Temperature Effects on Stripping Performance of Superpave Design Mix

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ABSTRACT

Climatic factor such as temperature and moisture has 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 types of binder, Penetration Grade (PEN) 80-100 (unmodified) and PEN 80-100 with rubber-polymer (modified binder). The HMA preparation follows the Superpave mix design AASHTO TP4 procedures. The optimum percentage of rubber crumb and Ethylene-Vinyl-Acetate (EVA) polymer was selected based on the previous research. Indirect tensile resilient modulus test was used to evaluate the stripping performance in both unmodified and rubber-polymer modified mixes. This study also documents the effect of different temperatures on tensile strength ratio (TSR) and resilient modulus ratio (RMR) on the HMA mixtures. Statistical analysis performed indicates that rubber-polymer modified binder mix (RPMM) significantly improved the resistance of the HMA mix to moisture damage compared to unmodified mix (UnM).

Keywords: *Hot mix asphalt, superpave mix design, stripping performance, polymer modified binder*

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Introduction

Aggregate stripping, pot holes and delamination are some of the problems that require due attention from authorities and researchers. Thus, many studies were conducted to improve the binder used in HMA mix to obtain long lasting pavements and minimise problems related to stripping. Such as study by Kanitpong and Bahia [1] which evaluated the effect of anti-stripping additives on asphalt mixtures.

One of the approaches to increase quality performance of hot mix asphalt (HMA) mix is by modification of the binder. 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 binder and the resulting asphaltic mixtures. A study by Rogge [2] showed that polymer additives to binder improve adhesion and cohesion and also resistance to moisture-induced damage and age hardening in HMA mix. However, if an additive is used when it is not needed or if it used incorrectly, adverse affects may occur, including an increased economic cost and early maintenance and or rehabilitation [3].

Moisture susceptibility of HMA mix, generally called stripping, is a major form of distress in asphaltic pavement. It is characterized by the loss of adhesive bond between the binder and aggregate or by a softening of the cohesive bonds within the binder (a failure within the binder), both of which are due to the action of loading under traffic in the presence of moisture. This research was conducted to improve and enhance the properties of the binder by adding rubber crumb and Ethylene-Vinyl-Acetate (EVA). The performance of the HMA with rubber polymer modified binder were performed using Modified Lottman test to determine the stripping potential of these mixes.

Experimental Design

The Superpave mix design method was used to design the HMA mix and this procedure involves careful material selection and volumetric proportioning as a first approach in producing a mix that will perform successfully. Granite aggregate with of 19 mm nominal maximum aggregate size (NMAS) and two types of binder; unmodified binder (UnM) and rubber-polymer modified binder (RPMM) were used to design the mix. The HMA mix was subjected to medium to high traffic loadings which is equivalent to 3 to 30 million design equivalent single axle loads

(ESALs) with 20 years design life. The laboratory experimental procedure of this research is as shown in Figure 1.

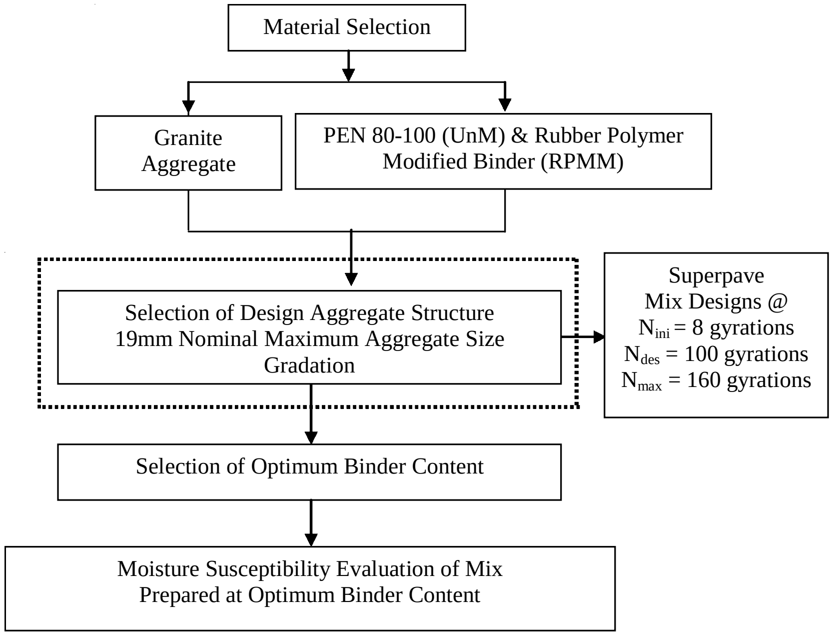

Figure 1: Laboratory Experimental Procedure

Superpave Mix Design

The Superpave mix design procedure (AASHTO TP4) was used to determine the design aggregate structure and optimum binder content of the HMA mix. The development and selection of design aggregate structure is the key features of a Superpave mix design method. In this study, the Superpave gradation developed for the mixtures is shown in Figure 2 and the selected gradation and proportioning of the 19mm aggregate grading is tabulated in Table 1.

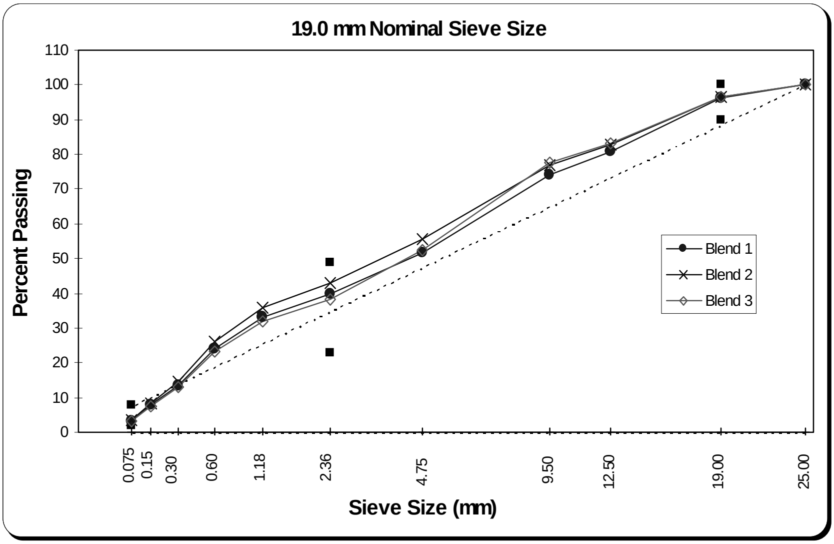

Figure 2: Aggregate Structure Gradation

Table 1: Aggregate Gradation

Mixture	19 mm NMAS
Metric Sieve (US)	Gradation (% Passing)
25 mm (1 in)	100
19 mm (3/4 in)	96.5
12.5 mm (1/2 in)	82.6
9.5 mm (3/8 in)	76.9
4.75 mm (No. 4)	55.6
2.36 mm (No. 8)	43.1
1.18 mm (No. 16)	36.0
0.6 mm (No. 30)	26.1
0.3 mm (0.50)	14.6
0.15 mm (No. 100)	8.3
0.075 mm (No. 200)	3.5

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 initial trial binder content for the three blends was estimated to 4.5 %. Two samples from each trial blends were compacted using Superpave Gyratory Compactor (SGC). The SGC compact the specimen at an angle of 1.25° gyration, pressure of 600 kPa and a speed of 30 rpm. Each specimen was compacted to N_{design} gyrations. The volumetric properties, Voids in Mineral Aggregate (VMA), Voids Filled with Aggregate (VFA), air voids (AV) and dust proportion (DP) of the mix were then determined.

A summary of the estimated blend properties of the mix to achieve 4 percent air voids at N_{design} is tabulated in Table 2. Results showed that both UnM and RPMM mix met the Superpave volumetric requirements and are qualified for use as design aggregate structures. The next step is to determine the optimum binder content of the mixtures.

Table 2: Summary of Estimated Blend Properties

Superpave mix design properties	UnM	RPMM	Criterion
% Trial binder content	4.5	4.5	-
% Est. binder content	5.1	4.9	4.0 %
% VMA	15.05	14.69	min 13
% VFA	73.4	72.4	65-76
Dust Proportion	0.8	0.8	0.6-1.2
% G_{mm}@N_{ini}	88.4	88.9	≤ 89

Further evaluation of this data is to determine the estimated binder content, $P_{b,est}$ to achieve 4 percent air voids at N_{design}. Selection of the optimum binder content consists of varying the amount of 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 percent air voids. The volumetric properties evaluation is one of the major components in determining stability and durability of HMA mix. The volumetric properties of design mixtures corresponding to optimum binder content of the mixtures along with mix design criteria is as shown in Table 3.

The optimum binder content obtained for UnM and RPMM mix is 5.3 and 5.2 percent respectively. Results indicate that the RPMM mix use less binder compared to UnM. Both mixtures meet the specified Superpave criteria as a requirement for good and durable mix.

Table 3: Summary of Volumetric Properties of Superpave Mixtures

Mix Design Properties	Superpave Mixtures UnM	RPMM	Criterion
Optimum 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
Dust Proportion Ratio	0.7	0.7	0.6-1.2

Moisture Susceptibility Evaluation Of Mixtures

Superpave volumetric design process requires the determination of the moisture susceptibility of the mix. Modified Lottman Test [AASHTO T283] and Resilient Modulus Test were conducted to verify whether the design trial mix formulated is susceptible to damage by moisture in the pavement. Moisture susceptibility test measures the loss of strength or stiffness of an asphalt mix due to moisture induced damage.

The Modified Lottman test [AASHTO T283] is performed by compacting samples to an air void level of 7 ± 0.5 percent. Three specimens were selected as a control and tested without moisture conditioning; and another three specimens were selected to be conditioned by saturating with water at 70-80 percent. After saturation process, the specimens were immersed in water for 24 hours at 60 °C in a water bath. The specimens were then tested for indirect tensile strength (ITS) at constant head rate of 50 mm/minute vertical deformation at 25 °C. Maximum compressive force required to break the specimens were recorded. The ratio of indirect tensile strength between the conditioned and unconditioned specimen were calculated to determine the Tensile Strength Ratio (TSR).

Results of the Modified Lottman test conducted on UnM and RPMM mixtures were tabulated in Table 4. Results showed that the tensile strength values for all conditioned specimens were lower compared to unconditioned specimens. This trend is similar for all mix tested at different temperatures (25 °C, 30 °C and 35 °C). As temperature increases, the tensile strength values of all mix decreases due to loss of stiffness in the mix. This indicates that temperature significantly affects the performance of the hot mix asphalt. The RPMM mixes have higher tensile strength values compared to UnM as temperature increases as shown in

Table 4: Indirect Tensile Strength and Tensile Strength Ratio Values

Mix Design		Superpave Mixtures					
		Un-modified Binder			Modified Binder		
	Test Temperature	25 °C	30 °C	35 °C	25 °C	30 °C	35 °C
Control	Ave Air Voids (%)	7.0	7.1	6.9	7.0	6.9	7.0
	Ave Tensile Strength (KPa)	1124	1041	974	1208	1104	1083
Conditioned	Ave 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
	Ave Tensile Strength (KPa)	959	826	749	1059	900	852
	TSR (%)	85.3	79.4	76.8	87.6	81.6	78.6

Figure 3. This findings show that rubber polymer modified binder does improve the stiffness of the mixes. With regards to the stripping potential of these mix, results showed that at 25 °C, both UnM and RPMM passed the 80 percent minimum requirement of the tensile strength ratio and at 30 °C, UnM mix failed to qualify except for RPMM mix. As temperature

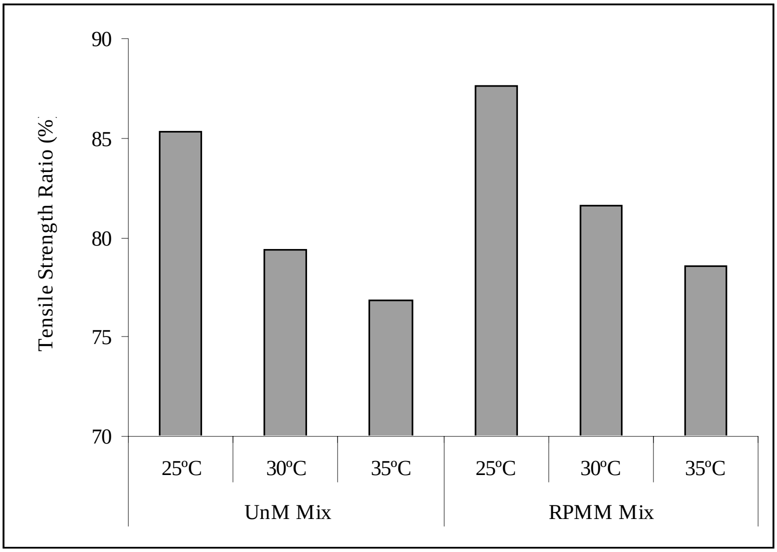

Figure 3: TSR Values at Different Test Temperatures

increases to 35 °C, both UnM and RPMM mix failed the moisture susceptibility test with TSR values of 76.8 and 78.6 percent.

In this study, the resilient modulus test was also conducted at unconditioned and conditioned specimens to determine the resilient modulus ratio (RMR) for UnM and RPMM mix. The specimens were saturated and conditioned similar to AASHTO T283 specimens. Results in Table 5 shows that resilient modulus values are lower for conditioned specimens compared to unconditioned specimens. This trend is also similar for all mixes when tested at 25 °C, 30 °C and 35 °C as shown in Figure 4. Variation in resilient modulus values is evident as temperature increases. RPMM mix exhibit higher resilient modulus values at all test temperatures compared to UnM mix. The rubber polymer modified binder certainly improves the stiffness of the mixtures. The RMR values calculated from the test showed that UnM and RPMM mix are not susceptible to moisture damage except for UnM mix tested at 35 °C. The RMR values for UnM range from 86 to 79.9 percent and 90.6 to 80.6 percent for RPMM mix.

Table 5: Resilient Modulus and Resilient Modulus Ratio (% RMR) Values

Mix Design	Superpave Mixtures						
		Un-modified Binder			Modified Binder		
	Test Temperature	25 °C	30 °C	35 °C	25 °C	30 °C	35 °C
Control	Ave Air Voids (%)	7.0	7.1	6.9	7.0	6.9	7.0
	Ave Resilient Modulus (KPa)	2615	1526	907	3415	1802	1249
Conditioned	Ave 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
	Ave Resilient Modulus (KPa)	2247	1236	724	3094	1521	1007
	RMR (%)	86	81	79.9	90.6	84.4	80.6

Conclusions

This research was conducted to determine the moisture susceptibility of unmodified and rubber polymer modified mix using AASHTO T283 and resilient modulus test. Results showed that the TSR and RMR value

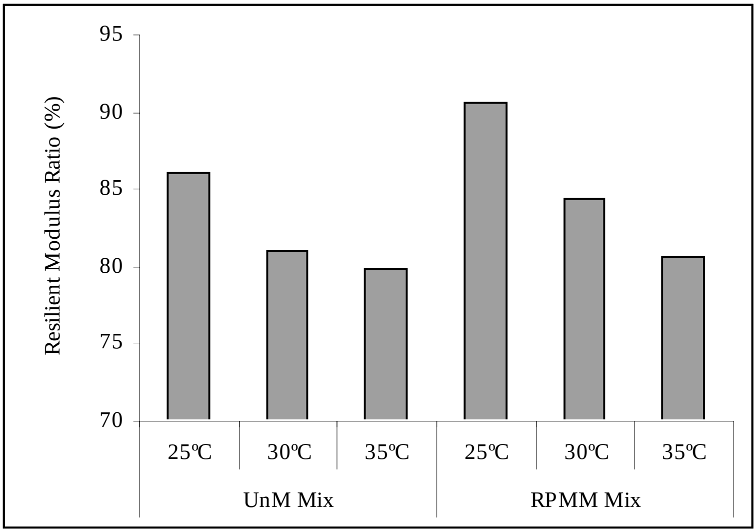

Figure 4: RMR Values at Different Test Temperatures

varies at different test temperature. The following conclusions can be drawn from the study:

1. The TSR and RMR values are higher for RPMM mix compared to UnM mix, which indicates that rubber-polymer modified binder demonstrates better resistance to stripping than those prepared using unmodified binder.
2. The effect of temperature variations on stripping resistance is significant and similar trend is observed for TSR and RMR for UnM and RPMM mix.
3. The rubber-polymer modified binder has certainly improved the stiffness, cohesion as well as adhesion properties of binder, hence the performance of HMA mix to stripping.

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