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Performance of Nano Silica as Modified Binder to Improve Rutting and Fatigue Resistance

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Abstract:

Nowadays, the utilisation of nanoparticle towards asphalt modification is increasing gradually. Nanomaterial is also potentially suitable in overcoming the problem related to polymer materials. Among the potential nanomaterial is nanosilica (NS), where this material is usually obtained from various natural sources like palm oil fuel ash as well as rice husk. Thus, this study intended to promote nanosilica as asphalt modifier to increase the property of penetration grade (PEN 60-70) asphalt binder in terms of fatigue index and rutting index values. The test involved is temperature sweep using Dynamic Shear Rheometer (DSR) equipment. This test is crucial to evaluate the performance of modified asphalt binder towards various temperature and ageing conditions. The result shows that 2% NS-MB provide the highest rutting index value, while 3% NS-MB produced the highest value of fatigue index. This clearly indicate that the existence of nanosilica provides better rutting resistance and fatigue resistance of asphalt binder under various temperatures and stresses.
***Keywords:** Binder, Fatigue, Nanosilica, Rutting*

I. INTRODUCTION

Previously, polymer materials were usually used to enhance the properties of virgin asphalt binder. Among the polymer materials used were ethylene vinyl acetate (EVA), ethylene glycol acrylate (EGA), styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR). But, these materials have major drawback which are producing low ageing resistance and poor storage stability for asphalt binder [1]. [2] utilized the polymer modified binder to improve the performance of asphalt binder at high and low temperatures. This study found that polymer can significantly enhanced the properties of binder especially in terms of its physical and chemical properties. The finding is consistent with a study by [3]. Asphalt binder modified with polymer material had been successfully laid at certain project locations such as intersections of busy roads, airplane tracks as well as race tracks. However, this material also faced a few drawbacks like providing poor storage stability and reduce the resistance towards ageing effect [1]. Hence, binder modification using different approach is essential to increase the properties of asphalt binder.

Besides using polymer to modify asphalt binder, the use of nanotechnology can also provide great potential in asphalt binder modification [4]. This modern material was previously used in enhancing the concrete behavior [5]. Nanotechnology is seen as one of a possible potential to be utilized as binder modification.

From the extensive literature review presented, nanomaterial has a high potential to be an effective modifier for asphalt modification. There are various types of nanomaterials in the industry, such as nanoclay, carbon nanotube and one of it is nanosilica [6]. Nanosilica is by-product of natural sources that content high amount of silicate. Nanosilica is expected to increase the properties of asphalt binder in terms of rutting and fatigue resistance. Other than that, since nanosilica is by-product of natural sources that can be easily obtained, the environmental preservation is promoted as well. Thus, it is crucial to evaluate the performance of asphalt binder with the addition of nanosilica.

II. MATERIALS AND METHODS

A. Asphalt Binder

This study utilised one type of asphalt binder which is

PEN 60/70 (penetration grade) as recommended by [7]. The physical properties of control specimen (0% NS-MB) is shown in Table I [8].

Table- I Physical Properties of PEN 60/70

Descriptions	
Softening Point	52.3°C
Penetration at 25°C	65.0 mm
Penetration Index at 25°C	+0.1
Ductility at 25°C	140 mm

B. Nanosilica

Amount of nanosilica used was in the range of 0% to 5% with the increment of 1%. The result of physical properties for various amount of nanosilica is shown in Table II [9].

Table- II Physical Properties of NS-MB

Test	Nanosilica (%)					
	0	1	2	3	4	5
Softening Point	52.3	58.9	60.3	62.4	63.4	60.0
Penetration at 25°C	65.0	43.5	41.1	33.3	29.1	30.7
Penetration index at 25°C	+0.1	+0.4	+0.8	+0.6	+0.5	0
Ductility at 25°C	140.0	129.0	85.5	70.2	51.7	46.3
Storage stability	0	0.2	0.2	0.2	0.3	0.5

C. Ageing Processes

There are three ageing conditions for this study which are unaged condition, short-term aged condition and long-term aged condition [10]. Unaged and short-term aged specimens were used to determine rutting index, while long-term aged specimens was used to evaluate fatigue resistance of NS-MB [11]. Rolling thin film oven (RTFO) equipment was used to prepare short-term aged specimens in accordance to ASTM D2872, while pressure aging vessel equipment (PAV) was used to prepare long-term aged specimens in accordance to ASTM D6521.

D. Dynamic Shear Rheometer

The rheological properties test was carried out using Dynamic Shear Rheometer. This test is crucial in determining the performance of NS-MB under various temperatures, stress levels and types of ageing conditions. Temperature sweep was performed to obtain rutting and fatigue parameter of NS-MB. Under varying temperature conditions (from 58°C to 82°C) and the stress level of 100 Pa and 3200 kPa, the dynamic shear rheological behaviours of the modified asphalt (1-5% NS-MB) and PEN60-70 (0% NS-MB) control samples of unaged, RTFO-aged and PAV-aged were evaluated. This test was in accordance to AASTHO T 315 Specification [12]. This characterization test was done to investigate the complex shear modulus (G*) and phase angle (δ) of asphalt binder over frequency sweep cycles. Furthermore, both parameters obtained from this test is essential in evaluating the performance of NS-MB in terms of fatigue resistance and rutting resistance.

III. RESULT AND DISCUSSION

A. Rutting Index

The value of G*/sinδ is usually used to represent rutting parameter (rutting index) while G*sinδ represent fatigue cracking parameter (fatigue index) of asphalt binder as shown from Fig. 1 to Fig. 6. Both parameters were the main properties evaluated from rheological properties test of asphalt binder especially at high temperature. Rutting parameter indicates the stiffness characteristic of asphalt binder, where the resistance of binder towards permanent deformation is mainly affected by the high temperature. Based on Superpave Design Specification, the value of G*/sinδ should be equal to 1 kPa for unaged specimen, while 2.2 kPa for short-term aged specimen (RTFO).

Fig. 1 shows the value of G*/sinδ for unaged. From the figure, it clearly shows that the G*/sinδ value decreases as the temperature increases for all NS-MB. For unaged specimen, all modified NS-MB passed the minimum requirement while for unmodified NS-MB, all the specimens also met the requirement except for the G*/sinδ value at 76°C. This indicates that nanosilica can increase and maintain permanent deformation resistance of asphalt binder especially at high temperature [13]. Based on Fig. 2, 2% NS-MB produced the highest value of G*/sinδ for three different temperature tests while Fig. 3 shows the significance value for the data of unaged specimens. It shows that for unaged condition, suitable amount of NS provides good permanent deformation resistance for the bitumen. This finding is consistent with a study by [14], where the utilisation of Rediset enhance the permanent deformation resistance for unaged specimen.

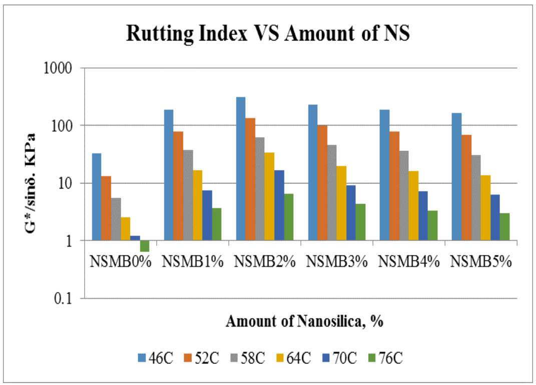

Fig. 1 G*/sinδ for Unaged NS-MB

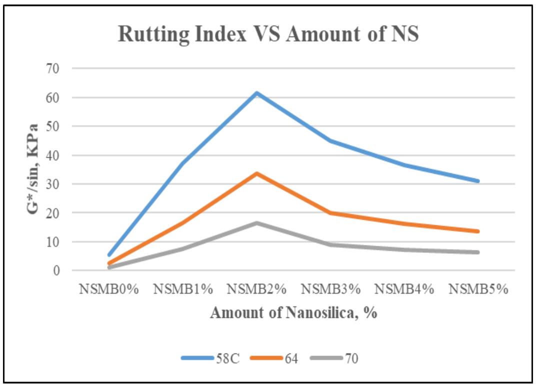

Fig. 2 Highest G*/sinδ for Unaged NS-MB

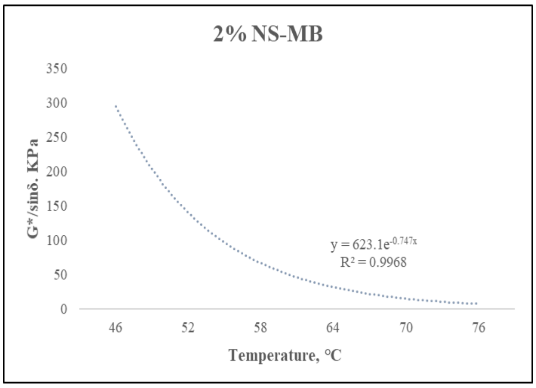

Fig. 3 G*/sinδ for 2% NS-MB

For short-term aged specimens, the value of G*/sinδ, where the trend is consistent with the unaged G*/sinδ result as illustrated in Fig. 4. Similarly, all specimens for both modified and modified specimen met the minimum requirement except for unmodified specimens at a temperature of 76°C. Next, Fig. 5 and Fig. 6 shows that 2% NS-MB for short-term aged specimen also produced the highest G*/sinδ value. From the results, it could be seen that the temperature significantly affected the rutting resistance (G*/sinδ). The finding also consistent with a study by [15], where higher test temperature reduced the rutting index of asphalt binder.

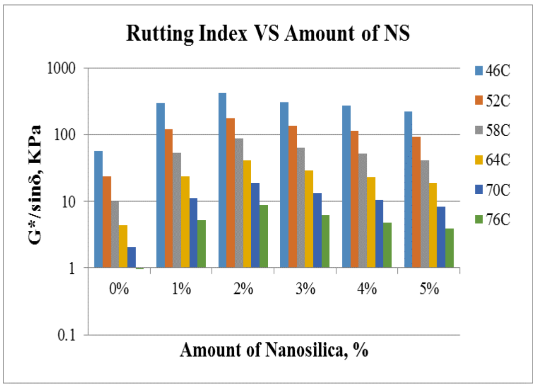

Fig. 4 G*/sinδ for Short-term Aged NS-MB

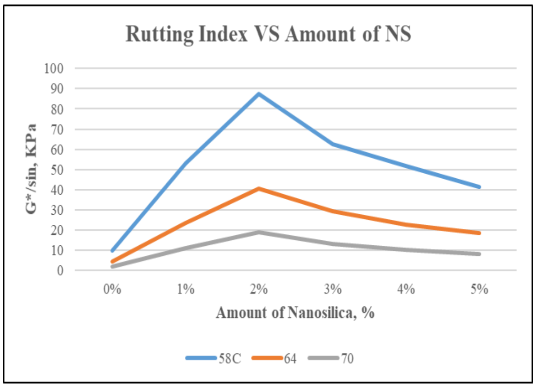

Fig. 5 Highest G*/sinδ for Short-term Aged NS-MB

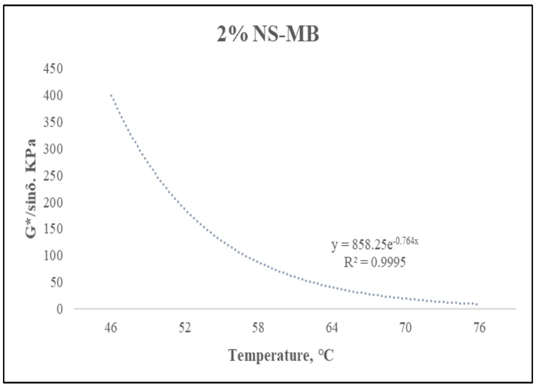

Fig. 6 G*/sinδ for 2% NS-MB

B. Fatigue Index

Fig. 7 shows the value of G*sinδ for long-term aged specimens (PAV) NS-MB at low temperature (28°C to 40°C). The G*sinδ value is commonly used to represent the fatigue cracking resistance of asphalt binder. Based on Superpave Design Specification, the value of G*sinδ should achieve 5000 kPA as this value is the limit for fatigue cracking resistance. From the figure, only modified NS-MB specimens at 28°C exceed this value while the G*sinδ value for other specimens were less than 5000 kPA. In addition, the G*sinδ values also decreased as the test temperature increased. Fig. 8 compares the value of fatigue index for highest test temperature (40°C) and lowest test temperature (28°C). From the figure, it clearly shows that the fatigue index decreases when the temperature increases. Fig. 8 and Fig. 9 also show that 3% NS-MB produce the highest fatigue index value. A study by [16] utilised carbon nano fiber (CNF) to improve fatigue resistance of asphalt binder. They found that the addition of CNF enhanced the fatigue resistance of asphalt binder. Even though fatigue index decreases due to the increment of test temperature, the value of fatigue index is still adequate especially at low temperature.

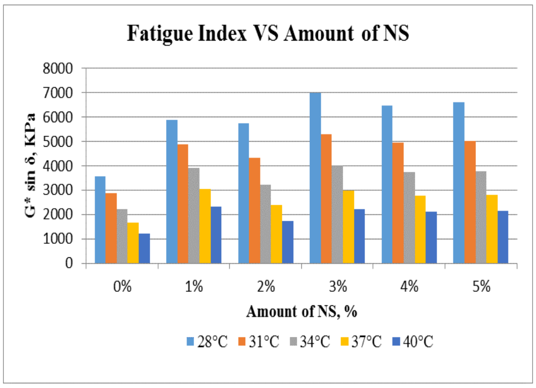

Fig. 7 G*sinδ for Long-term Aged NS-MB

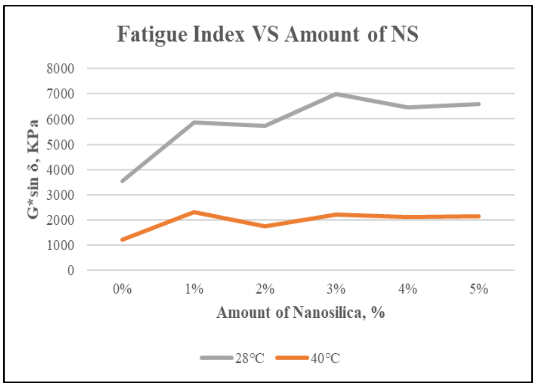

Fig. 8 Highest G*sinδ for Long-term Aged NS-MB

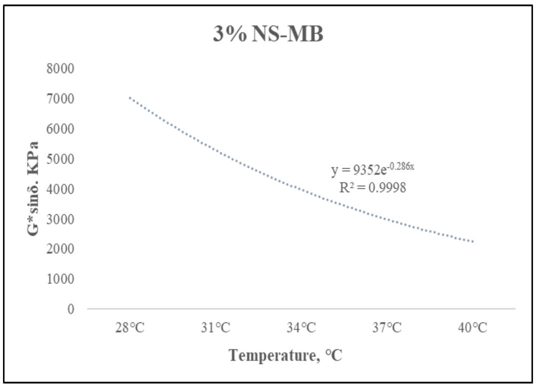

Fig. 9 G*sinδ for 3% NS-MB

IV. CONCLUSIONS

The effect of nanosilica towards the rheological characteristic of penetration grade bitumen was evaluated. Results showed that rutting index and fatigue index of nanosilica improved the performance of asphalt binder especially under various temperatures, stress levels and ageing conditions. However, the addition of more than 3% NS is not significant in enhancing the performance of asphalt binder.

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