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PERMANENT DEFORMATION INVESTIGATION OF RUBBER POLYMER MODIFIED BINDER IN SUPERPAVE HOT MIX ASPHALT MIXTURE

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Abstract

Moisture susceptibiltiy is one of the common types of pavement failure found in asphaltic pavements. Climatic factor such as temperature and moisture has a profound effect on the durability of hot mix asphalt pavements. Couple with high traffic loads/stresses made stripping of pavement materials inevitable. Thus, it has become necessary to improve the efficiency of the design of hot mix asphalt (HMA) for better performance and safe riding comfort. This study investigates and discusses the findings on the stripping performance of dense graded Superpave mixes using two type of binder; un-modified binder and rubber polymer modified binder (RPM) using Superpave mix design (AASHTO TP4) procedure. The RPM binder consists of 4% of both rubber crumb and EVA polymer. Modified Lottman and Resilient Modulus tests were used to evaluate the stripping performance in these mixtures and this study also documents the effect of different temperature on tensile strength ratio (TSR) and resilient modulus ratio (RMR) on the HMA mixtures. Experimental evidences show that the RPM binder mixes were found to have significantly improved the resistance to moisture damage compared to unmodified binder mixtures. The RPM binder application may able to alleviate problems related to aggregate stripping and potholes on our road. Statistical analysis showed good correlation between resilient modulus and tensile strength ratio.

Keywords: *Rubber Polymer, Resilient Modulus, stripping, Moisture Susceptibility, Tensile Strength*

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Introduction

Moisture susceptibility of Hot Mix Asphalt (HMA) mixtures, generally called stripping, is a major form of distress in asphalt concrete pavement. It is characterized by the loss of adhesive bond between the asphalt binder and the aggregate (a failure of the bonding of the binder to the aggregate) or by a softening of the cohesive bonds within the asphalt binder (a failure within the binder itself), both of which are due to the action of loading under traffic in the presence of moisture (Kakar et al., 2015). Aggregate stripping, potholes and delamination are some of the problems that require due attention from authorities and researchers. Thus, it is necessary to improve hot mix asphalt design for better performance and safe riding comfort thus minimizing these problems. Public agencies work hard to improve the road condition and willing to pay a higher initial cost for pavements with a longer service life which will reduce the risk of premature distress or failure and significantly reduce the cost of maintenance in long term use. Quality pavement production needs more attention to the selection of high quality materials, the design of asphalt mixtures, and quality control during construction.

Currently, many researchers have been conducted to modify binder with other additives such as rubber, polymer or mineral fibre. Studies have shown that polymer additives to asphalt materials improved several properties of asphalt mixes such as fatigue life, temperature susceptibility, and resistance to permanent deformation (Awad, 2019; Mohammad Amin Ganjei & Esmail Aflaki, 2019; Shaffie et al., 2018; Kamil Arshad et al., 2018; Shaffie et al., 2004). Polymer additives to asphalt materials are being advocated as having high potential for improving long-term pavement performance through their ability to improve the properties of the asphalt binder and the resulting asphalt concrete mix. Polymer additives to asphalt can also improve adhesion and cohesion and resistance to moisture-induced damage and age hardening (Abdul Hassan et al., 2019; Shaffie et al., 2018).

Two basic types of polymers commonly used for modification of the bituminous binder are elastomers and plastomers. Rubber crumb are classified as elastomers that resist deformation from applied stress by stretching and recovering their shape quickly when stress is removed. The use of crumb rubber is more suitable for road making in the scrap tire producing countries and to the fact that the utilized scrap tire as additives tend to improve viscosity and rheological and mechanical properties of asphalt cement and bringing greater service life expectancy (Al-maamori and Hussen, 2014). While Ethyl-vinyl-acetate (EVA) is classified as plastomer that modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation. The addition of EVA to binder resulted in an increase in the zero shear viscosity and in the relaxation time of the PMBs mixtures. The enhancement of the viscoelastic properties of the bitumen offers a better resistance to rutting, as demonstrated by the power law relationship between the rutting parameter obtained from Asphalt Pavement Analyzer (APA) rut depth (Brovelli et al., 2013). However, the influence of modified binder using two polymers; rubber crumb and EVA with virgin mixtures has not yet been identified clearly. Hence, this research was conducted to investigate how susceptible these rubber crumb and EVA polymer mixtures are to moisture induce damage. In this study, the Modified Lottman test (AASHTO T283) and Resilient Modulus test (ASTM D4123) is used to evaluate stripping potential. Emphasis of this study has been placed on analyzing the effects of rubber crumb and EVA with conventional binder on the moisture susceptibility. It is anticipated that the research results of this study will benefit the engineering practice of using these two polymers in hot mix asphalt and promotes its wider application.

Methods

Sampling

The study focused on the evaluation performance of Rubber Polymer modified Binder (RPM) of Hot Mix Asphalt (HMA) using Superpave design methods. The Superpave mix design procedure involves careful material selection and volumetric proportioning as a first approach in producing a mix that will perform successfully. The scope of the study consisted of designing and evaluating dense graded Superpave mixes. Granite aggregate with a 19 mm nominal maximum size and two types of asphalt binder: un-modified binder and RPM binder were used in the HMA mixtures. Granite aggregates used in this study were obtained from Hanson Quarry, Semenyih located in Klang Valley. Initially, the aggregates were processed by washing, oven drying and sieving. Aggregate testing properties were conducted in order to measure critical aggregate characteristics necessary to achieve good performance.

Results of the aggregate properties are tabulated in Table 1. Results showed that the aggregate properties are acceptable and fulfilled the Superpave mix design criteria.

Table 1 Aggregate properties test results

Test Method	Results (%)	Criteria (%)
Flakiness Index	7.71	< 20
Elongation Index	9.16	< 20
Fine Aggregate Angularity	49.18	45
Sand Equivalent Test	46.23	> 45
Toughness	23.30	< 45

Penetration binder 80-100 is used in this study. The binder was further modified using 40-mesh rubber crumbs and Ethylene-Vinyl-Acetate (EVA) polymer to enhance the performance of the binder. The rubber crumb and EVA polymer modified binder samples were prepared by means of a high shear laboratory type mixer rotating at 1500 rpm. An acceptable EVA and rubber crumb particle dispersion can be achieved by operating the high shear mixer at 175ºC and 1500-2000 rpm. Initially, binder PG 58-22 was heated to fluid condition (180 -185 ºC). Next, four percent of 40-mesh rubber crumbs and four percent EVA polymers by weight of binder were added slowly to the heated binder, little at a time. This optimum percentage of rubber crumb and EVA polymer was selected in this study based on the previous research (Ibrahim S.A, 2005). The binder mixture is stirred with high shear stirrer continuously for about 40 minutes. During mixing, the speed of the high shear stirrer was adjusted until the 'vortex' size of about 3 to 4 cm appeared on the surface. The RPM binder is then placed in small containers for storage and left to cool at room temperature.

Superpave Mix Design

The Superpave mix design procedure (AASHTO TP4) was used to determine the design aggregate structure and asphalt binder content. The major steps involved in volumetric testing and analysis process are (i) selection of materials; (ii) selection of design aggregate structure; (iii) selection of design asphalt content; and (iv) evaluation of moisture susceptibility of the design mixture (Mc Gennis et al., 1995). The design traffic level selected for this study was medium to high traffic of 3 to≤ 30 million equivalent single axle loads (ESALs). Two different mix were developed in this study; unmodified binder HMA mix (UMB) and rubber-polymer modified binder HMA mix (RPMB). The compaction process simulates the traffic load for medium to high roadway application which is equivalent to between 3 to 30 million design equivalent single axle loads (ESALs). At this traffic level, the compaction parameters are initial compaction ($N_{initial}$ = 8 gyrations), design compaction (N_{design} = 100 gyrations) and maximum compaction ($N_{maximum}$ = 160 gyrations). The volumetric properties of design mixtures corresponding to optimum binder content of the mixtures along with mix design criteria is as shown in Table 2. The design binder content obtained for Un-modified binder mixtures is 5.3% and 5.2% respectively for RPM mixtures. Results indicate that both mixtures meet the specified Superpave criteria as requirement for good and durable mix.

Table 2 Summary of Volumetric Blend Properties

Mix Design Properties	Superpave Mixtures		Criteria
	Un-modified Binder	RPM Binder	
Design binder Content (%)	5.3	5.2	-
Air Voids (%)	4.0	4.0	-
VMA (%)	15.7	15.5	14.0 min
VFA (%)	74.6	72.0	65-75
%G_{mm} @ N_{ini}	88.6	88.8	89% max
% G_{mm} @ N_{max}	96.9	96.5	98% max
DP Ratio	0.7	0.7	0.6-1.2

Superpave volumetric design process requires the determination of the moisture susceptibility of the mix. Modified Lottman Test (AASHTO T283) and Resilient Modulus Test were used to verify that the design trial mix formulated is susceptible to damage by moisture in the pavement. Moisture susceptibility test procedures measures the loss of strength or stiffness of an asphalt mix due to moisture induce damage. The specimen tested for Resilient Modulus samples were prepared and conditioned according to Modified Lottman procedure. The Tensile Strength ratio (TSR) and Resilient Modulus ratio (RMR) values in the both test is an indication of the potential for moisture damage. Higher TSR and RMR value indicates greater resistance of the mix to moisture damage. Retained tensile strength ratio (TSR) and retained resilient modulus (RMR) were used with 80% as the boundary between mixtures resistant and sensitive to moisture (AASHTO, 2008). The Modified Lottman test (AASHTO T283) is performed by compacting samples to an air void level of 7% 0.5%. Three samples are selected as a control and tested without moisture conditioning; and another three samples were selected to be conditioned by saturating with water at 70-80 percent followed by immersing in water for 24 hours at 60ºC in a water bath. The samples were then tested for indirect tensile strength (ITS) by loading the samples at constant head rate (50 mm/minute vertical deformation at 25ºC) and maximum compressive force required to break the specimens were recorded. Tensile Strength Ratio (TSR) results were determined by comparing the indirect tensile strength (ITS) of unconditioned samples with the control samples. In this study, the samples were tested at 25ºC, 30ºC and 35ºC for both unmodified and RPM mixtures.

Results and Discussion

Moisture Susceptibility Evaluation of Mixtures

Results of the Modified Lottman test conducted on both mixtures are as shown in Table 3. Results showed that the tensile strength values for all conditioned specimens were lower compared to unconditioned specimens. The trend of all the TSR results seem are similar when tested at different temperatures. RPM mixtures showed the most significant effect to reduce stripping potential with higher TSR value compared to unmodified mixture. This can be explained by the change in properties of the granite aggregates from hydrophilic to hydrophobic aggregate nature with the use of RPM binder. At above 30ºC, the un-modified binder mix is not resistant to stripping, however the TSR value more than 80% at 25ºC. The RPM mix showed better resistant to stripping and failure only occurred at 35ºC. Figure 1 showed the results of Tensile Strength Ratio (TSR) of both mixtures tested.

Table 3 Indirect Tensile Strength and Tensile Strength Ratio Values of Mixtures

	Superpave Mixture Design	Un-modified Binder			RPM Binder		
	Test Temperature	25ºC	30ºC	35ºC	25ºC	30ºC	35ºC
Control	Average Air Voids (%)	7.0	7.1	6.9	7.0	6.9	7.0
	Average Tensile Strength (KPa)	1124	1041	974	1208	1104	1083
Conditioned	Average Air Voids (%)	7.0	6.9	7.0	6.9	7.0	6.9
	Saturation level (%)	72.7	74.3	74.4	74.1	73.7	72.9
	Average Tensile Strength (KPa)	959	826	749	1059	900	852
	TSR	**85.3**	**79.4**	**76.8**	**87.6**	**81.6**	**78.6**

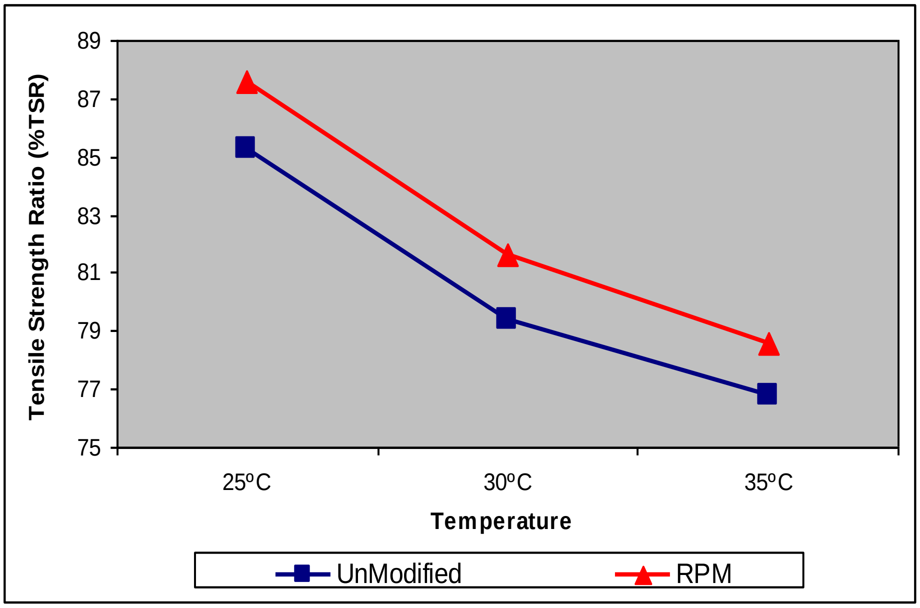

Fig 1 TSR values for binder used at different test temperatures

Table 4 shows the comparison of the Resilient Modulus Ratio (%RMR) for unmodified binder and modified binder mix at different test temperatures. A similar trend as to the modified Lottman test could be seen in this figure which indicates that RPM mix has improved the resistance to stripping. Figure 2 also presents that both unmodified and RPM mixes passed the RMR requirement of 80% when tested at different test temperatures.

Table 4 Indirect Tensile Resilient Modulus and Resilient Modulus Ratio (%RMR) of Mixtures

	Superpave Mixture Design	Un-Modified			Modified		
	Test Temperature	25ºC	30ºC	35ºC	25ºC	30ºC	35ºC
Control	Average Air Voids (%)	7.0	7.1	6.9	7.0	6.9	7.0
	Average Indirect Tensile Resilient Modulus (KPa)	2615	1526	907	3415	1802	1249
Conditioned	Average Air Voids (%)	7.0	6.9	7.0	6.9	7.0	6.9
	Saturation level (%)	72.7	74.3	74.4	74.1	73.7	72.9
	Average Indirect Tensile Resilient Modulus (KPa)	2247	1236	724	3094	1521	1007
	RMR	**86.0**	**81.0**	**80.0**	**90.6**	**84.4**	**80.6**

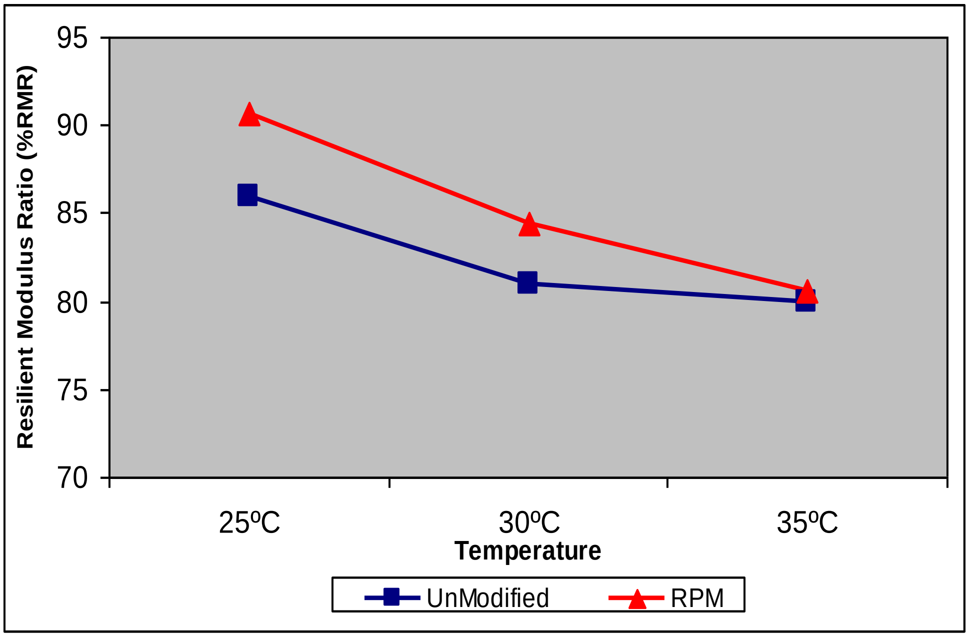

Fig 2 Resilient Modulus Ratio (RMR) for binder used at different test temperatures of Mixtures

Figure 3 shows a comparison between TSR and RMR ratio for both Un-Modified and RPM mixes at different test temperatures. The results indicated that the RMR showed a similar trend to the TSR result which indicated that the effect of temperature variations on stripping resistance is more significant at low temperature than high temperatures. Analysis was carried out to determine whether TSR and the RMR data from Table 4 and Table 5 showed the same tendency regarding moisture susceptibility. Indirect tensile strength represents the maximum load that a specimen resists before fracture under a diametral compressive load, while resilient modulus represents stiffness of a bituminous mixture. It is believed that indirect tensile strength, as well as, stiffness reduces when stripping occurs in a mixture (Behiry, 2013; Alvarez et al, 2011). A paired t-test was performed on the both TSR and RMR data to observe differences of the strength ratios. This statistical tests were done using 5.0% level of significance (α = 0.05). The null hypothesis for this analysis was that the mean difference in the mean strength for both TSR and RMR data was equal to zero (H_o: µTSR - µRMR = 0). The result shows the p-values of 0.00 was less than the α = 0.05, indicated that the null hypothesis was rejected. In other words, the hypothesis that the mean difference between RMR and TSR is significant and prediction of moisture susceptibility based on RMR and TSR could lead to similar judgments.

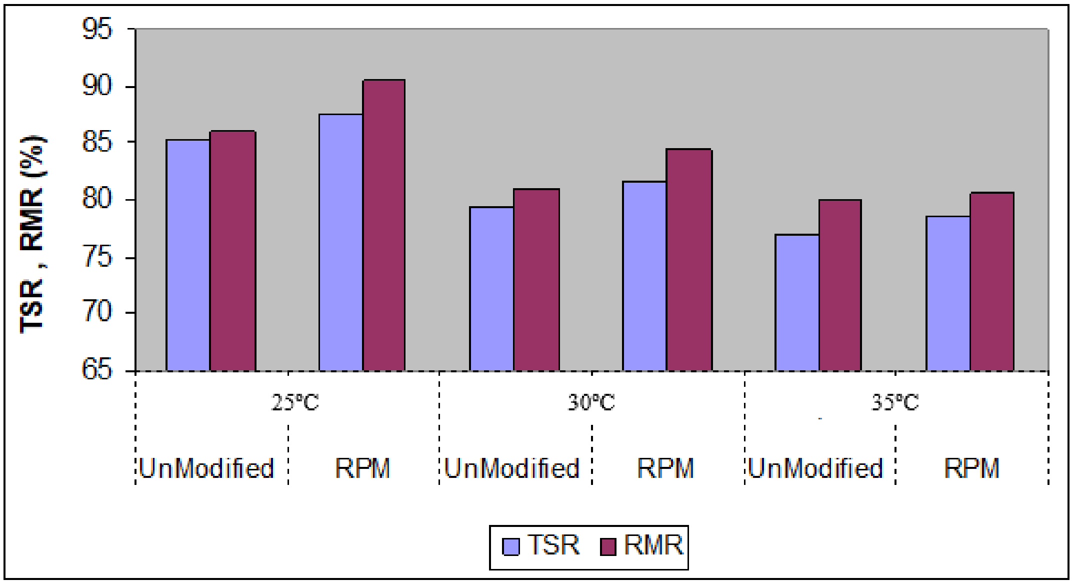

Fig 3 Comparison of Tensile Strength Ratio (TSR) and Resilient Modulus Ratio (RMR) of Mixtures

Conclusion

Extensive laboratory tests and evaluations of this research work made it possible to arrive at the following conclusion;

- Both unmodified and RPM mixtures to some extend are all resistant to moisture damage.
- The TSR and RMR values are higher for RPM mix compared to unmodified binder mix, which somehow indicates that RPM binder demonstrates better resistance to stripping than those prepared using unmodified binder due to rubber and polymer that were added to the binder coat the aggregate thus improving the stripping resistance.
- The results of TSR showed a similar trend with the RMR which indicated that the correlation between the ratios from resilient modulus and indirect tensile strength is good.

Thus, with addition of rubber crumb and EVA polymer to the binder has significantly improved the cohesion as well as adhesion properties of the binder, and hence the performance to stripping.

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