Jurnal
Teknologi

Full Paper

EMPIRICAL AND RHEOLOGICAL PROPERTIES EVALUATION OF MODIFIED ASPHALT BINDER CONTAINING NANOPOLYACRYLATE POLYMER MODIFIER

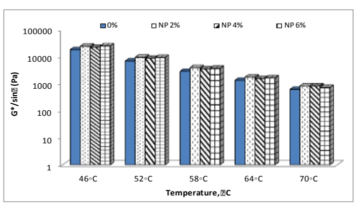
E. Shaffie[a]*, J. Ahmad[a], A. K. Arshad[a], D. Kamarun[b]

[a]Institute of Infrastructure Engineering and Sustainable Management (IIESM), Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia
[b]Faculty of Applied Science, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

Article history
Received
14 February 2015
Received in revised form
30 April 2015
Accepted
31 May 2015

*Corresponding author
eka@salam.uitm.edu.my

Graphical abstract



Abstract

In this paper, the effects of nanopolyacrylate (NP) in binder modification on the empirical and rheological characteristics of the conventional binder were explored. The empirical and rheological binder properties were characterized using penetration, softening point, viscosity and dynamic shear rheometer (DSR) respectively. These testings have become useful methods in characterizing of the binder performance on the pavement. The results indicated that NP polymer modification improved the physical properties of the conventional binder such as; penetration, softening point and temperature susceptibility. The results of viscosity test show that the NP polymer modified binder is more viscous than unmodified binder where viscosity increases with the increment of polymer content. The DSR results indicate that the NP polymer improves rheological properties of conventional binder, i.e. increasing the complex shear modulus (G∗) values and rutting parameters (G∗/sin δ), as well as decreasing the phase angle (δ) values. Therefore, it can be concluded that NP polymers considerably improves elastic properties and rutting resistance of binder and thus could be used for enhancing the asphalt pavement performance.

Keywords: Empirical, rheological, modified binder, nanopolyacrylate, rutting

1.0 INTRODUCTION

Increment in traffic density, tyre pressures, heavier trucks loading, construction and design errors and also environmental conditions have a significant effect on pavement performance. As a consequence, premature failures of asphalt pavement increased. This has resulted in the need to enhance the properties of asphalt material in order to create high performance of asphalt pavements. Asphalt binder is one of the important materials in asphalt pavement. However, in recent years the conventional asphalt binder has not performed well in most highway pavements as it no longer able to cater the existing problems that contributed to pavement failures. Therefore, polymer modified binder is one of the alternative approaches to improve the pavement performance[1].

Polymer modified binder (PMB) has been observed for a long time in improving asphalt pavement performance[2]. The application of polymers into binder has been proved to improve pavement performance such as stripping, rutting deformation, fatigue and low temperature cracking, wear resistance and ageing [3,4,5,6]. Some of the significant advantages of utilization of PMBs are higher elastic recovery, a higher softening point, greater viscosity, greater cohesive strength and greater ductility [1]. To date, researchers are interested in using the material at nano scale as one of asphalt modifier. Nanotechnology is a promising and creative technique in the material industry and nanomaterials have been widely applied to various fields world-wide [7]. The addition of nanomaterials in asphalt pavement mixtures has the potential to enhance further the mechanical properties of asphalt mixtures and overcome the shortcomings of using polymer in asphalt pavement mixes. Literature review shows that a few studies have been conducted using polymer nano composites consist of a blend of one (or more) polymer (s) with various nanomaterials such as nanoclays, carbon nanotubes, etc[8,9]. Most studies highlighted that the most commonly used nano materials is nano clay [10, 11,12]. The addition of nanoclay in asphalt mixture has been observed to increase the viscosity, thus has the potential to reduce rutting and fatigue problems in asphalt pavement[13]. The influence of modified binder using NanoPolyacrylate (NP) with virgin mixtures has not yet been identified clearly and the use of NP has not been explored in improving the properties of asphalt binder. In this research the use of nanopolyacrylate (NP) polymer as a modifier was investigated.

2.0 MATERIAL AND METHODS

2.1 Material

In this study, asphalt binder 80/100 penetration grade was selected and used as a conventional binder. The nanopolyacrylate (NP) with three different contents from 0%, 2%, 4% and 6% (by weight of asphalt binder) were used as the modifier in this study. The NP was obtained from Nan Pao Resin Chemical CO., Taiwan. Polyacrylate, also commonly known as acrylics belongs to a group of polymer which could be referred as plastic. This polymer is commonly used for their transparency and its ability to resist breakage and elasticity. The nanopolyacrylate consist of 39-40% polyacrylate resin with the average diameter of 50nm.

2.2 Preparation of Nanopolyacrylate (NP) Modified Binder

The samples prepared were unmodified binder sample and modified binder samples. For modified binder sample, nanopolyacrylate (NP) was added according to the weight percentage of the binder. The percentage used for NP content was selected at various range from 0% to 6% by weight of binder. For the preparation of a sample, 500g of base binder was melted at 110˚C and poured into a 500 ml container. Then, the binder was heated in the oven at 160˚C until it liquefies. The polymer was then added slowly into the liquid binder and sheared using a propeller mixer with mechanical stirrer. The polymer modified binder was then evaluated for further physical properties test.

2.3 Emprical Binder Test

The unmodified binder and modified binder samples were subjected to the following empirical binder tests: penetration, softening point and viscosity test. Penetration test was used to measure the consistency of the binder after heating. The penetration of binder can be defined as the distance to which a standard needle is able to penetrate under known condition of time, loading, and temperature. Penetration test was conducted accordance to ASTM D5. The softening point test was used to determine the softening point of a bitumen mixture which is used as indicator to characterize the rutting resistance. Softening point test is conducted accordance to ASTM D36. In addition, the temperature susceptibility of the modified bitumen samples was calculated in terms of penetration index (PI) using the results obtained from both penetration and softening point temperature tests. Temperature Susceptibility is defined as changes in the consistency parameter as a temperature function[14]. The viscosity test was evaluated to describe the resistance of flow fluids. This test was conducted using a Brookfield rotational viscometer and tested according to ASTM D4402 procedures.

2.4 Dynamic Shear Rheometer Test

Dynamic Shear Rheometer (DSR) testing was conducted according to AASHTO TP5. The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ) over a temperature range from 46°C to 70°C. The complex modulus (G*) and the degree of phase angle (δ) are used to determine the relationship between asphalt stiffness and the type of deformation: recoverable and non-recoverable. In Superpave requirements, the relationship G*/sinδ has been used as the indicator to determine the rutting of an asphalt binder at a high-performance temperature. The critical G*/sinδ values are 1000 for unaged conditioned at a reference temperature [7,15].

3.0 RESULTS AND DISCUSSION

3.1 Empirical Binder Properties

The empirical binder properties test (penetration, softening point and penetration index) were investigated for unmodified and modified polymer binder of NP. Table 1 below shows the summary of empirical binder properties results. The penetration value was decreased for all type of modified binder compared to unmodified binder. The maximum decrease in the penetration value was observed at 6% NP content. However, from the practical cost of view, the most suitable ratio for NP is 4% since there is no significant difference in penetration value between addition of 4% and 6% NP. In terms of softening point, the asphalt modified binders with NP demonstrate higher softening point compared to unmodified binder. It also presented that the softening point temperature increases with increasing in NP content. The maximum softening point temperature was achieved at 6 percent NP content. The increase of softening point temperature is used as an indicator of the stiffening effect of polymer modification which is stated that bitumen with higher softening point is less sensitive to permanent deformation (rutting) and also showed that the strength and compatibility of the modified asphalt binders were increased[16]. The temperature susceptibility of binder is determined by the Penetration index (PI) that was evaluated from the penetration and softening point test results. From the table, it is clearly stated that addition of NP polymer into asphalt binder has increased the PI value with increased NP polymer content. Increased values of PI indicate a significant reduction in temperature susceptibility of PMBs samples. This clearly shows that polymer modified binder induces less temperature susceptibility thus better resistance to low temperature cracking and permanent deformation[14]. In general, as shown in Table 1, the penetration decreased and the softening point increased with increasing of NP polymer content. The decrease in penetration and the increase in softening point indicate an increased hardness or stiffness of the modified binders. This table also shows that the viscosity at both temperature (135°C and 165°C) increased when the NP content increased. This results indicate that the modified binder more viscous than unmodified binder[17].

Table 1 Physical properties results

Binder Type	Penetration (dmm)	Softening point (°C)	Penetration index	Viscosity at 135°C	Viscosity at 165°C
0%	88	44	-1.4	0.5	0.1
NP 2%	70	47	-1.2	0.6	0.2
NP 4%	64	48	-1.1	0.7	0.3
NP 6%	63	49	-1.0	0.9	0.4

3.2 Rheological Binder Properties

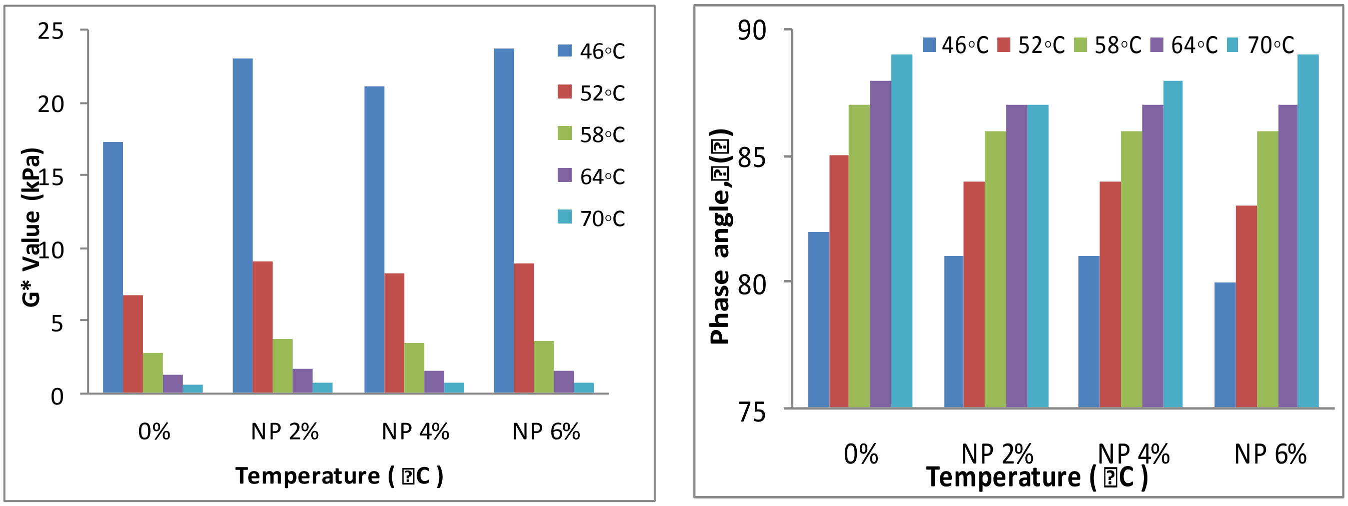
The DSR test data obtained for the unmodified and NP modified binder were analysed. The complex modulus (G*), phase angle (δ) and rutting characteristic (G*/sinδ) of binders were presented as below.

3.2.1 Complex Modulus and Phase Angle of Unaged Binder

Figures 1(a) and (b) illustrate the complex modulus (G*) and phase angle (δ), respectively, versus different NP polymer contents in the binder. In this figure, the G* value decreases and the phase angle (δ) increases when the temperature increases. The similar trend could be seen in all modified binder types. In general, the NP modified binder shows slightly higher complex modulus throughout the temperature range compared to unmodified binder. The higher complex modulus indicated that binder strength has increased which can be correlated to higher rutting resistance. From these results, it shows that the NP polymer modified binder may have the potential to reduce rutting failure in aspahlt pavement. Figure 1 also shows that the phase angle for modified binder is lower compared to conventional binder, As temperature increases, conventional binder totally loses it elasticity (phase angle to 90°C). However, modified binder for NP polymer is improved where the binder can retain its elastic respond or delay lost of its elasticity response at high temperature. This relationship follows the rationale that a binder with a high G* value is stiffer, which increases its resistance to deformation, and a binder with a low sinδ value is more elastic, whereby its ability to recover part of the deformation is increased [18].

3.2.2 Rutting Characteristic G/sinδ of Unaged Binder*

According to Strategic Highway Research Program (SHRP) specifications, the rutting factor G*/sinδ has been used in evaluation of the rutting resistance of asphalt binder under repeated load. In this study, rutting test was conducted at five different temperatures, 46°C, 52°C, 58°C, 64°C, and 70°C. The results of rutting characteristic G*/sinδ for unaged binder are illustrated in Figure 2. It could be observed that all binders have G*/sin δ values higher than 1.0 kPa (unaged condition) at 64°C testing condition. This shows that all modified asphalt binders meet the Superpave specification requirement at selected testing temperature. It could also be observed that G*/sin δ value for unaged increases for asphalt binders modified with NP polymer. Higher G*/sinδ indicates high rutting resistance for asphalt binders. NP 6% shows the highest G*/sinδ values compared to others. The minimum G*/sinδ is found for conventional binder. Therefore, it shows that the binder with NP reveals rutting resistance and significant to reduce rutting failure in asphalt pavement.



(a) (b)

Figure 1 (a) Complex Modulus (G*), (b) Phase angle (δ) versus different NP binder content

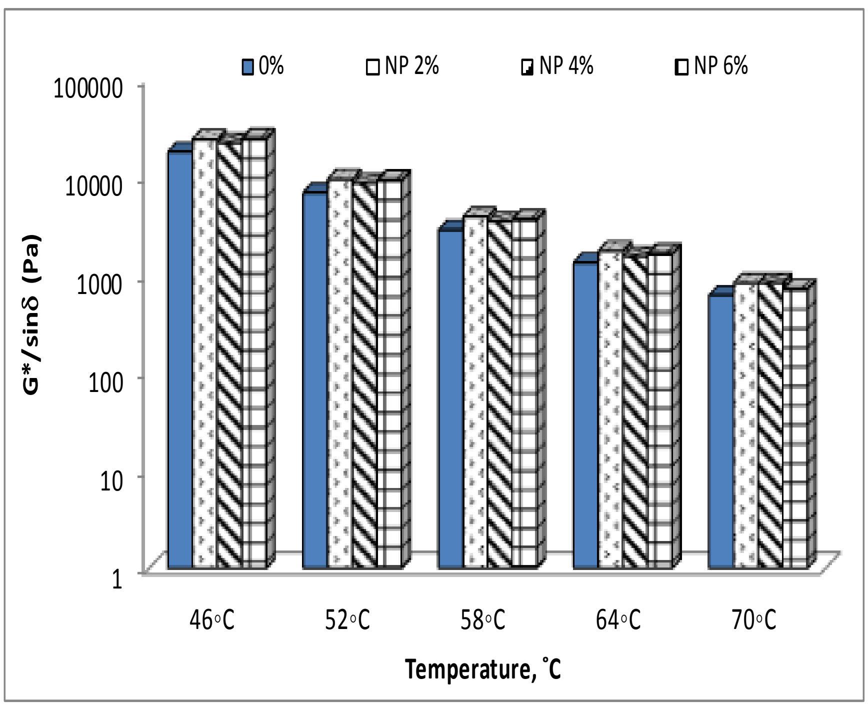


Figure 2 G*/sinδ of conventional and modified binders containing various NP content

4.0 CONCLUSION

Based on the results obtained from this study, the following conclusions could be deduced:

- The physical properties of NP modified binder shows significant improvement as compared to unmodified binder where the penetration decreases and the softening point, penetration index and viscosity increases with increasing of NP polymer content.
- The DSR test results indicate that the addition of NP polymer increases complex shear modulus (G∗) values and rutting parameters (G∗/sin δ), and decreases phase angle (δ) values. Therefore, it can be concluded that NP polymers considerably improves elastic properties and rutting resistance of binder.

- The use of NP polymer as modifier seems to have positive effects on empirical and rheological properties of the binders. Therefore, there is a potential to use the NP polymer for enhancing the performance of asphalt pavement.
- Further study on performance of hot mix asphalt mixture is needed in order to verify and generalize these findings.

References

[1] Yildirim, Y. 2007. Polymer Modified Asphalt Binders. *Constr. Build. Mater.* 21: 66-72.

[2] Awwad, M.T. and Shbeeb, L. 2007. The Use of Polyethylene in Hot Asphalt Mixtures. *Am. J. Appl. Sci.* 4: 390-396.

[3] Airey, G. 2003. Rheological Properties of Styrene Butadiene Styrene Polymer Modified Road Bitumens. *Fuel*. 82(14): 1709-1719.

[4] Isacsson, U. and Xiaohu, L. 2000. Rheological Characterization of Styrene-buta- diene-styrene Copolymer Modified Bitumens. *Constr. Build. Mater.* 11(1): 23-32.

[5] Stuart, K. and Yehia, A. 2002. Fracture Resistance Characterization of Chemically. 7: 557-566.

[6] Oncrete, A. S. U. C. 1999. F t c a -r c. 1: 287-294.

[7] Yao, H., You, Z., Li, L., Shi, X., Goh, S. W., Mills-Beale, J. and Wingard, D. 2012. Performance of Asphalt Binder Blended with Non-modified and Polymer-modified Nanoclay. *Constr. Build. Mater.* 35: 159-170.

[8] Gupta, R. K., Pasanovic-Zujo, V. and Bhattacharya, S. N. 2005. Shear and Extensional Rheology of EVA/layered Silicate-nanocomposites. *J. Nonnewton. Fluid Mech.* 128: 116-125.

[9] Alexandre, M. and Dubois, P. 2000. Polymer-layered Silicate Nanocomposites: Preparation, Properties and Uses of a New Class of Materials. *Mater. Sci. Eng. R Reports*. 28: 1-63.

[10] You, Z., Mills-Beale, J., Foley, J. M., Roy, S., Odegard, G. M., Dai, Q. and Goh, S. W. 2011. Nanoclay-modified Asphalt Materials: Preparation and Characterization. *Constr. Build. Mater.* 25(2): 1072-1078.

[11] Galooyak, S. S, Dabir, B., Nazarbeygi, A. E. and Moeini, A. 2010. Rheological Properties and Storage Stability of Bitumen/SBS/Montmorillonite Composites. *Constr. Build. Mater.* 24(3): 300-307.

[12] Jasso, M., Bakos, D., Stastna, J. and Zanzotto, L. 2012. Conventional Asphalt Modified by Physical Mixtures of Linear SBS and Montmorillonite. *Appl. Clay Sci.* 70: 37-44.

[13] Abdullah, M. E., Zamhari, K. A., Buhari, R., Nayan, M. N. and Hainin, M. R. 2013. Short Term and Long Term Aging Effects of Asphalt Binder Modified with Montmorillonite. *Key Eng. Mater.* 594-595: 996-1002.

[14] Djaffar, S. I. B., El Alia, B. P. and Ezzouar, B. 2013. Rheological Properties and Storage Stability of SEBS Polymer Modified Bitumen. *Int. J. Eng. Technol.* 5(5): 1031-1038.

[15] Polacco, G., Kříž, P., Filippi, S., Stastna, J., Biondi, D. and Zanzotto, L. 2008. Rheological Properties of Asphalt/SBS/Clay Blends. *Eur. Polym. J.* 44: 3512-3521.

[16] Trakarnpruk, W. and Chanathup, R. 2005. Physical and Rheological Properties of Asphalts Modified with Polyethylene-co-methylacrylate and Acids. *Met. Mater. Miner.* 15(2): 79-87.

[17] Aflaki, S and Tabatabaee, N. 2009. Proposals for Modification of Iranian Bitumen to Meet the Climatic Requirements of Iran. *Constr. Build. Mater.* 23: 2141-2150.

[18] Bahia, H. U. and Anderson, D. A. 1995. Strategic Highway Research Program Binder Rheological Parameters .