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Investigation on Rutting Resistance of Asphalt Mixture Containing Crumb Rubber

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Abstract: Crumb rubber is one of the modified materials included as an additive in asphalt mix to improve pavement quality in existing road structures. This raw material is made from recycled tires and undergoes several impurity removal processes before being cut to a specified size. The purposes of this study were to identify the Optimum Bitumen Content (OBC) for the rubberised asphalt mixture and to evaluate the rutting resistance of rubberised asphalt mixture. This study has decided that the crumb rubber size should pass 0.425 mm and 0.150 mm of sieve size with 1, 2 and 3 % of the rubber content would be added to the mixture. The preparation of all the test samples were complied with the Marshall mix design. The percentage of OBC applied to the sample performance test was 5.5% fulfilling the requirement in the JKR standard. The rutting resistance of the control mixture was the highest, while sample with 1% crumb rubber content had the closest results to control mixture compared to the 2% and 3% crumb rubber. All samples, including those with crumb rubber content, had passed the parameters of rutting resistance, which are dynamic modulus and creep steady slope as specified in the JKR standard.

Keywords: Rubberized Asphalt Mixture, Optimum Bitumen Content, Rutting Resistance

1. Introduction

Generally, Malaysia has been estimated to produce a total waste tire of approximately 8.2 million or accurately 57,391 tonnes every year and 60 % of the waste is believed to be disposed of in unknown areas [1]. Therefore, the application of the use of rubber in asphalt mixture seems to be preferable nowadays due to the increasing number of tire disposal in landfills. The mixing of crumb rubber in asphalt mixture has been conducted since the early 1960s by Charles Mc Donald [2]. In addition to that, an investigation conducted in the Michigan Department of Transportation had clarified that the rubber additive was prevented from resulting in the enhancement of hazardous compounds, except the inclusion of base asphalt and fuels [3]. The mixing process for the rubberised asphalt mixture can be categorized into two processes which are dry process and wet process. According to Unsiwilai and Sangpetngam [4], the dry process was focused on the modification of the mixture by adding crumb rubber directed to the asphalt mixture either as an additive or replacement material. Moreover, the wet

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process refers to the method of modifying the bitumen content with crumb rubber. In the wet process, the weighed crumb rubber was mixed and blended with hot bitumen for a specified duration at elevated temperature to allow the rubber particles to interact with bitumen [5].

The purpose of this research is to identify the optimum bitumen content (OBC) for the rubberised asphalt mixture and evaluate the rutting resistance of rubberised asphalt mixture. Bilema et al. [6] indicated that among the crumb rubber sizes of 0.075mm, 0.15mm and 0.3mm that were added into asphalt mixture, 0.075mm of crumb rubber, which is the smallest size, had produced the highest value of the tensile strength ratio (TSR). The smaller size of the crumb rubber can fill more air voids in the mixture, leading to a reduction of water level entering the asphalt mixture. In addition to that, the addition of 1 to 3 % crumb rubber content was the appropriate range to obtain positive results in the resistance to rutting of asphalt mixture [7]. This study is focuses on the rutting resistance of the rubberised asphalt mixture using a dry process.

2. Material and method

2.1 Material

In this study, the aggregates were sieved according to the grating of wearing course AC 14 which specified in the standard specification JKR/SPJ/2008-4. Regarding the type of bitumen, the penetration grade of 60/70 was used after obtaining the verification through the results from penetration test and the softening point test. Meanwhile, crumb rubber with sizes of 0.150 and 0.425 mm was prepared as 1, 2 and 3% additive by weight of the total mixture. Each size was weighed by 50% of each crumb rubber percentage.

2.2 Determination of optimum bitumen content (OBC)

The preparation of 4, 4.5, 5, 5.5 and 6 % bitumen content by total mix weight was performed as tests to obtain the actual percentage of the optimum bitumen content (OBC). Two types of laboratory tests were performed before analyzing the results for the optimum bitumen content (OBC). These tests were Marshall stability test and bulk specific gravity test. During the Marshall stability test, all samples were conditioned at room temperature for 24 hours before placed accordingly into water bath at a temperature of 60℃ with 5 minutes between samples. Each sample was kept in the water bath for 45 minutes before testing using Marshall compression machine.

During the bulk specific gravity test, the mass of equal volume of water at a temperature of 25℃ was obtained from the difference between the mass of surface saturated-dry sample and the mass of sample under water. The sample was first weighed in dry state after being kept in room temperature for a minimum one hour. The sample was then immersed in water bath with temperature of 25℃ for approximately 4 minutes to ensure that the water was filling the sample voids. After completing both tests, the analyzed parameters to identify the percentage of OBC were stability, flow, stiffness, bulk specific gravity, air voids in mixture (VIM) and voids filled with bitumen (VFB).

2.3 Sample preparation

The Marshall mix design was used for the preparation of the sample throughout this study. The prepared crumb rubber was poured onto half of the aggregate layer before completely covered. The mixture was stored in an oven with temperature of 165 ℃ for about two hours. The bitumen weighed according to percentage of OBC was placed inside the oven at the next hour. All materials were mixed at constant temperature of 165 ℃ for 2 minutes before pouring into a hot mold. Before starting the compaction process, the hot mold filled with the rubberised asphalt mixture was kept in an oven with temperature of 155 ℃. During the compaction process, the total blows for each face were 75 blows. To ensure a good shape of the outcome sample, the completed samples were kept inside the mold for 24 hours before performing a testing.

2.4 Dynamic creep test

To fulfill the second objective of this study, the rutting resistance of asphalt mixtures was tested using Dynamic creep test accordance to BS EN 12697-25. This laboratory test was performed using Universal Testing Machine (UTM). Minimum three dimensions for each diameter and height of the sample were measured to determine the volume and surface area of the sample. The conditioning process of test samples were completed for a duration of 4 hours at temperature of 40 ℃. During the set-up of the apparatus, the test sample was placed perfectly between two platens which centralized with the test axis before adjusting two displacement transducers on the loading platen. The transducers were positioned symmetrically to balance out the inhomogeneous deformation of the axial test sample. A stress load of 200 kPa was applied onto the sample until maximum of 3600 cycles was reached, which completed exactly in 2 hours.

The results obtained from these tests were used to analyse three rutting parameters which are dynamic creep modulus (DCM), creep steady slope (CSS) and permanent deformation. Eq. 1 and Eq. 2 show the formulas used to determine the results for both dynamic creep modulus and creep steady slope of asphalt mixture.

$$DCM = \frac{Applied\ load\ stress}{\varepsilon 3600 - \varepsilon 2000} Eq.1$$

$$CSS = \frac{log\ \varepsilon 3600 - log\ \varepsilon 2000}{log\ 3600 - log\ 2000} Eq.2$$

whereby ε2000 represents the accumulated strain at 2000 cycles, while ε3600 represents accumulated strain at 3600 cycles.

3. Results and Discussion

3.1 Optimum bitumen content (OBC)

The completed results of all parameters required to determine the OBC were presented in Table 1. It presents a general result in which the stability of the asphalt mixture will be reduced less when the bitumen content increases, as noticed by Keymanesh et al. [8]. In addition to that, different flow values are reflecting the condition of asphalt mixtures. Wagaw et al. [9] clarified that the asphalt mixture consists of a high flow value would easily deform due to traffic load. Meanwhile, a low flow of the asphalt mixture had greater risk of experiencing premature cracking due to the greater air voids which caused by insufficient bitumen content in the sample.

The bulk specific gravity values show a decreasing trend despite the increasing bitumen content. The higher bitumen content would increase the thickness of the binder films and contributed the asphalt mixture becoming denser. Thus, the dense asphalt mixture indicates a lower bulk specific gravity [10]. The increasing percentage of VFB contributed to the decrease in the percentage of VIM. Morova and Terzi [11] clarified that a higher bitumen content in the mixture would meant that more bitumen would be available to fill the air voids.

Table 1: Comparison of test results for each percentage of bitumen content

Parameter	Bitumen content (%)				
	4	4.5	5	5.5	6
Stability (N)	16665.5	15135.3	16240.3	14710.0	12843.0
Flow (mm)	1.926	2.477	2.488	3.039	3.287
Stiffness (N/mm)	8826.8	5890.1	6554.5	4921.3	3941.7
Bulk specific gravity	2.285	2.290	2.334	2.342	2.349
VIM (%)	8.96	8.07	5.62	4.60	3.61
VFB (%)	49.75	55.34	66.84	73.12	79.12

The designation of optimum bitumen content (OBC) was performed by computing the average from bitumen percentage of stability, flow, stiffness, VIM, and VFB. According to the results, the percentage of OBC is:

$$Average\ OBC = \frac{4.97 + 5.60 + 5.70 + 5.80 + 5.60}{5} = 5.5\%$$

The 5.5% of the average OBC was first considered as a trial value which must be compared with the limitation specified in the JKR standard (JKR/SPJ/2008). Based on the comparison between OBC results and the limitation in JKR specification as shown in Table 2, the application of 5.5% optimum bitumen content to the asphalt mixture was acceptable since all parameters have fulfilled the limitation.

Table 2: Comparison between OBC results and the JKR specification (JKR/SPJ/2008)

Parameter	Result	JKR specification (JKR/SPJ/2008)	Remark
Stability	15000 N	> 8000 N	OK
Flow	2.92 mm	2.0 – 4.0 mm	OK
Stiffness	5100 N/mm	> 2000 N	OK
VIM	4.5 %	3.0 – 5.0 %	OK
VFB	73.8 %	70 – 80 %	OK

3.2 Rutting resistance

Generally, the data which can be directly obtain after completing the dynamic creep test was accumulated strain. The comparison of the accumulated strain curve for each percentage of crumb rubber was shown in Figure 1. Compared to the 0% crumb rubber or control mixture, the accumulated strain for the 1% crumb rubber content had the closest difference with 53% higher values. The second largest difference was sample of 2% crumb rubber with an increase of 92% accumulated strain, while 3% crumb rubber had the highest percentage difference with a value of 126% greater compared to the control mixture. Zimmermann et al. [12] indicated that the higher percentage of air void content was caused by an increase in the rubber content in asphalt mixture. Thus, the consequences of a higher air void leads to increasing values of accumulated strain [13].

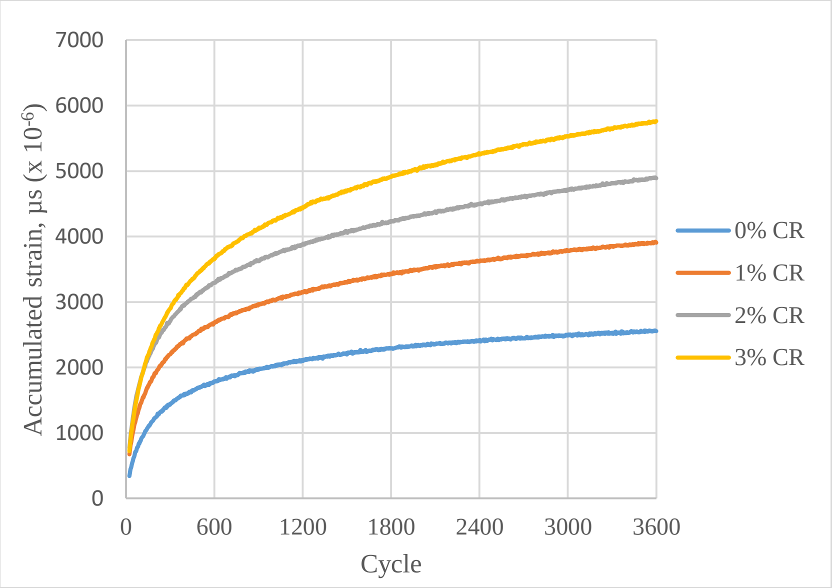

Figure 1: Graph accumulated strain against cycle based on crumb rubber content

Three parameters which are able to verify in detail the rutting resistance of rubberised asphalt mixture are dynamic creep modulus (DCM), creep steady slope (CSS) and permanent deformation. Table 3 shows the tabulation of Dynamic creep modulus (DCM), Creep steady slope (CSS) and permanent deformation for every percentage of crumb rubber content.

Table 3: Results of DCM, CSS and permanent deformation for each crumb rubber content

Crumb rubber content (%)	Dynamic creep modulus, DCM (MPa)	Creep steady slope, CSS	Permanent deformation (mm)
0	896.0	0.156	0.175
1	492.9	0.187	0.274
2	355.0	0.208	0.353
3	278.5	0.227	0.416

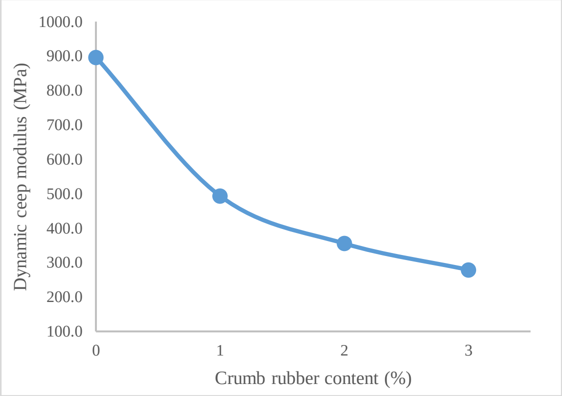

Figure 2. : Graph dynamic creep modulus against crumb rubber content

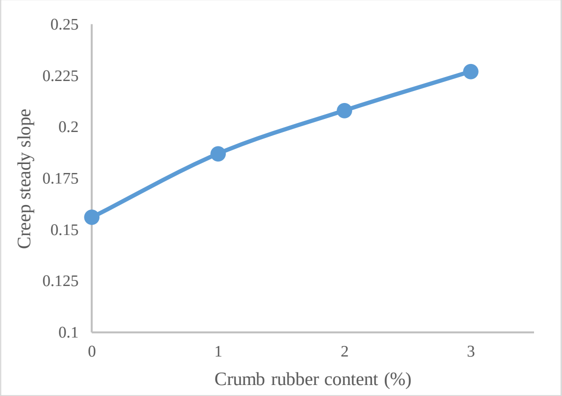

Figure 3.: Graph creep steady slope against crumb rubber content

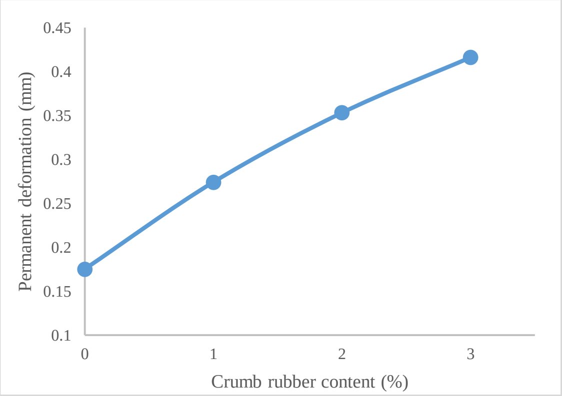

Figure 4: Graph permanent deformation against crumb rubber content

Figures 2 to 4 above show the plotted graph of dynamic creep modulus, creep steady slope, and permanent deformation against different percentages of crumb rubber content. The curve line in the graph dynamic creep modulus shows a decreasing trend as the crumb rubber content increased. Compared to the control mixture, the dynamic creep modulus for the 1% crumb rubber content had the closest difference with 45% of the lower values. The second highest difference was sample of 2% crumb rubber with the decreasing of 60% while 3% crumb rubber had the highest percentage difference with 69% which the lowest values of dynamic creep modulus. This result was proven by Bušić et al. [14]

who indicated that the application of a higher rubber content would reduce the static and dynamic modulus of the asphalt mixture that attribute to lower resistance to failure. The results of dynamic creep modulus for all percentages of crumb rubber had passed the JKR requirement which greater than 75 MPa.

The increase in creep steady slope values was related to the higher crumb rubber content. Wazeri et al. [15] clarified that the increasing of crumb rubber content had reduced the stiffness of asphalt mixture. Hence, the sample was unable to withstand the applied load due to higher strain value [16]. The curve line shows that the creep steady slope value for 1% crumb rubber content had an increase of 20% compared to the control mixture. The increasing trend was continued by sample with 2% crumb rubber, which had percentage difference of 33% higher while sample with 3% crumb rubber had the highest value of creep steady slope with 46% higher than control mixture. Compared to JKR standard, samples with 1, 2 and 3% crumb rubber content had complied with the limitation of creep steady slope which lower than 0.25.

According to Wang et al. [17], the consequence of the low value of dynamic creep modulus was the reduced ability of the asphalt mixture to resist permanent deformation. Moreover, the asphalt mixture would have a greater chance to undergo permanent deformation when the value of the steady slope was higher [18]. The value of permanent deformation for the 1% crumb rubber content had shown an increase of 57% compared to the control mixture. The increasing trend was continued by sampling with 2% crumb rubber which had a permanent deformation of 102% higher than the control mixture. The sample with 3% crumb rubber that had the highest permanent deformation value had an increasing of 138% values compared to the control mixture.

4. Conclusion

Based on the results obtained, the higher bitumen content had contributed to the reduction of air voids content in asphalt mixture. A positive correlation was shown between the bitumen content and percentage of void filled with bitumen (VFB), which indicated higher bitumen content leads to higher VFB. After analyzing and comparing the results obtained with JKR standard, the ideal percentage for the optimum bitumen content to be applied to the rubberised asphalt mixture was 5.5%. The high addition of crumb rubber content in the asphalt mixture lead to low resistance to permanent deformation. Compared to the sample with crumb rubber, 0% crumb rubber or best known as control mixture had the greatest rutting resistance. The result obtained from 1% of crumb rubber verified as the closest one to the control mixture compared to 2 and 3% of crumb rubber content.

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