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Permanent Deformation of Hot Mix Asphalt (HMA) using Dynamic Modulus Simple Performance Test

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Abstract*: Premature pavement breakdown can be caused by permanent deformation that can contribute to lower riding comfort for road users and an increase in maintenance costs. Dynamic modulus Simple Performance Test (SPT) test are considered to be significant in describing the permanent deformation of hot mix asphalt. In this study, Marshall method of mix design were used in order to prepare four asphalt mixtures comprising different content of Nanopolyacrylate (NP) polymer (0%NP, 2%NP, 4%NP and 6%NP). This study was aimed to evaluate the influence of the NP modified mixture on the permanent deformation. The Performance Grade PG64-22 was obtained by mixing the conventional bitumen (PG64-22) with nanopolyacrylate. Dynamic Shear Rheometer (DSR) at different aging condition were conducted in order to characterise the bitumen performance. While, the Simple Performance Test (SPT) was used to characterize rutting and fatigue on Marshall HMA mixes. Results from the study presented that, NP modified bitumen has a significant impact on the dynamic and rutting resistance. The addition of nanopolyacrylate significantly enhances the rheological properties of asphalt bitumen. The results revealed that 4%NP has high potential to improve rutting and fatigue resistance.

Keywords: Modified bitumen, Permanent Deformation, Simple Performance Test, Rutting Resistance

I. INTRODUCTION

Permanent deformation is the most common type of road pavement failure, particularly in hot climatic areas such as Malaysia. A climatic condition, especially temperature is one of the factors on asphalt concrete's permanent deformation. The bitumen has an important role to play in bituminous material performance. However, bitumen has certain weaknesses due to their limitation to temperature. Asphalt concrete tends to flow out at high temperatures. This condition will be affecting the mechanical properties of the mixtures. To address this issues, various studies have been conducted on the use of quality bitumen [1]. In order to obtain quality bitumen, a growing number of investigations have also started to design optimally performing pavements.

Polymer modification has been one of the important factors in improving the engineering and rheological properties of bitumen [2]-[5]. Various polymers were used such as polyethylene, polypropylene, ethylene– vinyl acetate, ethylene–butyl acrylate and styrene–butadiene–styrene [6]-[8]. The polymer modified bitumen (PMB) shows some improved properties of bitumen and performance of HMA mix, such as lower fatigue damage, stripping, aging and temperature susceptibility and also higher resistance to rutting and thermal cracking [9]-[12]. However, there are still have limitations of using PMB in asphalt mixture such as low ageing resistance and poor storage stability [13].

Currently, nanomaterials in asphalt pavement mixtures are capable of further enhancing the mechanical properties of asphalt pavement. It also offers a sufficiently great improvement in physical and rheological properties of bitumen leading to the development of superior nano-modified asphalt performance. Various types of nanomaterials have been used in asphalt bitumen. The most familiar nanomaterials used are carbon nanofiber, carbon nanotube, nanoclay and nanosilica [14]-[15]. Nano clay is generally utilized for asphalt alteration. The addition of nanoclay polymer into the control bitumen may improves the resistance to fatigue cracking, reduce the complex shear modulus and increase high service temperatures and rutting resistance of bitumen properties. It also can enfeeble the aging and oxidation effect [16]-[18]. Jahromi et al. investigated the effect of rheological properties on the conventional and Cloisite- 15A and Nanofil-15 modified bitumen. The results obtained show that nanoclay increases stiffness, decreases phase angle and improves ageing resistances [19].

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Zare-Shahabadi et al. explored the influence of bentonite clay (BT) and organically modified bentonite (OBT) on aging characteristics using Bending beam rheometer (BBR) test through short term aging rolling thin film oven (RTFO) and long-term aging (pressure aging vessel (PAV) process. The tests result showed that the modified asphalts have higher rutting resistance.

There are a variety of methods and devices that commonly used to determine the permanent deformation resistance in bituminous mixtures. The conventional method to determine the HMA performance is categorized inconsistent in developing some good indicator findings on permanent deformation of HMA [20]. In this study, dynamic shear rheometer and SPT test methods were used for assessing the resistance to permanent deformation. Dynamic shear rheometer is recognized as a powerful mix design tool to study the rheological characteristics. While, the Simple performance dynamic modulus test (SPT) is a test method(s) that accurately measures a parameter that is highly correlated to the occurrence of pavement distress over a diverse range of traffic and climatic conditions. The major SPT output is the dynamic modulus, also known as the E*, that identify the stiffness value for the asphalt pavement mixture. The dynamic modulus is defined as the material property that relates stress to strain for a linear viscoelastic material. The dynamic modulus SPT test has the potential to predict permanent deformation such as rutting, fatigue cracking, and thermal cracking in asphalt concrete pavements [20]. Ahmad et al. performed SPT dynamic modulus and Wessex wheel tracking tests and an analysis to assess the rut resistance of commonly used HMA dense grading mixture. The outcomes disclose that SPT dynamic modulus test was useful to recognize possible rutting of the HMA mix when tried at various extent of temperatures and loading frequencies. As such, the SPT dynamic modulus test is practical and dependable for rutting assessment [20]. Chen & Zhang investigated the physical and mechanical properties of CaCo3 composites, nano powdered rubber VP401 and VP501 and sepiolite. Test results show that 1% nano powdered rubber VP401 has better performance resistance to low temperature crack and rutting, compared to other nanomaterial modified asphalt bitumen [21].

Therefore, it will be required to investigate what nanomaterial gives in enhancing bitumen performance. Nonetheless, there are only a small number of published literatures and studies performed on asphalt mixtures modified with nano-materials. As such, an investigation on the performance characteristics and also the influence of polymer-modified bitumen mixture (PMB) combined with nanopolyacrylate (NP) is required. The rheological properties and performance asphalt mixture of PMB were characterize using dynamic shear Rheometer (DSR) and SPT dynamic modulus. It is envisaged that the employment of a nanopolymer modifier will further augment the performance properties of PMB. The specifics of the tests, results and discussion are presented in the subsequent sections.

II. MATERIALS AND METHODS

A. Materials

A Granite aggregates from Blacktop quarry in Selangor were used in this study. These aggregates properties were evaluated according to the Public Work Department of Malaysia's specification for Road Works (JKR/SPJ/2008) (Table I). Based on the result obtained, the aggregate properties are satisfactory the mix design criteria. The AC14 aggregate gradation was designed based on the mean of the gradation limit according to the JKR specification as presented in Table II and Fig. 1. Bitumen Performance Grade PG64-22 was selected and used as the bitumen for the asphalt mixture.

Table- I: Aggregate Tests Results

Test method	Flakiness	Elongation	LA Abrasion	Aggregate Impact Value
Result (%)	3.1	16.6	23.5	21.8
Criteria (%)	<25	<35	<25	<25

Table- II: Aggregate Tests Results

Sieve Size (mm)	% Passing	% Retained	JKR/SPJ/2008
20.00	100.0	0.0	100 – 100
14.00	95.0	5.0	90 – 100
10.00	81.0	14.0	76 – 86
5.00	56.0	25.0	50 – 62
3.35	47.0	9.0	40 – 54
1.18	26.0	21.0	18 – 34
0.425	18.0	8.0	12 – 24
0.15	10.0	8.0	6 – 14
0.075	6.0	4.0	4 – 8
Pan/Filler		6.0	
Total		100	

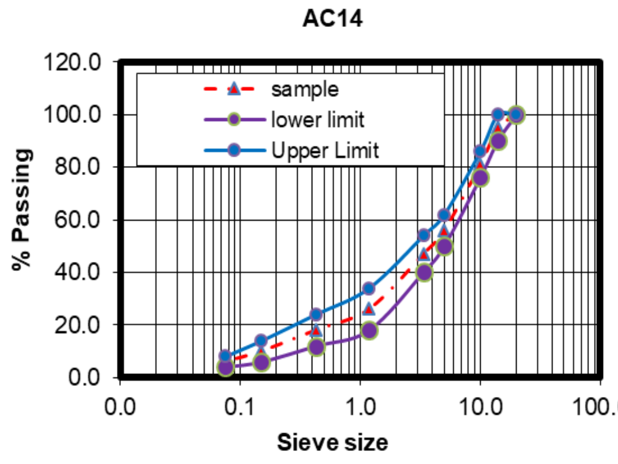

Fig. 1. AC14 Aggregate Gradation

B. Volumetric Properties of Marshall Mix

Specimens were formulated centered on the Marshall mix design method in accordance to ASTM D1559 for optimum asphalt bitumen content.

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Public Works Department of Malaysia's (PWD Malaysia) Specification for Road Works was used to evaluate the volumetric properties of mix design. A total of 15 specimens were compacted with the range of bitumen content from 4.0 percent to 6.0 percent. 3 replicate specimens for each percent were formulated for the control mix (0% NP) and the modified mixes with NP contents of 2% (NP2), 4% (NP4) and 6% (NP6) by weight of bitumen. Bulk specific gravity, air voids, voids filled with bitumen (VFB), stability and flow were evaluated through analyses and plotting graph the volumetric properties with bitumen content. Specimens for performance were prepared based on optimum bitumen content value obtained. The volumetric properties results are shown in Table III. Results showed that the Marshall stability and stiffness increased as the NP content increased. An improved adhesion between the materials in the mix can be attributed by the increase in stability [22]-[23]. However, Marshall flow and VFB showed a decreasing trend with increasing NP content. This result can be attributed to the existing NPs in the bitumen that affect its properties. As a conclusion, all the volumetric properties met the Public Works Department of Malaysia's (PWD Malaysia) Specification for Road Works.

Table- III. Volumetric Asphalt Mixtures of Marshall Mix

Mixture type	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	VTM (%)	VFB (%)
AC-Control	1120	3.56	314	3.6	77
AC-NP2	1170	3.46	341	3.8	74.5
AC-NP4	1270	3.35	382	4.2	74
AC-NP6	1298	3.28	392	4.4	73.5
(JKR/SPJ/ 2008)	>815	2.0-4.0	>203	3.0-5.0	70-80

The OBC as in Fig. 2 for these mixes were obtained from the individual plots of volumetric properties versus percent bitumen content. The OBC ranged from 5.2% to 5.6% which is show significant increase in the OBC of nanopolymer mixes compared to control mix. The absorption of asphalt bitumen by nanopolyacrylate polymer which increases the asphalt bitumen content can be attributes by the higher OBC value for AC-NP6 mix.

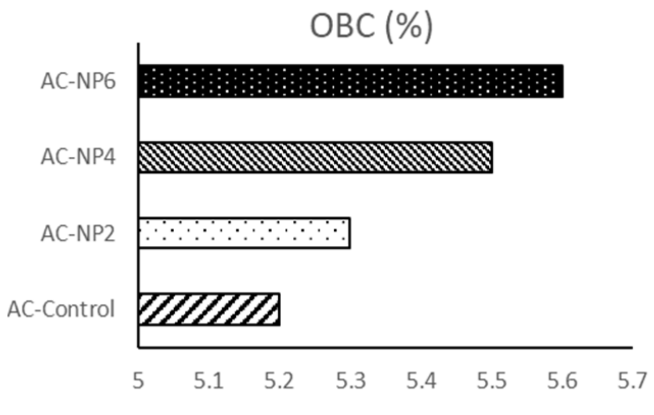

Fig. 2. The percentage of Optimum Bitumen Content (OBC)

C. Bitumen Characterization

The Conventional Performance Grade (PG 64-22) was used as a conventional bitumen. Nanopolyacrylate (NP) modifier was used as a modifier in this study. Nanopolyacrylate was obtained from the Nan Pao Resins Chemical CO., Taiwan. Polyacrylate is a type of thermoplastic polymer which is universally acknowledged as acrylics belongs to a group of polymers. The nanopolyacrylate contain of 39-40% polyacrylate resin with the average diameter of 50nm. Percentages of 2, 4, and 6 (by total weight) of NP, respectively were mixed with conventional Performance Grade (PG 64-22) to produce modified NP bitumen. The conventional Performance Grade (PG 64-22) and modified NP bitumen were tested using dynamic shear rheometer (DSR) for unaged and aging condition. These DSR tests were used to characterize the rheological properties of used bitumen at high, intermediate, and low temperatures. The DSR testing (AASHTO T-315) was done on unaged bitumen, as well as the Rolling Thin Film Oven (RTFO), AASHTO T-240, and the Pressure Aging vessel (PAV), AASHTO R-28, conditioned bitumen. The RTFO test simulates the asphalt bitumen aging (short-term) during the manufacture and construction of HMA pavements. While the PAV test simulates aging of an asphalt bitumen during the first 5-10 years of pavement service life. Fig. 3 shows the DSR testing setups.

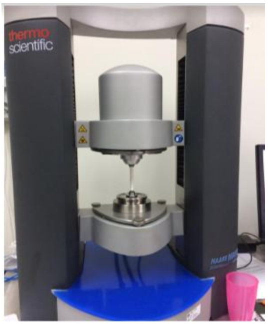

Fig. 3. Bitumen DSR Testing

D. SPT Specimens Preparation

Rutting potential of HMA mix was evaluated through Simple Performance Test (SPT) dynamic modulus. Approximately 6500 g of batch weight were required in order to prepare 150 mm diameter and 165 mm height of the dynamic SPT modulus specimens. 20 Superpave HMA specimens were prepared using the Superpave Gyratory Compactor (SGC). A diameter (101.6 mm) specimen was cored from the center of the gyratory specimens. The two ends of specimen were shaped and trimmed by approximately 5 mm to get a specimen with 150-mm in height. The bulk specific gravity and air voids of all the specimens were conducted through density test before further testing. The air voids for the test specimens were prepared at 7 ± 1.0%. The axial deformations were determined with displacement transducers referenced to gauge points connected to the specimens as shown in Fig. 4. The SPT tests were evaluated at several temperatures and frequencies according to dynamic modulus parameter as shown in Table IV.

The measurement of the dynamic modulus (|E*|) and phase angle (δ) of asphalt mixtures are the parameter included in the SPT dynamic modulus testing program. The dynamic modulus value of HMA mixture can be calculated as Equation as in (1).

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \quad (1)$$

Where

σ_o = dynamic stress

ε_o = peak recoverable axial strain

The phase angle value of HMA mixture can be calculated as Equation as in (2).

$$\phi = \left(\frac{t_i}{t_p}\right) 360 \quad (2)$$

Where

φ=dynamic stress

ti = time lag between a cycle of stress and strain

tp = time for a stress cycle

Fig. 4. Dynamic testing

Table IV. SPT Dynamic Modulus Parameter

Parameters	**Values**
Temperature (°C)	25, 30, 35,40, 45 and 50
Frequency (Hz)	25, 20, 10, 5, 1, 0.5
Contact Load (kPa)	15
Axial Strains	Between 75-150 microstrains
Dynamic Stress (kPa)	100

III. RESULT AND DISCUSSION

A. Bitumen Results and Analysis

The minimum limit for rutting parameter as specifies by the Superpave method is 1000 Pa for unaged asphalt bitumen condition and 2200 Pa for RTFO aged asphalt bitumen through the dynamic shear rheometer test. A lower limit rutting parameter is stated in order to warrant the asphalt bitumen has adequate stiffness to prevent rutting occur at high temperatures. It is desired to generate high rutting resistance asphalt bitumen that are recognized by an increase in the G* value and or the decrease in the phase angle (δ) [24]. The DSR test was carried out at five different temperatures, 46°C to 76°C, with increment of 6°C this study. However, in order to reflect the rutting temperature, a reference high test temperature of 64°C was selected. It is expected that rutting will occur when the temperature is near the maximum bituminous pavement temperature on a hot summer day which is around 60°C. Fig. 5 to Fig. 7 show the relationships between temperature and each of G*/sinδ (for unaged and RTFO specimens) and G*sinδ (for PAV specimens). It could be viewed that all asphalt bitumen has G*/ sinδ values higher than 1000 Pa (unaged condition) and 2200 Pa (RTFO aging condition) at 64°C testing condition. Furthermore, it also could be viewed that all asphalt bitumen has G*sinδ values lower than 5,000 Pa at 25°C testing condition. The Superpave requires a maximum limit for the fatigue parameter, G*sin δ of 5,000 Pa for asphalt bitumen aged using the Pressure Aging Vessel (PAV). This presents that all modified asphalt bitumen fulfills the Superpave specification at the selected testing temperature. Therefore, in conclusion, the NP modified bitumen demonstrates more rutting and fatigue resistance. This shows that the modified mixture is significant in reducing rutting and fatigue failure in asphalt pavement compared to control asphalt bitumen.

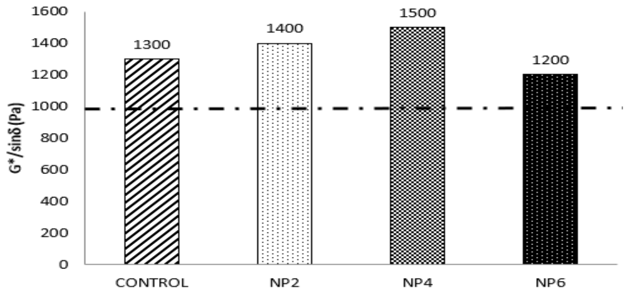

Fig. 5. Rutting Resistance of Unaged NP Bitumen

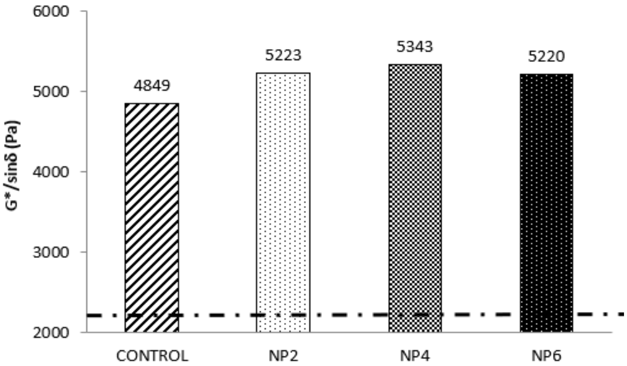

Fig. 6. Rutting Resistance of RTFO aged NP Bitumen

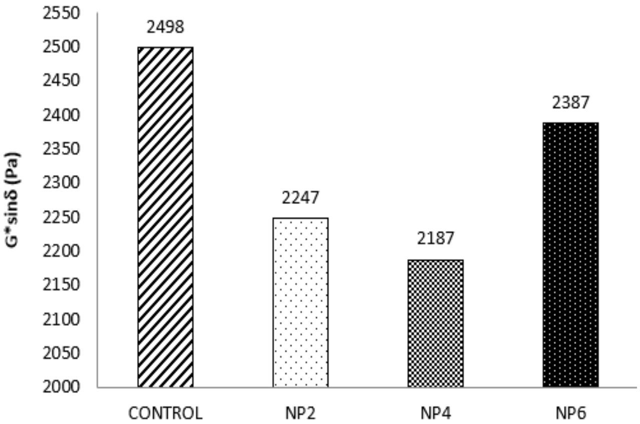

Fig. 7. Fatigue Resistance of PAV aged NP Bitumen

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B. Dynamic Modulus Results Analysis

Fig. 8 to 10 show the dynamic modulus values for AC14 mixtures for each bitumen type under the specified frequency domain. The dynamic modulus is a function of frequency at all temperatures. Based on the dynamic modulus results of SPT test for AC14 mix at 25°C as presented in Fig. 8 presents that the dynamic modulus value for AC-NP4 is the highest compared to other AC14 mixtures. The similar trend could be seen for the AC14 mixture at 40°C and 50°C as shown in Fig. 9 and Fig. 10, which indicate that AC-NP4 has the highest and AC-NP6 has the lowest dynamic modulus values under all frequencies compared to the other mixtures. AC-NP4 mixture is resistance to permanent deformation compared to the other mixtures due to the fact that it has a high viscosity, in which it will to provide a high holding ability to maintain the aggregate structure [25]. In conclusion, it was observed that the dynamic modulus of mix decreases as frequency decreases at increasing test temperature. This finding was perceived for all the mixtures regardless of the asphalt bitumen type. The variations in the HMA mixture behaviour at different traffic speeds is present by the difference in dynamic modulus at low and high frequencies. The dynamic modulus values are higher for asphalt mixtures compacted at higher temperatures compared to mixtures compacted at lower temperatures. With that, NP4 mixtures are higher dynamic modulus values compared to other AC14 mixtures.

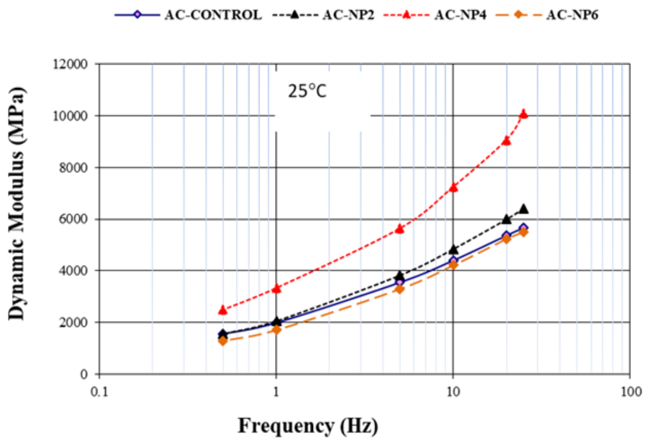

Fig. 8. Dynamic Modulus at 25°C of AC14 Mixes

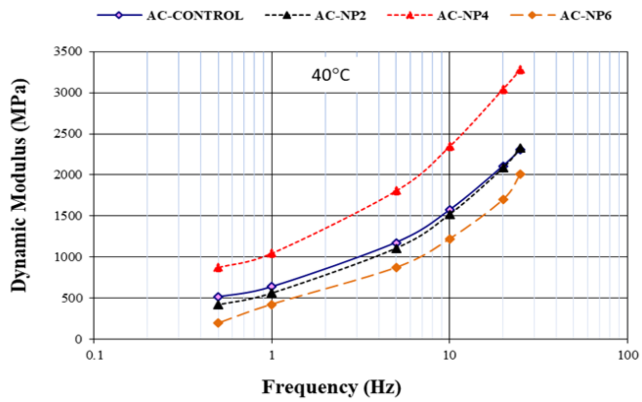

Fig. 9. Dynamic Modulus at 40°C of AC14 Mixes

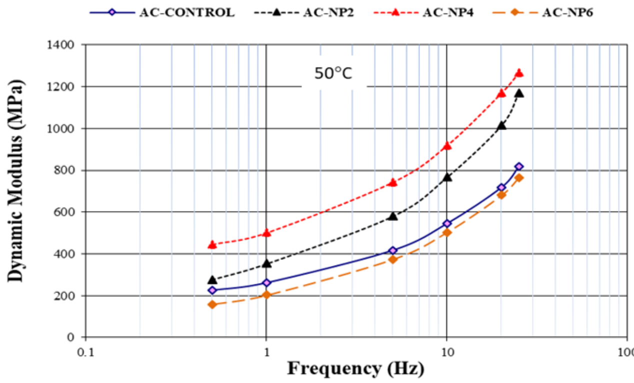

Fig. 10. Dynamic Modulus at 50°C of AC14 Mixes

The effect of test temperatures on dynamic modulus are shown in Fig. 11. The stiffness of asphaltic mixtures responds to variations in temperature could be observed from the dynamic modulus. The results present that the dynamic modulus of mix decreases as test temperature increases. The similar trend could be seen for all mixtures tested. The dynamic modulus values are higher at a lower test temperature and start to decrease as test temperature increases where at constant frequency. These finding also stated that increases the dynamic modulus increases by increasing of test frequency. The dynamic modulus results are also viewed to be less at higher temperature compared to lower temperature.

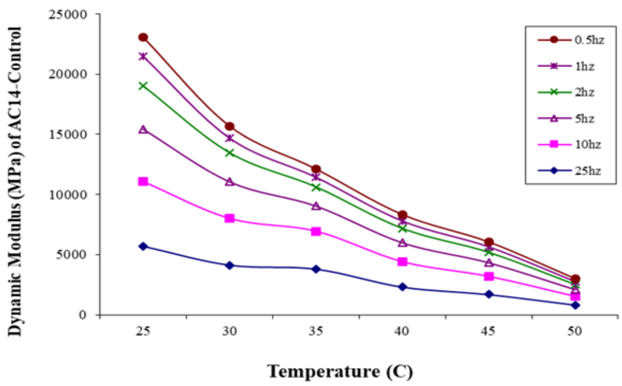

Fig. 11. Dynamic Modulus at different Test Temperature

IV. CONCLUSION

Based on the findings, it can be concluded that the nanopolyacrylate significantly enhances the rheological properties of asphalt bitumen and highly increase rutting resistance compared to the conventional bitumen. Nanopolyacrylate polymer increases the stiffness of bitumen, improves the strength, and decreases the temperature sensitivity in bitumen. In addition, considering results obtained from the SPT dynamic modulus test, nanopolyacrylate have positive effect on rutting resistance and elastic deformations. It improved the dynamic characteristics of HMA at elevated temperatures which presented that nanopolyacrylate modified bitumen has significant impact on measured dynamic modulus at high level of reduced times.

In conclusion, with appropriate content of nanopolyacrylate,4%NP has high potential to improve rutting and fatigue resistance. These findings ultimately increase the duration life span of the pavement and reduce premature pavement failure.

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REFERENCES

1. C. Gorkem and B. Sengoz, "Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime," Constr. Build. Mater., vol. 23, no. 6, pp. 2227–2236, Jun. 2009.
2. C. E. Sengul, S. Oruc, E. Iskender, and A. Aksoy, "Evaluation of SBS modified stone mastic asphalt pavement performance," Constr. Build. Mater., vol. 41, no. April, pp. 777–783, 2013.
3. S. I. B. Djaffar, B. P. El Alia, and B. Ezzouar, "Rheological Properties and Storage Stability of SEBS Polymer Modified Bitumen," Int. J. Eng. Technol., vol. 5, no. 05, pp. 1031–1038, 2013.
4. N. S. Mashaan, A. H. Ali, S. Koting, and M. R. Karim, "Performance evaluation of crumb rubber modified stone mastic asphalt pavement in Malaysia," Adv. Mater. Sci. Eng., vol. 2013, pp. 1–8, 2013.
5. D. Casey, C. McNally, A. Gibney, and M. D. Gilchrist, "Development of a recycled polymer modified binder for use in stone mastic asphalt," Resour. Conserv. Recycl., vol. 52, no. 10, pp. 1167–1174, Aug. 2008.
6. J. Zhu, B. Birgisson, and N. Kringos, "Polymer modification of bitumen: Advances and challenges," Eur. Polym. J., vol. 54, pp. 18–38, May. 2014.
7. P. Li, L. Liu, and Z. Sun, "Research on the Storage Stability Test Method of SBS Modified Asphalt," 2010 Int. Conf. Intell. Comput. Technol. Autom., pp. 178–181, May. 2010.
8. H. Liu, Z. Chen, W. Wang, H. Wang, and P. Hao, "Investigation of the rheological modification mechanism of crumb rubber modified asphalt (CRMA) containing TOR additive," Constr. Build. Mater., vol. 67, pp. 225–233, Sep. 2014.
9. S. S. Galooyak, B. Dabir, A. E. Nazarbeygi, and A. Moeini, "Rheological properties and storage stability of bitumen/SBS/montmorillonite composites," Constr. Build. Mater., vol. 24, no. 3, pp. 300–307, Mar. 2010.
10. X. Lu, H. Soenen, and P. Redelius, "SBS Modified Bitumens: Does Their Morphology and Storage Stability Influence Asphalt Mix Performance," in Proceedings of the 11th International Conference on Asphalt Pavements. Nagoya, Japan, pp. 1604–1613, 2010.
11. E. Shaffie, A. K. Arshad, J. Ahmad, and W. Hashim, "Evaluation of moisture-induced damage of dense graded and gap graded asphalt mixture with nanopolymer modified binder," IOP Conf. Ser. Earth Environ. Sci., vol. 140, no. 1, 2018.
12. E. Shaffie, W. M. M. Wan Hanif, A. K. Arshad, and W. Hashim, "Rutting resistance of asphalt mixture with cup lumps modified binder," IOP Conf. Ser. Mater. Sci. Eng., vol. 271, no. 1, 2017.
13. Shaffie, E., Ahmad, J., Arshad, A. K., Kamarun, D., & Kamaruddin, F "Stripping Performance and Volumetric Properties Evaluation of Hot Mix Asphalt (HMA) Mix Design Using Natural Rubber Latex Polymer Modified Binder (NRMB)," InCIEC 2014: Proceedings of the International Civil and Infrastructure Conference, pp. 873-884.
14. H. Taherkhani and R. Bayat, "Applied Nanomaterials in Enhancing the Properties of Asphalt Mixtures," Casp. J. Appl. Sci. Res., vol. 4, no. 3, pp. 36–40, 2015.
15. E. Iskender, "Evaluation of mechanical properties of nano-clay modified asphalt mixtures," Measurement: Journal of the International Measurement Confederation, vol. 93. pp. 359–371, 2016.
16. A. Zare-Shahabadi, A. Shokuhfar, and S. Ebrahimi-Nejad, "Preparation and rheological characterization of asphalt binders reinforced with layered silicate nanoparticles," Constr. Build. Mater., vol. 24, no. 7, pp. 1239–1244, Jul. 2010.
17. M. Abdelrahman, D. R. Katti, A. Ghavibazoo, H. B. Upadhyay, and K. S. Katti, "Engineering Physical Properties of Asphalt Binders through Nanoclay–Asphalt Interactions," J. Mater. Civ. Eng., vol. 26, no. 12, p. Art. no. 04014099, 2014.
18. H. Yao et al., "Rheological properties and chemical analysis of nanoclay and carbon microfiber modified asphalt with Fourier transform infrared spectroscopy," Constr. Build. Mater., vol. 38, pp. 327–337, Jan. 2013.S.
19. G. Jahromi and A. Khodaii, "Effects of nanoclay on rheological roperties of bitumen binder," Constr. Build. Mater., vol. 23, no. 8, pp. 2894–2904, 2009.
20. J. Ahmad, M. Y. A. Rahman, and M. R. Hainin, "RuttingEvaluation of Dense Graded Hot Mix Asphalt Mixture," Int. J. Eng. Technol., vol. 11, no. October, pp. 56–60, 2011.
21. S. J. Chen and X. N. Zhang, "Mechanics and Pavement Properties Research of Nanomaterial Modified Asphalt," Adv. Eng. Forum, vol. 5, pp. 259–264, 2012.
22. E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and P. Shafigh, "Using waste plastic bottles as additive for stone mastic asphalt," J. Mater. Des., vol. 32, no. 10, pp. 4844–4849, Dec. 2011.
23. O. M. Ogundipe, "Marshall Stability and Flow of Lime-modified Asphalt Concrete," Transp. Res. Procedia, vol. 14, pp. 685–693, 2016.
24. G. G. Al-Khateeb and K. Z. Ramadan, "Investigation of the effect of rubber on rheological properties of asphalt binders using superpave DSR," KSCE J. Civ. Eng., vol. 19, pp. 127–135, 2014.
25. I. Hafeez, M. Ahmad, M. Reza, and M. J. N. Msawil, "Effects of Hydrated Lime on Fatigue and Rutting Behavior of HMA Mixtures in Dynamic Modulus Testing," Transp. Res. J., vol. 1, no. 1, pp. 23–34, 2011.

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