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Rutting Assessment of Crumb Rubber Modifier Modified Warm Mix Asphalt Incorporating Warm Asphalt Additive

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Abstract - Warm Mix Asphalt (WMA) as a green technology, permits production of asphalt mixtures at lower temperatures compared to conventional HMA; emissions and energy consumption reduction, were among the key success of this technology, thus, enhancing social, economic, and environmental sustainability. But due to the reduced production temperature, WMA are more prone to rutting, to improve the rutting resistance of WMA mixtures and minimize pollution resulting from waste rubber tire. Therefore, the effect of wet processed Crumb Rubber Modifier (CRM) on rutting depth of WMA mixtures incorporating 2.5% Sasobit by weight of base binders were assessed in the laboratory. In this study, the asphalt mixtures were fabricated in accordance with Superpave, using; crush granite aggregate of 9.5mm NMAS and the four binders that were produced by blending the PG 64 binder with different contents of 40 mesh size CRM (0%, 5%, 10%, and 15%, by weight of the base binder). Rutting depths of the mixtures were assessed on 150mm diameter and 70mm thick cylindrical samples using wheel tracker, the wheel tracking test were carried out at 45^{o}C and 60^{o}C, in accordance with BS 598 Part 110 (1998). Based on the results of wheel tracking tests, CRM could improve the resistance of the WMA mixtures to rutting. It was also found from statistical Analysis of Variance (ANOVA), that the two influence factors; CRM, and the test temperature both having *p*-values less than the assumed significance at 95% confidence level, therefore they have significant effect on rutting in WMA.

***Key Words*: Rutting, Crumb Rubber, Warm Mix Asphalt, Sasobit, Wheel Tracking**

1. INTRODUCTION

Conventional Hot Mix Asphalt (HMA) production at higher temperatures results in intolerable high energy consumption, emissions of greenhouse gasses; exhaust, and odors [1], consequently, Warm Mix Asphalt (WMA) technology was introduced to cut down the production (mixing and compaction) temperatures of asphalt mixtures, to improve working conditions at site, and reduce its impact on the environment. The WMA technology allows asphalt production at 20°C to 30°C temperatures lower than conventional HMA [2]. The WMA is achieved through a variety of different warm asphalt technologies developed to lower the viscosity of the asphalt binder and allow proper mixing and compaction at these reduced temperatures. One of the most commonly used additives is a Fischer-Tropsch (FT) wax [3], named Sasobit. Sasobit is completely soluble in asphalt binders at temperatures above 115°C. At temperatures below its melting point Sasobit forms a lattice structure in asphalt binders that is a basis for the stability of asphalts modified with Sasobit [4, 5].

However, some issues arose regarding the performance and durability of WMA mixtures, because at lower production temperatures these mixtures are more susceptible to rutting [6], because the lower production temperature results in reduced aging of the WMA mixtures and increase their rutting potential [5].

Rutting is regarded as one of the major distress in asphalt pavement; it is the accumulation of permanent deformation in asphalt caused by repeated loads at high working temperatures [7]. Rutting affects the pavement ride quality and leads to serious safety issues to road users, rutting in the pavement can cause uncontrollable vehicle sliding with a high potential for traffic accidents [8].

According to Brown et al., [9], rutting is the permanent deformation of asphalt pavement and or the underlying base or sub base caused by repeated traffic loads. This failure mode appears as a depression in the wheel path or as uplift along the sides of the rut. Basically, there are two forms of rutting, the first which is known as surface rutting which is restricted to the uppermost asphalt surfacing layers, this does not adversely affects the structural integrity of the pavement unless it becomes excessive, while the second type which is the main component of rutting arise from the subgrade and is termed structural rutting. Also, the rutting resistance of asphalt mixtures depends on the binder rheology, road temperatures as well as traffic loads [8]. To offset this effect, the selection or use of modifiers to obtain stiffer asphalt binder is recommended [9].

There are a great number of modifiers that are used to improve some properties of asphalt mixtures or to reduce cost, CRM is one of such. Some technical reasons for their use include the following; to improve the overall performance of asphalt mixtures, to reduce life cycle cost of asphalt pavements and to obtain stiffer mixtures at high service temperatures to minimize rutting [8, 10].

On the other hand, the traditional method of waste tires management have been stockpiling or illegally dumping or landfilling, which is short term solution. Annually, about one billion, equivalent 9 million tons waste tires are produced in the world, due to the shortage of landfill space and environmental issues [11]. The global problem of landfill disposal of automobile tires can only be solved by the feasible option left, and that is recycling and utilization of these products. For environmental protection, rational waste rubber tire utilization is indispensable [12].

There are two most widely used processes of incorporating CRM into asphalt mixtures. The first process is called the wet process, whereby CRM is mixed with asphalt at high temperatures before mixing with the hot aggregates. The second process is known as dry process, whereby CRM replace a small quantity of the mineral aggregate in the asphalt mixture. The dry process although offers some advantages over the wet process, mainly regarding the costs involved and allowing higher CRM content to be used, but the wet process provides more satisfactory results regarding improvement in asphalt properties [4, 6, 13].

According to Shafabakhsh et al., [14], rubber powder can reduce the thermal sensitivity of HMA asphalt mixtures and increase their resistance to permanent deformation thus reduce rutting. Because CRM mixtures require higher production temperatures [15], warm asphalt additives are used to lower the mixing and compaction temperatures [4, 15]. Also, wet processing of crumb rubber modified asphalt improves rutting resistance [16]. Recently, CRM has been used and found to have the potential to enhance WMA rutting resistance [17]. However, only a few literatures were available on the rutting performance of WMA mixtures modified with CRM. Therefore, a lot should be done in this regard.

The objective of this study was to conduct a laboratory study, to assess the effect of wet processed CRM on rutting resistance of WMA mixtures incorporating warm mix additive via wheel tracking.

2. MATERIALS AND METHODS

2.1 Materials

Crush granite aggregate of 9.5mm Nominal Maximum Aggregate Size (NMAS) were washed and oven dried at a temperature of 110°C for 8 hours, thereafter it was sieved into various sizes in accordance with AASTO T27-99, and 1.5% hydrated lime by total weight of the aggregate was added gradually and mixed thoroughly with the aggregate, it was used as an anti-stripping agent [6, 15, 18] to improve binder-aggregate bonding [9], the use of lime as a filler or anti-stripping agent should not exceed 2% by total aggregate weight per batch according to Malaysian Public Works Department [19]. Table 1 summarizes the aggregate properties.

And 80/100 penetration grade bitumen which corresponds to PG 64 in performance grading system was obtained from a single source and warm mix additive named 'Sasobit' was utilized, The purpose of using Sasobit is to lower the mixing and compaction temperatures [4]. While the CRM used in this study, was supplied by Miroad Rubber Industries Sdn Bhd, Malaysia, and according to the supplier, the CRM was produced by mechanical shredding followed by grinding at ambient temperature, The CRM gradation is presented in Table 2.

Table -1: Aggregate Properties

Properties	Test values	Test standard
Apparent specific gravity	2.679	AASHTO T 85
Apparent specific gravity	2.658	AASHTO T 85
Absorption (%)	0.8	AASHTO T 85
Los Angelo's Abrasion	50	AASHTO T 96

Table -2: Gradation of CRM

Sieve size (mm)	0.425	0.3	0.18	0.15	0.075
Retained (%)	0	9.8	36	38.9	15.3
Cumulative Retained (%)	0	9.8	45.8	84.7	100

2.2 Binder Preparation

The CRM modified warm asphalt binders were prepared by blending the 80/100 bitumen with Sasobit and CRM by a wet process, in this process, the CRM replaces a certain amount of the base binder [14, 16]. 0%, 5%, 10% and 15% CRM by weight of the base binder was added to produce crumb rubber modified binders; blending with CRM was conducted at 177°C while continuously mixing for 30min, using a high shear mixer (Figure 1) at 700rpm [20]. Then, 2.5% Sasobit by weight of the base binder which is within the recommended dosage of 0.8 to 3% [18, 21] was then mixed at 120°C, while, the shearing rate and time used were 1000 rpm and 10 minutes respectively. Table 3 summarizes the properties of these binders. The prepared CRM modified warm asphalt binders were used immediately, to avoid segregation upon storage due to their poor storage stability [22].

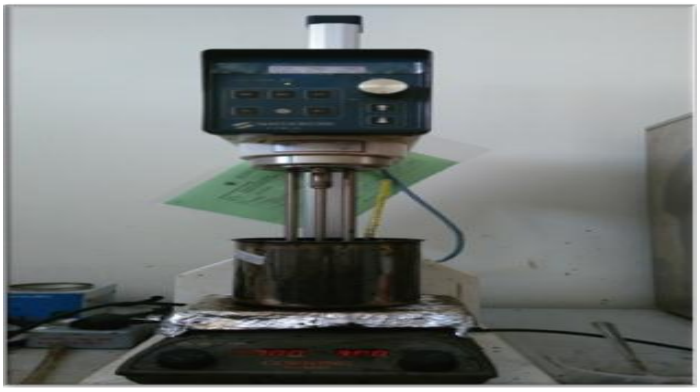

Fig -1: Binder Mixing With High Shear Mixer

Table -3: Properties of CRM modified warm asphalt binders incorporating 2.5% Sasobit

CRM (%)	Penetration (mm) AASHTO T49-03	Softening Point (°C) AASHTO T53-96	G*/sinδ (kPa) Unaged AASHTO T315-1	Binder Grade PG System
0	68	54	1.685 at 64°C	PG 64
5	59	57	2.196 at 70°C	PG 70
10	49	60	5.008 at 76°C	PG 76
15	42	64	4.583 at 76°C	PG 76

2.3 Superpave Mix Design

The results of the Superpave volumetric mix design are shown in Table 4, the Optimum Binder Contents (OBC) for the four warm asphalt mixtures incorporating 2.5% Sasobit, were found to be; 5.7%, 6.1%, 6.4%, and 6.5% for the control (0% CRM) mixture, and the mixtures with 5%, 10%, and 15% CRM modified binders respectively. The OBC was determined using the established 9.5mm NMAS design aggregate structure is shown in Figure 2; the designed aggregate structure met the Superpave 9.5mm NMAS gradation requirement of AASHTO MP-2. The Superpave specimens were prepared in accordance with AASHTO T312-4, and for this purpose, 150 mm diameter and 115 mm height specimen, with a total aggregate mass of 4700g was used. As recommended by the Asphalt Institute [23], the batched aggregate and the binder were oven heated at the mixing temperature before mixing for 4hrs and 1.0hrs respectively, and after mixing, the loose mixtures were then aged for 2hrs at the compaction temperature. This is to allow binder absorption into the aggregate and to simulate the delay during asphalt production in practice [23].
The projected traffic level chosen in this study was medium to high traffic load which is equivalent to 10 to <30 million ESALs, therefore, Superpave Gyratory Compactor (SGC) was used to compact these specimens, and the most important volumetric properties were established at the design number of gyrations, N_{design} =100 gyrations.

Table -4: Results of Superpave mix design at N_{design}

CRM (%) in Binder	OBC (%)	V_A (%)	VMA (%)	VFA (%)
0	5.7	4.0	15.2	73.7
5	6.1	4.0	15.4	74.0
10	6.4	4.0	15.8	74.7
15	6.5	4.0	16.1	75.2
Specification	-	4.0	at least 15%	65 - 75

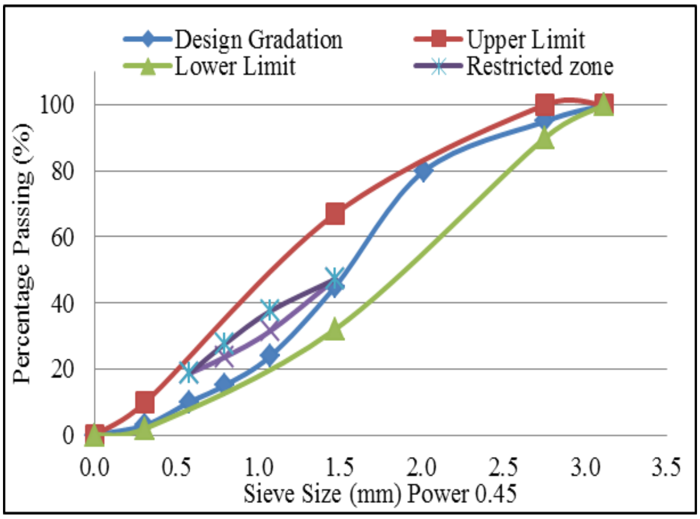

Figure -2: Aggregate Gradation for 9.5mm NMS on 0.45 Powers Chart

2.4 Specimen Preparation

To prepare the 150mm diameter and 70mm thick wheel tracking specimens, appropriate aggregate quantities were batched into a metallic bowl to produce asphalt mixture specimen of 2560g approximate weight. These aggregates were preheated in an oven at the mixing temperature (145°C) for 4 hours, then appropriate amount of binder depending on the mixture (Table 4) was heated at the same temperature for 1hour, electrically propelled asphalt concrete mixer (Figure 3) was employed to blend these mixtures at the mixing temperature for 5minute. The loose mixture known as 'rice' was subjected to short term aging at the predetermined compaction temperature (135°C) for 2 hours [23]. These mixtures were compacted using SGC (Figure 4) at 135°C, applying 600kpa compaction pressure, while constantly rotating at 30 rpm; and mold gyration angle was 1.25 degrees, the compactions were completed after 100 gyrations based on the projected traffic level.

2.5 Wheel Tracking Test

The wheel tracking test was conducted in accordance with BS 598 Part 110 [24] procedure, using Wheel Tracker (BS DD 184: 1990) Shown in Figure 5. To determine the rut depth of the asphaltic concrete, cylindrical samples of 150mm diameter and 70mm thick were used.

The testing was carried out at 45°C and 60°C, under an applied load of 700N while tracking at 42 passes per minute. Three samples were tested for each mixture to determine the average rut depths. Prior to testing, the samples were conditioned at the test temperature for 8 hours; this is necessary for the mixture to attain the test temperature isotropically, which is within the range of 4 hours to 16 hours recommended by the test standard. The wheel tracker was also preheated at the test temperature for 1hour, before any testing begun.

Fig -3: Asphaltic Concrete Mixer

Fig -4: Superpave Gyratory Compactor (SGC)

3. RESULTS AND DISCUSSIONS

3.1 Wheel Tracking Results

The results of wheel tracking in Figure 6 shows that when the tracking test was conducted at 60°C. The rut depths values ranges between 1.5mm to 2.0mm, the highest rut depth value of 2mm was observed at the control warm asphalt mixture (0% CRM), the rut reduces by 5% when 5% CRM was used. And with further addition of CRM to 10% and 15%, the rut depth decreases by 25% and 20% respectively. Although, the lowest rutting at this test temperature occurs when 10% CRM is used among the mixtures considered in this study, but from this chart, the trend shows decrease in rut depth with increasing CRM content in the mixture, with coefficient of determination (R^2) of 75%, this findings was in agreement with the previous studies that, CRM modified asphalt mixtures have improved rutting performance [20, 25, 26], the reduction in rut depths with increasing CRM content in the asphalt mixture might be due it's reduced thermal sensitivity, thus improving the mixture rut resistance [14].

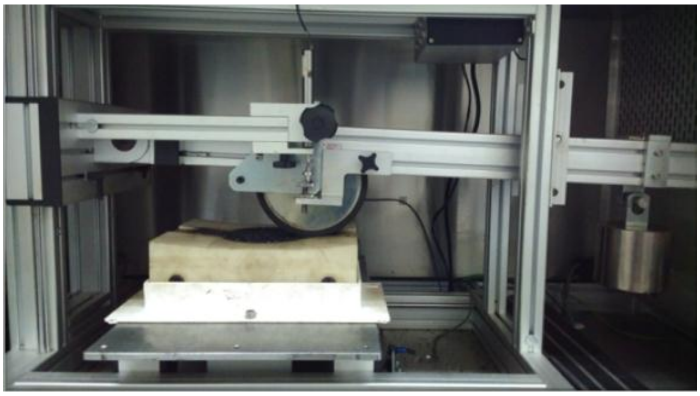

Figure -5: Wheel Tracker (BS DD 184: 1990)

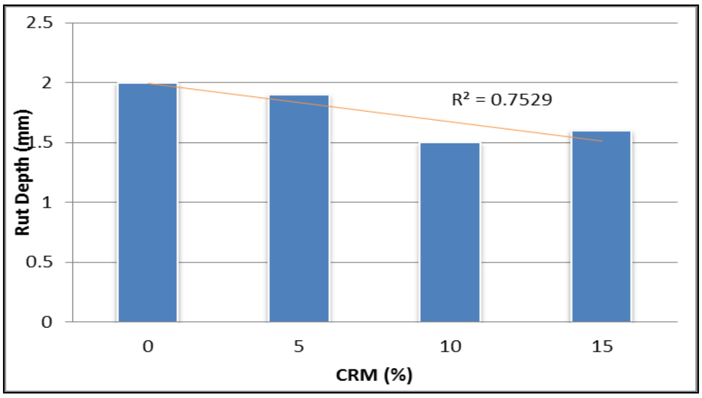

Figure -6: Effect of CRM on rutting depth in WMA at 60°C

Similarly, Figure 7 compares the effect of CRM on rutting depth of the warm asphalt mixtures tested at 45°C; the trend shows an apparent progressive decrease in rutting depth of the warm asphalt mixture with increasing CRM content, the determination coefficient between rut depth and CRM content is about 95% (R^2 = 0.9542). The higher the CRM used up to 15% the lower the rut depth [14, 20, 25, 26]. The rut depth decreased by 5% with 5% CRM, and further reduces by 29% with 10% CRM addition, the highest reduction in rut depth up to 41% was realized when 15% CRM was used.

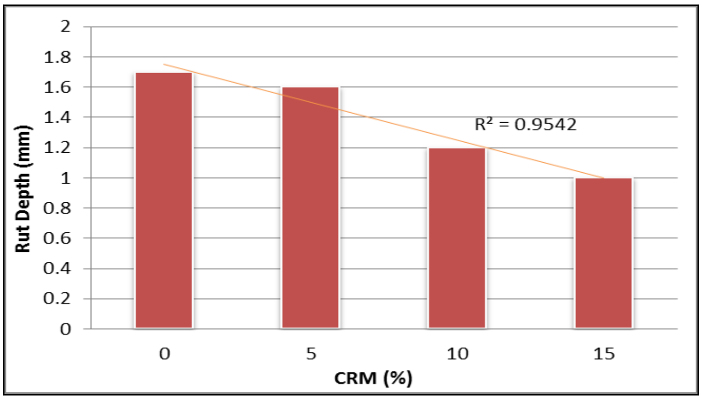

Figure -7: Effect of CRM on rutting depth in WMA at 45°C

Figure 8, compares the wheel tracking test results at the two testing temperatures (45°C and 60°C) on the effect of CRM on rutting depth of warm mix asphalt mixtures. The result shows that the rutting depths are higher at 60°C on a general note compared the result at 45°C for the corresponding mixture irrespective of the mixture composition [6, 17] this indicates that rutting depth of warm asphalt mixtures increases with increase in test temperature. Although, the resistance of an asphalt mixture is closely tied to the stability of aggregate skeleton, however, the plastic strain of the aggregate skeleton is greatly influenced by the binder [27]. This is because According to Thom [27] at low temperature the asphalt binder takes much of the stress away from the aggregate particle contacts, while as the temperature increases, the binder softens. As a result, the stress carried across the aggregate particle contact increases, leading to increased danger of inter-aggregate particle slip. The asphalt binder being viscoelastic in nature may recover over time [9] but the aggregate skeleton will be permanently deformed [27].

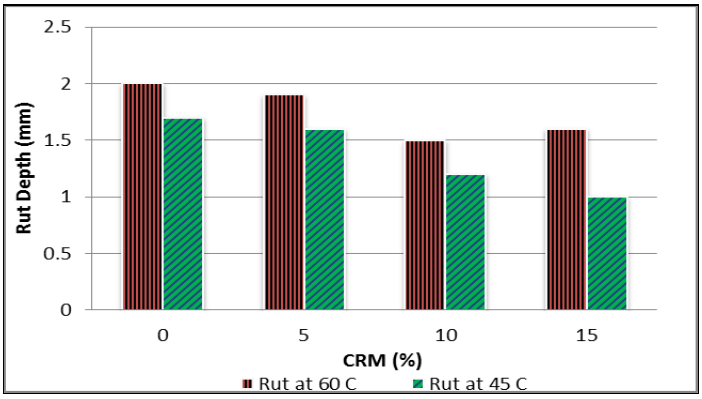

Figure -8: Comparing the Effect of CRM on rutting depth in WMA at 45°C and 60°C

To assess the significance of the Crumb Rubber Modifier (CRM) and test temperate (Test Temp) as the influence variables, on the rutting depth of the warm asphalt mixture incorporating Sasobit ANOVA was performed based on 95% confidence level, the result of this analysis is shown in Table 5. The ANOVA result signifies that CRM and test temperature have significant influence on rutting depth of the warm mix asphalt mixtures considered, this is because the p-values are less than the assumed 0.05.

Table -5: ANOVA result on effect of CRM and test temperature on rut depth

Source	*P*-value	DF	SS	MS	F	Regression
Intercept	0.138254	2	0.7015	0.35075	22.7022	R^2 = 0.90080
Temp(°C)	0.007965	5	0.07725	0.01545	-	Adjusted
CRM (%)	0.003423	7	0.77875	-	-	R^2 = 0.86112

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusions

Based on the outcome of this study, the following conclusions were made:
WMA modified with CRM shows lower rutting depths compared to those without CRM. Also, the rutting resistance of the CRM modified WMA mixtures decrease with increasing test temperature, but increase with increasing CRM content.
From the ANOVA analysis result of rutting test, CRM and test temperature at which the tracking test was conducted, have a significant effect on rutting depths of the mixtures, both having *p*-values less than the assumed 0.05 at 95% confidence level.

4.2 Recommendations

i. It is recommended that a study has to be carried out to evaluate the fatigue behavior of the CRM modified warm mix asphalt mixtures.
ii. There is also a need to assess the moisture sensitivity of the CRM modified warm asphalt mixtures, especially under low compaction temperature, to rule out stripping tendency.
iii. It is also recommended to conduct a similar type of study utilizing different CRM sources and sizes to facilitate generalization of findings of this study.

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