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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Physical and Chemical Properties of Nano Zinc Oxide Modified Asphalt Binder

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DOI: https://doi.org/10.30880/ijie.2022.14.09.017
Received 26 June 2022; Accepted 15 September 2022; Available online 30 November 2022

Abstract: Nanotechnology has recently been applied in various branches of research, including pavement engineering, because the materials it offers are promising and improving. The process of modifying asphalt binder has developed gradually, and now many kinds of nanomaterials are used. In this study, a flake-structured nano zinc oxide was used as an asphalt binder modifier. At 3%, 5%, and 7%, respectively, of penetration grade 60/70 asphalt binder, the nano modifiers were added. Physical properties of the modified asphalt binders were then examined, including storage stability, penetration, softening point, and viscosity. Meanwhile, the chemical property was determined using Fourier-Transform Infrared Spectroscopy. It was discovered that 3% nano zinc oxide produced the best results. Nano zinc oxide was found not to show separation at high temperatures in a storage stability test. The addition of nano zinc oxide to the asphalt binder also reduced the penetration, increased the softening point, and reduced the viscosity. The high penetration index value also indicates that the asphalt binder treated with nano zinc oxide is thermally resistant.

Keywords: Nanotechnology, asphalt binder, nano zinc oxide, physical properties, chemical properties.

1. Introduction

Temperature, heat, sunlight, and oxidation can impact the asphalt binder's physical and chemical qualities [1]. Rapid changes in the new era of technology in this globalization nowadays enable all engineers and researchers to discover new technology to improve road performance. Nanotechnology is an innovative field that promises significant benefits in a variety of fields, including industry and commerce, as well as the built environment and construction. Since of the huge number of materials utilized, construction is an essential industry for the application of nanomaterials because it represents a significant market for novel products. Nanotechnology has been used in pavement engineering over the last few decades to extend the life of asphalt and reduce maintenance costs. The findings showed that nanomaterials can improve the resistance to fatigue and rutting at high, middle, and low temperatures of asphalt mixes. As a result, the utilization of nanomaterials as asphalt binder modifiers has become popular to enhance the performance of asphalt binder.

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Moreover, importance of cohesion in asphalt binder from the fact that the materials in a modified asphalt binder must stick and bridge together for each particle [2]. The interlocking of the asphalt binder and modifier forms the bridge in order to achieve strength bonding between them.

The addition of nano zinc oxide can increase the asphalt binder's total surface free energy [3], as well as the asphalt mixture's properties [4]. Furthermore, when compared to other nanomaterials, modified asphalt binder with nano zinc oxide improves ultraviolet (UV) ageing resistance [5]. In order to modify the asphalt binder, this study used nanoscale zinc oxide with a flake structure.

2. Materials and Methods

2.1 Materials

Asphalt binder employed was penetration grade 60/70 asphalt binder, while the modifier was nano zinc oxide. Zinc nitrate-6-hydrate and sodium hydroxide 99 percent were the main chemical precursors used in this study to produce nano zinc oxide via a hydrothermal method. Fig. 1 shows the flake structure of nano zinc oxide captured by Field Emission Scanning Electron Microscopy (FESEM) test.

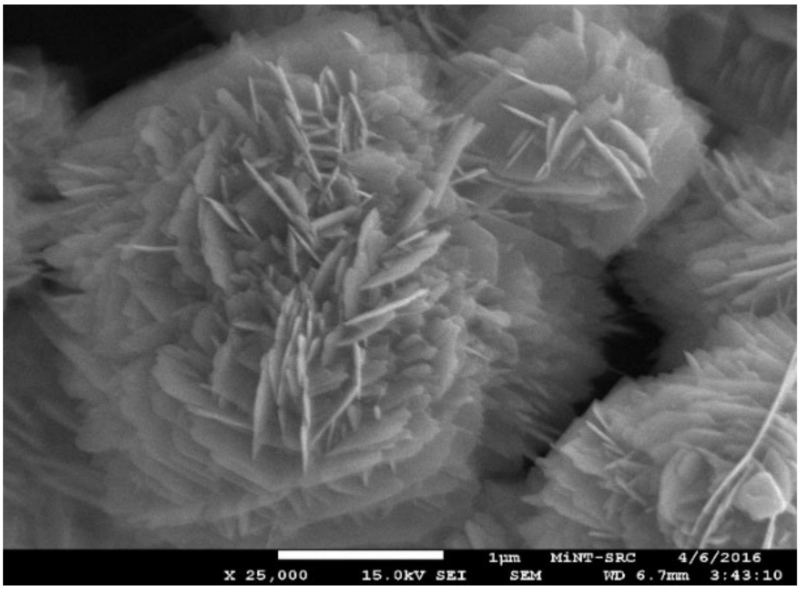

Fig. 1 - Nano zinc oxide with flake structure

2.2 Sample Preparation

The modified binder was prepared by adding the nano zinc oxide at 3%, 5% and 7% with base binder. A Silverson L4RT high shear mixer was used to execute the mixing process at temperature 135 - 140°C at 2000 rpm for 30 minutes.

2.3 Storage Stability Test

Measurement of the storage stability of both unmodified and modified asphalt binders in accordance with BS EN 13399:2010. [6]. The samples were put inside a 30 mm diameter by 170 mm height aluminium foil tube. For 72 hours, the foil tubes were sealed and kept vertically in a 180°C oven. The samples were then divided horizontally into three equal halves and chilled to room temperature in a vertical posture. In order to evaluate the storage stability of the asphalt binder modified with nanoscale zinc oxide nanoparticles, the softening points of the top and bottom sections were measured using samples taken from the top and bottom sections. The samples were deemed to have satisfactory high temperature storage stability if there was less than a 2.5°C temperature difference between the top and bottom parts. The samples were deemed unstable if the changed asphalt binders' softening points differed by more than 2.5°C [7].

2.4 Penetration Test

According to ASTM D5, the penetration test was performed to evaluate the asphalt binder's consistency [8]. Before being poured into the penetration cup for around 50g, the asphalt binder was warmed in the oven. The sample was placed in a water bath for an hour after being allowed to cool to room temperature. The penetration value was calculated using the depth of a standard needle inserted into asphalt binder while it was subjected to a 100 g load for 5 seconds.

2.5 Softening Point Test

The asphalt binder's temperature susceptibility is calculated using its softening point. According to ASTM D36, this testing was completed. In order to create a smooth sample surface, the hot asphalt binder was poured into two rings, let to cool at room temperature, and then trimmed. These two rings, along with two ball-centering guides, were mounted on the ring holder and submerged in a liquid. Each sample received two 3.5 g steel balls. The beaker containing the water bath, ring, and balls was placed on the infrared heating apparatus [9] in this study. This automatic ring and ball apparatus measured the temperature of the asphalt binder as it came into contact with the bottom plate.

2.6 Rotational Viscosity Test

The resistance of fluids to flow is described by viscosity, which is a fundamental property of bitumen. A rotating viscosity test can be performed to assess an asphalt binder's flow properties. According to ASTM D4402 [10], this test was conducted. Rotational viscosity was calculated using the force necessary to maintain a cylindrical spindle's constant rotational speed at 20 rpm while submerged at a constant testing temperature. When the viscosity of the asphalt binder was directly correlated to the torque, the torque function would automatically determine the viscosity.

2.7 Fourier-Transform Infrared Spectroscopy (FTIR) Test

The chemical composition of a nano zinc oxide modified asphalt binder was studied using Fourier-transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR). The main goal of the FTIR test was to measure the materials' infrared (IR) absorption [7]. In this study, the spectra were recorded from 600 to 4000 cm^{-1}. The sample was subjected to the radiation, which caused the molecules bonds to vibrate and rotate at discrete frequencies. This was due to the fact that some of the radiation emitted during the test was absorbed by the material while others passed through it. The transmitted infrared radiation was then absorbed by the detector, yielding an absorbance spectrum toward wavelength. The functional groups that exist in the material can be identified.

3. Results and Discussions

3.1 Storage Stability of Nano zinc oxide Modified Asphalt Binder

The results of the storage stability test are shown in Table 1. Less than 2.2°C separated the modified bitumen's top and bottom in terms of temperature [11]. Additionally, the nano zinc oxide modified asphalt binder's greater softening point suggests that the asphalts are growing harder than the unmodified asphalt binder.

Table 1 - Storage stability of nano zinc oxide modified asphalt binders

Nano zinc oxide (%)	Temperature of Softening Point (°C)		
	Top Section	Bottom Section	Difference
0	53.3	54.4	1.1
3	56.4	55.9	0.5
5	55.7	56.0	0.3
7	56.3	55.8	0.5

3.2 Penetration Test

A penetration test can determine the degree of softness and consistency of asphalt. At 25°C, Fig. 2 shows the penetration of control asphalt binder and nano zinc oxide modified asphalt binder. It shows how the penetration value changes as the percentage of asphalt binder modified nano zinc oxide increases. The penetration value decreases with the addition of nano zinc oxide. The penetration value of nano zinc oxide modified asphalt binder increased by 9.91%, 14.15%, and 27.83%, respectively, for 3%, 5%, and 7% nano zinc oxide modifier. Nano zinc oxide hardens and enhances the consistency of the modified asphalt binder, according to the findings. Increased hardness can increase the mix's rutting resistance, but it can also reduce the asphalt binder's flexibility by making the asphalt binder stiffer, reducing resistance to fatigue cracking.

3.3 Softening Point Test

The higher the value of the softening point increment, the worse the asphalt ageing index [12]. It is therefore ideal for use in areas with a high average annual temperature or a high volume of traffic. Fig. 3 shows a graph of the softening point changes for the modified asphalt binder with varied percentages of nano zinc oxide. Asphalt binder containing 3% nano zinc oxide had a higher softening point than asphalt binder containing 5% and 7% nano zinc oxide, as demonstrated. The softening point test was carried out to identify and quantify the degree of softening by measuring the temperature of the asphalt binder.

Fig. 3 depicts the increase in softening point temperature after the asphalt binder was mixed with nano zinc oxide as a modifier in the asphalt binder. 3% of nano zinc oxide exceeded 5%, while 7% of nano zinc oxide above 5%. According to the results, 3% nano zinc oxide achieves the maximum temperature to soften the asphalt binder, hence increasing the asphalt binder's hardness. It can be linked to nano zinc oxide's development of strong links between asphalt binder chemical compositions, as well as its high heat capacity, which allows the asphalt binder to be more stable against flowing and so increases the softening point.

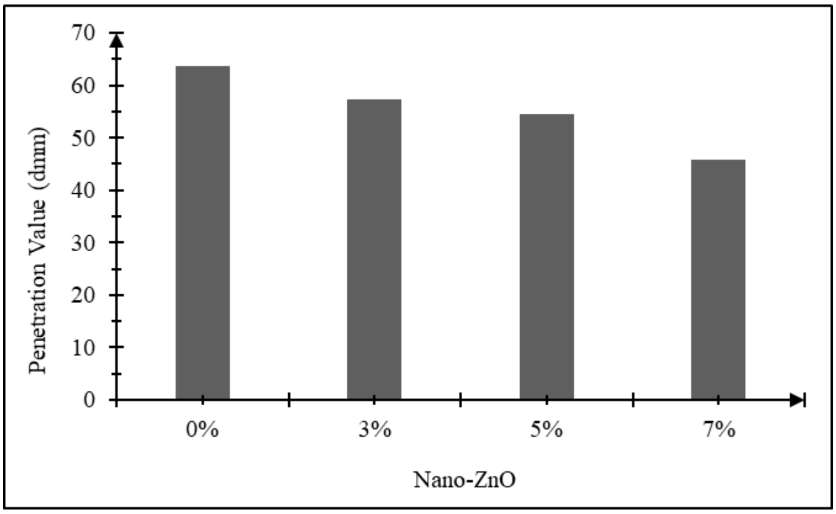

Fig. 2 - Penetration values of nano zinc oxide modified asphalt binder

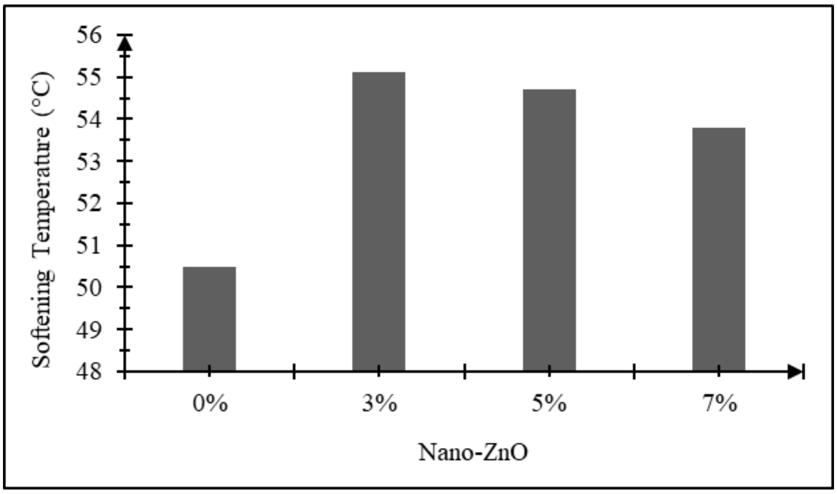

Fig. 3 - Softening of Nano zinc oxide modified asphalt binder

3.4 Temperature Susceptibility

Based on the results of penetration at 25°C and softening point temperature, the penetration index was computed using a nomograph [13]. A higher penetration index (PI) value increases the asphalt binder's temperature susceptibility. Fig. 4 depicts the relationship between PI and the percentage of nano zinc oxide used as a modifier in asphalt binder. Thus, the PI values show that 3 percent of nano zinc oxide obtain a higher value than other samples, indicating lower temperature susceptibility, which contributes to asphalt binder resistance to cracking and rutting. One advantage of using a modified asphalt binder is its lower temperature susceptibility.

A higher softening point temperature, in general, suggests lesser temperature susceptibility and is favoured in hot climate weather. The PI value for high-temperature susceptible asphalt binder ranges from around -3 to about +7 for fully blown low temperature susceptible (high PI) asphalt binder. Temperature susceptibility increases as PI values rise [14].

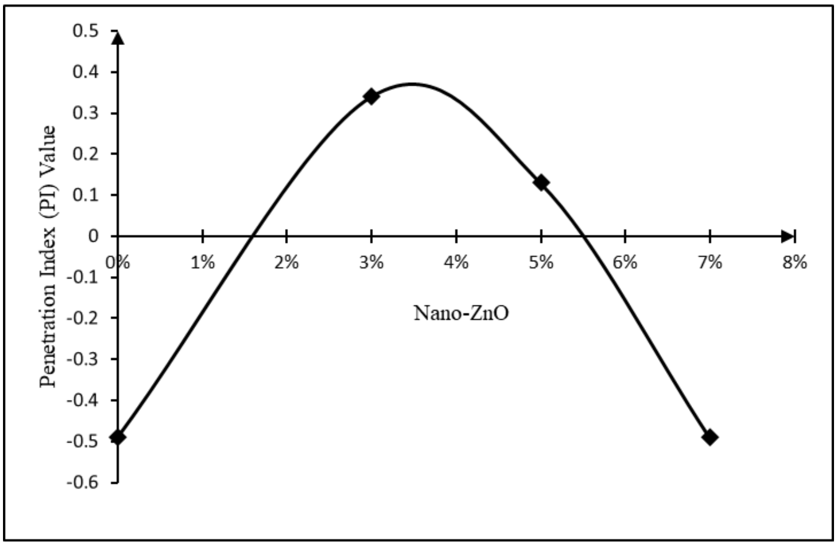

Fig. 4 - PI value of control and nano zinc oxide modified asphalt samples

3.5 Rotational Viscosity Test

The viscosity test measures the flow resistance of asphalt binder. The effects of nano zinc oxide on the rotational viscosity of asphalt binder are shown in Table 2 and Fig. 5. The modified asphalt binder line is higher than the control asphalt binder line. This suggests that the viscosity of the control asphalt binder is lower than that of the nano zinc oxide modified asphalt binder. The viscosity of the asphalt binder reduced as the temperature rose, making it more fluid. Nonetheless, the viscosity of 3% nano zinc oxide in asphalt binder enhanced the dynamic viscosity at low temperature as the curve line was greater than the control asphalt binder and decreased the kinematic viscosity at high temperature, as expected. According to the viscosity results, the most temperature sensitive asphalt binders are nano zinc oxide modified asphalt binders, while the least temperature sensitive asphalt binders are control asphalt binders. The higher the viscosity, the more stable it is over temperature fluctuations.

Table 2 - Rotational viscosity at specific temperature

Nano zinc oxide (%)	Viscosity at Specific Temperature (Pa.s)			
	120°C	135°C	150°C	165°C
0	2.033	0.913	0.477	0.237
3	2.341	1.047	0.528	0.263
5	2.308	0.999	0.497	0.264
7	2.175	0.938	0.480	0.246

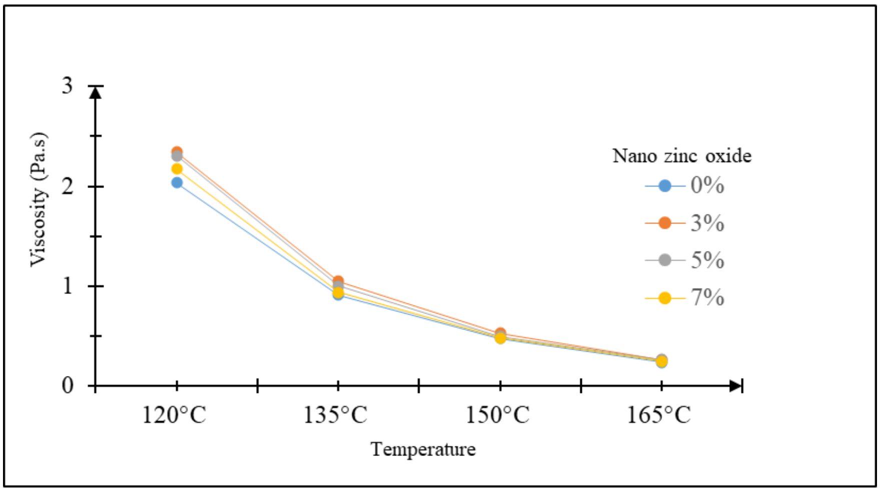

Fig. 5 - Viscosity value of modified asphalt binder with nano zinc oxide

3.6 Fourier-Transform Infrared Spectroscopy (FTIR) Test

During the FTIR test, the peak detection was detected, and the higher the peak detect, the higher the intensity. This hypothesis demonstrates that the existing bonding between the sample's structures was strong and dominant. The flat line or lower peak explained that there will be less hydroxide (OH) or that OH will be finished. Fig. 6 depicts the split method between samples of the average for peak detection of formatting 2.0% of the threshold for nano zinc oxide powder, 0%, 3%, 5%, and 7% of the nano zinc oxide modified asphalt binder. Peak values were 2917.57 cm-1, 2918.14 cm-1, 2917.78 cm-1, and 2918.31 cm-1 for 0%, 3%, 5%, and 7% nano zinc oxide modified asphalt binder, respectively. The hypothesis was formed based on the highest peak among all the samples in Figure 6, which were the nano zinc oxide powder categories in the functional group's CH bending vibration while subgroup categories in CH3. They were assigned to the functional group CH stretching vibration for 0%, 3%, 5%, and 7% of the cases. All samples were assigned to the CH2 subgroup. The higher the peak, the greater the intensity of absorbance in the sample. Figure 6 shows that 7% nano zinc oxide has the highest peak. The presence of chemical bonding between the particles within the modified asphalt binder demonstrates that the sample was dominant. IR penetrates the sample and detects space, causing it to generate noise.

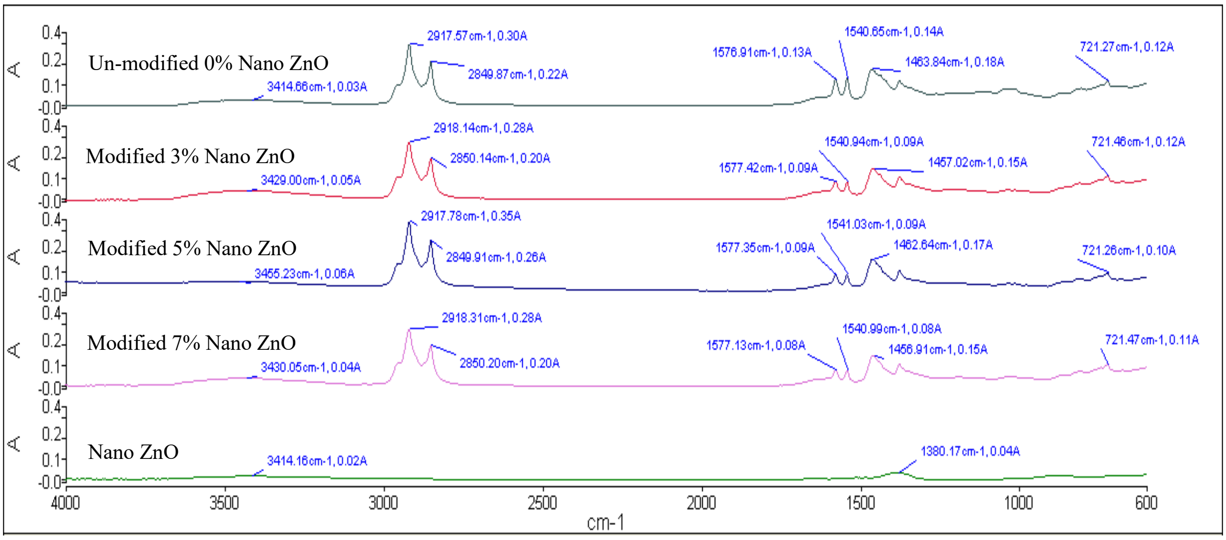

Fig. 6 - FTIR spectrum for nano zinc oxide modified asphalt binder

4. Conclusions

This study was conducted to determine the physical and chemical properties of nano zinc oxide with flake structure modified asphalt binders. The following conclusions are possible:

- The softening point test results for top and bottom samples revealed that the presence of nano zinc oxide has no effect on the storage stability of asphalt binder.
- The use of nano zinc oxide raised asphalt binder softening point while decreased penetration. As a result, nano zinc oxide has the ability to improve asphalt binder hardness and stiffness.
- The addition of 3% nano zinc oxide to the modified asphalt binder reduced temperature susceptibility as determined by the softening point test. The PI value of nano zinc oxide modified asphalt binder falls within the specified ranges for road construction.
- The FTIR test findings showed that as the concentration of nano zinc oxide grew, so did the peak detection.
- The optimal concentration of nano zinc oxide was discovered to be 3%. In terms of physical properties performance, 3% nano zinc oxide outperformed other percentages of nano zinc oxide in terms of softening point, penetration, and viscosity.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through TIER 1 (H833) grant. The author also would like to thank for the technical support provided by Advanced Highway Engineering Laboratory, Faculty of Civil Engineering and Built Environment as well as Universiti Tun Hussein Onn Malaysia (UTHM) for providing facilities in the area of study.

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