Research Article

Investigating Effects of Nano/SBR Polymer on Rutting Performance of Binder and Asphalt Mixture

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Abstract

Rutting is one of the most common distresses in flexible pavements and can affect vehicle controlling features. Although asphalt binder constitutes a small percentage of the asphalt mixture, its properties play a crucial role in pavement performance and its rutting resistance. One way of improving binder properties and rutting resistance is to use additives. In this research, nanoclay and SBR polymer have been simultaneously used to modify 60–70 penetration binder to study rutting resistance of binder and asphalt mixture. To this end, the storage stability, rotational viscosity, DSR, and RCR tests on binder and marshal stability were performed, and dynamic creep and wheel track tests on asphalt mix were performed to assess rutting performance. The test and statistical analysis results indicated that nanoclay has considerably positive impact on rutting and elastic deformation of neat and SBR-modified asphalt binder and mixture.

1. Introduction

Asphalt pavements are subject to increased tensions due to increased traffic volume and truck traffic (higher tire pressure) which cause cracking, permanent deformation, and surface wear and reduce the asphalt skid resistance [1–3]. Rutting or permanent deformation is a main failure distress that affects asphalt pavement performance especially in areas with hot climate and heavy traffic load. Rutting is the result of cumulative deformations caused by repetitive loads during the pavement life. Development of permanent deformations reduces the service life of asphalt pavements. Furthermore, this distress could decrease the level of safety in road transportation networks and causes road maintenance agencies to incur considerable costs [4–8]. Factors affecting asphalt mixture rutting include materials’ physical characteristics, bitumen properties, and pavement volumetric features. However, since asphalt mixture behavior depends on time and temperature, bitumen plays an important part in the creation of rutting especially under high temperature and low-speed heavy load [9, 10]. There are various methods to modify and improve properties of bitumen appropriate for the preparation of asphalt mixture. One method is to use additives and polymers each of which changes some bitumen features [11]. In another approach, microcapsules containing rejuvenator are used to improve the cracking performance of the asphalt pavement by increasing its self-healing properties [12]. Modifying bitumen with additives is usually applied to change phase combination and to improve the mechanical properties of the asphalt mixture [5, 13]. On the contrary, nanoparticles are among the known additives used for the modification of bitumen features [14–16]. Nanoclays are unique materials used as additives to make nanocomposites and to considerably improve the properties of polymeric materials. Structure of nanoclays include small, irregular plates, which are 1 nanometer in thickness and a few hundred nanometers in diameter. One of the most important characteristics of nanoclays which has profound effect on its performance is the very high length/thickness ratio of individual plates (from 300/1 to 1500/1) [17].
Since using additives is an acceptable way of enhancing bitumen properties and nanoclay is capable of improving the asphalt mixture performance, this research is aimed at finding effectiveness of nanoclay and its combination with styrene-butadiene-rubber (SBR) on the rutting of asphalt binder and mixture. Accordingly, a conventional binder test, storage stability, rotational viscosity, dynamic shear rheometer (DSR), and repeated creep and recovery (RCR) tests were performed on neat and modified bitumen and marshal stability, and dynamic creep and wheel track tests were performed on asphalt mixtures.

2. Materials and Preparation

2.1. Materials. In this research, the binder was 60-70 penetration bitumen (PG 58-22) whose properties are listed in Table 1.

Moreover, Cloisite 15A nanoclay and SBR 1502 polymer (both separately and simultaneously) were utilized to modify binder properties, as listed in Table 2.

Also, limestone mineral aggregates with 19 mm nominal maximum aggregate size (NMAS) and limestone powder as filler were used. Table 3 presents their physical properties.

2.2. Sample Preparation. In order to blend modified asphalt binders, SBR was gradually added into the 170°C heated asphalt binder, while high shear mixer was rotating at the rate of 6000 rpm. Nanoparticle was dispersed in unmodified and modified binder using a 60 W ultrasonic mixer for 20 min at a temperature of 150°C.

Using the scanning electron microscope (SEM), the dispersion of nanoparticles in the asphalt binder media was captured. Figure 1 shows that the nanoparticles dispersion that ranged in size from 25 to 5 µm and are homogeneously distributed.

In this research, the nanoparticle-modified binder contained 6% nanoclay by mass of the binder in the optimum case [18, 19] and polymer-modified binder contained 4% SBR polymer by mass of the binder; when applied simultaneously, there were two combinations one of which had 2% NC plus 4% polymer (N2S4) and another had 3% NC plus 3% polymer (N3S3).

2.3. Mix Design. To determine optimal binder content (OBC), use was made of Marshall mix design conforming to MS-02 according to which the OBCs for AC, NC, SBR, N2S4, and N3S3 were 4.9, 5.6, 5.2, 5.5, and 5.5%, respectively. After determination of OBC, cylindrical specimens, which were used in the dynamic creep and wheel track tests, were fabricated by the superpave gyratory compactor (SGC).

3. Experimental Methods

3.1. Dynamic Shear Rheometer (DSR) Test. It is used to assess binder rutting strength under high temperature. The DSR test evaluates effects of time and temperature and measures rheological properties of asphalt binder (phase angle γ and shear modulus G*) under medium/high temperature. Rutting strength can be found by measuring γ and G* parameters at a known temperature range and finding G*/sinγ which should be at least 1 kPa for original asphalt binder under test temperature (or maximum pavement performance temperature) so such rutting can be minimum [20, 21].

3.2. Repeated Creep and Recovery (RCR) Test. Repeated creep and recovery (RCR) were proposed in NCHRP 549 Report in 2001 for the assessment and description of binder rutting strength using the DSR device.
3.3. Dynamic Creep Test. The resistance of asphalt mixtures against plastic deformation can be quantitatively investigated by means of repeated load dynamic or cyclic creep test. Rutting resistance of asphalt mixture can be determined using dynamic creep tests; the results of which are presented as a curve showing cumulative strain versus number of cycles; the curve has 3 zones in the third one of which strain is considerably increased due to large deformations under repetitive loading; the number of this zone’s starting cycle is called “flow number” which is a criterion for the investigation and assessment of rutting in asphalt mixtures ([24, 25]; NCHRP 465, 2002 [26]).

3.4. Wheel Track Test. The wheel track test is one of the common methods to measure permanent deformation of asphalt mixture. This test was conducted according to AASHTO Standard T 324 (AASHTO, 2011), to investigate the rutting performance of samples.

4. Results and Discussion

4.1. Binder Conventional Test. As demonstrated in Figure 2, using nanoclay and SBR decreases the amount of penetration in asphalt binder; therefore, the stiffness of asphalt binder should be increased compared to that of base binder. Increase in stiffness led to higher resistance of modified binder against rutting at higher temperatures.

Increases, which confirms the strength of binder against permanent deformation at higher temperatures.

The penetration index (PI) is a simplest factor in evaluating binder performance against temperature variation. Binders with higher PI values consider having lower susceptibility to temperature and the resulted damages. Since binder in asphalt mixes experiences temperature variation during seasonal changes, higher PI values up to +2 would result in favorable characteristics. The PI is calculated according to the following equation:

$$PI = \frac{1952 - 500 \times \log(\text{Pen}_{25}) - 20 \times SP}{50 \times \log(\text{Pen}_{25}) - SP - 120},$$  \hspace{1cm} (1)$$

where Pen$_{25}$ is the penetration at 25°C and SP is the softening point temperature.

The amount of PI of control specimens is presented in Figure 4. As it is shown, the amount of PI for control samples is negative. However, asphalt binder modified with nanoclay and SBR polymer cause an increase in the amount of PI in modified binder and decrease the temperature susceptibility.

4.2. Storage Stability Test. To study the storage capability and phase separation between binder and additive under high temperature, use has been made of the storage stability test (according to AASHTO PP5) which evaluates the storage stability by measuring softening points of upper and lower parts of a cylindrical container that is divided into three equal parts. The cylindrical specimen is kept at
a temperature of 163 °C for 48 hr. The difference of softening points of upper and lower parts is limited to 2.5 °C in order to consider thermally stable [27].

The results in Table 4 show that the nanoclay-modified binder is stable but the modified binder by the SBR polymer is not stable enough because it experiences phase separation between binder and polymer. In specimens modified by nanoclay and polymer simultaneously, the temperature difference of the ductility points is less than 2.5 °C meaning...
that there is conformity between binder and SBR polymer which is due to the presence of nanoclay in the combination.

4.3. Rotational Viscosity Test. The rotational viscosity (RV) test is used to assess the modified binder efficiency at high temperature ranges and shows that if asphalt binder has enough ductility for being pumped, displaced, and mixed with aggregates; RV is not to exceed 3 Pa·s at a temperature of 135 °C for this purpose; in this study, the test was done in accordance with the AASHTO T316 at the mentioned temperature [28].

Figure 5 shows that RV for all specimens lies in the allowable range. SBR polymer increases binder viscosity more compared to nanoclay, and the highest viscosity belongs to N2S4 (2% nanoclay and 4% SBR).

4.4. Dynamic Shear Rheometer (DSR) Test. This test has been done at a temperature range of 30–80 °C with a frequency of 10 rad (1.59 Hz). The results in Figure 6 show that adding SBR and nanoclay to asphalt binder increases its rutting resistance from 127 to 383% at a temperature of 80 °C compared to neat binder.

The results of this test show that the performance of the SBR-modified binder is by far better than that modified by only nanoclay or SBR.

4.5. Repeated Creep and Recovery (RCR) Test. In this research, the test in strain control state was performed with a shear tension of 300 Pa at a temperature of 60 °C using a plate 25 mm in diameter and a gap opening of 1 mm; loading time was 1 sec with 9 sec rest (according to NCHRP 549 Report).

According to the results in Figure 7, nanoclay and SBR polymer enhance the rutting resistance of the modified binder compared to neat one. Contrary to the DSR test, RCR showed that the synergic performance of binder modified with SBR-nanoclay combination is better than that modified with only nanoclay or SBR. Based on these results, the best performance was that of the N2S4 specimen. Results also revealed that when binder is modified, especially with a combination of nanoclay and SBR, its elastic behavior is significantly improved.

4.6. Dynamic Creep Test. Dynamic creep was carried out at a tension level of 450 kPa with a loading frequency of 0.5 Hz (500 m·sec loading, 1500 m·sec rest) to evaluate the rutting resistance of asphalt mixture according to the Australian code, AS-2891.12.1, at 50 °C; in this study, use was made of the “Goh and You” method [29] to determine the flow number (FN).

According to the results in Figure 8, nanoclay and SBR polymer cause modified specimens to have higher strength against deformation compared to the unmodified mixture; modification, especially with a combination of nanoclay and SBR, causes shear deformations to occur in higher cycles, while the unmodified mixture has larger deformations in the first phase of loading.

4.7. Wheel Track Test. In this test, cylindrical specimens are tested by wheel track apparatuses. Ambient temperature was 50 °C, and loading frequency was 1 Hz. All in all, the specimens were loaded by 8000 cycles, and then depths of rutting in each specimen were measured.

As it is shown in Figure 9, the specimen modified with nanoclay and SBR polymer shows lower depth of the rutting in asphalt mixture. The results indicate that using both of these modifiers at the same mixture considerably increases the stiffness in asphalt mixture.

### Table 5: ANOVA pairwise Tukey statistical analysis for rutting and flow number.

<table>
<thead>
<tr>
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<th>Sum of squares</th>
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<th>F</th>
<th>Significance</th>
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Pairwise Tukey statistical analysis

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<th>N2S4</th>
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<tr>
<td>N3S3</td>
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<td>Flow number</td>
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α = 0.05; N, not significant; S, significant.
4.8. ANOVA Analysis. Analysis of variance (ANOVA) was employed to conduct pairwise Tukey statistical analysis with $\alpha = 0.05$. With respect to pairwise Tukey statistical analysis tabulated in Table 5, rutting decreases in the mixtures containing both modifiers (N2S4 and N3S3) more than that in the SBR-modified mixture which is mainly due to nanoparticles penetration into the SBR matrix structure in the nanoscale and more microstructural resistance against permanent deformation [30]. Therefore, it can be inferred that nanoclay and its combination with SBR lead to greater rutting resistance compared to the SBR-modified and neat asphalt mixes. It is worth noting the mixtures containing NC and N2S4 have approximately the same rutting performance, and greater portion of nanoclay in SBR and nanoclay compound reduces the flow number.

5. Conclusion

The major objective of the present research was to evaluate the impact of introduction of nanoclay and SBR copolymer and their combination into the asphalt binder on rutting performance. Based on the results of tests and analyses, the following conclusions can be drawn:

1. Since polymers do not have enough stability in asphalt binder, it can be stated that the presence of nanoclay in binder containing polymer will cause polymer-binder compatibility to enhance and storage stability of the modified binder with SBR/nanoclay to lie in the allowable range.

2. Using nanoclay and polymer increases the stiffness of binder, improves the strength, and decreases the temperature sensitivity in binder.

3. Adding nanoclay and SBR polymer and their combination to binder increase viscosity and OBC of neat asphalt binder.

4. The DSR test results show that SBR and nanoclay modified binders enhance its rheological properties and highly increase rutting resistance compared to the neat binder.

5. According to the RCR test results, it can be stated that adding nanoclay and SBR polymer to binder not only increases its strength against rutting but also enhances its elastic properties; deformations in the modified binder with SBR/nanoclay are recovered though.

6. Considering results obtained from the dynamic creep test, nanoclay, SBR, and their combination have positive effect on rutting resistance and elastic deformations.

7. Wheel track test results shows asphalt mixtures containing modified binder have less rutting depth. These results are in line with the dynamic creep test.

8. A review of the results of all the tests shows that N2S4 has the best performance and rutting resistance which can be attributed to the presence of nanoclay, with its unique binder improving features, in combination with the SBR polymer.

Data Availability

Underlying data will be provided by email upon any request from readers.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


