

Research Article

Macroscopic and Microscopic Characterization of the Effect of “Activation” Process on the Performance of Buton Rock Asphalt-Modified Asphalt

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In the process of using Buton rock asphalt- (BRA-) modified asphalt, in order to improve the utilization rate of Buton rock asphalt and the performance of the modified asphalt, this paper puts forward the process of “activation” treatment of Buton rock asphalt, that is, grinding and heating of BRA to make natural asphalt precipitate. Laboratory tests show that compared with modified asphalt without activation process, the penetration of the modified asphalt decreases, the softening point rises, the ductility at 5°C and the kinematic viscosity at 135°C all have been increased, and the performance of the modified asphalt increases with the increase of the content of activated BRA. In order to further clarify the effect of “activation” process on the properties of BRA-modified asphalt from microlevel, atomic force microscopy (AFM) was used to test the microproperties of Buton rock asphalt before and after activation. It is found that the Derjaguin–Muller–Toporov (DMT) modulus of the modified asphalt is about 2.5 times that of base asphalt, which indicates that the viscous degree of modified asphalt with activated BRA has been greatly increased and the modification effect is remarkable.

1. Introduction

Buton rock asphalt (BRA) is natural rock asphalt produced in the Buton island of Indonesia. It is an asphalt residual substance derived from the combined action of heat energy, pressure, oxidation, and catalyst bacteria after the seepage and overflow of ancient oil after hundreds of thousands of years of deposition and change. Buton rock asphalt is a special asphalt-mineral blend with stable properties and strong peeling resistance, which has developed micropore and strong adsorption capacity for free asphalt. The surface and interior of active minerals with high crystallinity also have strong adsorption capacity for pure asphalt with high viscosity. It usually has high softening point, high viscosity, strong oxidation resistance, and antimicrobial corrosion ability. It contains no wax, has a large molecular weight, is easy to store and process, and has a good water sensitivity

and weather resistance. Similar to the chemical structure of matrix asphalt, it has good compatibility and no segregation. Modified asphalt as a modifier can improve the performance of asphalt pavement, especially high temperature stability, water damage resistance, and durability. Social and economic benefits are very significant [1–4].

Li et al. found the presence of more calcium carbonate in BRA. In the BRA-modified asphalt, asphalt and BRA particles were present infiltrated, forming a two-phase continuous structure with interlacing. The number of aggregates in BRA-modified asphalt decreased, and the temperature stability is improved [5]. Liu et al. revealed that the asphalt in Buton rock can obviously improve the high-temperature performance of base asphalt but, at the same time, reduce its low-temperature performance [6]. Zou et al.’s test results show that, with increasing BRA content, the binder’s penetration decreased, softening point increased, dynamic

viscosity at 60°C increased, and complex modulus increased. The incorporation of BRA in the binder also changed the viscoelastic property of the asphalt binder [7]. Liu et al. used the uniaxial penetration test to study the high-temperature performance of Buton rock asphalt mixture with different mixing process in a mixing plant. The results showed that the high-temperature performance of Buton rock asphalt mixture prepared by BRA postprocessing process was better than that of conventional process [8]. Wu et al. systematically studied the high-temperature performance of Buton rock asphalt-modified asphalt through the conventional high-temperature performance test and dynamic shear rheological test. They found that the high-temperature performance of Buton rock asphalt-modified asphalt was significantly better than that of No. 70 base asphalt [9].

Li et al. studied the effect of BRA on the physical and mechanical properties of asphalt binder and asphalt mixture. They found that the activation treatment can effectively enhance the molecular polarity of Buton rock asphalt but the micromechanism needs to be explained [10]. Tan and Guo studied the cohesion and adhesion of asphalt mastic by using surface free energy method. They found that a good correlation exists between complex modulus G^* of asphalt mastic and work of adhesion [11]. Furthermore, they investigated the interaction between asphalt and mineral fillers and its correlation to mastics' viscoelasticity in detail and found that the interfacial behavior had a significant effect on the bulk property [12]. These findings imply that BRA could be improved by some interface treatment. The BRA looks like the asphalt mastic, but it has more complicated interfacial structure.

The content of natural asphalt in Buton rock asphalt ranges from 20% to 30%. Most of the natural asphalt is distributed in the cracks of BRA. If it is not treated, it can be modified directly by blending it with base asphalt, which results in the effective asphalt that can play a very few role [10, 13]. Nowadays, China only regards natural asphalt as a special asphalt modifier and has not formed a set of relatively perfect technical performance standard system. Most of the existing related research is limited to the mix design and road performance verification of modified asphalt mixtures, lacking in-depth study on the modification mechanism of natural asphalt [14]. In order to improve the utilization rate of Buton rock asphalt and improve the performance of modified asphalt, this paper puts forward the "activation" treatment of Buton rock asphalt; that is, the natural asphalt in the cracks of Buton rock asphalt can be precipitated after grinding the BRA to a certain size range and heating at 150–180°C. In order to clarify the effect of "activation" process on the performance of BRA-modified asphalt, the following research is carried out in this paper.

2. Materials and Methods

2.1. Raw Materials. Buton rock asphalt raw material is made of BRA dry powder produced by Hubei ZhengKang Natural Asphalt Technology Co., LTD., and the base asphalt is road asphalt 70. Specific performance indicators are shown in Tables 1 and 2. The technical indicators meet the specifications [15–17].

TABLE 1: Technical index of BRA.

Items	Units	Test results	Technical indices
Colour character	—	Brown powder	Black or brown powder
Ash content	%	73.6	≤80
Moisture content	%	<0.6	<2

TABLE 2: Technical index of #70 road petroleum asphalt.

Items	Unit	Test results	Technical requirements
Penetration at 25°C	0.1 mm	73	60~80
Softening point	°C	47	>46
Ductility at 5°C	cm	100	100
Kinematic viscosity at 135°C	m ² /s	0.45	<3

2.2. Activation Technology of Buton Rock Asphalt. The crushed BRA particles with particle size less than 3 mm were added to the activation equipment, dehydrated, stirred, and maintained for 9 minutes at 150°C–180°C, and the moisture content of dehydrated BRA particles was controlled below 2%. The process activates the resin composition in natural BRA, and the activated oil was coated with sand grains, which can transform the original BRA into colloidal asphalt, which is beneficial to improve the use effect of asphalt. Through microscopic image characterization, we observed the preactivated and activated BRA, in which the activated BRA surface was covered with a large number of natural asphalt, as shown in Figure 1 [18].

3. Results and Discussion

3.1. Effect of "Activation" of Buton Rock Asphalt on the Performance of Modified Asphalt. Unactivated and activated Buton rock asphalt was added into matrix bitumen according to 10%, 20%, 30%, and 40%, respectively. Modified bitumen with different content of Buton rock asphalt was prepared by an indoor small colloidal mill. The penetration at 25°C, softening point, ductility at 5°C, and kinematic viscosity at 135°C were measured. The specific test results are shown in Figures 2–5.

From Figures 2–5, it can be seen that the penetration and ductility at 5°C of modified asphalt decrease with the increase of BRA content, and the softening point and viscosity increase with the increase of BRA content, regardless of whether the former or the latter, indicating that the viscosity of asphalt increases with the increase of BRA, which is beneficial to the improvement of the high-temperature deformation resistance of modified asphalt.

Compared with BRA-modified asphalt before activation, the penetration of modified asphalt decreased, softening point increased, and ductility at 5°C and kinematic viscosity at 135°C increased after adding activated BRA, and the trend became more and more obvious with the increase of the content of activated BRA, indicating that the activation process further enhanced the viscosity of BRA-modified asphalt. Specifically, when the content of

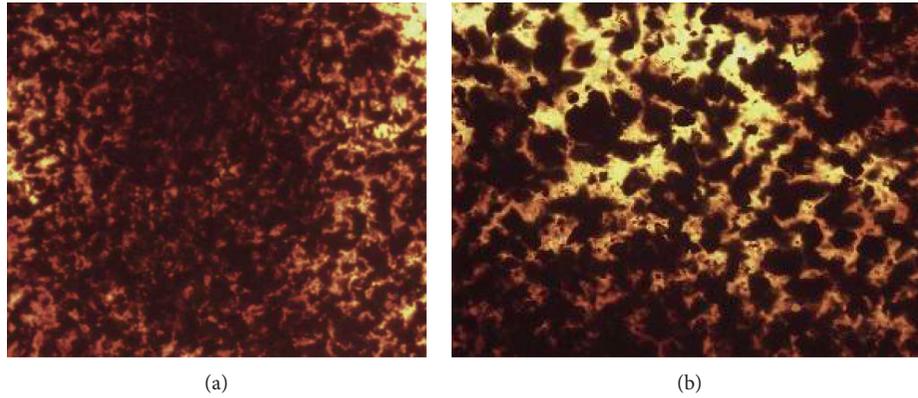


FIGURE 1: Preactivated (a) and activated (b) BRA microscopic images.

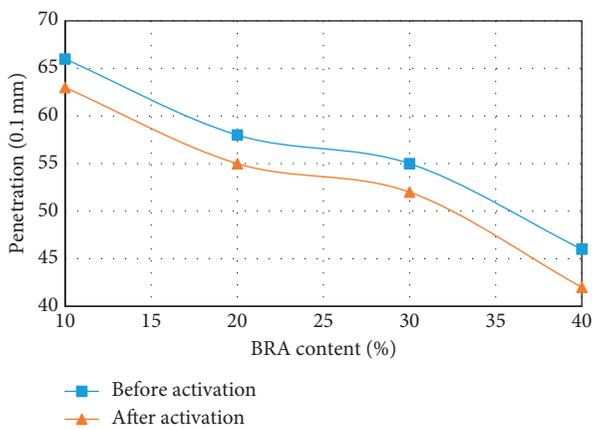


FIGURE 2: Chart of penetration of BRA-modified asphalt with dosage before and after activation.

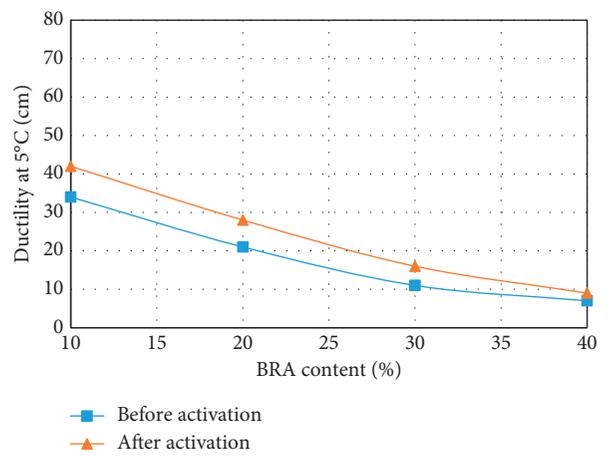


FIGURE 4: Map of ductility at 5°C of BRA-modified asphalt with dosage before and after activation.

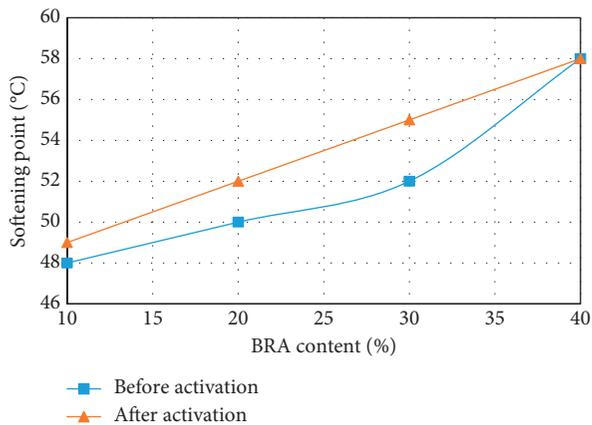


FIGURE 3: Softening point of BRA-modified asphalt before and after activation.

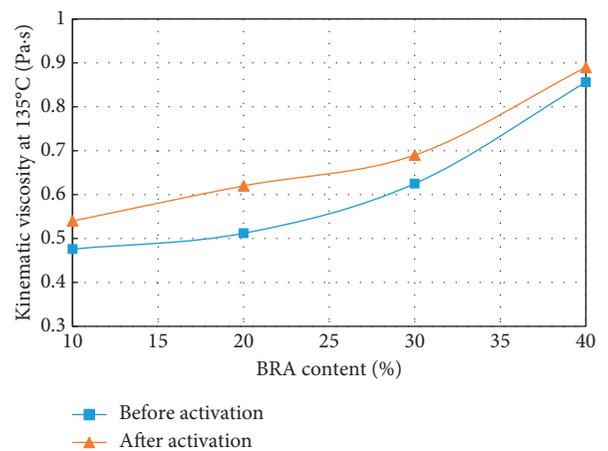


FIGURE 5: Chart of kinematic viscosity at 135°C of BRA-modified asphalt with dosage before and after activation.

activated Buton rock asphalt is more than 30%, the ductility index attenuates seriously. This is due to the ash content of Buton rock asphalt in BRA-modified asphalt. During the ductility test, it is easy to produce stress concentration at

ash particles, which results in low ductility index, indicating that this test method is not suitable for evaluating BRA-modified asphalt.

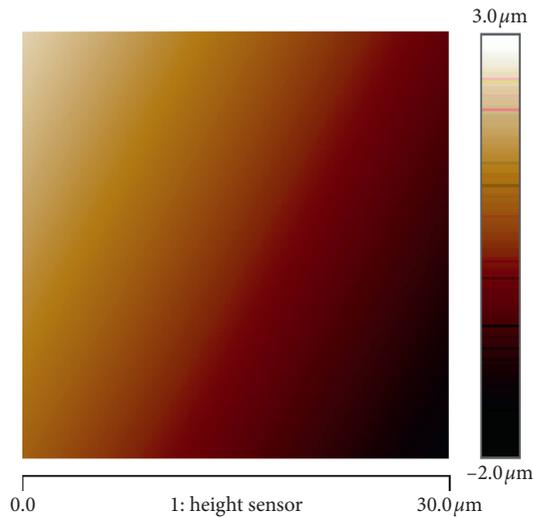


FIGURE 6: Nanomorphology diagram of #70 matrix asphalt.

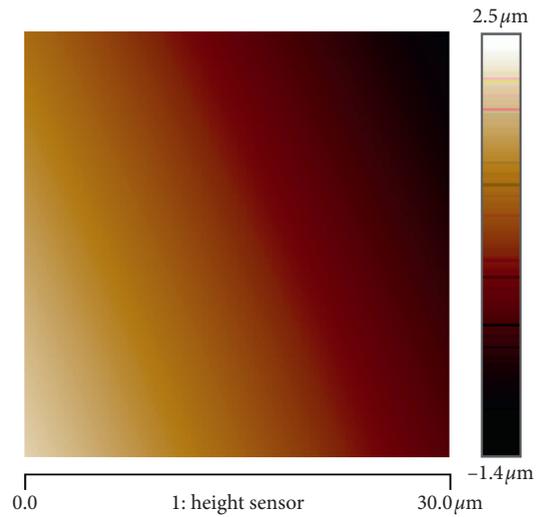


FIGURE 8: Nanomorphology of #70 matrix asphalt + 30% activated Buton rock powder.

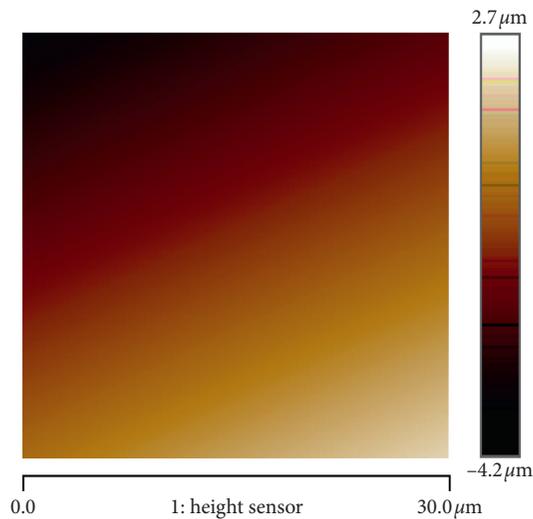


FIGURE 7: Nanomorphology of #70 matrix asphalt + 30% pre-activated Buton rock powder.

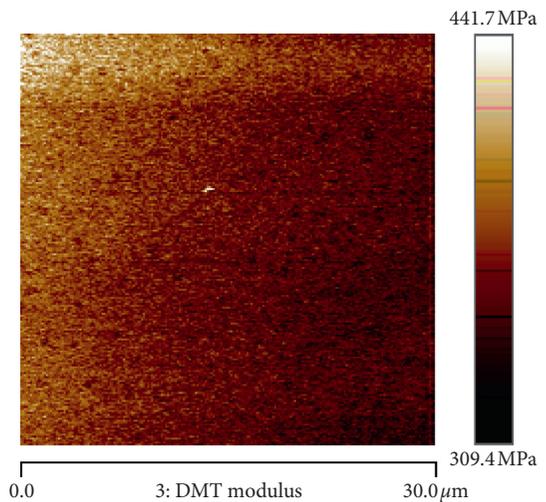


FIGURE 9: DMT modulus diagram of matrix asphalt.

3.2. Study on Microstructure of BRA-Modified Asphalt before and after Activation Based on Atomic Force Microscope.

In order to study the effect of activation process on the properties of BRA-modified asphalt from the micropoint of view, in this paper, the nanomorphology of the modified asphalt doped with 30% activated precursor asphalt and activated BRA was observed by atomic force microscopy [19].

The peak force QNM mode is selected for the AFM test. The cantilever end of AFM is RFESPA of Bruker company. Its nominal resonance frequency is 75 Hz, and its nominal elastic constant is 3 N/m (the real elastic constant measured by the “thermal tune” method is 4.3 N/m). The tip material is silicon with a height of 15–20 μm and a nominal tip radius of 8 nm. The peak force set point is 10 nN, the scanning frequency is 0.5 Hz, the scanning angle is 90° , and the scanning area is $30 \mu\text{m} \times 30 \mu\text{m}$.

3.2.1. Nanotopography. Figures 6–8 show that the nanomorphology of modified asphalt and that of #70 road asphalt have not changed much after adding BRA.

3.2.2. Nanoadsorption. Since there is no significant difference between BRA-modified asphalt and #70 road asphalt in nanomorphology, the surface nanoadhesion force of asphalt samples was characterized by the atomic force microscopy (AFM) DMT model [20]. In 1977, Tabor introduced a kind of dimensionless parameter [21], which can be used to distinguish the applicability of JKR and DMT models. The DMT model is suitable for contact with small deformation and large elastic modulus. The DMT model can describe the real force between probe and sample and estimate the adhesion work reasonably. The typical results are shown in Figures 9–11.

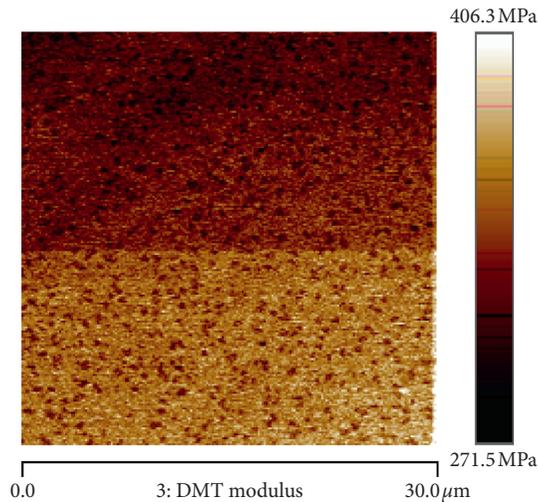


FIGURE 10: DMT modulus diagram of #70 matrix asphalt + 30% preactivated Buton rock powder.

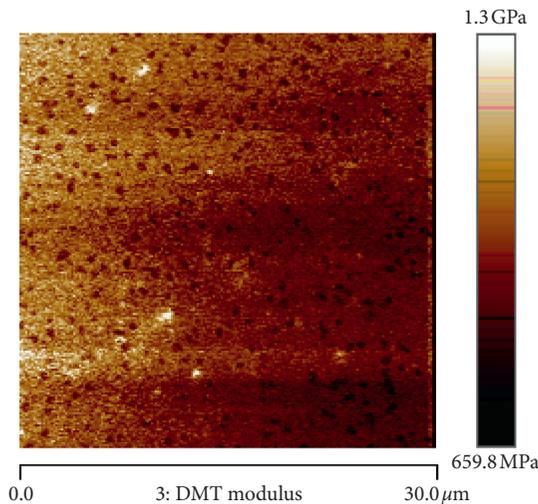


FIGURE 11: DMT modulus diagram of #70 matrix asphalt + 30% activated Buton rock powder.

From Figures 9–11, it can be seen that adding 30% activated Buton rock powder can slightly reduce the surface DMT modulus of base asphalt but adding 30% activated Buton rock powder can significantly improve the surface DMT modulus of base asphalt.

In order to study the overall regularity of different modification effects on asphalt, this part takes the average of the nanoadhesion force of all samples on the area of $30\ \mu\text{m} \times 30\ \mu\text{m}$, and the results are shown in Figure 12.

From Figure 12, it can be seen that before 30% activation, Buton rock powder can slightly reduce the DMT modulus of asphalt. However, 30% activated Buton rock powder can significantly improve the DMT modulus of asphalt, and the DMT modulus of modified asphalt is about 2.5 times that of base asphalt. This shows that the viscous degree of activated BRA-modified asphalt has greatly increased, which confirms the macro test results.

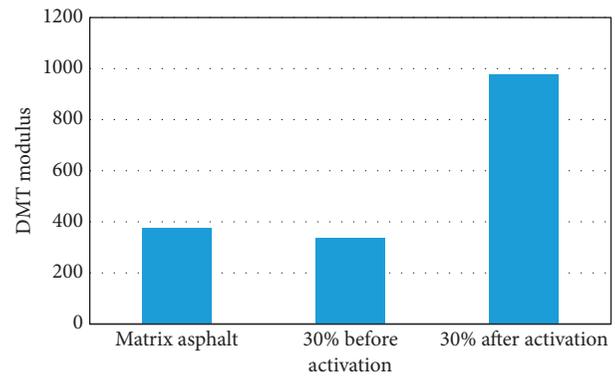


FIGURE 12: Effect of activation on mean modulus of DMT of BRA-modified asphalt.

4. Conclusions

- (1) “Activation” technology activates the resin composition in BRA, and the activated oil is coated with sand grains, which can transform the original rock state asphalt into colloidal state asphalt, which is beneficial to improve the use effect of asphalt.
- (2) Laboratory tests show that the penetration of modified asphalt decreased and softening point, ductility at 5°C , and kinematic viscosity at 135°C of the modified asphalt with “activation” process are higher than those without “activation” process, and the trend is more obvious with the increase of the content of the modified asphalt.
- (3) Atomic force microscopy (AFM) was used to test the microproperties of Buton rock asphalt before and after activation. It is found that the DMT modulus of modified asphalt is about 2.5 times that of base asphalt, which indicates that the viscous degree of modified asphalt with activated BRA has been greatly increased and the modification effect is remarkable.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors’ Contributions

Yafei Li and Meng Guo conceived and designed the experiments; Yafei Li performed the experiments; Yafei Li and Xu Liu analyzed the data; Yafei Li contributed reagents/materials/analysis tools; and Meng Guo and Xu Liu wrote the paper.

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