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Effects of nanoclay on hot mix asphalt performance

Mahmoud Ameria, Shams Nobakhta, Keyvan Bemana, Mostafa Vamegha, and Hamed Rooholaminib

aSchool of Civil Engineering, Iran University of Science and Technology, Tehran, Iran; bCivil and Environmental Engineering Department, Tarbiat Modares University, Tehran, Iran

ABSTRACT
The purpose of this study was to evaluate of nanoclay effects as an additive on performance of asphalt mixtures. Two types of montmorillonite nanoclay, namely CA and CB, were used at concentrations of 2%, 4%, and 6%. Marshall, indirect tensile strength, resilient modulus, and dynamic creep tests were performed to investigate the effect of additives on moisture susceptibility, structural response, and rutting resistance. The results showed improvement of the asphalt mixture performance by adding nanoclay with respect to all tests. According to the results, samples containing nanoclay CA have better performance in comparison with the samples containing CB.

KEYWORDS
Asphalt mixture; dynamic creep; moisture susceptibility; nanoclay; rutting resistance;

1. Introduction
The performance of asphalt mixes heavily depends on physical characteristics of their components as well as the mixture's homogeneity. Therefore, their microstructure has important role on their performance. The idea of using different additives in bitumen to modify its properties has been developed by numerous researchers and different additives have been used for different purposes.

Many studies have been carried out regarding modified polymers with nanoclay (Golestani et al., 2015; Golestani et al., 2012). However, there are few studies on modified bitumen with nanoclay and effect of type of nanoclay and polymer used on asphalt binder and mixture. Moreover, a lack of research has employed an appropriate method for mixing to achieve a homogeneous nanocomposite.

In this research, various tests were performed on asphalt binder and mixture to find the impact of two types of nanoclay, namely Cloisite 15A and Cloisite 30B, on performance and engineering properties of them.

2. Materials

2.1. Bitumen
The neat bitumen used in this study was 60/70 bitumen by penetration whose properties are presented in Table 1. It supplied from Pasargad Oil Company, Tehran, Iran.

2.2. Nanoclay
In this study, high montmorillonite nanoclays, with specifications given in Table 2, were used at concentrations of 2%, 4%, and 6% by the weight of bitumen. Blending them with asphalt binder was done...
at 150°C for 20 min with Ultrasonic mixer apparatus at the power of 65 kW. To ensure uniform distribution of nanoparticles and preventing them from agglomeration, nanoclay was added to bitumen in 10 steps.

Scanning electron microscope (SEM) was used at several zoom levels to capture image of the dispersion of nanoclay in asphalt binder. As shown in Figure 1, it is homogeneously distributed without agglomeration.

### 2.3. Aggregates

Properties of crushed limestone aggregates used in this study is given in Table 3. Furthermore, selected gradation, shown in Figure 2, falls within upper and lower limits of No.4 gradation of Iran Highway Asphalt Paving Code (Ministry of Road and Transportation Research and Education Center, 2003).

### 3. Test methods

#### 3.1. Bitumen tests

Rotational viscosity at 135°C was determined for asphalt binder samples modified by CA and CB. Moreover, dynamic shear rheometer (DSR) was used to evaluate impact types of nanoclay used in this research on complex shear modulus and phase angle. Complex shear modulus is composed of viscous and elastic behavior of asphalt binder and the ratio of complex modulus to \( \sin \delta \) \( (G^*/\sin \delta) \) is used as an index for rutting resistance evaluation of bitumen.

#### 3.2. Mix design

Optimal binder content (OBC) was determined based on Marshall mix design procedure (ASTM D1599). For CA, 5.4%, 5.5%, and 5.6% were OBC of 2%, 4%, and 6% concentrations, respectively. For CB, 5.2%, 5.3%, and 5.4% were calculated for 2%, 4%, and 6% concentrations, respectively. Control mix has 4.9% OBC. Both types of nanoclays increase OBC but it is greater for CA compared with CB.

### Table 1. Physical properties of base bitumen.

<table>
<thead>
<tr>
<th>Property/unit</th>
<th>Specification</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity at 25°C</td>
<td>1.03</td>
<td>ASTM D70</td>
</tr>
<tr>
<td>Penetration at 25°C, dmm</td>
<td>64</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Softening point, °C</td>
<td>54</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Ductility at 25°C, cm</td>
<td>102</td>
<td>ASTM D113</td>
</tr>
<tr>
<td>Flash point, °C</td>
<td>305</td>
<td>ASTM D92</td>
</tr>
<tr>
<td>Ignition point, °C</td>
<td>317</td>
<td>ASTM D92</td>
</tr>
</tbody>
</table>

### Table 2. Nanoclay properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Cloisite 15A</th>
<th>Cloisite 30B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic modifier</td>
<td>2M2HT</td>
<td>MT2EtOH</td>
</tr>
<tr>
<td>Modifier concentration</td>
<td>125 meg/100 g</td>
<td>90 meg/100 g</td>
</tr>
<tr>
<td>Moisture</td>
<td>&gt;2%</td>
<td>&gt;2%</td>
</tr>
<tr>
<td>Weight loss on ignition</td>
<td>43%</td>
<td>30%</td>
</tr>
<tr>
<td>Anion</td>
<td>Chloride</td>
<td>Chloride</td>
</tr>
<tr>
<td>Density</td>
<td>1.66 g/mL</td>
<td>1.98 g/mL</td>
</tr>
<tr>
<td>X-ray result (d001)</td>
<td>31.5 Å</td>
<td>18.5 Å</td>
</tr>
</tbody>
</table>
Figure 1. SEM at different focus levels.

Table 3. Aggregate properties.

<table>
<thead>
<tr>
<th>Property/unit</th>
<th>Specification</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasion loss (Los Angeles), %</td>
<td>22.3</td>
<td>AASHTO T96</td>
</tr>
<tr>
<td>Flakiness index, %</td>
<td>16</td>
<td>BS 812</td>
</tr>
<tr>
<td>Two or more crushed faces, %</td>
<td>93</td>
<td>ASTM D5821</td>
</tr>
<tr>
<td>Coarse aggregate water absorption, %</td>
<td>2.2</td>
<td>AASHTO T85</td>
</tr>
<tr>
<td>Fine aggregate water absorption, %</td>
<td>2.4</td>
<td>AASHTO T84</td>
</tr>
<tr>
<td>Coarse aggregate specific gravity, g/cm³</td>
<td>2.59</td>
<td>ASTM C127</td>
</tr>
<tr>
<td>Fine aggregate specific gravity, g/cm³</td>
<td>2.32</td>
<td>ASTM C128</td>
</tr>
</tbody>
</table>
3.3. Dynamic creep test

The resistance against plastic deformation can be evaluated by repeated creep test. The main outcome of this test is accumulated permanent strain versus number of cycles composing of three zones: primary zone, secondary zone, tertiary zone (Imaninasab et al., 2016). The cycle Number that the third zone initiates is defined as Flow Number that is an indicator of rutting resistance (Witzcak, 2002). In this study, the test was performed according to Australian Code of AS 2891.12.1 using UTM 5 apparatus.

For each type of mixture 6 identical cylindrical specimens were prepared by Superpave Gyratory Compactor (SGC) to undergo dynamic creep test at stress levels of 300 and 450 kPa, three samples for each stress level, and the average of three represents the value for each mixture type. Before carrying out the experiment, samples were placed in the UTM’s chamber with ambient temperature of 50°C for at least 4 h.

3.4. Moisture susceptibility

The modified Lottman test procedure is one of the most common tests process to evaluate moisture damage resistance of asphalt mixes. Tensile strength ratio (TSR) as an index for moisture susceptibility is defined as the ratio of wet to dry indirect tensile strength (ITS) of samples compacted with air void content of 7 ± 1. This test is performed on the compacted samples with air percentage of 7 ± 1. Equations (1) and (2) are used to compute ITS and TSR, respectively (Shirini and Imaninasab, 2016).

\[
ITS = \frac{2P}{\pi Dt} \quad (1)
\]

where \( P \) is maximum load (N), \( D \) is diameter (mm), and \( t \) is thickness of the sample (mm).

\[
TSR = \frac{ITS_{Sat}}{ITS_{Dry}} \quad (2)
\]

4. Results and discussion

4.1. Rotational viscosity

As shown in Figure 3, nanoparticle type CA (Nanoclay Cloisite 15A) increases viscosity while CB (Nanoclay Cloisite 30B) reduces it in comparison with neat asphalt binder. There is substantial increase with CA introduction and RV value increases with CA increase but the value did not exceed 3 Pa.sec, which is the threshold with respect to pumping efficiency. On the other hand, NB has no great influence on viscosity.
4.2. **Dynamic shear rheometer**

By performing DSR at different temperature, from 30 to 80°C with increment of 2°C, it was found (Figure 4) that both types of nanoclays enhance rutting with CA being more effective than CB; 2%, 4%, and 6% CA increase rutting parameter of \( \frac{G^*}{\sin \delta} \) by 20%, 73%, and 173% with comparison to neat binder, respectively. It is 11%, 46%, and 127% for 2%, 4%, and 4% CB, respectively.

4.3. **Dynamic creep test**

As shown in Figure 5, within the range of 0–6%, both types of nanoclays result in rutting resistance enhancement. CA is more effective than CB at all concentrations and there is improvement with nanoclay dosage increase. Both levels of stress comply similar trend with respect to rutting resistance of different mixes type ranking suggesting validity of obtained results at high stress level. It indicates that nanoclay introduction preserves elastic property of asphalt binder at higher temperatures.

4.4. **Moisture susceptibility**

ITS test is most frequently used for providing information on moisture sensitivity of HMA mixture since the presence of water often results in premature failure of pavements. It may also help to predict cracking potential, rutting, and fatigue life (Roberts et al., 1996). According to Figure 6, both types of nanoclay addition increase dry ITS. Wet ITS of asphalt mixtures containing CA increase with CA nanoclay addition.
increase while in mixtures containing CB nanoclay, maximum ITS belongs to 4% CB. CA is more effective than CB and all percentages of CA have greater dry ITS than 4% CB. Greater dry ITS at 25°C indicates less cracking potential and greater resistance against permanent deformation.

As shown in Figure 7, both types of nanoclays improve resistance against moisture damage, and 6% CA results in the most improvement in moisture susceptibility. In comparison with CB, although CA has more positive impact on moisture damage resistance at 6%, it is greater for CB at 2%. At concentration of 4%, both types were found equally effective.

5. Conclusion

The aim of this study was to determine the effect of two types of nanoclay additives on performance of asphalt binder and mixture. The following conclusions are drawn in accordance with obtained results:

Figure 5. Flow number at stress level of (a) 450 kPa and (b) 300 kPa.

Figure 6. Indirect tensile strength (a) dry and (b) wet.

Figure 7. Tensile strength ratio.
• Adding nanoclay increases OBC.
• According to the results of dynamic creep test, the resistance of mixtures modified with nanoclay particles against permanent deformations increases. Moreover, performing DSR revealed that nanoclay improves resistance against shear deformation at temperature range of 30–80°C.
• Moisture sensitivity of nanoclay type CA improves the most at 6% while it is 4% for nanoclay type CB.

References


