Research Article

Durability Capacity Change of Rubber Powder Composite BRA Modified Asphalt Mixture

Qiyu Pan and Huandong Pang

Shandong University of Science and Technology, School of Civil Engineering and Architecture, Qingdao 266590, China

Correspondence should be addressed to Huandong Pang; phd2050@sdust.edu.cn

Received 3 March 2022; Accepted 23 April 2022; Published 17 May 2022

Copyright © 2022 Qiyu Pan and Huandong Pang. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Both engineering practice and literature confirm that the high modulus asphalt mixture has superior performance. If modified, the final asphalt mixture can effectively improve the service life of asphalt pavement. Therefore, the design and test of this paper are trying to mix rubber powder and BRA to prepare high modulus Sup-13 asphalt mixture. Through a series of experimental studies, this paper discusses the effect of adding rubber powder and BRA separately and the effect of adding both rubber powder and BRA into asphalt mixture on its durability. The experimental part mainly focuses on the composite modified asphalt mixture water resistance test, the high temperature stability test, and the low temperature crack resistance test, and it is concluded that the rubber powder and the BRA compound modification can equalize the improvement effect of strength, modulus, and strain. For this reason, if the rubber powder with finer particle size is adopted to modify the asphalt mixture, the low temperature crack resistance of the specimen will improve apparently.

1. Introduction

With the rapid growth of the national economy, more and more people have cars, which leads to the increase of traffic flow and the rapid growth of axle load. Asphalt is widely used in pouring roads, but pavement constructing with unmodified asphalt mixture cannot withstand such a rapid increase in axle load. Therefore, this paper studies the modified asphalt mixture in order to extend its design life.

Waste tyres treatment is a worldwide problem, and related data show that 800 million waste tyres are scrapped every year, in which China has occupied a great share. By the end of 2018, China had 240 million cars and the rubber tyres industry had produced 816 million pieces, of which about 648 million were automobile tyres [1, 2]. Recently, the main treatment of used tyres has involved direct landfill and combustion, which leads to serious soil and air pollution. In 2007, the waste tyres that were burned in the United States accounted for 54.1 percent of its annual waste tyre production; that figure fell slightly to 43 percent in 2017 [3]. In Brazil, waste tyres are mainly used to produce fuel, which leads to the emissions of a large amount of toxic [4].

China is a country with extremely scarce rubber resources. More than 75% of natural rubber and more than 40% of synthetic rubber are imported each year. The total external dependence of rubber resources is more than 70%, which is larger than oil and iron ore, and it far exceeds the national strategic resource security warning line [5]. According to statistics released by China Industrial Information Network (2018), about 14.58 million tons of waste tyres were produced in 2018, but only 5.69 million tons of tyre were recovered to produce fuel, so the recovery efficiency of waste tyres was less than 40 percent [6]. In view of the above severe situation, it is urgent to find new ways to recycle used tyres.

The unmodified asphalt pavement is not enough to meet the requirements of long-life asphalt pavement because of its structure, which determines the water stability, high temperature stability, low temperature crack resistance, and fatigue stress performance of the mixture. Through various data investigation, it is found that the high modulus asphalt...
mixture has superior performance. When modifying the asphalt mixture and increasing its modulus at the same time, the asphalt mixture may meet the requirements of long-life asphalt pavement.

Many scholars have carried out a lot of research on modified composite asphalt mixture, such as adding SEBS and PPA to modify the asphalt mixture at the same time [7] or adding heavy calcium carbonate and SBS [8] or modifying with bio-oil and Buton rock asphalt [9]. Furthermore, Chengduo Qian et al. have studied the influence of rubber powder as modifier on asphalt mixture [10, 11] and analyzed its road application potential [12]. At the same time, Chen Yu et al. have studied the high modulus asphalt mixture [13]. Combined with the above two studies, Liu Li has made a series of experiments after compound modification of asphalt and obtaining high modulus asphalt mixture. The studies show that [14] the high temperature stability, water stability, and fatigue resistance durability of the composite modified asphalt mixture with rubber powder and Qingchuan rock asphalt as modifier are very superior. However, the durability study of asphalt mixture modified with rubber powder and BRA has been little reported.

To investigate the change rule, rubber powder and BRA are used to prepare high modulus Sup-13 asphalt mixture. Through a series of experiments and research work, a study was carried out on the effectiveness of adding rubber powder and BRA separately and the result of adding both rubber powder and BRA into asphalt mixture on the durability. The research focuses on experimental data and feasibility demonstration for environmental protection BRA and waste tyre rubber powder for asphalt mixture modification.

2. Raw Materials

2.1. Minerals. Aggregate occupies 80–85% volume of hot mix asphalt mixture, which accounts for about 95% of mixture weight. The characteristics and quality of aggregates are the main factors affecting the performance of hot mix asphalt mixtures. In the early 1990s, an expert group in SHRP discussed the aggregate properties that are most important for pavement performance. The properties selected included coarse aggregate angularity, fine aggregate angularity, slender and flat particles, clay content, and gradation [15]. Based on the instruments and equipment of the experimental center, this paper completes the mineral test with reference to the relevant technical indexes and test methods stipulated in the Test Methods of Aggregate for Highway Engineering (JTG E42-2005) [16].

2.1.1. Coarse Aggregate. In view of the continuous improvement of the performance requirements of asphalt upper layer on high-grade highway and municipal road, basalt aggregate and modified asphalt are widely used. The coarse aggregate studied in this experiment adopts three kinds of basalt aggregates of different specifications, 10–15 mm, 5–10 mm, and 3–5 mm, which were produced in Lianyungang City in eastern China. Referring to the relevant provisions of the Technical Specifications for Construction of Highway Asphalt Pavements (JTG F40-2004) [17], according to the JTGE42-2005 test of coarse aggregate [18], the results show that the materials used in this paper conform to the technical specifications.

2.1.2. Fine Aggregate. The fine aggregate should be clean, dry, weathered, and impurity-free and have appropriate particle gradation [18], as required by item 4.2.2 of the JTGF40-2004. In this paper, the fine aggregate is made of limestone debris from Anhui Province in central China.

2.1.3. Mineral Powder. The asphalt mixture uses mineral powder as filler, and mineral powder must be ground by hydrophobic stone such as strong basic rock in limestone or magmatic rock [19]. The limestone mineral powder produced in Anhui Province is used in this paper.

2.2. Asphalt. Generally speaking, modified asphalt should be used in the surface layer of high-grade road to increase the high- and low-temperature performance and durability of asphalt surface. The purpose of this paper is to investigate the road properties of rock asphalt and rubber powder modified asphalt mixture. For this, the A-70# heavy road petroleum asphalt commonly used in Jiangsu Province (eastern China) is utilized as the base asphalt. Based on matrix asphalt, Budunyan asphalt and rubber powder are used to improve the modification effect and explore the modification mechanism.

2.3. Modified Admixtures

2.3.1. Buton Rock Asphalt. Buton rock asphalt (referred to as BRA) is produced in the South Pacific Indonesia Bouton Island, which is divided into soft and hard, in which hard Bouton rock asphalt is often used in asphalt pavement engineering. After being excavated and broken into fine-grained powder, the BRA appears dark brown; the content of asphalt in BRA is about 20–30%, making it belong to high-viscosity asphalt (rock asphalt, referred to as RA); the rest are active ash minerals (Buton rock, referred to as BR), which are not only finer but also good at absorbing asphalt. It has the function of strengthening the adhesion between asphalt and aggregate and is called asphalt active agent in Indonesia as well.

2.3.2. Rubber Powder. Road rubber powder should use the powder which was ground at room temperature by waste tyres, and it is advisable to choose oblique tyre rubber powder or rubber powder with high content of natural rubber [19]. Rubber powder should be black homogeneous powder, and particle size should be within a range of 30 meshes to 80 meshes. In this paper, the market purchase of four kinds of rubber powder for comparison experimental analysis is shown in Figure 1. The measured particle gradation of rubber powder is shown in Table 1, and the particle size of rubber powder 1# to 4# is from coarse to fine.
3. Marshall Experiment of Modified High Modulus Asphalt Mixture

According to the relevant regulations of the current Technical Specification for Highway Asphalt Pavement Construction, Sup-13 asphalt mixture needs to be verified by Marshall experiments, including void ratio, stability, and flow value, and other indicators meet the technical requirements stipulated in the Code [17].

Dry aggregate in 105 ± 5°C oven to constant weight. Heat asphalt with oven to specified mixing temperature. Take 6 groups of asphalt mixture raw materials according to Table 2 and mix them; the percentage of asphalt in Table 2 is oil-stone ratio. Put raw materials into the mold and flatten the mixture surface. Use the Marshall compaction instrument to hit each side of the mixture 75 times to obtain the standard Marshall specimens. The diameter of the standard Marshall specimen is within the 101.6 ± 0.2 mm range, and the height of the specimen is within the 63.5 ± 1.3 mm range.

### Table 1: Composition of rubber powder particles.

| Meshes | Size of sieve hole (mm) | Rubber powder number |
|--------|-------------------------|----------------------|
|        |                         | 1# | 2# | 3# | 4# |
| 200    | 0.075                   | 1.6 | 44.6 | 34.3 | 48.7 |
| 100    | 0.15                    | 14.1 | 75 | 79.1 | 93 |
| 50     | 0.27                    | 40 | 93 | 99.8 | 99.7 |
| 30     | 0.55                    | 100 | 100 | 100 | 100 |

3.1. Physical Performance Indicators. At present, the mix ratio design of asphalt mixture stipulated in the Technical Specification for Highway Asphalt Pavement Construction in China is still a chivalrous volume design index; for example, the control parameters of mixture design include void ratio of specimen, effective asphalt saturation, and clearance rate of mineral aggregate [17]. Mixture design of superpave asphalt is based on the principle of “coarse aggregate embedding and fine aggregate filling,” which also involves volume index. Different from Marshall design method, rotating compaction instrument is used to form the specimen and then to test related volume index.

In this paper, according to the current Code [17], molding standard Marshall specimens are shown in Figure 2, and testing related physical performance indicators are shown in Table 3.

According to the measured physical and technical indexes, the mineral void of the 2# ratio specimen was further filled by the mineral in BRA modified admixture, and the index of water absorption and void ratio of the relative reference ratio specimen (1# ratio specimen) is obviously reduced, which leads to the increase of gross volume density. The increase of the theoretical density indicates that the density of the BRA is higher than that of gravel and mineral powder, and the natural asphalt density in BRA is also higher than that in matrix asphalt.

There are obvious differences in the physical properties of the four kinds of rubber powder, which leads to the obvious differences in the physical technical indexes of Marshall standard specimens and asphalt mixtures made of the four kinds of rubber powder. There are more fine fibers in 1# rubber powder, the rubber particles of itself are relatively coarse, and the elastic recovery of the rubber particles makes it difficult to compact in the molding process, so the water absorption and void ratio of 3# specimen are relatively large. The density of the 3# ratio specimen is relatively low and the density of 6# ratio specimen is relatively high, mainly due to the density of modified admixture itself. The curves in Figure 3 also show that the finer the rubber powder, the better the filling performance of the Marshall specimen and the denser the specimen. Figure 4 shows the cross section of each group of Marshall specimens. If carefully observing the coarse aggregate skeleton and the filling rate of coarse aggregate gap, it can be found that the six groups of specimens basically form the skeleton embedded extrusion structure, and the filling rate of fine aggregate is high. Mix gradation design meets the design requirement of superpave asphalt mixture.

3.2. Testing of Mechanical Properties. In accordance with the relevant test standard, the specimens in Figure 2 should be soaked in 60°C water for 30 min, and then the Marshall stability and flow value are tested immediately. The results are shown in Table 4 and Figure 5.

The measured stability and flow value show that the mechanical properties of asphalt mixture are obviously improved by BRA modified admixture. The BRA content of 4% increases the stability of 2# ratio specimen by 24.2%, while the flow value decreases by 25.2%. It reflects the modification characteristics of high modulus asphalt mixture. It is worth noting that although 1# rubber powder contains a certain amount of fine fiber, because of its coarse particles and other reasons, the compactness of the specimen is poor, resulting in a decrease in stability. Among the four kinds of rubber powder, the mixture modified with the 4# glue powder which has smallest particle diameter is most stable, and the stability is increased by 48.2% and 19.3%, respectively, compared with the 1# benchmark mixture and...
the 2# BRA modified mixture, which indicates that the dry rubber powder modification also increases the viscosity of asphalt and further reduces the temperature sensitivity of asphalt mixture on the basis of BRA modification. Compared with BRA single modification, the asphalt mixture modified by both rubber powder and BRA can increase the flow value and reduces the rigidity of Marshall specimen.

### 4. Experimental Study on Water Stability

The asphalt film on the asphalt pavement is often stripped from the aggregate surface because of the rainwater immersion, combined with the vacuum suction of vehicle wheel rolling, dynamic water pressure, and other factors. Low-temperature embrittlement of asphalt binder and frost heaving of water-bearing asphalt mixture lead to micro-cracks in asphalt pavement structure. In the presence of the previously mentioned defects, the traffic load causes the asphalt surface to be loose, that is, the water damage of the asphalt pavement. The water damage of asphalt pavement is partly due to the unreasonable design of waterproof and drainage structure, and the other is the poor water stability of asphalt mixture itself. The water stability of asphalt mixture refers to the exfoliation resistance of asphalt mixture after forming an adhesive layer between asphalt and aggregate to asphalt replacement under water condition [20, 21]. Water stability of asphalt mixture is often tested by immersion Marshall test and freeze-thaw splitting test [18, 19]. During the molding standard Marshall specimen, the residual stability specimen (75 times of double-sided

| Table 2: Proportion of modified asphalt mixture. |
|------------------------------------------------|
| Serial no. | Proportion of mixture (%) |
| 1 | 2# Aggregate | 3# Aggregate | 4# Aggregate | 1# rubber powder | 2# rubber powder | 3# rubber powder | 4# rubber powder |
| 1 | 22 | 30 | 10 | 36 | 2 | 5.20 | 0 | 0 | 0 |
| 2 | 22 | 30 | 10 | 33 | 1 | 4.20 | 4 | 0 | 0 |
| 3 | 22 | 30 | 10 | 34 | 1 | 4.45 | 3 | 1 | 0 |
| 4 | 22 | 30 | 10 | 34 | 1 | 4.45 | 3 | 0 | 1 |
| 5 | 22 | 30 | 10 | 34 | 1 | 4.45 | 3 | 0 | 0 | 1 |

**Figure 2: Standard test specimen for Marshall test.**

| Table 3: Physical performance index of Marshall specimens. |
|------------------------------------------------|
| Technical parameters | 1 | 2 | 3 | 4 | 5 | 6 | Normative limits |
| 1 Benchmark mixture | Gross volume density | 2.396 | 2.425 | 2.403 | 2.426 | 2.419 | 2.436 | — |
| Water absorption (%) | 0.76 | 0.51 | 0.91 | 0.41 | 0.46 | 0.31 | — |
| 2 BRA modification | Measured theoretical density | 2.526 | 2.534 | 2.516 | 2.531 | 2.526 | 2.539 | — |
| Void ratio (%) | 5.15 | 4.30 | 4.49 | 4.15 | 4.24 | 4.06 | 3 ~ 6 |
| 3 BRA+1# glue powder modification | Technical parameters | 1 | 2 | 3 | 4 | 5 | 6 | Normative limits |
| 4 BRA+2# glue powder modification |  |  |  |  |  |  |  |  |
Figure 3: Curve of physical and technical parameters of Marshall test standard specimen. (a) Relative density of specimen gross volume, (b) water absorption of specimens, (c) theoretical maximum relative density, and (d) voidage of specimens.

Figure 4: Cross-sectional photograph of six Marshall standard specimens.

Table 4: Stability and flow value of Marshall specimen.

| Technical parameters | 1 Benchmark mixture | 2 BRA modification | 3 BRA+1# glue powder modification | 4 BRA+2# glue powder modification | 5 BRA+3# glue powder modification | 6 BRA+4# glue powder modification | Normative limits |
|----------------------|---------------------|--------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|-----------------|
| Stability (kN)       | 9.05                | 11.24              | 10.09                            | 12.75                            | 11.87                            | 13.41                            | ≥8              |
| Stream value (mm)    | 3.26                | 2.44               | 2.99                             | 2.95                             | 3.14                             | 2.87                             | 2 ~ 4           |
compaction) and freeze-thaw split specimen (50 times of double-sided compaction) are formed under the same conditions and corresponding tests are carried out after placing specimen at room temperature for 1 day.

It is well known that low-temperature embrittlement of asphalt binder and frost heaving of water-bearing asphalt mixture lead to the microcracks in asphalt pavement structure.

4.1. Marshall Residual Stability Test. According to the test method stipulated in the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [22], Marshall Stability is tested after soaking the specimen in 60°C water for 48 h, when the stability test described in Section 2.2 is performed simultaneously. The residual stability is calculated by dividing the 48-hour Marshall stability by the 0.5-hour Marshall stability measured in Section 2.2:

\[ \text{MS}_0 = \frac{\text{MS}_1 \times 100}{\text{MS}} \]  \hspace{1cm} (1)

In the above formula, \( \text{MS}_0 \) is residual stability of Marshall specimen (%); \( \text{MS}_1 \) is stability of specimen immersed in water for 48 hours (kN); \( \text{MS} \) is stability of specimen immersed in water for 0.5 hours (kN).

The measured residual stability for 48 hours is shown in Table 5 and Figure 6. The residual stability of the BRA modified asphalt mixture was improved by 11.75%, the natural asphalt component in BRA and the matrix asphalt blend and significantly improve the water stability of the mixture. On this basis, using rubber powder instead of partial BRA will reduce the content of the natural asphalt and decrease the residual stability. Although the residual stability of 5# specimen is lower than that of 4# specimen, the residual stability of 5# specimen is higher than that of 3# specimen, which still shows that increasing the mesh number of rubber powder can improve the water stability of Marshall specimen.

4.2. Freeze-Thaw Splitting Test. The water resistance of asphalt mixture is evaluated by freeze-thaw splitting strength test, which is mainly to calculate the splitting strength ratio between freeze-thaw specimen and non-thaw specimen. Compared with the residual stability test, freeze-thaw...
splitting mainly represents the ability of Marshall specimen to withstand freezing failure in water saturated state.

The test uses a standard Marshall specimen with a diameter of 100 mm and a height of 63.5 mm, and the void ratio is controlled between 6% and 8%. According to the relevant regulations of Test Code for Asphalt and Asphalt Mixture in Highway Engineering, the Marshall specimen is compacted 50 times on double sides, with each mixture being formed into 8 specimens, and divided into two groups: A and B. The specimens of group A are kept at room temperature for reserve. The specimens of group B are placed in a vacuum machine to saturate their water absorption, after being sealed and stored in sealed bags, freezing under −18°C ± 2°C conditions for 16 hours, and then taking out specimens and removing the plastic bag and putting it into 60°C ± 0.5°C constant temperature for 24 hours. After completion of the above steps, groups A and B of specimens are immersed in 25°C ± 0.5°C constant temperature flume for 2 hours. After being taken out and testing at the loading rate of 50 mm/min, the splitting strength is calculated according to the following formula:

\[
R_T = \frac{0.00628PT}{h}. \tag{2}
\]

In the above formula, \( R_T \) is split tensile strength of specimens (MPa); \( P_T \) represents test load values for individual specimens (N); \( h \) is the height of each specimen (mm).

The results of freeze-thaw splitting test are shown in Table 6 and Figure 7.

The results of freeze-thaw splitting tensile strength of each group of asphalt mixture specimens show that the splitting tensile strength of each group decreases in varying degrees after freeze-thaw cycle. The strength of 1# reference mix ratio reduces by 16.62%, and the decreased strength of 4# mixture which is modified with rubber powder and BRA is minimum (7.86%). Although the void ratio of 3# mixture modified with rubber powder and BRA is relatively high, the frost resistance is relatively good because of the reinforcement of fine fibers and the elasticity of rubber particles with slightly larger particle size. The 4# specimens modified with rubber powder and BRA were least affected by freeze-thaw due to the highest density and less void.

Figure 8 shows the vertical compression deformation of each specimen under the maximum splitting load. From Figure 8, it is seen that the BRA modified mixture is brittle, corresponding to the relatively high strength value in Figure 7, and its deformation modulus is relatively high. After adding rubber powder to the BRA, the toughness of the modified mixture specimen is obviously improved. The modification effect of the finer rubber powder on the matrix asphalt is obvious, and the cementation ability and toughness are enhanced simultaneously.

5. Experimental Study on High-Temperature Stability

Because of channelized traffic, high temperature, heavy load, and other factors, phenomena such as uplift, passage, rutting, and other early damages often occur in asphalt pavement. These diseases may be due to problems such as insufficient construction compaction and vehicle overrun, but the more important factor is the lack of strength, stiffness, and thermal stability of asphalt and asphalt mixture itself. Sup-13 mixture design has considered the establishment of an embedded coarse aggregate skeleton system, but it is also necessary to increase the viscosity of the binder and the adhesion to the aggregate. At present, the high-temperature stability of asphalt mixture is mainly tested by rutting test, which includes test of rutting plate in indoor wheel mill, test of large ring road, and direct test of actual pavement. The test parameter provided by the current Test Code for Asphalt and Asphalt Mixture in Highway Engineering is dynamic stability [22].

5.1. Sample Preparation and Experimental Equipment. According to the test method in the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [22], after making the mixture, 30 cm × 30 cm × 5 cm rutting plates are formed by a wheel mill, and they are left to rest for 1 day at room temperature. Then in the 60°C ± 1°C oven, heat preservation holds 5~6 hours. Further the rutting test machine starts to test, the walking direction of the test wheel was the same as that of the forming direction of the specimen, the pressure of the test wheel was 0.7 MPa ± 0.5 MPa, the test wheel walks 42 times per minute, and the test temperature is maintained at 60°C ± 1°C. The test data include the running times of the test wheel and the rutting deformation. The dynamic stability is calculated according to the following formula:

\[
DS = \frac{(t_2 - t_1)NC_1C_2}{(d_2 - d_1)}. \tag{3}
\]

In the above formula, DS is dynamic stability of asphalt mixtures (times/mm); \( d_1 \) is deformation corresponding to \( t_1 \) (mm); \( d_2 \) is deformation corresponding to \( t_2 \) (mm); \( C_1 \) is test machine type coefficient, and crank connecting rod drive loading wheel round trip operation mode is 1.0; \( C_2 \) is coefficient of testing machine, and test piece with 300 mm width prepared in laboratory is 1.0; \( N \) is round trip rolling speed of test wheels, usually 42 times per minute.
5.2. Analysis of Test Results. Figure 9 shows the specimen after the experiment, and Table 7 gives the test result. The measured dynamic stability of each group of specimens shows that the dynamic stability of the specimen which has 4% BRA incorporation is 2.6 times than that of the reference ratio specimen, so BRA can effectively enhance the high-temperature stability of asphalt mixture. The test results from 3# to 6# show that the characteristics of rubber powder have a great influence on the improvement of high-temperature stability of asphalt mixture, and the rubber powder with fine particle size is more conducive to enhance the dynamic stability of asphalt mixture. The properties of 6# samples modified with rubber powder and BRA are superior, and the dynamic stability is further heightened compared with those modified with BRA alone.

Figure 10 is a typical curve of rutting test of each group of specimens. On the whole, the development of rutting deformation of 1# reference ratio specimen is sustained. Compared with that, the rutting deformation of 2# and 6# specimens tends to be flat after 120 times of wheel rolling. The increase magnitude gets less, which means that the thermal stability of BRA and fine rubber powder modified asphalt mixture is better, and the development of deformation can be restrained in the initial stage of loading. The rutting deformation in the early stage of the 3# matching specimen develops rapidly, and the whole deformation is larger. It is due to the fact that the rubber powder contains fine fiber and coarse rubber particles, which leads to the low compaction degree of the mixture. Therefore, under high temperature, the deformation caused by test wheel is large. At the beginning of loading, the rutting deformation of 5#
specimen is less than that of 3# specimen; it indicates that the high-temperature stability of the 5# specimen is not bad.

6. Experimental Study on Low-Temperature Crack Resistance

Asphalt and asphalt mixture are typical temperature-sensitive materials. Under low temperature, although the strength is improved, it shows obvious brittleness. Buton rock asphalt can significantly enhance the high-temperature stability of asphalt mixture, because the natural asphalt aromatic fen and other light components are less, while the asphalt content is higher, and the temperature sensitivity is not strong. Many experiments show that the low temperature of modified asphalt obviously reduces the ductility [23, 24]. However, some research works have demonstrated that the low-temperature BRA mixture under multifactor coupling is better than that of matrix asphalt mixture in bending and freezing test [25]. As a result, the low-temperature performance of BRA modified asphalt mixture is still controversial, but it is generally accepted that rubber powder has good chemical stability, flexibility, elasticity, and deformation ability in a wide temperature range. This can significantly improve the noise reduction ability, deicing ability, and low-temperature performance of asphalt mixture [26]. Hence, it is very necessary to explore the low temperature performance of rubber powder/BRA composite modified asphalt mixture.

The low-temperature performance of asphalt mixture mainly lies in whether it can improve the low-temperature embrittlement problem. The fracture strength of asphalt mixture under low temperature is investigated by indirect tensile method in the relevant test rules. In the following part, we study the influence of rubber powder/BRA on the low-temperature performance of asphalt mixture with reference to the T0175 low-temperature trabecular bending test and T0716 low-temperature splitting test in the Test Code for Asphalt and Asphalt Mixture in Highway Engineering.

6.1. Low-Temperature Bending Test of Trabecular Beams

In accordance with the methods prescribed in the Test Procedures, the rutting specimen of 300 mm × 300 mm × 50 mm is made and then cut into 30 mm × 35 mm × 250 mm trabecular specimen. After being blown dry by the fan, it is placed in a constant temperature environment box of −10°C ± 0.5°C for 2 hours. Then it is immediately transferred to the universal testing machine environment box, keeping heat preservation for 10 min. After the temperature is restored to the specified temperature, the pressure is started to load for bending test.

Experimental control loading rate is 50 mm/min, and the test parameters include maximum load PB of trabecular fracture and corresponding midspan deflection d. The following formula is used to calculate the flexural strength RB:

$$RB = \frac{PB}{d}$$

Table 7: Results of rutting test of mixture.

| Specimen number | 1# | 2# | 3# | 4# | 5# | 6# |
|-----------------|----|----|----|----|----|----|
| $d_1$ (mm)      | 3.800 | 2.165 | 1.374 | 1.836 | 2.133 | 2.084 |
| $d_2$ (mm)      | 4.214 | 2.412 | 1.480 | 1.971 | 2.280 | 2.285 |
| DS (times/mm)   | 1522 | 2551 | 5943 | 4667 | 4286 | 3134 |
| DS (times/mm)   | 2036 | 5305 | 3710 | 3343 | 3520 | 6431 |

Figure 10: Typical curves of rutting test in each group.
In the above formula, \( RB \) is the width of cross-sectional specimens (mm); \( h \) is the height of cross-sectional specimen (mm); \( L \) indicates the span of specimen, take 200 mm.

The test results are shown in Table 8, and they are drawn in Figure 11 for easy analysis and comparison.

Experimental results show that the contribution of BRA to the flexural strength of asphalt mixture is higher than that of rubber powder, but the flexural strain capacity is poor; BRA greatly raises the stiffness modulus of asphalt mixture, and mixing it with rubber powder significantly reduces the stiffness modulus of modifier. Mixing rubber powder with BRA can balance the improvement effect of strength, modulus, and strain.

6.2. Low-Temperature Splitting Test. The low-temperature splitting test is also an indirect tensile test to investigate the low-temperature tensile properties of asphalt mixture. This specimen is more convenient to prepare than the trabecular

| Group | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|---|---|---|---|---|---|
| Benchmark mixture | | | | | | |
| BRA modification | 9.351 | 15.290 | 11.273 | 11.029 | 14.381 | 16.068 |
| Compared to benchmark mixture (%) | — | 63.5 | 20.6 | 17.9 | 53.8 | 71.8 |
| Maximum flexural strain (\( \mu \varepsilon \)) | 0.016 | 0.010 | 0.015 | 0.011 | 0.013 | 0.015 |
| Bending stiffness modulus (MPa) | 576.0 | 1520.4 | 743.9 | 990.9 | 1135.2 | 1080.1 |
| Compared to benchmark mixture (%) | — | 164.0 | 29.1 | 72.0 | 97.1 | 87.5 |

Figure 11: Histogram of trabecular bending test results.
bending specimen, and the error of specimen size is relatively small, so it is constantly used. In this paper, a double-sided compaction of 75 times is also used to mold standard Marshall specimen. By setting aside the specimen at room temperature for 1 day and putting it with the beam specimens into −10°C ± 0.5°C environment box for 2 hours, the universal testing machine is transferred, which has environment box for a better precision.

The test results are listed in Table 9. As can be seen from Figure 12, compared with the reference specimen, the splitting tensile strength of BRA modified asphalt mixture increases by 20.3%, and the compression modulus increases.
by 11.7%. As can be seen from the histogram, for composite modification with both BRA and 4# rubber powder, the improvement of splitting tensile strength and compression modulus is larger.

7. Conclusion

Based on the compound modified Sup-13 mixture of Buton rock asphalt and waste rubber powder, an experimental study on long-life modified asphalt mixture is designed in this paper. This research has mainly covered the Sup-13 composite modified asphalt mixture with water resistance damage performance test, the high-temperature stability test, and the low-temperature crack resistance performance test. The following conclusions are drawn:

(1) BRA modified admixture significantly improves the mechanical properties of asphalt mixture, and the BRA content of 4% increases the stability of the 2# ratio specimen by 24.2% and reduces the flow value by 25.2%, which reflects the modification characteristics of high modulus asphalt mixture.

(2) The difference of physical characteristics of rubber powder has obvious influence on the relevant technical indexes of asphalt mixture. The mixture modified with most fine-grained and 4# rubber powder has the highest stability, and its stability increases by 48.2%, 19.3%, 32.9%, and 5.2%, respectively, compared with the first four groups of mixtures, indicating that the increments of particle size of rubber powder and the fiber content are not conducive to the improvement of physical and mechanical properties of asphalt mixture.

(3) The residual stability of BRA modified asphalt mixture with 4% content is higher than that of matrix asphalt specimen. The decrease of freeze-thaw splitting tensile strength is smaller, only 11.2%. Meanwhile, the decrease of freeze-thaw splitting tensile strength of matrix asphalt specimen is 16.6%, which suggests that the water resistance of BRA modified asphalt mixture has also been improved.

(4) Modifying the asphalt mixture with both rubber powder and BRA can not only guarantee the effective improvement of the water resistance of the mixture but also increase the toughness of the specimen. The improvement of high-temperature stability of asphalt mixture with BRA is quite obvious, and dynamic stability of 4% BRA modified asphalt mixture is 2.6 times as high as that of base mixture.

(5) The thermal stability of asphalt mixture modified by BRA and fine rubber powder is reliable and the development of asphalt mixture deformation is inhibited in the initial stage of loading. The low-temperature crack resistance of asphalt mixture modified by BRA and fine rubber powder is better. Comparing the specimens, the flexural tensile strength, the low-temperature splitting tensile strength, and the compression modulus all increase.

(6) The composite modification of rubber powder and BRA can equalize the effect of strength, modulus, and strain improvement. For this reason, the low-temperature crack resistance of the specimen will be better if the rubber powder with finer particle size is used to modify the asphalt mixture [7–9].

Data Availability

All data were through experiment in lab.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] W. Wu and J. Xia, "Prediction of China’s car ownership by grey neural Network with simpson formula," Journal of Chongqing Jianzhu University, vol. 9, pp. 101–108.

[2] J. Quan, J. Yu, J. Xu, J. Xu, and G. Li, "Recycling of waste tyres,” Shanghai Energy Saving, vol. 4, pp. 262–270, 2019.

[3] E. B. Machin, D. T. Pedrosco, and J. A. de Carvalho, "Energetic valorization of waste tires," Renewable and Sustainable Energy Reviews, vol. 68, no. 1, pp. 306–315, 2017.

[4] F. O. Okonkwo, A. A. Njan, C. E. C. C. Ejike, U. U. Nwodo, and I. N. E. Onweurah, "Health implications of occupational exposure of butchers to emissions from burning tyres," Annals of Global Health, vol. 84, no. 3, pp. 387–396, 2018.

[5] Z. Liu, “Treatment and utilization of waste rubber,” Integrated utilization of tyre resources in China, vol. 5, pp. 33–35, 2019.

[6] China Statistics Press, “China Energy Statistical Yearbook,” 2018, http://www.stats.gov.cn/tjssj/tjpyw/201806/t20180612_1604117.html.

[7] F. Zhang, C. Hu, and Y. Zhang, “Research for SEBS/PPA compound-modified asphalt,” Appl. Polym. Sci. vol. 135, pp. 1–10, 2018.

[8] L. Jing, S. Yang, Y. Liu, Y. Muhammad, Z. Su, and J. Yang, “Studies on the properties of modified heavy calcium carbonate and SBS composite modified asphalt,” Construction and Building Materials, vol. 218, 2019.

[9] S. Lv, Y. Jiang, X. Peng et al., “Performance and optimization of bio-oil/Buton rock asphalt composite modified asphalt,” Construction and Building Materials, vol. 264, 2020.

[10] C. Qian, W. Fan, G. Yang, L. Han, B. Xing, and X. Lv, “Influence of crumb rubber particle size and SBS structure on properties of CR/SBS composite modified asphalt,” Construction and Building Materials, vol. 235, 2020.

[11] B. Liu, Li Jing, M. Han, Z. Zhang, and X. Jiang, “Properties of polystyrene grafted activated waste rubber powder (PS-ARP) composite SBS modified asphalt,” Construction and Building Materials, vol. 238, 2020.

[12] Q.-Z. Wang, N.-N. Wang, M.-L. Tieng, Y.-M. Huang, and N.-L. Li, “Waste tyre recycling assessment: road application potential and carbon emissions reduction analysis of crumb rubber modified asphalt in China,” Journal of Cleaner Production, vol. 249, 2020.

[13] Y. Chen, H. Wang, S. Xu, and Z. You, “High modulus asphalt concrete: a state-of-the-art review,” Construction and Building Materials, vol. 237, 2020.

[14] L. Liu, “Study on technical performance of NES rock asphalt and rubber powder composite modified asphalt and its mixture,” Highway Engineer, vol. 41, no. 4, pp. 124–129, 2016.
[15] American Asphalt Association, Jiangsu Provincial Institute of Traffic Sciences, *Basic Reference Manual for High Performance Asphalt Pavement (Superpave)*, People’s Communications Press, Beijing, China, 2005.

[16] Code of China, “Test Methods of Aggregate for Highway Engineering,” Code of China, China, JTG E42-2005, 2005.

[17] Code of China, “Technical Specifications for Construction of Highway Asphalt Pavements,” Code of China, China, JTG F40-2018, 2018.

[18] Code of China, “Technical Specification for Construction of Asphalt Pavement,” Code of China, China, JTG F40-2004, 2004.

[19] DG/T, J08-2109-2012, Shanghai Engineering Construction Code: Technical Code for Rubber Asphalt Pavement, Shanghai Building Materials Industry Market Management Station, Tongji University Press, Shanghai, China, 2012.

[20] H. Li and J. Zhou, “Study on water stability of SBS rubber powder modified asphalt mixer,” *Test Proceedings of the Symposium on Highway Scientific maintenance and equipment Technology*, pp. 230–235, 2017.

[21] Q.-G. Ren, “Study on the difference of water stability evaluation of asphalt mixture by different test methods,” *Northern Communications*, vol. 9, pp. 78–81, 2020.

[22] JTG E20-2011, *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering*, Research Institute of Highway Ministry of Transport, China Communications Press, Beijing, China, 2011.

[23] L. Yang, “High modulus asphalt mixture durability test based on low grade asphalt and rock asphalt blending technology,” *Highway Engineering*, vol. 41, no. 4, pp. 297–301, 2016.

[24] M. Karami, N. Hamid, S. Surya, and L. Irianti, “Laboratory experiment on resilient modulus of BRA modified asphalt mixtures,” *International Journal of Pavement Research and Technology*, vol. 11, no. 1, pp. 38–46, 2018.

[25] F. Gao, “Etc. Experimental study on low temperature crack resistance of budunyan asphalt modified asphalt mixture,” *Construction technology*, vol. 43, no. 13, pp. 141–144, 2017.

[26] Y. Xue, Z. Qian, and R. Xia, “Research on rubber particles epoxy asphalt mixture based on low temperature performance,” *Journal of Hunan University*, vol. 43, no. 9, pp. 120–128, 2016.