2.1. Investigation of High-Temperature Performance of High Modulus Asphalt. High-temperature performance, as the main optimization performance of high modulus asphalt, is the key technical index of high modulus asphalt. Zou and Liu clarified the evolution law of high-temperature performance of different types of low-grade high modulus asphalt, and high modulus asphalt suitable for high-temperature environment was recommended [23]. Feng prepared high modulus asphalt with waste polyethylene (PE), antirutting agent, and deoil asphalt (DOA), respectively, and found that the high-temperature performance of waste PE modified asphalt was the best, followed by antirutting agent modified asphalt, and DOA modified asphalt had the worst high-temperature performance [24]. Xiong et al. used 8%, 16%, and 24% hard asphalt to modify asphalt and found that the phase angle of modified asphalt decreased, the rutting factor increased, and the high-temperature deformation resistance increased after modification [25]. Hu prepared four kinds of asphalt mixtures with different gradations (AC14-EME, FAC-13, AC-13, ATB-25) by low-grade hard asphalt, and the antirutting performance was as follows: ATB-25 > FAC-13 > AC14-EME > AC-13 [26]. Peng studied the evolution of high-temperature performance of high modulus asphalt prepared by different processes (distillation deep drawing, propane deasphalting, mild oxidation, and composite
modifier modification) by means of rheological means, and the rutting factor of high modulus asphalt prepared by mild oxidation process was the highest [27]. Song tested the high-temperature rheological properties of 15 #, 20 #, and 25 # hard asphalt, and the rut factor of hard asphalt at 64°C is 7.4 times, 6 times, and 3.9 times of 70 # asphalt [28]. Based on cross-linking reaction, Wang et al. prepared ultra-high-molecular-weight polyethylene (UHMWP) high modulus

Figure 2: Softening point test of high modulus asphalt: (a) asphalt test mold of softening point; (b) softening point test instrument.

Figure 3: DSR test of high modulus asphalt: (a) DSR tester; (b) asphalt specimen.

Figure 4: BBR test of high modulus asphalt: (a) BBR tester; (b) asphalt specimen.
asphalt, and the softening point and rutting factor of UHMWP high modulus asphalt were significantly improved, and the rutting factor at 70°C could reach 1.81 kPa.

Based on the research results of Chinese scholars, the softening point and rutting factor of high modulus asphalt are systematically investigated. The specific survey results are shown in Figure 5 [9, 23–34]:

2.2.2. Investigation of Low-Temperature Performance of High Modulus Asphalt. Under low-temperature environment, asphalt binder is easy to lose its viscosity and brittle fracture, which causes low-temperature cracking of high modulus asphalt mixture. Therefore, it is of great significance to study the low-temperature performance of high modulus asphalt to ensure the low-temperature crack resistance of high modulus asphalt mixture. Peng studied the low-temperature fracture behavior of high modulus asphalt with different processes based on BBR test, and the high modulus asphalt prepared by composite modifier has superior low-temperature crack resistance [27]. Song compared and evaluated the low-temperature crack resistance of 15 #, 20 #, and 25 # hard asphalt and 70 # asphalt. The low-temperature performance of the three hard asphalt 20# asphalt is the best, but they are not as good as 70# asphalt [28]. Based on BFE (binder fracture energy) test, Chen et al. evaluated the low-temperature fracture behavior of high modulus asphalt in the viscoelastic range. Due to the fluffy internal structure, the stress concentration of high modulus asphalt leads to brittle fracture, which is characterized by insufficient low-temperature crack resistance [35]. Geng et al. studied the low-temperature fracture behavior of different kinds of high modulus asphalt by means of single-edge notched bending beam test, and fracture energy was proposed as the low-temperature performance evaluation index of high modulus asphalt [36].

At present, the relevant Chinese specifications of high modulus asphalt do not require the ductility index, but some researchers use the low-temperature BBR test of asphalt to reflect the low-temperature performance of high modulus asphalt. The specific indexes are the creep stiffness modulus (S) and the creep rate (n). The investigation results are shown in Figure 6 [9, 23–34].

2.3. Performance Evaluation of High Modulus Asphalt. It can be seen from Figure 5(a) that for the softening point of high modulus asphalt, the smaller quartile Q1 of the softening point of the basic modified high modulus asphalt is 52.4°C, the median Q2 is 57.6°C, and the larger quartile Q3 is 63.4°C. 50% of the softening point of high modulus asphalt is concentrated between 52.4°C and 63.4°C, indicating that the softening point difference of high modulus asphalt prepared by different research units or regions could reach 10°C or even higher. Composite modified high modulus asphalt softening point Q1–Q3 is 83.0°C, 88.7°C, 94.0°C, 50% of the data concentrated between 83°C and 94°C. The softening point of matrix asphalt is generally 48.5°C. In terms of median, the softening point of basic modified high modulus asphalt is 18.76% higher than that of matrix asphalt, while the softening point of composite modified high modulus asphalt is 82.89% higher than that of matrix asphalt. The results show that high modulus asphalt has excellent high-temperature performance, and the incorporation of modifiers such as SBS and crumb rubber has obvious improvement on the high-temperature performance of high modulus asphalt.

As the high-temperature performance parameter of asphalt, the larger the rutting factor G*/sinδ is, the smaller the energy dissipation is, and the smaller the permanent deformation of asphalt at high temperature is [33]. It can be seen from the analysis in Figure 5(b) that for the rutting factor of high modulus asphalt, the smaller quartile Q1 of the basic modified high modulus asphalt is 1.02 kPa, the median Q2 is 1.63 kPa, and the larger quartile Q3 is 2.45 kPa, and 50% of the rutting factor of high modulus asphalt is between 1.02 kPa and 2.45 kPa, indicating that the difference in the research results of different units can reach 1.43 kPa or more. The rutting factor of composite modified high modulus asphalt is concentrated in 4.12–5.39 kPa. On the other hand, the rutting factor of 70 # matrix asphalt is only 0.48 kPa, and the rutting factor of two kinds of high modulus asphalt is 239.58% and 897.92% higher than that of matrix asphalt respectively, indicating that the high modulus asphalt has greatly improved the resistance to high-temperature deformation, and the incorporation of modifiers will greatly strengthen its advantages in high-temperature deformation resistance. The reason may be that the hard component content of low-grade asphalt and blended asphalt is higher, and high modulus agent, crumb rubber, and SBS can also improve the consistency of asphalt which improves the high-temperature performance of asphalt.

According to the requirements of Chinese specification DB21/T1754-2009 [19], the creep stiffness modulus of asphalt material is ≤ 300 MPa, and the creep rate is ≥ 0.3. It can be seen from Figures 6(a) and 6(b) that the creep stiffness modulus and creep rate of the composite modified high modulus asphalt can meet the specification requirements and have good low-temperature performance. However, the creep stiffness and creep rate of more than 50% of the basic modified high modulus asphalt do not meet the specification requirements. The samples that do not meet the requirements include the high modulus asphalt prepared by adding rock asphalt, the high modulus asphalt prepared by adding direct-input high modulus additive, and the low-grade asphalt of the finished low-grade asphalt. It is not difficult to find that high modulus asphalt can greatly improve the high-temperature performance of asphalt while damage its low-temperature performance; that is, the high- and low-temperature performance of asphalt is contradictory. High modulus asphalt is mostly used in hot areas where the high-temperature process affects significantly to reduce the rutting disease of roads, and this kind of area basically has no influence of low-temperature process, so the requirements for low-temperature performance of high modulus asphalt are not rigorous [37]. The reason may be that the low-grade asphalt is brittle and has poor stress relaxation ability. Adding SBS, crumb rubber can form a cross-linked network inside the asphalt, absorb asphalt fracture energy, and
improve the high- and low-temperature performance of asphalt, which is an important means to improve the performance of high modulus asphalt and improve its classification level.

3. High Modulus Asphalt Mixture

3.1. Test Methods

3.1.1. Dynamic Modulus of High Modulus Asphalt Mixture. According to the Chinese test specification JTG E20-2011, the uniaxial compression method is used to test the dynamic modulus of high modulus asphalt mixtures. Firstly, the asphalt mixture cylinder with diameter of 100 mm ± 2 mm and height of 150 mm ± 2 mm is prepared by rotary compaction method. Then, the mixture specimens are placed in a 15°C incubator for 4-5 h. Finally, the loading test was carried out under the condition of 10 Hz, 15°C, and the dynamic modulus of high modulus asphalt mixture is measured.

3.1.2. Rutting Test of High Modulus Asphalt Mixture. According to the Chinese test specification JTG E20-2011, rutting test is used to test the high-temperature stability (dynamic stability) of high modulus asphalt mixture. Firstly, the asphalt mixture plate specimens with a length of 300 mm × width 300 mm × thickness 50 mm are prepared by the wheel rolling machine, and then, the mixture specimens are placed in an incubator at 60°C ± 1°C for 5-12 h. Finally, the test machine was started to make the test wheel walk around for 1 h. The dynamic stability is calculated by the following equation:

\[ DS = \frac{N(t_2 - t_1)}{d_2 - d_1} \times C_1 \times C_2. \]  

In the formula: DS—dynamic stability, times/mm; \( d_1 \)—the deformation corresponding to time \( t_1 \), mm; \( d_2 \)—the deformation corresponding to time \( t_2 \), mm; \( C_1 \)—testing machine type factor, take the value 1.0; \( C_2 \)—specimen factor, take the value 1.0; \( N \)—test wheel round-trip rolling speed, take the value 42 times/mm.

3.1.3. Low-Temperature Beam Bending Test of High Modulus Asphalt Mixture. According to the Chinese test specification JTG E20-2011, the low-temperature performance of high modulus asphalt mixture is evaluated by low-temperature beam bending test. Firstly, the asphalt mixture plate specimens are cut into beam specimen with a length of 250 mm, a width of 30 mm, and a height of 35 mm. Then, the mixture specimens are placed in methanol water solution at 0°C for 24 h. Finally, the mixture specimens are placed in a -18°C incubator for 24 h. The slender rate of beam bending is tested under the condition of -18°C, the test speed is 0.1 mm/min, the bending span is 400 mm, and the thickness of beam specimen is 35 mm. The slender rate is calculated by the following equation:

\[ \text{Slender rate} = \frac{L}{h} \times \frac{d_2 - d_1}{d_1} \times \frac{C_1}{C_2}, \]  

In the formula: \( L \)—test span, mm; \( h \)—beam thickness, mm; \( d_1 \)—the deformation corresponding to time \( t_1 \), mm; \( d_2 \)—the deformation corresponding to time \( t_2 \), mm; \( C_1 \)—testing machine type factor, take the value 1.0; \( C_2 \)—specimen factor, take the value 1.0; \( N \)—test wheel round-trip rolling speed, take the value 42 times/mm.
-10°C ± 0.5°C for 3 h. Finally, the universal material testing machine is started, and the maximum load (PB) and mid-span deflection (d) are measured in the load-deflection curve. The ultimate flexural-tensile strain is calculated by the following equation:

\[
\varepsilon_B = \frac{6 \times h \times d}{L^2}.
\] (4)

In the formula: \(\varepsilon_B\) — ultimate flexural-tensile strain, \(\mu\); \(h\) — the height of cross-interrupt interview pieces, mm; \(b\) — the width of cross-interrupt interview pieces, mm; \(L\) — the span of the test piece, mm.

3.1.4. Residual Stability of High Modulus Asphalt Mixture. According to the Chinese test specification JTG E20-2011, the water stability of high modulus asphalt mixture was evaluated by the immersion Marshall test. Firstly, Marshall specimens with diameter of 101.6 mm ± 0.2 mm and height of 63.5 mm ± 1.3 mm are prepared by compaction method. Secondly, Marshall specimens are kept in a constant temperature water bath for 48 h. Finally, the loading equipment is started to make the specimen bear the load, and the loading speed is 50 mm/min ±5 mm/min. The maximum load in the pressure-deformation curve is the Marshall stability of asphalt mixture, and the residual stability of high modulus asphalt mixture is calculated by the following equation:

\[
MS_0 = \frac{MS_i}{MS}.
\] (5)

In the formula: \(MS_0\) — residual stability, \(\mu\); \(MS_i\) — stability of specimen immersed for 48 hours, kN; \(MS\) — stability of specimen without immersed, kN.

3.1.5. Freeze-Thaw Splitting Test of High Modulus Asphalt Mixture. According to the Chinese test specification JTG E20-2011, the freeze-thaw splitting test was used to evaluate the water stability of high modulus asphalt mixture. Firstly, the Marshall cylindrical specimens with 50 times compaction on both sides are prepared, and after the specimens are vacuum-saturated with water, they are kept in an environment with a freezing temperature of -18°C ± 2°C for 16 h, and after freezing, they are placed in a 60°C constant temperature water tank for 24 h. Then, the specimens are taken out and immersed in a constant temperature water tank at 25°C for 2 h. Finally, the splitting test is carried out. After the test, the freeze-thaw splitting strength ratio (TSR) of high modulus asphalt mixture is calculated by the following equations:

\[
R_{T1} = \frac{P_{T1}}{h1},
\] (6)

\[
R_{T2} = \frac{P_{T2}}{h2},
\] (7)

\[
TSR = \frac{R_{T2}}{R_{T1}} \times 100.
\] (8)

In the formula: \(R_{T1}\) — splitting tensile strength of single specimen in non-freezing-thawing group, MPa; \(R_{T2}\) — splitting tensile strength of single specimen in freezing-thawing group, MPa; \(P_{T1}\) — load value of single specimen in non-freezing-thawing group, N; \(P_{T2}\) — load value of single specimen in freezing-thawing group, N; \(h1\) — the height of single specimen in non-freezing-thawing group, mm; \(h2\) — the height of single specimen in freezing-thawing group, mm; TSR — freeze-thaw splitting strength ratio, %; \(R_{T1}\) — average splitting tensile strength of freeze-thaw group, MPa; \(R_{T2}\) — average splitting tensile strength of no-freeze-thaw group, MPa.

3.2. Investigation of Performance of High Modulus Asphalt Mixture. Guided by the establishment of the grade evaluation standard of high modulus asphalt mixture, the mechanical properties and road performance of high modulus asphalt mixture in China are systematically investigated, and the dynamic modulus [38], dynamic stability, ultimate flexural strain, residual stability, and TSR indexes of high modulus asphalt mixture are evaluated [39]. Ouyang et al. used deoiled hard asphalt, vacuum deep drawing residue, and hard asphalt modifier for high modulus composite modification of asphalt mixture and tested the high-temperature deformation resistance and mechanical properties of high modulus asphalt mixture [33]. Xia et al. designed and tested the road performance of a French high modulus asphalt mixture EME2 and proposed a road performance evaluation index suitable for Chinese climate [29]. The high modulus asphalt mixture prepared by Peng using propane deasphalting had excellent road performance such as high-temperature stability and water stability, and its dynamic modulus was significantly higher than that of SBS asphalt mixture [27]. Song tested the mechanical properties and road performance of three low-grade asphalt mixtures. The dynamic modulus of low-grade asphalt mixture was 2.9 times, 1.8 times, and 1.4 times that of 70 # asphalt mixture respectively, and the high-temperature performance and water stability of high modulus asphalt mixture were excellent, but the low-temperature performance did not meet the specification requirements [28]. Dong et al. compared and analyzed the mechanical properties of high modulus asphalt mixture with skeleton gradation and suspension gradation, and the results showed that the dynamic modulus of skeleton gradation asphalt mixture was higher than that of the latter, and the deformation resistance was stronger [32]. Wang et al. compared and analyzed the deformation recovery performance of rock asphalt (RA) modified high modulus asphalt mixture and polyolefin (PR) modified high modulus asphalt mixture by means of rheology. The rutting resistance of PR modified high modulus asphalt mixture was better than that of RA modified high modulus asphalt, but the fatigue performance was opposite [40]. Zou et al. used PRs and PRM modifiers to prepare high modulus asphalt mixtures that have significantly improved mechanical properties, high-temperature performance, and water stability compared to SBS asphalt mixtures [41].
According to the existing research results [42], the above survey results of each index of high modulus asphalt mixture are summarized in Figures 7–9. It is worth mentioning that although the fatigue performance is also the key road performance index of high modulus asphalt mixture, it is not included in the scope of investigation because the test methods and test conditions of fatigue performance of high modulus asphalt mixture are quite different, resulting in large gaps in test results and cannot be compared.

3.3 Performance Evaluation of High Modulus Asphalt Mixture. From Figures 7(a), 8(a), and 9(a), it can be seen that the dynamic modulus of the three types of high modulus asphalt mixture is significantly improved. The quartile range of dynamic modulus of low-grade high modulus asphalt mixture, self-blending high modulus asphalt mixture, and admixture high modulus asphalt mixture are 17580–23893 MPa, 12953–16916 MPa, and 12086–17680 MPa, respectively. The dynamic modulus data of three kinds of high modulus asphalt mixtures have little difference.

For the dynamic stability, the medians of dynamic stability of three types of high modulus asphalt mixtures in Figures 7(b), 8(b), and 9(b) are 2838 times/mm, 5675 times/mm, and 8836 times/mm, respectively. The high-temperature performance of admixture high modulus asphalt mixture is the best. The reason may be that the low-grade high modulus asphalt mixture and self-blending high modulus asphalt mixture are limited by the maturity of China’s production process and cannot be comparable with the finished high modulus admixture.

For the ultimate flexural-tensile strain, from Figures 7(c), 8(c), and 9(c), it can be seen that the medians of three types of high modulus asphalt mixtures are 2607 με, 3056 με, and 2490 με, respectively. The low-temperature performance of asphalt mixtures is not very different, all of which can meet the requirements of the specification T/CHTS 10004-2018 [18], and the processing technology has little effect on the low-temperature performance of high modulus asphalt mixtures.

It can be seen from Figures 7(d), 8(d), and 9(d) that the quartile ranges of residual stability of three types of high modulus asphalt mixtures are 86.0–92.4%, 90.0–94.2%, and 92.3–96.1%, respectively. The quartile ranges of TSR of three types of high modulus asphalt mixtures are 84.3–88.2%, 85.7–90.2%, and 84.1–92.9%, respectively. The water stability of the admixture high modulus asphalt mixture has a slight advantage, but in general, there is little difference in the data of the three high modulus asphalt mixtures, and they all meet the requirements of the specification T/CHTS 10004-2018 [18].

Figure 7: Performance of low-grade high modulus asphalt mixture [28, 30, 32, 36, 39, 42–54]: (a) dynamic modulus; (b) dynamic stability; (c) ultimate flexural-tensile strain; (d) residual stability and TSR.
Figure 8: Performance of self-blending high modulus asphalt mixture [28, 30, 32, 36, 39, 42–54]: (a) dynamic modulus; (b) dynamic stability; (c) ultimate flexural-tensile strain; (d) residual stability and TSR.

Figure 9: Performance of admixture high modulus asphalt mixture [28, 30, 32, 36, 39, 42–54]: (a) dynamic modulus; (b) dynamic stability; (c) ultimate flexural-tensile strain; (d) residual stability and TSR.
4. Performance Classification of High Modulus Asphalt and Its Mixture

4.1. Performance Classification of High Modulus Asphalt. In order to evaluate the performance of high modulus asphalt more scientifically and accurately, the high modulus asphalt is divided into four grades, excellent, good, general, and poor, according to the survey data and relevant specifications [18–21]. The smaller quartile Q1, median Q2, and larger quartile Q3 of the box figure should be rounded appropriately as the classification criteria for each individual index. The high-temperature performance of high modulus asphalt is the main optimization performance, while the low-temperature performance requirements are not very strict. Therefore, softening point and rutting factor are selected as the key index in the classification, and creep stiffness modulus and creep rate are selected as reference index. The classification of high modulus asphalt is shown in Table 1.

4.2. Performance Classification of High Modulus Asphalt Mixture. In order to compare and evaluate the individual performance level of different types of high modulus asphalt mixture, referring to the classification method of high modulus asphalt, the classification standard of individual performance level of high modulus asphalt mixture is proposed, based on the survey results, relevant specifications [18–21], and mathematical statistics. The data of each individual performance index of the mixture are arranged from large to small by four grades of excellence, good, general, and poor, and the data at 75%, 50%, and 25% are taken and properly integrated as the classification standard.

### Table 1: Classification standard of high modulus asphalt.

<table>
<thead>
<tr>
<th>Grades</th>
<th>Key index</th>
<th>Reference index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Softening point (°C)</td>
<td>Rutting factor (kPa)</td>
</tr>
<tr>
<td>Excellent</td>
<td>[63, +∞)</td>
<td>[2.5, +∞)</td>
</tr>
<tr>
<td>Good</td>
<td>[58, 63)</td>
<td>[1.6, 2.5)</td>
</tr>
<tr>
<td>General</td>
<td>[53, 58)</td>
<td>[1.0, 1.6)</td>
</tr>
<tr>
<td>Poor</td>
<td>[0, 53)</td>
<td>[0, 1.0)</td>
</tr>
</tbody>
</table>

Note 1: the rutting factor in the table was measured at 10 Hz and 70°C in the temperature scanning test; note 2: the creep stiffness modulus and creep rate in the table were measured by bending creep stiffness test at -12°C for 60 s.

### Table 2: Classification standard of low-grade high modulus asphalt mixture.

<table>
<thead>
<tr>
<th>Grades</th>
<th>Dynamic modulus (MPa)</th>
<th>Dynamic stability (times/mm)</th>
<th>Ultimate flexural-tensile strain (με)</th>
<th>Residual stability (%)</th>
<th>TSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>[24000, +∞)</td>
<td>[6850, +∞)</td>
<td>[3400, +∞)</td>
<td>[93, +∞)</td>
<td>[92, +∞)</td>
</tr>
<tr>
<td>Good</td>
<td>[20000, 24000)</td>
<td>[2850, 6850)</td>
<td>[2600, 3400)</td>
<td>[89, 93)</td>
<td>[87, 92)</td>
</tr>
<tr>
<td>General</td>
<td>[17600, 20000)</td>
<td>[2000, 2850)</td>
<td>[1900, 2600)</td>
<td>[86, 89)</td>
<td>[85, 87)</td>
</tr>
<tr>
<td>Poor</td>
<td>[14000, 17600)</td>
<td>[0, 2000)</td>
<td>[0, 1900)</td>
<td>[80, 86)</td>
<td>[80, 85)</td>
</tr>
</tbody>
</table>

Note 1: specification requires dynamic stability >2000 times/mm, does not meet the requirements is considered to be poor level; note 2: specification requirements ultimate bending strain >1900 times/mm, do not meet the requirements is considered to be poor level.

### Table 3: Classification standard of self-blending high modulus asphalt mixture.

<table>
<thead>
<tr>
<th>Grades</th>
<th>Dynamic modulus (MPa)</th>
<th>Dynamic stability (times/mm)</th>
<th>Ultimate flexural-tensile strain (με)</th>
<th>Residual stability (%)</th>
<th>TSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>[17000, +∞)</td>
<td>[9600, +∞)</td>
<td>[3700, +∞)</td>
<td>[94, +∞)</td>
<td>[90, +∞)</td>
</tr>
<tr>
<td>Good</td>
<td>[15500, 17000)</td>
<td>[7300, 9600)</td>
<td>[3100, 3700)</td>
<td>[92, 94)</td>
<td>[87, 90)</td>
</tr>
<tr>
<td>General</td>
<td>[14000, 15500)</td>
<td>[5200, 7300)</td>
<td>[2300, 3100)</td>
<td>[90, 92)</td>
<td>[85, 87)</td>
</tr>
<tr>
<td>Poor</td>
<td>[0, 14000)</td>
<td>[2000, 5200)</td>
<td>[1900, 2300)</td>
<td>[80, 90)</td>
<td>[80, 85)</td>
</tr>
</tbody>
</table>

Note 1: the specification requires dynamic modulus >14000 MPa, which is based on the specification requirements.

### Table 4: Classification standard of admixture high modulus asphalt mixture.

<table>
<thead>
<tr>
<th>Grades</th>
<th>Dynamic modulus (MPa)</th>
<th>Dynamic stability (times/mm)</th>
<th>Ultimate flexural-tensile strain (με)</th>
<th>Residual stability (%)</th>
<th>TSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>[19500, +∞)</td>
<td>[12500, +∞)</td>
<td>[3000, +∞)</td>
<td>[96, +∞)</td>
<td>[93, +∞)</td>
</tr>
<tr>
<td>Good</td>
<td>[17500, 19500)</td>
<td>[9250, 12500)</td>
<td>[2600, 3000)</td>
<td>[94, 96)</td>
<td>[89, 93)</td>
</tr>
<tr>
<td>General</td>
<td>[15500, 17500)</td>
<td>[9250, 6800)</td>
<td>[2250, 2600)</td>
<td>[92, 94)</td>
<td>[83, 89)</td>
</tr>
<tr>
<td>Poor</td>
<td>[14000, 15500)</td>
<td>[2800, 6800)</td>
<td>[1900, 2250)</td>
<td>[80, 92)</td>
<td>[80, 83)</td>
</tr>
</tbody>
</table>
of each grade. The classification of high modulus asphalt mixture is shown in Tables 2–4.

5. Conclusion

(1) After high modulus modification, the high-temperature performance of asphalt is significantly improved, and the composite modified high modulus asphalt has the best performance. Compared with the matrix asphalt, the softening point of the composite-modified high modulus asphalt is increased by 82.89%, and the rutting factor is increased by 9 times. However, the improvement effect of low-temperature performance of high modulus asphalt is not obvious.

(2) After high modulus modification, the mechanical properties and road performance of asphalt mixture are significantly improved. The high modulus asphalt mixture prepared by adding admixtures has the best high-temperature stability, but the preparation process has little effect on the low-temperature performance and water stability of the mixture.

(3) Taking excellent, good, general, and poor as comments, softening point and rutting factor are selected as key indicators of high modulus asphalt performance, and creep stiffness modulus and creep rate are selected as reference indicators, and the classification standard of high modulus asphalt performance is proposed. Selecting dynamic modulus, dynamic stability, ultimate flexural-tensile strain, residual stability, and TSR as indicators, the classification standard of high modulus asphalt mixture performance is proposed.

(4) This paper systematically reviews the research trends of high modulus asphalt in China and establishes the classification standard of high modulus asphalt and its mixture. In the later stage, high modulus asphalt and its mixture can be prepared based on scientific test methods, and relevant performance indexes can be tested to further verify the scientificity of the classification standard.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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