Investigation of Possible Improving of Bitumen Properties Using Nano-Materials

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Abstract: In Iraq, asphalt roads suffer a lot of problems because of the high traffic and climatic conditions represented by high temperatures in the summer, which reduce the service life of the road, so it became necessary to improve the rheological and physical properties of asphalt and thus improve the performance of asphalt paving. Nanotechnology is one of the methods used for improvement has been adopted in the research. The possibility of improving the properties of asphalt was studied using Nano silica (NS) and Nano hydrated lime (NHL) with percentages (1,3,5 and 7)% by total weight of asphalt. Tests were performed to evaluate the enhancement in softening point, penetration, kinematic viscosity and penetration index of the asphalt with penetration grade (60-70). The results of the laboratory study show the improvements in the properties of asphalt by reducing the amount of penetration and increasing the softening point of the asphalt, thus it becomes more stiffer and less sensitive to temperatures than the original asphalt, in addition to that, the results showed that an improvement in the values of viscosity and penetration index, and this in turn leads to an increase in the adhesion and cohesion of asphalt and asphalt mixture as well as the possibility of using modified asphalt with Nano-materials in areas with high temperatures and traffic load.

Keywords: Nano-materials, bitumen, hydrated lime, silica, penetration index, softening point, viscosity.

1. Introduction

Nano-materials is one of the methods used to improve the rheological and physical properties of high penetrating gradient asphalt and use it in asphalt mixtures to improve the performance of asphalt pavement. Nano materials are small particles that are measured in nanometers and have a dimension of less than 100 nanometers. In previous studies, we find many researchers who used this technique by adding Nano materials to asphalt as an enhancer or as a filler to be added to the asphalt mixture. Various additives have been used to improve the properties of bitumen (penetration, softening point, viscosity) and performance of asphalt paving. Among these materials we mention; Nano-clays (NC), carbon nanotubes (CNT), Nano-calcium oxide (CaO), Nano silicate, Nano hydrated lime and Nano-titanium dioxide (TiO2).

Bitumen or asphalt is a black substance that is present naturally or artificially, consisting of a mixture of hydrocarbons with a solid or semi-solid texture, and is included in the composition of asphalt mixture at approximately 5% of the total weight of the mixture. Asphalt is a thermo-material that is greatly affected by temperature, so the variation in temperatures between night and day leads to expansion and contraction causing cracks to appear, as well as being affected by air that works to change the physical properties and chemical composition of it, causing what is called aging, so it has become necessary to use techniques to improve the properties of asphalt In order to extend the life of the paving[1]. It has been found that the effect of two types of Nano materials, NS, NC, as they showed...
that they had a significant effect on enhancing the properties of the asphalt mixture by improving stability and resistance to indirect tensile strength, but the amount of decrease in stability was higher than the unmodified mixture. As for the asphalt, a decrease in the penetration value was observed with an increase of NS to 5%, which means an increase in the temperature of softening point and the rotational viscosity at 135°C and 165°C [2].

Metally and others used asphalt with a penetrating gradient (85-100) in the asphalt mixture. The optimum asphalt content is higher compared to the normal mixture, which led to a deterioration in flow and stability, so it is not economical, but by using Nano-silica, the properties of high penetration asphalt were improved by reducing the amount of penetration from 9.1 mm to 7 mm, increasing the amount of Marshall stability by 32.5% and reducing creep by 18.9%[3].

It has been found that the temperature susceptibility decreases by increasing the percentage of silica through the increase in the softening point and penetration index, which leads to an increase in resistance against permanent deformations and cracking that occurs due to lower temperatures [4]. The use of Nano hydrated lime reduces the occurrence of rutting in the modified asphalt mixture at high temperatures due to its improvement of the rutting factor compared to the controlled asphalt mixture. When adding 5%, 10% and 15% of NHL at temperature 58°C, it was found that the amount of improvement in the rutting factor was 56.9, 98.7 and 111.8% respectively [5]. Adding Nano-particle from Ca(OH)2 to the asphalt improves the physical and mechanical properties of both the asphalt and the asphalt mixture. By adding 5% of Ca(OH)2 it reduces the penetration gradient by approximately 30% and increases the softening point by 15°C. Indirect tensile strength improves significantly. At 4% of Ca(OH)2 compared to unmodified asphalt mixture. That is, the use of Nano Ca(OH)2 in asphalt is ideal in areas with high traffic and hot climates[6].

using of Nano-charged ash was evaluated after grinding for 15 hours, to a volume of 57.7 nm and adding it to asphalt at a ratio of (1.5,3,5,6,7.5) which had an effective role in improving the rheology and physical properties, and at the same time the rutting was at the highest level compared with other sizes NCA. The best NCA ratio is 6%, which resists rutting to the extent of 76°C, in addition to cracking resistance to the limit of 22°C, which means increasing the cohesion between nanoparticles with a large surface area with asphalt leading to increased rigidity and extended service life of asphalt paving[7]. Adding NS to the asphalt positively improves the properties of the asphalt and asphalt mixture, so it can be used to build more durable pavements, thus reducing the cost of pavement rehabilitation[8].

In this research, laboratory tests of the physical properties with a number of modified bitumen with Nano-silica (NS) Nano-hydrated lime (NHL) were examined and evaluated. Nano-silica and Nano-hydrated lime modified bitumen have been laboratory produced by mixing with five NS,NHL contents. They were added into bitumen at concentrations of (1, 3, 5 and 7)% by weight of bitumen. The NS,NHL modified bitumen tests the conventional properties such as the kinematic viscosity, penetration test, softening point were carried out for NS,NHL modified bitumen binders’ characteristics evaluation.

2-Benefits of Nanotechnology

By observing previous studies, it has been found that the use of Nano-materials as an enhancer to the properties of asphalt used in paving roads leads to increased durability, improved performance and reduced cracks and costs used to extend the life of paving compared to unmodified paving, in addition to that Nano-materials are waste and this means reducing the cost of disposal by using them. As enhancers Nano-materials has the following benefits:

1. Storage stability in modified asphalt
2. Reduce the sensitivity to moisture under water, snow and ponds

3. Enhance properties of asphalt mixtures at low temperatures
4. Improves durability of asphalt
5. Reduce maintenance needs [9].

3-Experimental Program and Methodology of Research

3.1: Materials

3.1.1: Asphalt Cement

Asphalt is produced from the distillation process of petroleum under the influence of high pressure and temperatures. Asphalt is used as a basic binder material that works to bind the components of the asphalt mixture used in road paving. In this research, asphalt with penetrating gradient (60-70) was used. It was brought from Dora refinery in Iraq. The experimental results for the physical properties of asphalt were presented in table (1).

3.1.2: Nanosilica powder

Nano silica used in this research is characterized by its white color, high smoothness, large surface area and high purity. It can be used as an additive to asphalt to improve its properties and thus improve the performance of the asphalt mixture. Physical properties of Nano silica are presented in table (2).

3.1.3: Nano hydrated lime powder

It is a white powder with high fineness and has the ability to dissolve in water. It is produced from mixing quicklime (calcium oxide) with water. The physical properties of Nano hydrated lime are presented in table (2).

| Test                  | Unit     | Specification No. | Results | SCRB/R9 |
|-----------------------|----------|-------------------|---------|---------|
| Penetration           | 1/10 mm  | ASTM-D5           | 65      | 60-70   |
| Flash point           | °C       | ASTM-D92          | 270     | >232    |
| Softening point       | °C       | ASTM-D36          | 44      | -----   |
| Ductility             | cm       | ASTM-D113         | 135     | >100    |
| Kinematic viscosity   | c. stock | ASTM-D2170        | 310     | -----   |
| Specific gravity      | -------- | ASTM-D70          | 1.03    | -------- |

Table 1: Physical properties of asphalt (60-70) using in research

| properties      | silica | Hydrated lime |
|-----------------|--------|---------------|
| color           | white  | white         |
| Appearance form | powder | powder        |
| Chemical formula| SIO2   | CA(OH)2       |
| Density (g/cm³) | 2.19   | 2.21          |
| Size of particle (nm) | 14   | 18            |
| The degree of purity | 99.7 | 95            |

Table 2: Physical properties of Nano (silica, hydrated lime) using in research
3.2: Process of Modification and Tests

The process of modification of the asphalt is done by gradually adding nano-silica and nano-hydrated lime after heating the asphalt to (140-150) °C to transform it from a semi-solid state to a liquid state. To obtain a homogeneous mixture of modified asphalt, use a conventional mechanical mixer at a rate of 2000 rpm for a period of 45 minute on average. In this study, NS, NHL were added to original asphalt with ratios of (1, 3, 5 and 7) % by total weight of asphalt and were evaluated using American standards approved tests as softening point ASTM-D36, penetration ASTM-D5, kinematic viscosity, ASTM – D2170 and penetration index to demonstrate the effect of these materials on the physical and rheological properties of asphalt through comparison with unmodified asphalt.

4. Laboratory Results and Discussion

4.1: Effect of Nano Materials on Softening Point and Penetration

Figure (1) shows softening point test results for different percentages of NS and NHL. According to the results, with addition of different percentages of NS and NHL, the softening point is increased. The best results for the bitumen used in this research obtained in the bitumen modified with 7% for both NS and NHL. In fact, with addition of 7% NS and NHL, the softening point of asphalt (60-70) can be enhanced by 18.18%, 23.86 % respectively. from figure (1) we find that the relationship between the softening point and percentage of Nano-silica is stronger than Nano-hydrated lime as shown in equation (1). The improvement in the softening point of the asphalt as a result of adding Nano materials can reduce the susceptibility of the asphalt to temperatures, this means the possibility of using modified asphalt with Nano-silica and Nano-hydrated lime in areas with high traffic loads and high temperatures.

\[
y = -0.0738x^2 + 1.7304x + 43.702 , \quad R^2 = 0.989 \quad ...... \text{for NS} \quad \text{equation (1)}
\]

Figure (2) shows a decrease in the penetration gradient of the asphalt from 65 to 43 with an increase in Nano-silica to 7%, while the penetration gradient decreases with an increase in Nano-hydrated lime to 5% and then returns increases at 7%. The best results for the asphalt modified obtained in the 7% Nano silica, which is 33.8 % lower than the unmodified asphalt. This means, the penetration of asphalt (60-70) can be improved by 33.8% By adding 7% of the Nano-silica.
Equation (2) shows relationship between penetration of modified asphalt and percentage of Nano-silica is stronger than Nano hydrated lime.

\[ y = 0.2484x^2 - 4.6536x + 63.918, \quad R^2 = 0.9828 \quad \text{......for NS} \quad \text{equation (2).} \]

The decrease in the value of the penetration of asphalt at certain limits using Nano materials makes the modified asphalt more rigid than the original, which means that the asphalt mixture will be more resistant to rutting. On the other hand, the decrease in penetration makes the asphalt more rigid and brittle and thus it is prone to fatigue under the influence of traffic loads. It is worth noting, however, that the amount of improvement in stiffness was not high enough to make the asphalt more brittle.

From the laboratory results, it becomes clear to us that the addition of Nano-materials to the asphalt leads to a decrease in the penetration value, which is indicative of an increase in the hardness of the asphalt at moderate temperatures (25°C) and an increase in the softening point, which indicates a decrease in the sensitivity of the asphalt to high temperatures, which in turn leads to an increase in crack resistance at low temperatures and permanent deformations occurring at high temperatures.

In fact, such materials linked as a bridge between bitumen particles at low or operated temperature which lead to stable bitumen particles against deformation. It is therefore that penetration value decreases and softening point increases.

4.2: Effect of Nano-materials on temperature susceptibility and viscosity

The temperature has a very big effect on the consistency of the asphalt, at high temperatures the viscosity of the asphalt decreases and it becomes softer while it becomes stiffer with lower temperatures and increased the viscosity. There are several equations that show the way in which the consistency of asphalt changes with the change in temperature. Among the most famous of them, the equation developed by Pfeiffer and Van Doormaal [10].

\[ PI = \frac{1952 - 500 \log(\text{pen}) - 20 \times SP}{50 \log(\text{pen}) - 3P - 120} \quad \text{equation (3)} \]

where;

PI: penetration index

Pen: penetration, 25°C

SP: softening point, °C

penetration index is very important so as to predict the behavior of the asphalt for any application from the results of the research for the penetration at 25°C and the softening point tests of modified asphalt, the results showed that the penetration index increases with increasing proportions of Nano-materials (NS,NHL) compared to unmodified asphalt as shows in figure (3), amount of improvement in the penetration index for NHL (from -2.25 to -0.05) and for NS (from -2.25 to -1.05) This gives an indication of the decrease in the amount of temperature susceptibility for asphalt and it became possible to reduce the cracking that occurs to the asphalt pavement and extend the service life of the road.
For viscosity test at 135°C, as shown in figure(4), the increase in viscosity by increasing the proportion of NHL more than NS. Increase the viscosity of bitumen lead to a difficult satisfaction of adhesion force between bitumen and aggregate. More importantly, increasing the viscosity of bitumen makes it less diffused into aggregate particles.

5. Conclusions

From laboratory tests of the original and modified asphalt by adding Nano-materials in specific proportions and according to the results obtained from these tests and depending on the American standard specifications, it was reached:

1. The physical and rheology properties of asphalt can be improved by using Nano-materials.
2. Adding 7% Nano-silica to the asphalt reduces penetration values by 33.8%, while the best NHL ratio at 5% reduces penetration by 23.07% of the original penetration and this means that the modified asphalt becomes stiffer than the unmodified.
3. The softening point of the asphalt increases by 18.18% when adding Nano-silica and 23.86% for Nano-hydrated lime. The improvement in softening point reduces the temperature susceptibility of modified asphalt.
4. The penetration index value increases from (-2.25) to (-0.05) when adding NHL, while adding NS increases the penetration value from (-2.25) to (-1.05) this is an indication of a decrease in the temperature susceptibility of modified asphalt.
5. The increase in viscosity occurs when adding NHL is higher than NS compared with unmodified asphalt.
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