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INVESTIGATION ON RUTTING PERFORMANCE OF NANOPOLYACRYLATE AND NATURAL RUBBER LATEX POLYMER MODIFIED ASPHALT BINDER MIXES

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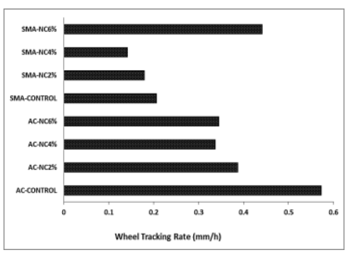
Graphical abstract



Abstract

This paper discussed a research carried out to study the rutting performance of dense graded (AC) and Stone Mastic Asphalt (SMA) pavement using nanocomposite polymer modified binder. The study also focused on the determination of optimum proportion of additive to be used in the mixing process. Two types of asphalt binder with penetration grade, PEN 80/100 and performance grade PG 76 were added with nanopolyacrylate and natural rubber latex as asphalt modifier. The nanocomposite polymer modified binder was prepared by adding 6 percent of Nanopolyacrylate (NC) to the asphalt binder. Both SMA and AC asphaltic mixtures conformed to the Marshall volumetric properties criteria which indicate that these mixtures are durable. The Asphalt Pavement Analyzer (APA) rutting test was performed to determine the rutting performance of AC and SMA asphaltic mixtures showed that the rut values for SMA14 mix varies from 0.8 mm to 1.9 mm and AC14 mix varies from 1.7 mm to 2.3 mm respectively. This indicates the beneficial use of Nanocomposite polymer as modifier especially on SMA14 mix.

Keywords: Rutting;nanocomposite;polymer; modified binder;stone mastic asphalt

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1.0 INTRODUCTION

The increasing traffic volumes, truck loadings and higher tire pressures are the major factors that contribute to premature pavement failures. One of the most common forms of distress of asphalt concrete pavements is rutting (permanent deformation). Rutting is defined as the progressive accumulation of permanent deformation of each layer of the pavement structure under repetitive loading [1]. Rutting can result in hydroplaning which can endanger the driver's life. Rutting can also significantly increase the cost of maintenance of roads, increase fuel consumption as well as reduce the service life of the pavement. These conditions will cause the road structures to deteriorate more rapidly than the designed life, increase the expenses to repair and maintain the roads. Therefore, there is the need to enhance the properties of existing asphalt material [2].The crucial demand for superior performance of bituminous mixture has led to researchers to use new methods anddesign in order to improve the existing asphalt material related to its performance and effective service life of bituminous mixtures [3-4].

Stone Mastic Asphalt (SMA) is an approach to the improvement of asphalt pavement performance. Previously, studies have shown that the use of

SMAmiximproves resistance to rutting and also increasespavement durability compared to other types of asphalt mixture [5].SMA for road pavement surfacing has been reported to increase the durability of the mixes and providing high resistance to rutting distresses. Previous study on SMA found that the SMA mixture is more resistance to rutting compared to dense graded asphalt mixtures. This result attributeddue to coarse aggregate skeleton as well as higher asphalt content while providing stone-on stone contact among the coarse aggregate.

Polymer Modified Binder (PMB) has been observed for a long time in improving asphalt pavement performance [6].The application of polymers to binder has been proved to improve pavement performance such as stripping, rutting deformation, fatigue and low temperature cracking, wear resistance and ageing [7-8].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 [9].Although many research had been conducted on PMB which used several types of additives and modifiers such as natural rubber latex (NR), Styrene Butadiene Styrene Block Copolymer (SBS), Styrene Butadiene Rubber Latex(SBR) and Ethyl Vinyl Acetate (EVA),but only few are satisfactorily from both the performance and the cost points of view [10].

Nowadays, researchers are interested in using materials at nano scales as asphalt modifier [11]. The addition of nanomaterial in asphalt pavement mixes has the potential to enhance further the mechanical properties of asphalt mixes and to overcome the shortcomings of using polymer inasphalt pavement mixes. Literature review has shown few studies have been conducted using polymer nano composites consists of a blend of one (or more) polymer (s) with various nanomaterials such as nanoclays, carbon nanotubes,nanosilica and etc[11-14]. Another study by Morteza et al. [15] 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 mixture[15].A Study by Goh et al. [16]reported that addition of nanoclay and carbon microfiber improves the stripping performance mixtures or decreases the potential of moisture damage [16]. Yoa et al. [14] conducted a study on nanosilica in asphalt pavement. The findings from this study show that the the addition of nanosilica in the control asphalt mixture significantly improves the dynamic modulus, flow number, and rutting resistance of asphalt mixtures[14].

The influence of modified binder using nanocomposite (NC) polymer with virgin mixtureshave not yet been identified clearly and the use of NC has not been explored in improving the properties of asphalt binder.In this research, the use of NC polymer as a modifier was investigated. The main purpose of this research was to determine the effects of incorporating NC polymer on the engineering properties of SMA and Asphaltic Concrete (AC) mixturesand also to evaluate rutting performance of polymer modified mix compared to control mix for both gradation. It is thought that, if the enhanced characteristics of asphalt pavement using both NC polymer as modified asphalt binder are significant, the nanopolymer could potentially be used as a modifier in HMA mixes with superior environment and traffic loading resistance. Hence, nanotechnology technique can be applied to enhance pavement engineering materials.

2.0 EXPERIMENTAL

Investigation of this study began with the preparation of AC and SMA mixes using NC modified binder and rutting performance evaluation of the mix, in accordance to Malaysian Public Works Department (PWD), American Association of State Highway and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) specifications.

2.1 Material

Granite aggregates, nanopolyacrylate and natural rubber latex polymers, asphalt binder of PEN 80/100 and PG 76 asphalt binder are the main materials used in this research. Asphalt binder of PEN 80/100 was used for dense graded (AC) and PG76 binder was used for control SMA14. Granite aggregates were supplied by Blacktop Quarry, Rawang, SelangorDarulEhsan. The aggregates were processed by washing, oven drying and sieving. All the aggregates were sieved to the appropriate size and stored in individual bins according to the size and were tested according to physical testing aggregate standard requirement. Nanopolyacrylate and natural rubber latex was used in this study. Nanopolyacrylate was provided by the Nan Pao Resins Chemical CO., Taiwan and natural rubber latex was provided by MTD group, Klang. The matrix for the Marshall preparation and mix designation for conventional and polymer modified binder mixture samples are shown in Table1.

Table 1 Test Design matrix for Marshall HMA mix

Factor	Details
Mixture Grading	All gradation satisfies Marshall upper and lower limits AC14 & SMA14
Mix Design Method	Marshall mix design method
Aggregate Source	Granite aggregate source from BlackTopQuarry
Binder Type	Penetration Grade (PEN) 80/100 Performance Grade (PG) 76

2.2 Polymer modified binder preparation

The NC modified binder was produced by modifying the optimum proportion of 4% nanopolyacrylate with the addition of 2%, 4% and 6% of natural rubber latex polymer by weight of asphalt binder respectively. The optimum proportion of nanopolyarylate obtained from previous study conducted by Shaffie et al. [17]. For the preparation of a sample, 500 g of virgin asphalt binder was melted at 110 ^{0} C and poured into a 500 ml container. Then, the asphalt binder was heated in the oven at 150 ^{0} C until it became liquid. The 4% nanopolyacrylate followed by natural rubber latex was added slowly into the liquid asphalt binder and was sheared with a high shear mixer with mechanical stirrer at blending velocity of 1650 rpm, blending temperature of 140°C with blending time of 60 minutes. Binder modification was conducted by adding several different percentages ranges of natural rubber latex (2, 4 and 6% by weight of binder). PMB was then used for further physical properties testing in order to determine the optimum binder content (OBC).

2.3 Marshall Mix Design

The Marshall mix design method according to Malaysian PWD, JKR/SPJ/2008-S4[18] specifications was used to determine the OBC.Mix designation for conventional and PMB mixture samples are shownin Table 2.In this study, SMA 14 and AC 14 mixtures were used to evaluate the use of NC polymer as a modifier in the binder. Figure 1 shows the aggregate grading curves for both the mixtures used in this study.

Table 2 Mix designation for control and polymer modified binder mixture samples

Mixture Grading	Mixture Type	Polymer Content (%)	Binder Type	Marshall Compaction
AC-14 (Dense graded)	AC14-CONTROL	0	80/100 PEN	75 blows/side
	AC14-NC2	2		
	AC14-NC4	4		
	AC14-NC6	6		
SMA-14 (Gap graded)	SMA14-CONTROL	0	PG76	50 blows/side
	SMA14-NC2	2	80/100 PEN	
	SMA-NC4	4		
	SMA-NC6	6		

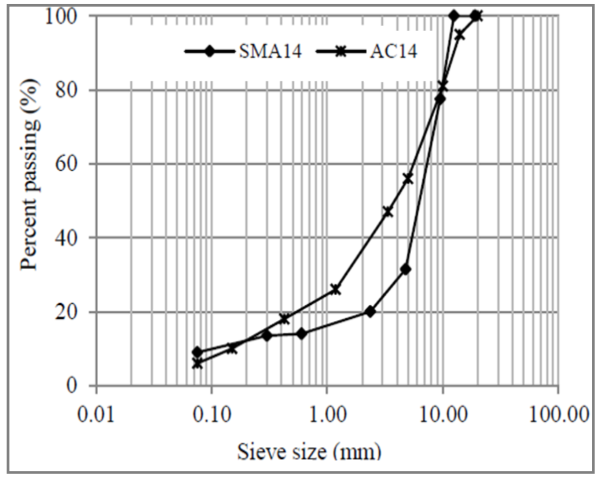

Figure 1 Aggregate Grading of AC14 and SMA14

Wet mix method was adopted in preparing the modified asphalt mixes. A total of fifth teen samples were prepared for each SMA 14 and AC 14 mixture in order to determine the OBC. The binder content ranged from 5 to 7% for SMA 14 and from 4.5 to 6.5% for AC 14.Marshall samples were weighed about 1200g and then were heated for mixing and compacting process.Two percent of hydrated lime was used as stabilizing agent and was incorporated as part of the total combined aggregate. The hydrated lime was treated as an anti-stripping agent to prevent moisture-induce damage.The samples were mixed and compacted.The samples were placed at room temperature for 24 hours before proceed with the Marshall testing. All SMA 14 Marshall samples were subjected to 50blows/face of compaction and all the AC14 Marshall samples were subjected to 75 blows/face compaction. SMA Samples only used 50blows/face compaction compared to 75 blows/face for HMA because they easily tend to break down the aggregate and would not cause in a significant increase in density over that provided by 50 blows.SMA mixtures have been more easily compacted on the roadway to the desired density than the effort required for conventional HMA mixtures[19]. After 24 hours of setting time, the bulk specific gravity [20] test of compacted sample was then conducted before stability and flowtest procedure. Stability and flow test are the measurements of the maximum magnitude of load sustained and resistance to plastic flow of cylindrical samples of bituminous on the lateral surface by means of the Marshall apparatus. An average value of Theoretical Maximum Density was obtained using a rice method for each different mixes in loose condition to determine the void in total mix for each sample. Results from the Marshall volumetric analysis were used to select the OBC in order to form strong and stable mix.All Marshall samples were analysed in order to determine the OBC which were refer to the result of volumetric properties.The mean OBC was determined by averaging four (4) OBC as specified in

JKR/SPJ/2008 [18]. The minimum SMA requirements as stipulated in Malaysian PWD specification are tabulated in Table 3.

Table 3 AC14 and SMA14 mix requirement

Parameter	AC14	SMA14
VTM	3-5 %	3 – 5 %
VMA	70 % - 80 %	Min 17%
Stability	>13000	Min 6200N
Flow	2-5 mm	2 – 4 mm

2.4 APA Rutting Test

Rutting or permanent deformation of the laboratory designed mixtures was evaluated using the Asphalt Pavement Analyzer (APA) in accordance to AASHTO TP 63-03 [21]. For the APA rutting testing, three cylindrical samples for each mix with different percentage of NC were compacted using the Superpave gyratory compactor. The desired of HMA mixture was obtained by adjusting the weight of the mixture. Prior to testing, the sample was first conditioned in the APA chamber machine for two hours. Testing on the APA machine was performed at 60°C with the sample sides in full confinement and the pressure of rubber hose and wheel load was respectively set up at 690 kPa (100psi). The analysis of rut depth was determined by measurements of rutting collected at 0, 25, 4000 and 8000 loading cycles.

3.0 RESULTS AND DISCUSSION

3.1 Volumetric mix design

Table 4 presented the OBC results and their volumetric properties for both AC14 and SMA14 mixes used in this study. It was found that both volumetric properties of AC14 and SMA14 mixes meet the Malaysian PWD specification requirement. OBC from Marshall mixturedesign method for dense graded-ACW14 mix was found to be 5.2% and OBC for gap graded-SMA14 mix was 5.9%. The result shows the OBC value of SMA14 mix was higher than ACW14 mix. This could be due to the absorption of asphalt with the higher filler material in SMA14 mix which increased the binder content needed.

3.2 APA Rutting Result

Figure 1 shows the result of rutting for both AC14 and SMA14 mixtures. From this result, SMA14 mixtures exhibited good rutting resistance compared to AC14 mixtures. SMA14 mixtures rutting values varies from 0.8 mm to 1.9 mm compared to AC14 mixtures with exhibit higher rutting values ranging from 1.7 mm to 2.3 mm. This indicates the higher resistance of SMA14 mixtures compared to AC14 mixtures. This can be attributed to the different aggregate interlocking characteristics between them. The addition of NC polymer in the mixture improves the rutting resistance. The same trend were found for polymer modified SMA14 and AC14 mixtures, where the mixtures exhibit higher rutting resistance with an increase in NC polymer content except for SMA14-NC6 which high rut value compared to SMA14-NC2 and SMA14-NC4. In this study, the effect of NC content on both mixture types was found significant, where an increase in the NC content has enhanced its rutting resistance due to greater elasticity offered by the nanopolyacrylate and natural rubber particles. When comparing rutting resistance for SMA14 mixtures, SMA14-NC4 shows a better performance compared to other mixtures with the rut depth of 0.8 mm, followed by SMA14-NC6 (1.3 mm), SMA14-NC2 (1.4 mm), and SMA14-Control PG76 (1.9 mm). Comparing rutting resistance for AC14 mixtures, the result shows that AC14-NC6 shows better performance compared to other mixtures with the rut depth 1.7 mm, followed by AC14-NC4 (1.8 mm), AC14-NC2 (2.1 mm) and AC14-Control (2.3 mm). In this study, SMA14-NC mixture exhibits a good rutting resistance compared to AC14-NC which showed an improvement in rut resistance by approximately 41% and 23% compared to Control AC14 and control-SMA14.

Table 4 Summary design mixture properties

Properties	AC14	SMA14
OBC(%)	5.20	5.90
Stability(Kg)	1453	1254
Flow (mm)	3.1	3.7
Stiffness(Kg/mm)	480	375
Air Voids (%)	4.0	4.0
VFA (%)	75	80
VMA(%)	15.6	20.0

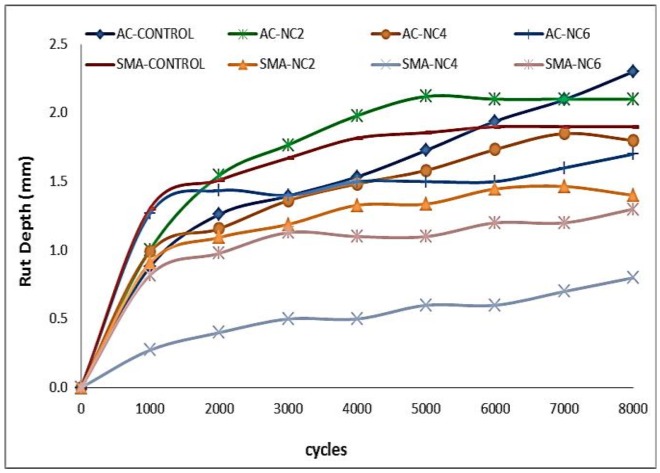

Figure 1 Wheel Tracking Rut Test Results

The wheel tracking rate is measured as the primary measure of the resistance to rutting. The wheel tracking rates for all mixture types were evaluated as shown in Figure 2. Based on the results, different types of gradation between AC14 and SMA14 have adverse effect on the wheel tracking rate. As can be seen from the table above, the SMA14 asphalt mixes have lower wheel tracking rate compared to dense graded AC14 asphalt mixes.

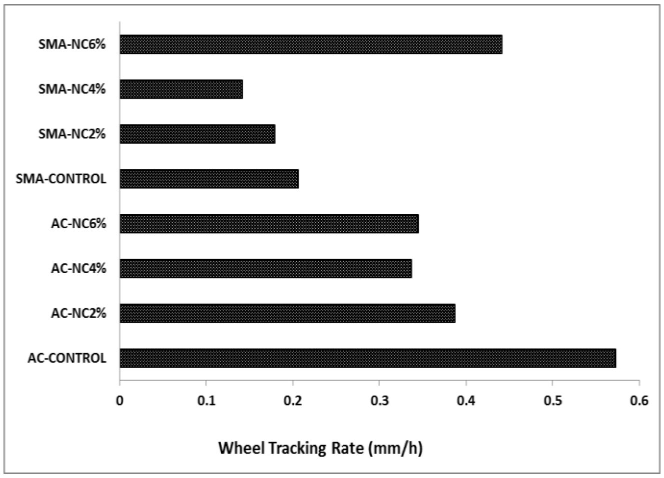

Figure 2 Wheel Tracking Rate of Mixes

4.0 CONCLUSION

From this study, the results of volumetric properties obtained by the AC14 and SMA14 mixes were compliedto all MalaysiaPWD specification requirements. In addition, the NC polymer can be utilized to modify asphalt binder. Also, the APA Rutting performance result with respect to rut depth and wheel tracking rate values are lower for NC mix compared to control mix. This indicates that NC demonstrates better resistance to rutting than those prepared using control mix due to theNC polymer that were added thus improving the rutting resistance. SMA14-NC mixture exhibits a good rutting resistance compared to AC14-NC which showed an improvement in rut resistance by approximately 41% and 23% compared to Control AC14 and control-SMA14. As a conclusion, the SMA-NC4% was selected as the best mix to overcome the rutting resistance.

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