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Characteristic of Nano Zinc Oxide Modified Asphalt Binder and Asphalt Mixture

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Abstract: Asphalt mixture is a composite material that is used in road construction. However, the aging of the asphalt mixture has caused the asphalt material to embrittle and stiffer, which would affect the durability of the asphalt mixture and lead to cracking. This study aimed to identify the influence of different amounts of nano-ZnO modified asphalt regarding the aging of asphalt concrete and determine the relationship between nano-ZnO modified asphalt mixture and the aging performance of asphalt mixture. To improve the aging performance of conventional asphalt mixture, a small amount of nano-ZnO is added to the asphalt mixture. This study review the sets of journal article that conducting several experiment with different dosages of nano-ZnO modified asphalt mixture. The samples were tested by penetration test, softening test point test, ductility test and bending rheometer test to determine the physical properties. For rheological characteristics, dynamic shear rheometer test is used to identified. Based on articles, the results can be collected and further analyses can help to find out the most appropriate percentage of nano-ZnO required to be added into original asphalt to produce the most efficient road pavement material.

Keywords: Aging Performance, Properties, Nano-Zno Modified Asphalt Mixture, Systematic Literature Review

1. Introduction

Asphalt mixture can be named as hot mix asphalt (HMA), cold mix asphalt (CMA), bituminous mix, bituminous concrete and so on. Different types of asphalt mixture will have different performance characteristics and can be used in different fields. Generally, the primary ingredients of asphalt mixture are asphalt cement and aggregates. Asphalt mixture is usually used in road paving. However, many studies have shown that the aging problem of asphalt mixture has caused a serious impact on road users. [1]. In recent years, nanotechnology encompasses a very broad range of materials, manufacturing processes and technologies that are used to create and enhance many products people use everyday.

Therefore, it goes with the purpose of this research which is to identify the influence of the different percentages of nano-ZnO modified asphalt mixture regarding the aging of asphalt mixture and determine the relationship between nano-ZnO modified asphalt mixture and the aging performance of

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asphalt mixture. Normally, nano-ZnO is available in white powder form. According to Gholam *et al.*, [2] stated that the total surface free energy (SFE) of the asphalt mixture can be improved by adding nano-ZnO.

In Malaysia, Public Work Department (PWD) standard is used as a guideline for road construction. The process of constructing a road must follow the guideline to fulfil the minimum requirement for road construction. However, there is still a problem that arises due to road surfaces defects. It is important to improve the quality of asphalt mixture to make sure the safety of road users. Asphalt mixture is a composite material that is commonly used to surface road, the core of embankment dams and so on. However, the aging of the asphalt mixture has caused the asphalt material to embrittle and stiffen, which would affect the durability of the asphalt mixture and lead to cracking. It is necessary to study the effect of nano-ZnO modified asphalt mixture toward the aging performance of the asphalt mixture. Therefore, it requires a solution to extend the lifespan of the asphalt mixture [3].

In this study, it focuses on review several factors that can improve the aging performance of the asphalt mixture from the previous study. A set of tests are conducted to obtain the aging performance and properties of the asphalt mixture. The different percentages of nano-ZnO modified asphalt mixture are tested to identify the aging performance and properties of the asphalt mixture [4]. The result of the test from journal articles are selected and analyzed. By doing this, it can help develop the most appropriate percentage of nano-ZnO required to be added into original asphalt to produce the most efficient road pavement material. With the addition of nano-ZnO as a modifier, it can improve the aging property of the asphalt mixture. This has bring a positive impact on the engineering field as it has solving a general engineering problem, especially for the pavement engineering environment.

2. Systematic Literature Review

The collection of journal articles is one of the most crucial phases of making this work a success. The process of obtaining the data will be defined from the step of determining the research approach, the research method to the data analysis stage. A systematic literature review can be completed through few guidelines [5]. Initially, the purpose of the literature review must be emphasized. Then, search engine is used to search for the literature. Screening the suitable research articles is the next action must be taken. The not relevant article can be eliminated and the relevant article can be kept. The journal articles kept are then studied deeply to filter and make sure the content can be used. The method of systematic literature review would be used to help identify research paper that related to the study. [6]

This method aims to identify, evaluate, and summarize the findings of all relevant individual studies over a related issue, thereby making the available evidence more accessible to decision makers specifications and properties of materials, equipment, and other resources used in the current study. The usage of search database of “Google Scholar” and “Science Direct” combine with the Boolean search method words or phrases such as “AND”, “OR” and “NOT” that restricts, expands and defines the search results. The keywords such as “nano zinc oxide”, “modified asphalt mixture” and “aging performance” are used for Boolean operators to obtain relevant research articles that can be used. This can allow us to limit down the search and obtain the relevant journal articles in a very short time.

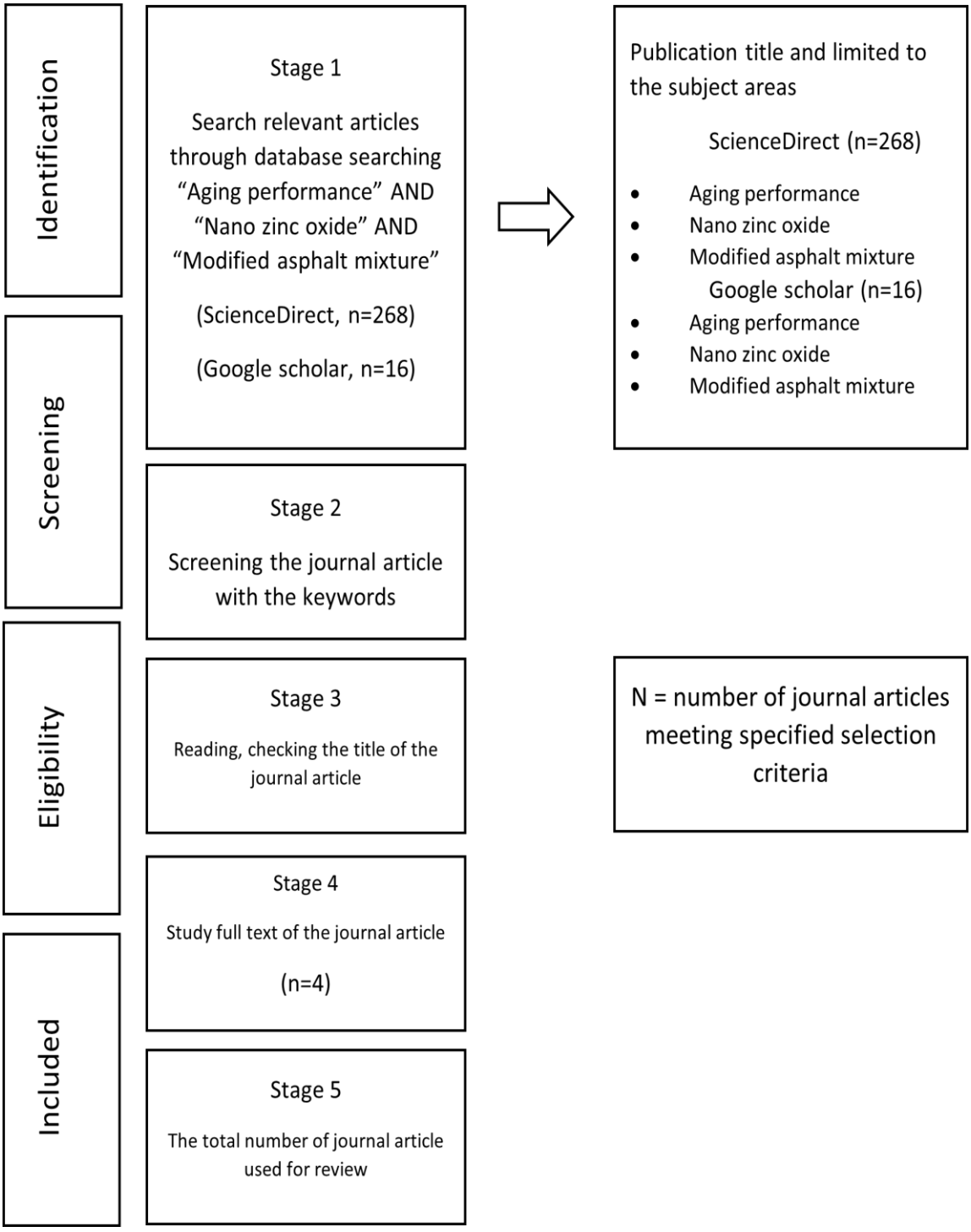

Figure 1 : Systematic literature review flow chart

From the selected journal, the data then would be collected and further analysis about the results can be done. From there, the laboratory test results of the 4 journal articles from previous study are recorded and analyzed to make sure able to meet the objective of the study. By doing this, it can help develop the most appropriate percentage of nano zinc oxide required to be added into original asphalt to produce the most efficient road pavement material.

3. Results and Discussion

This section presents the results obtained from selected journal article that related to the aging performance and properties of nano zinc oxide modified asphalt mixture from the previous study. There

are few experiments carried out by the researchers to obtain the results of aging performance and properties of nano zinc oxide modified asphalt mixture. The data obtained from the experiment has been analysed and further discussion have been made.

There are few journals that being selected to be included on this study. The first journal is titled Physical properties and anti-aging characteristics of asphalt modified with nano-zinc powder [7]. In this journal, a sets of different percentage of nano-ZnO are added into the original asphalt to produce a nano-ZnO modified asphalt mixture. Then, the physical properties of nano-ZnO modified asphalt mixture such as penetration test, softening point test and ductility test have been tested and the results are shown below.

For the softening point test, the result is shown in figure 1. From the figure, it shows that the softening point of the nano-ZnO modified asphalt increase after aging treatment. From the study by X. Xu *et al.*, [7] it can conclude that the greater amount of nano-ZnO dosage added into the modified asphalt mixture, the greater value of the softening point. In this test, the most suitable nano-ZnO dosage adding into the original asphalt to achieve the best result is 3%.

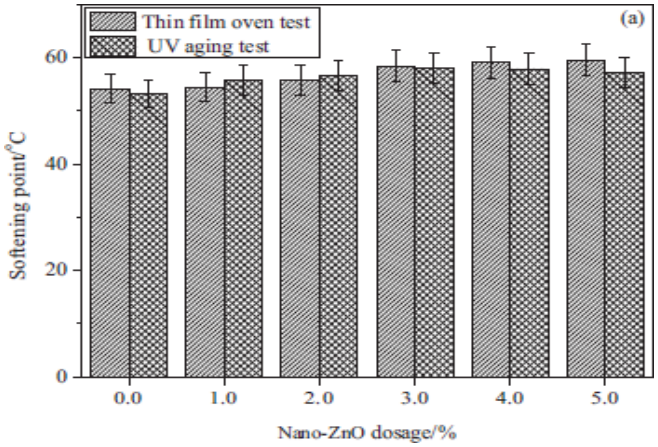

Figure 2: Effect of different nano-ZnO dosage on physical properties of aged asphalt: Softening point [7]

For the ductility test, the result done by X. Xu *et al.*, [7] shows that the value of ductility of nano-ZnO modified asphalt gradually increases until 3% dosage of nano-ZnO and decreases after 3% dosage of nano-ZnO. It stated that a steady increase in the result of ductility from 1% of nano-ZnO dosage to 3% of nano-Zn-O dosage but decreases when the nano-ZnO dosage is 4% and 5%. It can conclude that 3% of nano-ZnO is the most suitable dosage to add into original asphalt to improve the low-temperature ductility.

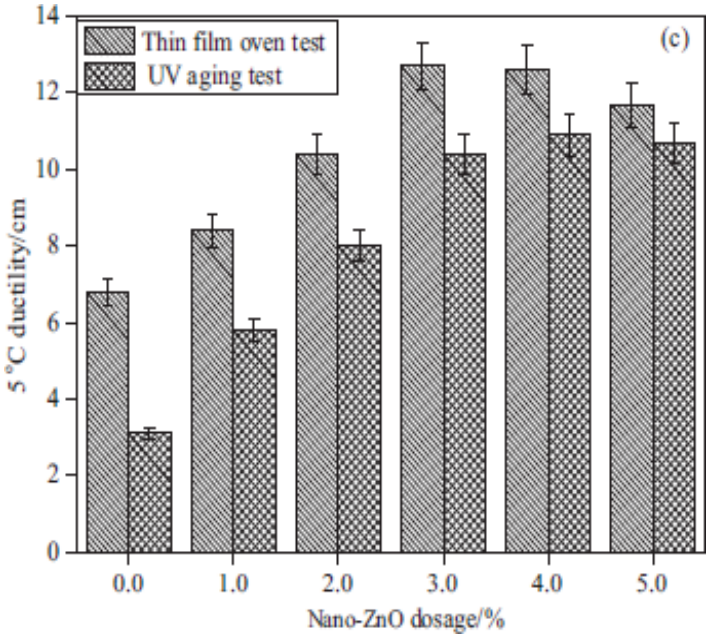

Figure 3: Effect of different nano-ZnO dosage on physical properties of aged asphalt: Ductility [7]

For the penetration test, the result done by X. Xu *et al.*, [7] shows that the increase of nano-ZnO dosage from 1% to 3% will lead to the increase of penetration of modified asphalt and the penetration decrease after 3% dosage of nano-ZnO. The penetration of nano-ZnO modified asphalt mixture increases smoothly when the percentage of nano-ZnO dosage is 1%, 2% and 3%. When 4% and 5% of nano-ZnO dosage are added into original asphalt, it shows a slight decrease in the penetration result. With the addition of nano-ZnO into the asphalt mixture, the temperature sensitivity ofthe original asphalt can be improved. Consequently, 3% is the most suitable nano-ZnO dosage adding into original asphalt to achieve the best result for penetration test.

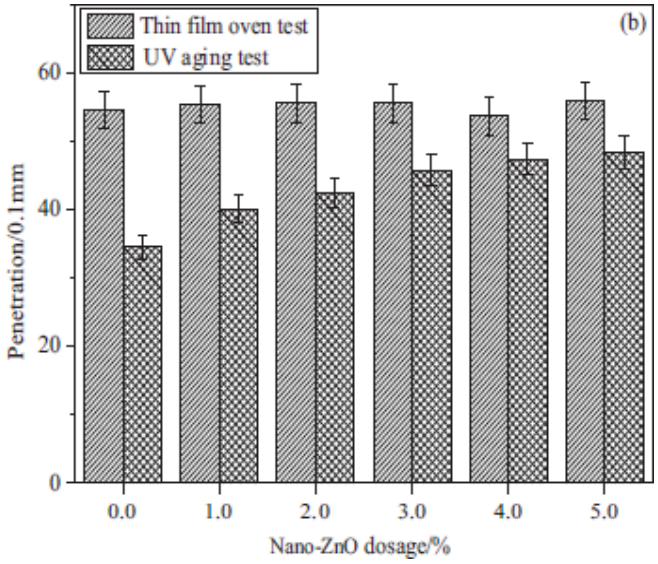

Figure 4: Effect of different nano-ZnO dosage on physical properties of aged asphalt: Penetration [7]

In terms of dynamic shear rheometer tests by X. Xu *et al.*, [7] the tests would be conducted under 3 different temperatures to determine the complex shear modulus(G*) and phase angle. The value of complex shear modulus (G*) enables us to determine the resistance to deformation of the nano-ZnO modified asphalt mixture while phase angle can determine the viscosity of the material. The three temperature conditions are 52°C, 58°C and 64°C respectively. The graph shows that the result is in

increasing trend for complex shear modulus while decreasing trend for phase angle when the dosage of nano-zinc oxide added into original asphalt increased.

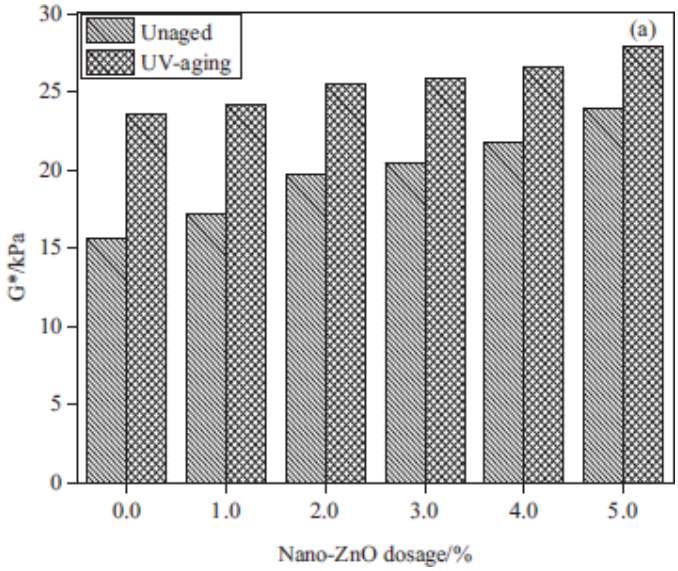

Figure 5: Effect of different nano-ZnO dosage on rheological properties of aged asphalt: Complex shear modulus [7]

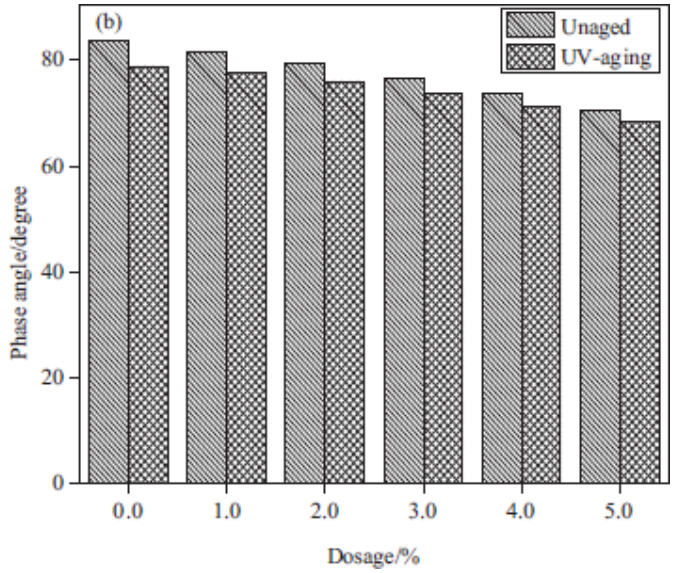

Figure 6: Effect of different nano-ZnO dosage on rheological properties of aged asphalt: Phase angle [7]

Based on the study by X. Xu *et al.*, [7] the UV absorption curve of asphalt with different nano-ZnO dosage is plotted. A UV-Vis-infrared spectrophotometer is used to analyze the UV absorption of the modified asphalt. From the result, it shows that the UV absorption of modified asphalt is greater compared with original asphalt. With the increasing nano-ZnO dosage, it also increases the ultraviolet light absorption value. The peak position of ultraviolet light absorption value lies at the wavelength around 300nm. We can conclude that the addition of the nano-ZnO into original asphalt can improve the anti-UV aging performance of asphalt. Nevertheless, the dosage of nano-ZnO shows the best improvement in UV absorption ability when it is adding 3% of nano-ZnO into the original asphalt. Therefore, 3% of nano-ZnO is the ideal dosage to add to original asphalt to improve the anti-UV aging performance of the asphalt.

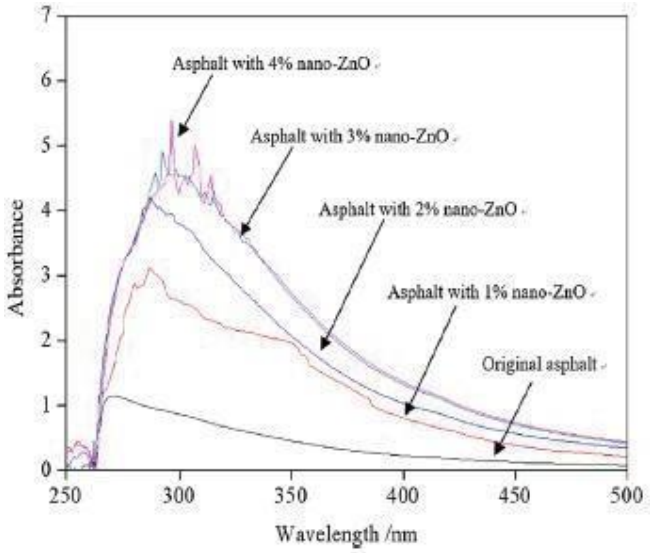

Figure 7: UV absorption curve of asphalt with different nano-ZnO dosage [7]

Based on the journal article with titled the effect of nano-ZnO particle size on properties of asphalt and asphalt mixture [8]. The main aim of this study is to identify the effect of nano-ZnO particle size on the property of the asphalt mixture. The effects of different nano-ZnO particle sizes on the properties of asphalt mixture were tested through a series of laboratory tests. The result of the test that being conducted by the researchers is shown as below.

For the softening point test by H. Zhang *et al.*, [8] the figure 7 shows the effect of nano-ZnO particle size on softening point of asphalt. In the test, the softening point of the asphalt increase when the nano-ZnO particle size decrease. Besides, the softening point of asphalt is highest when the dosage of nano ZnO particles added into the original asphalt is 4%.

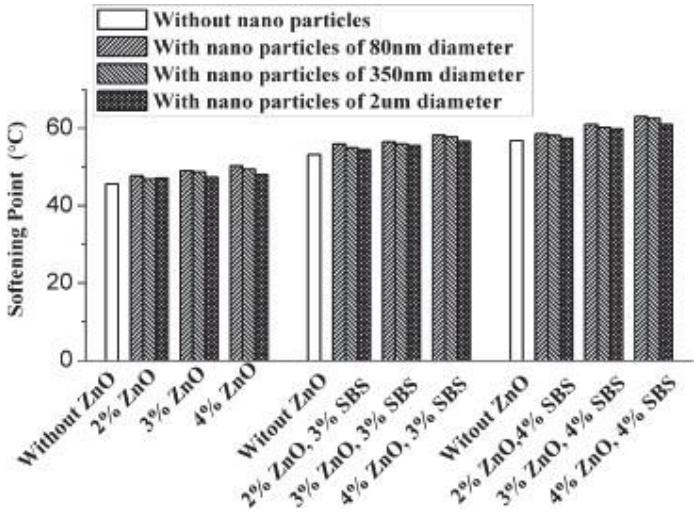

Figure 8: Effect of nano-ZnO particle size on softening point of asphalt [8]

For the ductility test by H. Zhang *et al.*, [8] it is conducted to determine the effect of nano-ZnO particle size on the ductility of asphalt. In the test, the ductility of the asphalt decreases when the dosage of nano-ZnO particle increases. It shows the highest ductility value which is greater than 200cm when 2% of nano-ZnO particle is added into original asphalt.

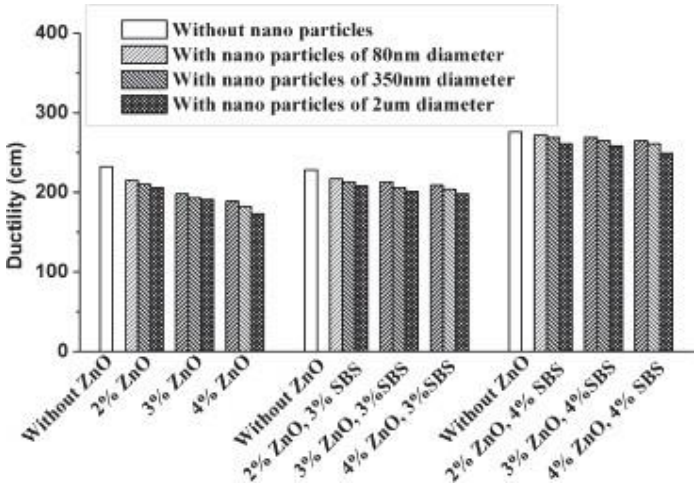

Figure 9: Effect of nano-ZnO particle size on ductility of asphalt [8]

For the penetration test by H. Zhang *et al.*, [8] the result is shown in the figure below. The softness or hardness of asphalt can be determined by a penetration test. The van der Waals of energy between nano-ZnO particles and asphalt molecules increase with the decrease of particle size. Therefore, the penetration of the asphalt decrease and become more stable when the percentage of nano-ZnO particle added into original asphalt increase. When the dosage of nano-ZnO particles is 4%, the penetration value of modified asphalt shows the lowest.

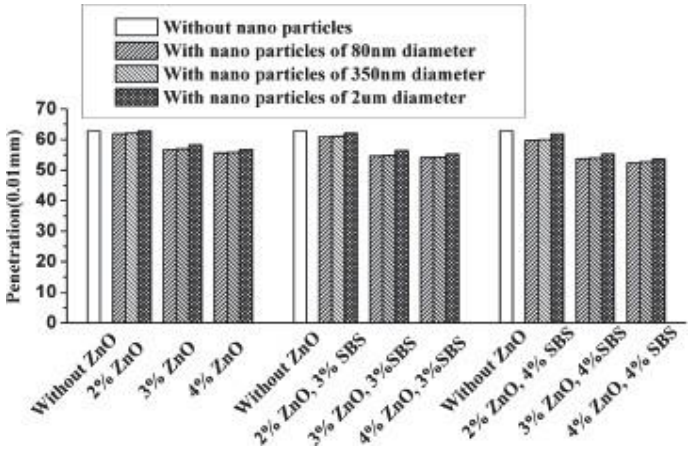

Figure 10: Effect of nano-ZnO particle size on the penetration of asphalt [8]

For linear amplitude sweep test, it can be used to determine the fatigue performance of asphalt mixture. The figure below shows the shear stress-strain curvesin the linear amplitude sweep test. Overall, the yield stress of nano ZnO modified asphalt shows greater value compared with original asphalt. However, the graph shows the yield stress increase at first then decreases with the increase of dosage of nano ZnO. From the figure, it shows 2% is the most suitable nano-ZnO dosage adding into original asphalt to achieve the best result forshear stress-strain curves in linear amplitude sweep test.

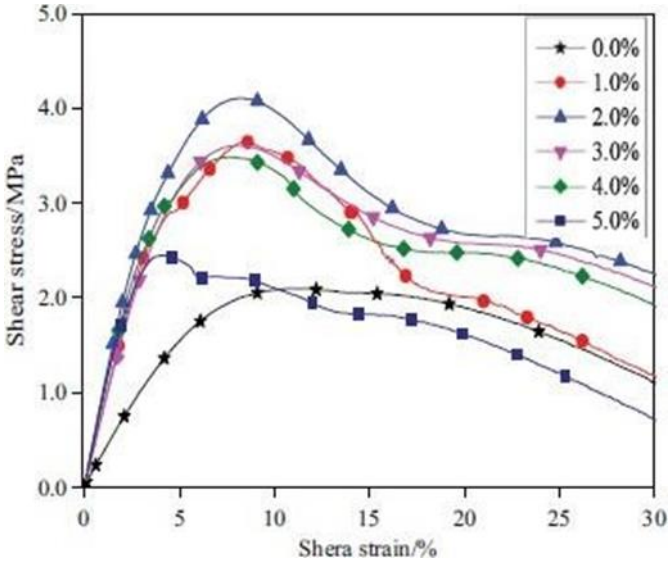

Figure 11: Shear stress-strain curves in linear amplitude sweep test [7]

By refer to the Standard Method of Test for Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep (AASHTO TP 101-2012) [9], the fatigue performance parameters of linear amplitude sweep test with different dosage of nano ZnO under different strains can be calculated. From the result, it shows that the fatigue resistance of asphalt can be improved by the addition of nano ZnO into the original asphalt. For the linear amplitude sweep test at 2.5% and 5.0% strain level, it shows that 2% is the most suitable nano-ZnO dosage adding into original asphalt for both conditions to achieve the best result for the test.

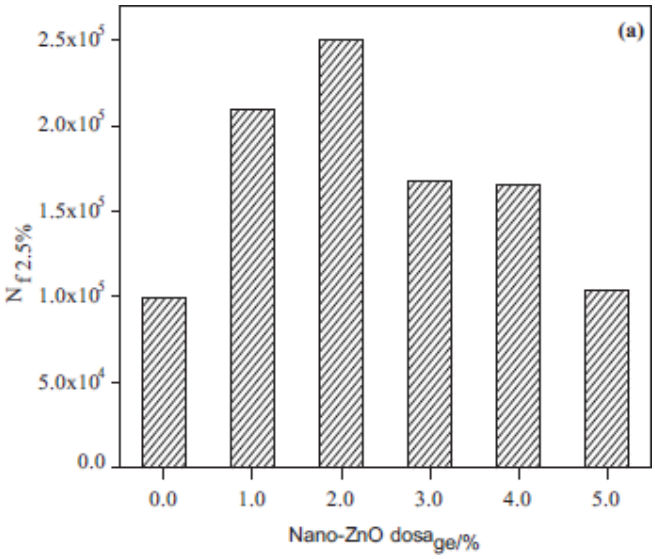

Figure 12: Fatigue performance parameters of linear amplitude sweep test :2.5% strain level [7]

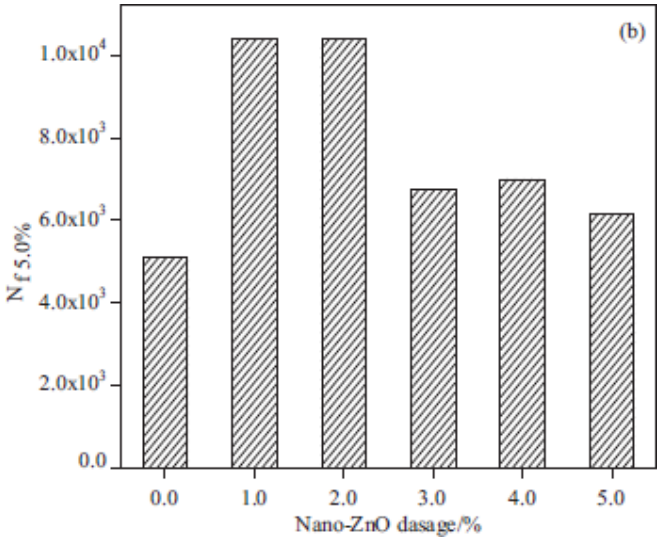

Figure 13: Fatigue performance parameters of linear amplitude sweep test: 5.0% strain level [7]

Based on the journal article with titled the effect of adding nano clay and nano-ZnO on asphalt mixture [10]. The aim isto identify the effects on the asphalt mixture by adding nano clay and nano-ZnO into it. Nano-ZnO with 1%, 2% and 3% by the weight of asphalt cement is added. It is to study the significant effect of adding nano Clay and nano-ZnO on the rheological properties of asphalt mixture.

For the rotational viscosity test by M. Taamneh *et al.*, [10] it shows that the viscosity value increase when the dosage of nano ZnO added into original asphalt increase. This indicates that the modified asphalt mixture becomes harder and resistant to flow compared with the original asphalt. It can be concluded that 3% of the nano ZnO by the weight of the asphalt mixture provides the greatest viscosity value.

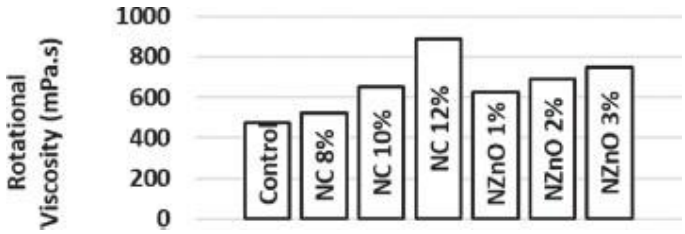

Figure 14: Rotational viscosity test results [10]

In terms of bending beam rheometer test by H. Zhang *et al.*, [10] the different sizes of nano-ZnO is added into original asphalt mixture to conduct the laboratory test. The creep stiffness and creep rate of the asphalt mixture can be identified by the bending beam rheometer test. The greater the value of creep rate indicates more stress relaxation. The lesser the value of mixture stiffness means less tensile stress. Therefore, asphalt mixture with a high creep rate and low stiffness is the most desirable condition. The result of the bending beam rheometer test is shown in the figure below. The creep stiffness of asphalt decreases and the creep rate of asphalt increases when the size of the nano ZnO particles added into the original asphalt decrease. This indicates that the low-temperature cracking resistance of asphalt can be improved by the addition ofsmaller nano ZnO particles into the original asphalt. When the nano ZnO particles are added to the original asphalt, it will produce higher activation energy.

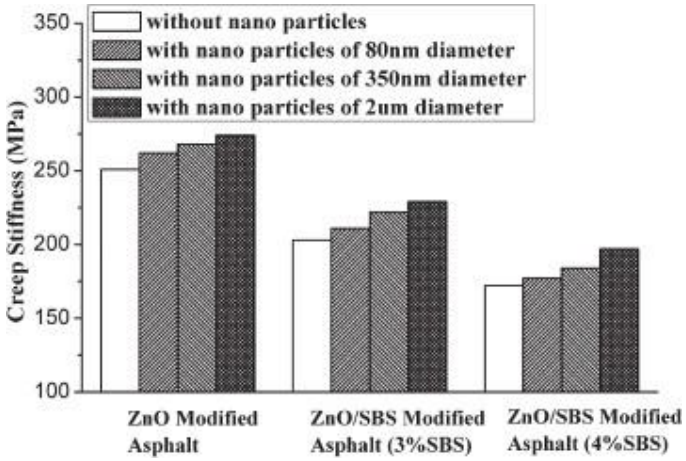

Figure 15: Effects of nano-ZnO size on the creep stiffness of asphalt [8]

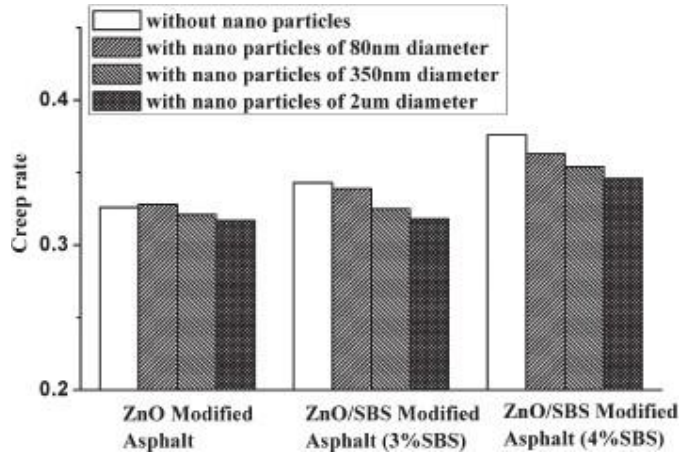

Figure 16: Effect of nano-ZnO size on the creep rate of asphalt [8]

4. Conclusion

For conclusion, the results of nano-ZnO modified asphalt mixture provides better aging performance compared with the original asphalt mixture. From the result of the laboratory tests, nano-ZnO modified asphalt mixture shows a positive effect on aging performance. The properties of asphalt mixture such as softening point, penetration, durability and so on are improved in all the aspects when 4% of nano-ZnO is added into original asphalt mixture, which can help in improving the aging performance and properties of asphalt mixture. It shows that the different percentage of nano-ZnO added into original asphalt will produce different efficiency. Therefore, it is crucial to determine the most appropriate percentage of nano-ZnO that should be added into original asphalt mixture to achieve the best performance.

As for the recommendation, there are still many addictive such as nano clay, nano silicon dioxide and nano titanium dioxide can be added into asphalt mixture. Therefore, future studies also can be recommended to identify the most suitable material to be added into the original asphalt mixture to increase its efficiency. As the different addictive are added into the asphalt mixture, it will also produce different data for the laboratory test. It is recommended to keep looking for the better addictive through the research and study in the future.

Acknowledgement

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