

Evaluation Of Volumetric Properties And Resilient Modulus Performance Of Nanopolyacrylate Polymer Modified Binder (NPMB) Asphalt Mixes

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Graphical abstract



Abstract

This paper presents the potential benefits of nanopolyacrylate (NPA) for the asphalt mixtures used on pavement. This research evaluates the resilient modulus performance of dense graded Superpave-designed HMA mix. Two different types of dense graded Superpave HMA mix were developed consists of unmodified bitumen mix (UMB) and nanopolyacrylate modified bitumen mix (NPMB). Nanopolyacrylate polymer modified bitumen was prepared from addition of 6 percent of NPA polymer into asphalt bitumen. Resilient modulus results from Resilient Modulus test were determined to evaluate the performance of these mixtures. Results showed that all the mixes passed the Superpave volumetric properties criteria which indicated that these mixtures were good with respect to durability and flexibility. The Resilient modulus result of NPMB demonstrates better resistance to rutting than those prepared using UMB mix. It was estimated that the average resilient modulus values for both UMB and NPMB mixtures are decreased by 80 percent when the test temperature increased from 25°C to 40°C. In conclusion, the addition of NPA to the binder has certainly improved the bitumen properties significantly and hence increase the resistant to rutting of the asphalt mixture.

Keywords: Nanopolymer, polymer modified bitumen, resilient modulus, Superpave mix design

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1.0 INTRODUCTION

Malaysia spends a substantial amount of money on road maintenance due to the premature and rapid deterioration of asphalt pavements. One of the principle factors for the rapid deterioration is due to the low durability of the asphalt pavement mix used. Furthermore, the increment of the heavy load traffic nowadays may greatly give an impact that will accelerated deterioration of the transportation infrastructure. Due to the increases in speed of passenger cars and tire pressure for heavy vehicles, the conventional bitumen is not be able to resist against the dynamic mechanical loads of the past traffic [1]. Polymers have traditionally been used to a certain extent to improve the durability of the asphalt pavement bitumen and mix properties. However, there are shortcomings in using polymers such as requirements of high mixing temperature, long digestion times and problems of compatibility with the bitumen. A lot of studies have been conducted by researchers to modify asphalt bitumen to prepare hot mix asphalt (HMA) in order to prolong the service life of the road system. From the study, they have proven that polymer modified asphalt can improve asphalt bitumen performance [2]. Study conducted by yildirim (2005) found that the polymer modified bitumen have been found to improve several properties of asphalt

mixtures such as fatigue life, temperature susceptibility, and resistance to permanent deformation. They also prevent raveling and stripping [3].

Nowadays, researchers are interested in using the material at nano scales as one of asphalt modifier. The addition of nanomaterials in asphalt pavement mixes has the potential to enhance further the mechanical properties of asphalt mixes and overcome the shortcomings of using polymer in asphalt pavement mixes. Literature review has shown 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. [4,5]. Other study by Mojtaba on the potential benefits of nano-SiO₂ powder and SBS in asphalt mixtures concluded that the asphalt mixture modified by 5% SBS plus 2% nano-SiO₂ powder could be the optimum proportion which increases physical and mechanical properties of asphalt bitumen and mixtures [6]. Much of the work to date in pavement engineering has dealt with nanoclay and nano-titanium oxide. These studies were found that the nanoclay may enhance the mechanical properties of the asphalt bitumen. Study by Abdullah (2012) found that the addition of nanoclay and warm asphalt additives (WAA) in asphalt bitumen can improve the physical properties of asphalt [7]. Study by Goh reported that

addition of nanoclay and carbon microfiber improves the stripping performance mixtures or decreases the potential of moisture damage [8].

The influence of modified bitumen using nanopolyacrylate with virgin mixtures has not yet been identified clearly and the use of nanopolyacrylate has not been explored in improving the properties of asphalt bitumen. In this research, nanopolyacrylate was used as a polymer modifier to determine the physical properties of bituminous modified asphalt bitumen and also to evaluate resilient modulus performance of HMA modified mix compared to unmodified bitumen (UMB) mix.

The resilient modulus is defined as the ratio of the applied stress to the recoverable strain when a dynamic load is applied. The indirect tensile resilient modulus test is used to determine the elastic modulus of the bituminous mixture in order to establish the structural response of the pavement to wheel loads. The resilient modulus is determined from a repeated load test. Peak values of stress and recoverable (resilient) deformation occurring in the test are used to calculate the resilient elastic constants even though peak stress and recoverable deformation do not occur at the same time in a dynamic testing. Resilient modulus is the most important variables that is used in the mechanistic design of pavement structures.

Besides, the effects of this polymer modified mixtures on resilient modulus performance needs to be investigated in detail. The importance of resilient modulus test in this study is to assure that the pavement achieved adequate stiffness. The increase in resilient modulus is related to the reduction of asphalt film thickness. Therefore, in this research, a new asphalt bitumen based on nanosized polyacrylates (NPA) will be evaluated in terms of their physical properties, mixture properties and also resilient performance of polymer modified bitumen HMA mix. The application of NPA in modified asphalt bitumen is expected to improve engineering properties and performance of asphalt bitumen.

2.0 EXPERIMENTAL

The experimental design of this research is presented in Figure 1. In this research, Superpave mix design procedure was used to design HMA mix. The procedure to develop Superpave specimens follows the AASHTO T312 procedure published by Asphalt Institute's Superpave Mix Design, SP-2, third edition, 2000 "Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by means of the Superpave Gyrotory Compactor" and AASHTO practice, PP-28-2000, Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt. The scope of the study consisted of designing and evaluating dense graded Superpave HMA mixes with unmodified bitumen (UMB) and nanopolyacrylate modified bitumen (NPMB).

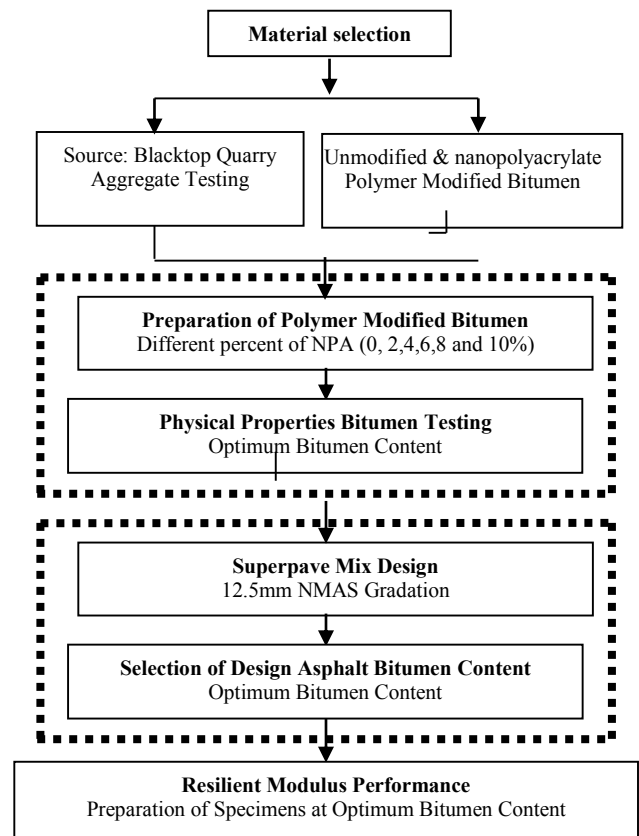


Figure 1 Flowchart of experimental design

2.1 Material Selection

Granite aggregates used in this study were obtained from Blacktop Quarry, Rawang located in Klang Valley. The aggregates were processed by washing, oven drying and sieving. All the aggregates were sieved to the appropriate size using sieving machine and then stored in individual bins according to the size of aggregates. The specific gravity of the coarse and fine aggregate was determined according to ASTM standard procedures. The asphalt bitumen used in this study was 80/100 penetration grade from SHELL company. Nanopolyacrylate (NPA) was used in this study, which was provided by the Nan Pao Resins 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 Polymer Modified Bitumen Preparation

The bitumen used to prepare HMA mix consisted of unmodified bitumen (UMB) and nanopolyacrylate polymer modified bitumen (NPMB). In this study, the base bitumen of 80/100 penetration grade asphalt bitumen was modified with NPA polymer. For the preparation of a sample, 500 g of base asphalt bitumen was melted at 110 °C and poured into a 500 ml container. Then, the asphalt bitumen was heated in the oven at 150 °C until it became liquid. The NPA was added slowly into the liquid asphalt bitumen and was sheared with a high shear mixer with mechanical stirrer at selected blending velocity and time. Bitumen modification was conducted by adding several different percentages ranges (0, 2, 4, 6, 8, and 10% by weight of bitumen). Polymer modified Asphalt bitumen

was then used for further physical properties testing in order to determine the optimum bitumen content.

2.3 Mix Design

Superpave mix design procedure was used to design asphaltic mixtures. The major steps involved in volumetric testing and analysis process are selection of materials, selection of design asphalt content and evaluation of performance of the design mixture [9]. The design traffic level selected for this study was medium to high traffic of 3 to ≤ 30 million equivalent single axle loads (ESALs). For Superpave-designed mix, the acceptable volumetric properties at 4% air void are based on the established Superpave criteria at design number of gyrations. The traffic load for medium to high roadway application in this study requires compaction parameters at initial compaction ($N_{\text{initial}} = 8$ gyrations), design compaction ($N_{\text{design}} = 100$ gyrations) and maximum compaction ($N_{\text{maximum}} = 160$ gyrations). The purpose of Superpave mix design is to determine the estimated asphalt content, $P_{b,\text{est}}$ to achieve 4% air voids (96% G_{mm}) at N_{design} . Selection of the design optimum bitumen content consists of varying the amount of asphalt binder in the design aggregate structure to obtain acceptable volumetric properties when compared to the established mixture criteria based on the SGC specimens with 4% air voids. Each specimens was compacted to N_{design} gyrations and the volumetric properties, optimum binder content (OBC), voids in mineral aggregate (VMA), voids filled with aggregate (VFA), air voids (AV) and dust proportion (DP) of the mixtures were determined. Two different mixes were developed in this study; unmodified binder (UMB) mix and nanopolyacrylate polymer modified binder (NPMB) mix. Table 1 shows the Superpave aggregate gradation of the mix.

Table 1 Superpave mix design aggregate gradation

Sieve size (mm)	% Passing
19.0	100
12.5	93.0
9.5	81.0
4.75	58.0
2.36	46.0
1.18	24.0
0.6	17.0
0.3	11.0
0.15	6.5
0.0075	4.0

2.4 Resilient Modulus Test

The resilient modulus procedure (ASTM D4123) is used to measure the stiffness modulus of the design asphalt mixtures. Resilient Modulus is an important parameter that is used in the mechanistic pavement design as it is being used as an input to the multilayer layer elastic theories or finite element models to compute pavement response under traffic loading [10]. Resilient modulus of asphalt mixtures, measured in the indirect tensile mode (ASTM D 4123), is the most popular form of stress-strain measurement used to evaluate elastic properties. In this study, the test was carried out at two different temperatures, 25°C and 40°C. The samples were conditioned for two hours prior to testing until the test temperature was achieved. The test was conducted based on the indirect tensile resilient modulus test standard parameter as shown in Table 2. Figure 2 shows the IPC UTM-5P Universal Testing Machine which is used in conducting resilient modulus test.

Table 2 Indirect tensile resilient modulus test parameters

Test Condition	
Temperature (°C)	25 and 40
Load pulse width (ms)	100
Pulse Repetition Period (ms)	1000, 2000, 3000
Peak loading force (N)	900
Conditioning pulse count	5



Figure 2 IPC UTM-5P testing machine

3.0 RESULTS AND DISCUSSION

3.1 Bitumen Results

In this study, the penetration grade 80/100 bitumen was used. The bitumen was further modified using NPA polymer to enhance the performance of the bitumen and then used for further physical properties testing in order to determine the optimum bitumen content. The blending time of 1650 rpm at blending temperature of 140°C with blending time of 60 minutes were used as mixing variables in this stage. Figure 3 and 4 shows the results of all two bitumen tests including penetration test and softening point test. According to Figure 3, the results showed that when percentage of NPA polymer is increased, the penetration value will decreased. The result shows that, the penetration value decreased from 92 to 69.67 and 63.73 respectively with the addition of 2 and 4 percent NPA, which shows the tendency of strength and finally reached a minimum value at 6% of NPA. After that, the addition of more NPA content (8 and 10 percent) increased the penetration value from 64.5 and 65.5 respectively. Again, these penetration results have shown that, excess NPA content will affect the dispersion of NPA in asphalt and will cause the mixture to become softer which is indicated by the higher penetration value [11]. From the softening point result as shown in Figure 4, it can be seen that the softening point temperature increases with the increase in NPA content at the beginning point. After that, it was gradually decreased when adding more NPA content. The lowering of the softening point temperature may be due to the excess NPA content which is affect the dispersion of polyacrylate in the asphalt and cause the mixture to become softer. This means that percentage of modifier has exceeded the limit and causes the modified bitumen become softer. The suitable reason is that as polyacrylate reffered as plastic which has ability to resist breakage and elasticity will cause difficulty to soften the mixture [11-13]. The optimum content of NPA that should be added as modifier is 6% by the weight of bitumen because at 6% the penetration and softening

point value shows a return point. At that particular point the percentage for optimum content of polyacrylate was selected.

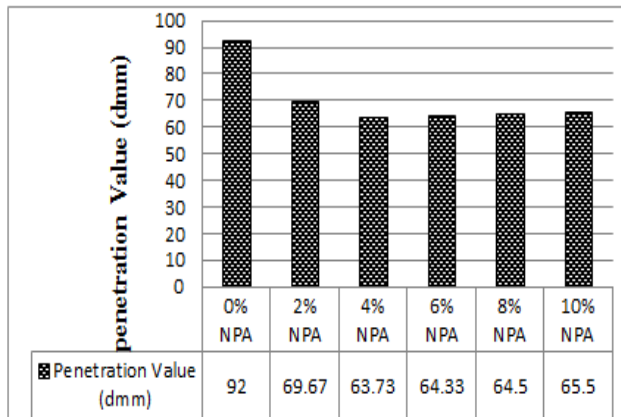


Figure 3 Penetration value versus NPA content (%)

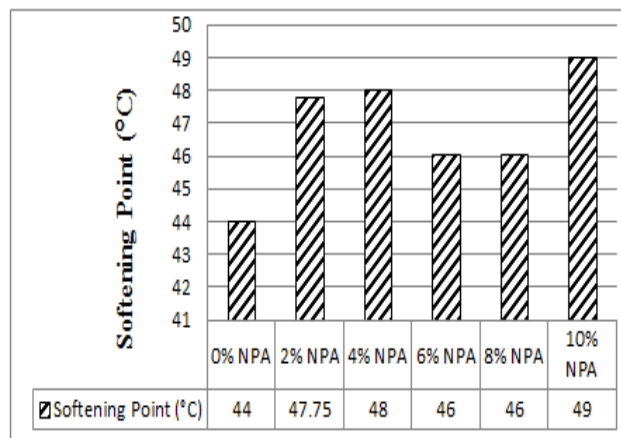


Figure 4 Softening point versus polyacrylate content

3.2 Superpave Mix Design of HMA

In Superpave mix design, selection of design asphalt bitumen content was obtained based on 4% air voids specimens. All other mixture properties were checked at the design binder content to verify that they meet the criteria. Volumetric properties of hot mix asphalt (HMA) consist of voids in mineral aggregate (VMA), voids in total mix (VTM) and voids filled with bitumen (VFB). Based on the result obtained, relationship between volumetric properties and Bitumen Content were evaluated. The initial trial asphalt binder content for the blends was estimated based on the specific gravity obtained from the aggregate testing results. The volumetric properties of design mixtures corresponding to optimum bitumen content of the mixture along with mix design criteria is as shown in Table 3. The design bitumen content of 5.7 percent and 5.5 percent were the values that corresponds to 4.0% air voids at $N_{des}=100$ gyrations for unmodified (UMB) mix and nanopolyacrylate polymer modified bitumen (NPMB) mixes. For both mixtures type, the OBC showed a significant difference between the UMB mix and NPMB mix which is 5.7 percent for UMB and 5.5 percent for NPMB mix respectively and thus resulted 0.2 percent less than the UMB mix. As expected, all the Superpave volumetric mix design properties for each mixture were found very close to the target value, which implied that the design mixture was good with respect to durability and flexibility.

Table 3 Design mixture properties

Superpave mix design properties	UMB	NPMB	Criterion
Asphalt content (%)	5.7	5.5	
% Air Voids	4.0	4.0	4.0%
%VMA	15.8	15.9	min 13
%VFA	74.5	74.9	65-76
Dust Proportion	0.7	0.8	0.6-1.2
%Gmm@Nini	85.5	86.0	≤89

3.3 Resilient Modulus

The final part of this research is to focus on the performance evaluation through resilient modulus test. The performance test was carried out to assure that the pavement achieved adequate stiffness. The increase in resilient modulus is related to the reduction of asphalt film thickness. The resilient modulus is determined from a repeated load test. Evaluation and analysis of those test results will lead to the understanding of the effect of nanopolyacrylate (NPA) polymer in hot mix asphalt mix compared to unmodified bitumen (UMB). The behavior of HMA mix can predicted as corresponding to the test temperature. At 25°C, the resilient modulus is an indication of mixture resistance to fatigue whereas resilient modulus at 40°C indicates mixture resistance to rutting. The resilient modulus results for both UMB and NPMB mixtures are presented in Figure 5.

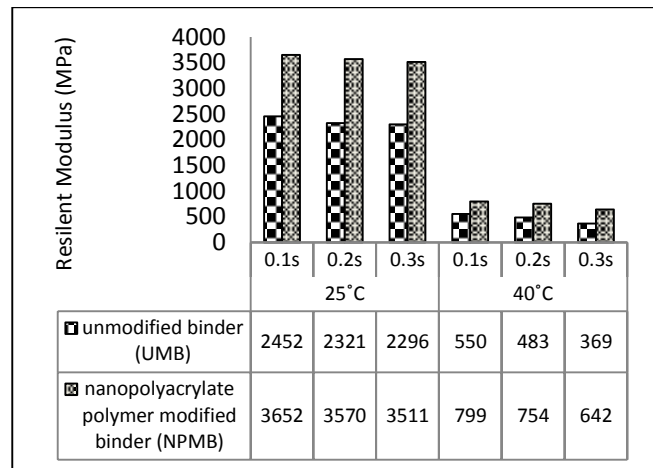


Figure 5 Resilient modulus result of UMB and NPMB mixes

The resilient modulus values are higher for NPMB mixtures compared to UMB mixtures when tested at 25°C. Based on these figure, the result shows that as the pulse repetition period during loading time increase from 0.1s to 0.3s, the resilient modulus values also decreases. At a pulse repetition period of 0.1s of the resilient modulus test, the results showed that the most resistant to rutting is NPMB at 25°C with the highest resilient modulus values of 3652 MPa, followed by UMB at 25°C (2452 MPa), NPMB at 40°C (799 MPa) and UMB at 40 °C (550 MPa).With regards to temperature used, It was estimated that the average resilient modulus values for both UMB and NPMB mixtures are decreased by 80 percent when the test temperature increased from 25°C to 40°C. This result shows that the temperature was found to significantly influence the resilient modulus of asphalt mixes. Study was shown that the resilient modulus of the asphalt

specimens tested decreased by more 80% when the test temperature increased from 25°C to 40°C. It was stated that bitumen becomes brittle at low temperature and the bituminous mix tended to crack at lower temperature [14-18]. Study conducted by Ahmad (2014) it is estimated that the average resilient modulus values of Superpave mixtures are 30% higher when tested at 25°C, and approximately 32% higher at 40°C compared to Marshall mixtures [19].

As temperature increase from 25°C to 40°C, the resilient modulus value dropped for every pulse repetition period. From the observation, UMB specimens of resilient modulus show lower values than NPMB specimens. From these results, it can be shown that NPMB mixes were higher stiffer compared to the control specimens mixes. As mentioned earlier, pavement distress associated with low to intermediate temperatures is fatigue and at high temperature, rutting is prone to occur. At low to intermediate temperatures, the maximum resilient modulus values of 3652 MPa for NPMB mix and the minimum resilient modulus values of 2296 MPa for UMB mix. As temperature increases which is at high temperature all NPMB mix showed a higher resilient modulus value compared to the UMB mix. This indicated that NPMB mixes are resistance to rutting than UMB mixes. In conclusion, the addition of NPA to the binder has certainly improved the bitumen properties significantly and hence increase the resistant to rutting of the asphalt mixture.

4.0 CONCLUSION

From this study, the nanopolyacrylate (NPA) polymer can be utilized to modify asphalt bitumen and the physical properties of asphalt bitumens are improved by means of nanopolyacrylate polymer modifications. This is evident when 6 percent of NPA polymer was the optimum content that could be added to the asphalt bitumen which is increase in softening point and decrease in penetration value whereby indicate that NPMB mix have more strength and durability than using UMB mix. Results have provided significant findings on the resilient modulus result performance of NPMB mix which somehow indicates that NPMB demonstrates better resistance to rutting than those prepared using UMB mix due to nanopolymer that were added to the binder coat the aggregate thus improving the rutting resistance. Both unmodified (UMB) mix and nanopolyacrylate polymer modified bitumen (NPMB) mix also satisfies the Superpave volumetric mix design criteria which were found very close to the target value, which implied that the design mixture was good with respect to durability and flexibility. Thus, with addition nanopolymer to the binder has significantly improved the properties of the binder, and hence the performance of the mixtures.

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