

Evaluation on Mix Design and Rutting Resistance of Dry Mixed Rubberised Asphalt Mixtures

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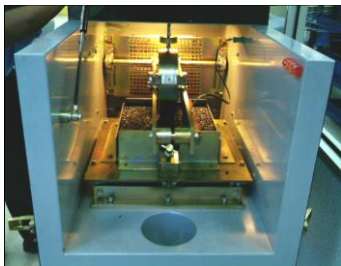
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Graphical abstract



Abstract

This study presents a laboratory evaluation on the properties of crumb rubber modified asphalt mixture using a dry process method in which the fine crumb rubber is added to substitute the aggregates portion and acts as elastic aggregates within the mix. The effect of crumb rubber in the mixture was investigated in terms of the volumetric properties using Marshall Mix Design and rutting performance using Wheel Tracking Test. The crumb rubber was added between 1 to 3% in steps of 1% by weight of aggregates to modify a dense graded mix, Asphaltic Concrete (AC14) and a gap graded mix, Stone Mastic Asphalt (SMA14) according to the Malaysian mix design. Based on the result, it was observed that the performance of the asphalt mixtures was significantly affected with the addition of crumb rubber. Rubberised asphalt mixtures for AC14 were found to have a greater resistance on rutting deformation compared to the conventional mixture. However, the use of fine rubber in SMA14 mixture with 80/100 bitumen cannot provide enough binder modification to perform as good as conventional SMA14 mixture with polymer modified bitumen. Furthermore, based on detailed review, a set of procedures for producing dry mixed rubberised asphalt mixture was identified and recommended for future studies.

Keywords: Crumb rubber modified asphalt mixtures; crumb rubber; dry process; rutting, wheel tracking

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1.0 INTRODUCTION

Many studies have been conducted to modify the Hot Mix Asphalt (HMA) with crumb rubber over the past few decades to improve the pavement performance.¹⁻¹³ Crumb rubber has been identified to be a potential modifier in asphalt mixture in order to get a better performance. There are two methods of incorporating crumb rubber in asphalt mixture: dry process which substitutes the aggregate portions and the wet process which modifies the bitumen binder. Initially, only the coarse rubber was used in the dry process method. By limiting the reaction time between bitumen binder and rubber particles and specifying a coarse granulated rubber with low surface area, the rubber particles are able to retain their physical shape and rigidity.¹ However, previous studies with the rubberised asphalt mixtures indicated better durability with an increase of fine rubber content.² Hence, after 1981, 20% of the used coarse rubber was replaced with fine rubber (passing 850 µm sieve). The design of dry mixed rubberised asphalt mixture is typically accomplished using the conventional Marshall mix design method. Based on previous studies, the gradation of aggregates and crumb rubber,

bitumen binder content as well as low air voids are found to be the keys of success in the design of rubberised asphalt mixture.²⁻⁵ In a gap graded mixture, the gaps provided between the fine and coarse aggregate is allocated to the rubber particles within the mixture. On the other hand, in a densely graded mixture, the aggregate gradation must be on the coarser side of the specification to provide spaces for rubber particles to accommodate themselves within the mixture.¹ A number of studies found that asphalt mixture modified with crumb rubber usually requires higher bitumen content due to the rubber-bitumen interaction that could end up with high variations in the total air void content among the replicate samples.³⁻⁵ Therefore, to counter the absorbed bitumen fraction into rubber particles, the optimum bitumen content is selected at low target air void content, with 3% usually desired in the design of rubberised asphalt mixture. Furthermore, higher bitumen content than the conventional asphalt mixture is significant to ensure the workability of the mixture. In addition, rubberised mixtures yield lower stability and higher flow due to their elastic properties compared to the conventional mixtures. Therefore, a proper

mixture design is critical to produce samples with low air voids content and adequate stability.

Previous studies claimed that the addition of crumb rubber into asphalt mixtures will make the mixtures more elastic at higher temperature thus enhancing their rutting resistance.⁶⁻⁸ Other studies have evaluated that the rutting resistance of the rubberised asphalt mixture at the temperature of 60 °C using Wheel Tracking Test can simulate the effect of permanent deformation under traffic loading. It was discovered that higher number of cycles had to be applied for rubberised mixture in order to reach the same rut depth as conventional mixture. In addition, the resistance against permanent deformation can be improved by using fine rubber.⁹⁻¹³ This study was conducted to investigate the effect of crumb rubber on the properties of asphalt mixture using dry process method according to Malaysian mix design. In order to achieve this, the Marshall properties and rutting performance of the mixture were investigated.

2.0 MATERIALS AND METHODS

2.1 Material Properties and Sample Preparation

Two mixture types namely, dense graded asphaltic concrete (AC14) and stone mastic asphalt (SMA14) were used in this study. The mixtures were modified with 1, 2 and 3% crumb rubber to produce Rubberised Asphalt Concrete (RAC) and Rubberised Stone Mastic Asphalt (RSMA) and compared to the conventional mixture. The amount of crumb rubber added to the mixtures was expressed in the percent of the total weight of aggregates. Figure 1 shows the aggregate grading curves for both the mixtures used in this study. The specific gravity of the materials used in this study is summarised in Table 1. Samples were prepared using Marshall mix design in accordance with Malaysian Public Works Department (JKR/SPJ/2008-S4). Details of the sample preparation are summarised in Table 2. The fine crumb rubber was added as part of the aggregate component prior to blending with bitumen binder. The crumb rubber was processed from scrap truck tires of sizes in between 0.3 to 0.6 mm. Penetration grade bitumen (80/100 PEN) was used for all the mixtures except for conventional mix of SMA14. According to the specification, Performance Grade binder, PG76 (polymer modified binder) is recommended for the production of SMA14. However, for RSMA mixtures, 80/100 PEN bitumen was used as a binder with the purpose of evaluating the effect of rubber-bitumen interaction under one hour curing over the conventional SMA added with polymer-modified bitumen, PG76. The optimum bitumen content (OBC) was determined at 4% air voids or VTM (void in total mix) as referred to the National Asphalt Pavement Association (NAPA). In this study, a few modifications were made for procedures in preparing rubberised mixtures.

Detailed procedures recommended by previous studies are summarised in Table 3.

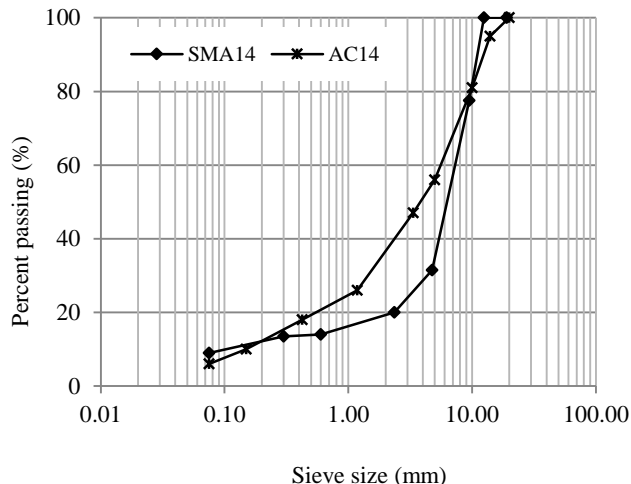


Figure 1 Aggregate grading curve of SMA14 and AC14

Table 1 Specific gravity of materials used in this study

Materials	Specific gravity
Bitumen (80/100 and PG76)	1.030
Aggregate	2.627
Crumb rubber	1.100
Ordinary portland cement (anti-stripping agent)	3.130

2.2 Wheel Tracking Test

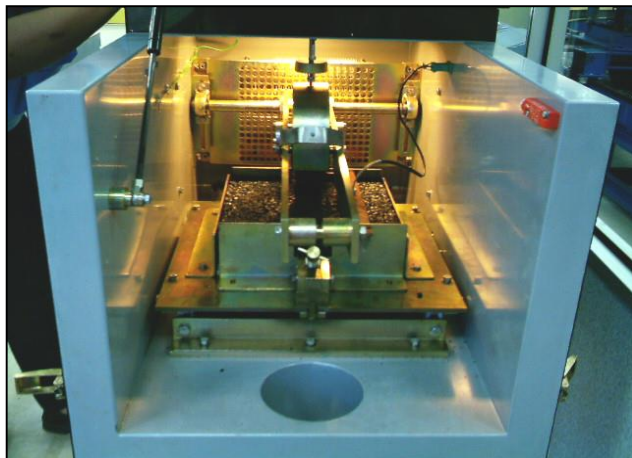
Wheel Tracking Test was performed to evaluate the rutting resistance of crumb rubber modified asphalt mixtures. Two slab samples of sizes 305 mm (width) × 305 mm (width) × 50 mm (height) for each type of asphalt mixture were tested. Figure 2 shows the Wessex S867 Wheel Tracking machine and prepared slab for testing. The machine meets the requirements of both BS 598 and BS EN 12697-22 1999. The slab was designed to have 7 ± 1% air voids (as referred to AASTHO T283) and the testing temperature was selected at 50 °C to simulate the field condition. The rutting potential was determined by measuring the accumulated rut depth at the interval of 25 load cycles where the machine was set to stop after 5,000 load cycles or when the rut depth achieves 15 mm. The results were then compared between the conventional asphalt mix (control sample) and rubberised asphalt mixtures.

Table 2 Details of conventional and rubberised asphalt mixture samples

Mixture grading	Mixture type	Rubber content (%)	Bitumen content (%)	Bitumen type	Curing period	Marshall compaction
AC14 (dense graded)	Conventional mix	0	5.0	80/100 PEN	No curing	75 blows/side
	RAC1	1	5.1			
	RAC2	2	5.3			
	RAC3	3	5.6			
SMA14 (gap graded)	Conventional mix	0	7.3	PG76	No curing	50 blows/side
	RSMA1	1	6.7	80/100 PEN	1 hour at	
	RSMA2	2	6.8		160°C before	
	RSMA3	3	7		compaction	

Table 3 Procedures recommended by previous studies for the preparation of rubberised mixture¹⁻¹³

Procedures Recommended	Review	Details
Aggregate temperature before mixing with crumb rubber	177 to 218°C	Higher aggregate temperature is said to ensure better reaction between bitumen and crumb rubber.
Duration of aggregates in the oven before dry mixing with crumb rubber	12 hours	Aggregates will be placed in the oven for at least 12 hours before mixing.
Crumb rubber temperature before dry mixing with aggregates	Ambient temperature	Crumb rubber is maintained at room temperature will be mixed with hot aggregates.
Bitumen temperature before mixing with aggregates and crumb rubber	135 to 149°C	Bitumen will be maintained around 135°C to 149°C prior to mixing it with aggregates-rubberised mixture.
Mould temperature for sample preparation	135°C, 160°C	The mould temperature must comparable with the mixture temperature to prevent the mixture from cooling quickly.
Duration of mixing aggregate and crumb rubber	15 seconds	15 seconds of mixing time.
Duration of mixing aggregate and crumb rubber with bitumen	2 to 3 minutes	Intimate mixing and mixing temperature of 135°C is essential.
Temperature of compaction hammer and hot plate	149 to 160°C	The compaction hammer face is maintained at 149 to 160°C.
Mould treatment before adding the mix	Coat the inside of the mould with grease	Grease is used to coat the inner side of the mould for ease in removing the sample.
Type of compaction	Marshall (50 blows or 75 blows), gyratory	Compaction is used to represent the traffic condition.
Curing	160°C, 191°C, no curing	No curing is recommended for dense mixture and 1 hours curing at 160°C is recommended for gap graded mixture.
Sample extrusion	After setting in the mould overnight	After 6 hours or overnight is recommended.



(a)



(b)

Figure 2 (a) Wessex S867 Wheel Tracking Machine and (b) sample for testing

3.0 RESULTS AND DISCUSSION

3.1 Effect of Crumb Rubber on Mix Design Parameters

Table 4 compares the results obtained from the Marshall mix design for different mixture types particularly the conventional (unmodified) and rubberised asphalt mixtures. The values of OBC increasing with the increase of crumb rubber. This could be due to the bitumen binder-rubber interaction, where the rubber particles tend to absorb the lighter oil fraction from the bitumen binder

composition and reduces its viscosity or the bitumen's ability to coat the aggregate particles. This is supported by the reduction in void filled bitumen (VFB) and increment in void in mineral aggregate (VMA) with the increase in the percent of crumb rubber that caused the reduction of the effective bitumen content as a result of bitumen absorption by the rubber particles. Furthermore, the fine rubber particles accelerate this process due to the high surface area. The addition of rubber also seems to reduce the stiffness of the mixture as indicated by a reduction in the Marshall stability. Similar trends were observed in the case of modifying the SMA14

mixture. The addition of crumb rubber using dry process reduces its stiffness which indicates that one hour curing does not permit adequate reaction between bitumen binder and the rubber particles to produce modified binder. It shows that the resulted binder through dry process modification is incomparable to PG76 that was used for conventional mix. Overall, based on the percentage of crumb rubber used in this study, most of the volumetric properties met the JKR specifications except for rubberised mixture modified with 3% rubber (RAC3 and RSMA3) which concludes that the optimum rubber content is lies between 1 and 3%. The mixture's elasticity can increase the mixture's ability to recover its deformation under repeated loading. Therefore, after considering mixtures that satisfy most the specification, all mixtures except RAC3 and RSMA3 were selected for further investigation on the rutting resistance.

3.2 Effect of Crumb Rubber on Rutting Resistance

Figure 3 shows the result of rutting for both AC14 and SMA14 mixtures, excessive rutting was observed for AC14. This can be contributed by the different aggregate interlocking characteristics between them. Therefore, to facilitate meaningful comparisons, trends in performance were compared within a mixture type (dense and gap graded) to investigate the effect of increasing rubber content on the rutting resistance. In this study, the effect of rubber

content on both mixture types was found significant, where an increase in the rubber content has enhanced its rutting resistance due to greater elasticity offered by the rubber particles. As shown in Figure 4, the addition of crumb rubber in dense graded mixture improves the rutting resistance but the sample reached 15 mm rut depth before completing 5000 load cycles. Similar trends were observed for both RAC1 and RAC2, those do not differ significantly after 2500 load cycles. The same trends were obtained for rubberised gap graded mixtures, where the mixtures exhibit higher rutting resistance with an increase in crumb rubber content as shown in Figure 5. However, 80/100PEN bitumen binder in the rubberised mixtures with one hour curing period for the rubber-bitumen reaction did not significantly enhance the bitumen properties to that of PG76 binder as used in conventional mix. When comparing rutting resistance for RSMA mixtures, RSMA2 shows a better performance compared to RSMA1 with the rut depth less than 15 mm after 5000 load cycles. It should be noted that through dry process, the crumb rubber particles were added to substitute a portion of aggregates and to function as elastic aggregates. The elastic aggregates will then provide elastic contacts within the asphalt mixture. As a result, the elastic contacts will offer higher ability in the mixture to absorb energy under the imposed stress (by the repetitive loading) and helps to retard the rate of the permanent deformation.

Table 4 Marshall mix design results for conventional and rubberised mixtures

Mixture grading	Mixture type	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	VTM (%)	VMA (%)	VFB (%)
AC14 (dense graded)	Conventional mix	1314	2.27	881.9	3.4	14.6	79.5
	RAC1	1159	2.20	526.9	3.8	17.3	75.7
	RAC2	1093	2.52	434.6	4.3	19.8	64.6
	RAC3	587	3.68	159.7	4.6	22.2	59.9
	Specification (JKR/SPJ/2008-S4)	>815	2.0-4.0	>203	3.0-5.0	-	70-80
SMA14 (gap graded)	Conventional mix	996	2.24	445.6	3.4	19.2	79.0
	RSMA1	812	2.52	322.9	4.2	19.9	69.1
	RSMA2	762	2.60	293.0	4.4	22.3	63.8
	RSMA3	510	2.72	187.4	4.9	24.7	59.2
	Specification (JKR/SPJ/2008-S4)	>632	2.0-4.0	-	4 ± 1 (NAPA)	min 17	-



(a)



(b)

Figure 3 Samples after Wheel Tracking Test for (a) AC14 and (b) SMA14

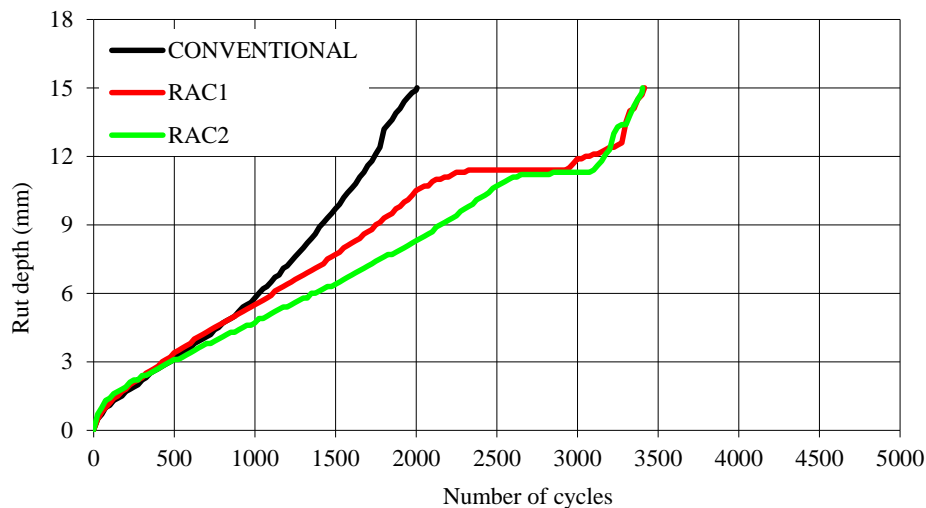


Figure 4 Results of Wheel Tracking Test for conventional and rubberised dense graded mixtures

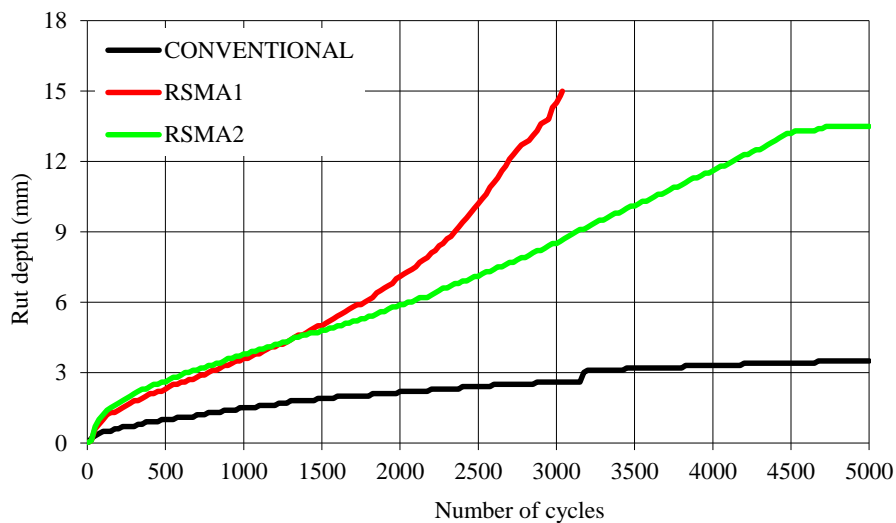


Figure 5 Results of wheel tracking test for conventional and rubberised gap graded mixtures

4.0 CONCLUSION

From the test results, it can be concluded that the addition of crumb rubber in asphalt mixture using dry process affects the mix design and its rutting resistance. The Marshall properties obtained show that stability and stiffness of the asphalt mixture are reduced after the addition of the crumb rubber due to its elasticity. The increase in the rubber content has resulted in higher optimum bitumen content and VMA, and lower VFB that is possibly due to the bitumen binder absorption by the rubber particles. For the rutting evaluation, the rubberised dense graded asphalt mixtures show higher rutting resistance compared to the conventional dense graded mixture, with RAC2 shows the least rut depth after 2,500 load cycles. This could be contributed by the elastic recovery of the rubber particles. Whereas the rubberised gap graded asphalt mixtures with 80/100 bitumen expose higher rutting resistance with an increase in crumb rubber but not as good as the conventional gap graded mixture added with polymer modified bitumen, PG76. It shows that, one hour curing period provided for the rubber-bitumen interaction cannot improve the bitumen properties to perform as good as the polymer modified bitumen. From observation, the scope of this study can be

extended to a variety of crumb rubber, sizes and percentages. This is because of a small variation in the rubber content or rubber properties can cause a change in the asphalt mixture properties. In addition, efforts should be taken to establish a standard related to the application of crumb rubber in road construction that could be adopted for Malaysian practice.

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