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Performance Review of Crumb Rubber as A Modifier in Asphalt Pavement

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Abstract: The rising number of wheeled transportations has led to an increasing waste tire in the country. Thus, it is always experiencing pavement failure such as cracking, potholes, depression, and raveling, which bring uncomfortable feelings to road users. Therefore, the modified pavement is needed for solving these problems by adding crumb rubber to the asphalt mixture. In this study, the crumb rubber from previous studies was used to determine the performance of crumb rubber as a modifier in asphalt pavement. Six crumb rubber-modified pavement data consist of 8.00 %, 10.00 %, and 12.00 %, with the different bitumen grades (PEN 60-70, PEN 70-80, and PEN 80-100) prepared and analyzed. The laboratory testing of Penetration Test, Softening Test, and Ductility Test found the most suitable bitumen grade used in Malaysia is PEN 60-70. Besides, the Marshall Stability test and Indirect Tensile Strength test are performed and indicate that 10.00 % is the optimum percentage of crumb rubber added in the mixture. Hence, the study found that the addition of crumb rubber in asphalt pavement can improve the pavement's strength, quality, and performance.

Keywords: Crumb Rubber, Modified Pavement, Performance, Waste Tire.

1. Introduction

In terms, the road can be defined as a surface relationship consisting of a fixed structure. The function is designed either as a national liaison network to a smaller town and rural areas. The most common pavement type used in Malaysia is flexible pavement. This type of pavement can be interpreting as a pavement layer consists of aggregates and bitumen mixture. Then, the top road surface is heated with hot mix asphalt (HMA).

Following this, the road of wheel transportation users overgrows each year may bring pros and cons to this country. Malaysia has a 28.3 million population, were 17.4 million owned private vehicle automobiles, and 11.7 million registered as drivers in 2010 [1]. The rising number of vehicles will affect the roadway conditions when failed to maintain the pavement conditions. Therefore, Malaysia also has a high rate of road pavement damages as one of the developed countries [2]. In only a few years of

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construction road completion in Malaysia, severe problems have occurred and changed to a damaged state [3]. Damage to the pavement is influenced by water intrusion, load from heavy vehicles, temperature change, and subjection to the sun. Hence, the study decided to use waste tire as the primary material for the modified pavement to solve these problems. A waste tire features that elastic, long-lasting, and waterproof may improve the quality of asphalt pavement. This study may also provide new information about the ability of crumb rubber to improve the performance of road pavement. As shown in Figure 1, the crumb rubber can also reduce waste management in a landfill as well as pollution.

Figure 1: Crumb rubber

This research analyzing the findings from the previous study consists of various percent of crumb rubber, which 8.00 %, 10.00 %, and 20.00 %. The bitumen test determines the mechanical properties of the modified pavement. Simultaneously, the data from the Marshall Stability Test and Indirect Tensile Strength test were compared to determine the optimum percentage of crumb rubber as a modifier in asphalt pavement. All results from previous studies compared with a specification of modified pavement from The Jabatan Kerja Raya (JKR).

2. Materials and Methods

The method used in this study is comparing the previous studies with the Jabatan Kerja Raya (JKR) specification. The flow chart in Figure 2 shows the process of data collection and testing involved in this study. The methodology aims to ensure that the methods used are appropriate for the hypotheses to be investigated and achieve the objectives.

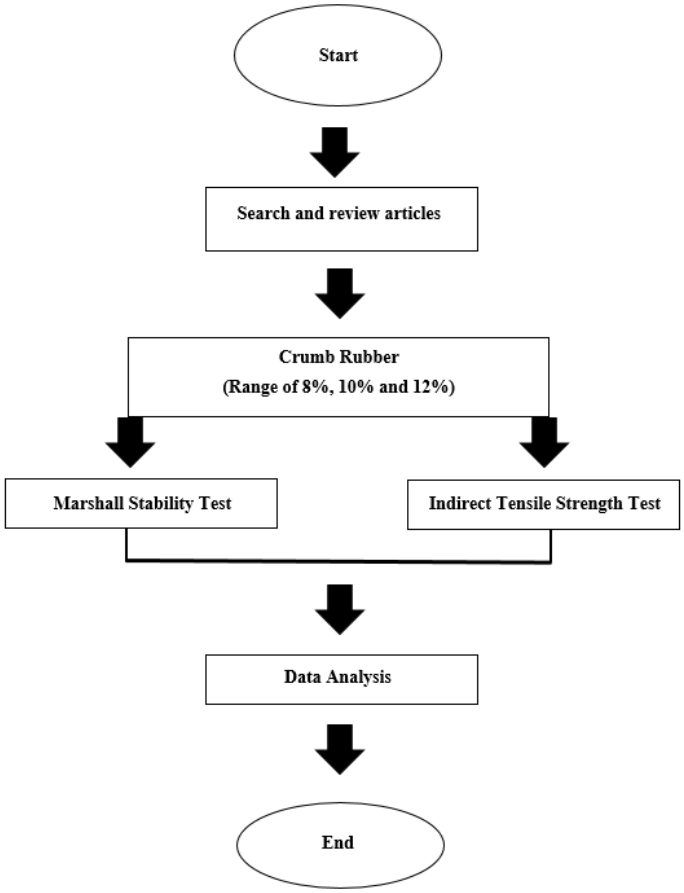

Figure 2: Flowchart of Methodology

2.1 Preparation of Sample

The collected data from six previous studies are 8.00 %, 10.00 %, and 12.00 % of crumb rubber as a modifier in asphalt pavement used in this study. The readings of the sample taken when testing on bitumen, then the Marshall Stability test and Indirect Tensile Strength test performed onto the mixture of pavement. The data used in this study is from the modified bitumen using the wet method. The wet method has more benefits than a dry method such as higher performance, economic, and environmental benefits. The wet method is a process of crumb rubber, and bitumen mixed before the aggregate added, as shown in Figure 3.

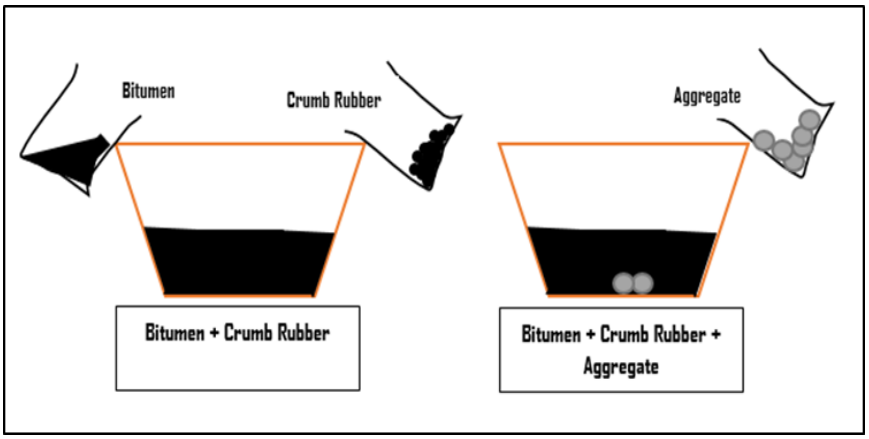

Figure 3: Wet method process

2.2 Crumb Rubber

Crumb rubber is any substance produced by reducing scrap tires or other rubber into uniform granules with the inherent reinforcing materials such as steel and fiber separated along with any different kind of inert contaminants such as dust, glass, or rock. Crumb rubber is also made from two primary feedstock: tire reinforcements, a rethreading tire by-product, and rubber scrap tires.

The recycled material used in this study was produced at factories as crumb rubber shown in Figure 4. The tire smashed at factories to make it into a specific size.

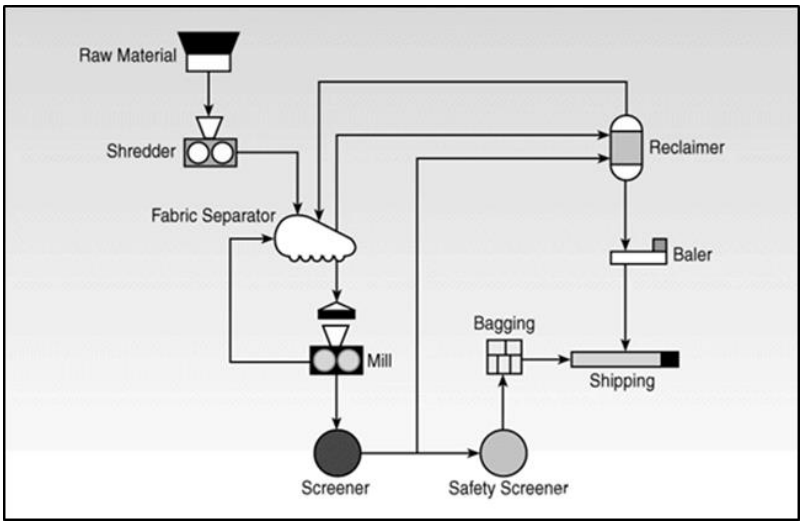

Figure 4: Crumb Rubber Process [4]

2.3 Bitumen Test

The bitumen used in this study include the PEN 60-70, PEN 70-80, and PEN 80-100. The value means where the penetration value is in the range between the number indicated. The bitumen properties will be determined through a penetration test, softening, and ductility test. Firstly, the penetration will measure the hardness or softness of bitumen. While the softening is to indicate the material's ability to flow at elevated temperatures. Lastly, the bitumen feature undergoes excellent deformation or elongation proved by ductility test. The bitumen test will decide which bitumen grade suitable for this study by comparing it to the JKR specification shown in Figure 5.

Characteristic	ASTM Test Method	Penetration Grade	
		60-80	80-100
Penetration at 25 C (1/100 cm)	D5	60-80	80-100
Softening Point (°C)	D36	not less than 48 & not more than 56	not less than 45 & not more than 52
Ductility at 25°C (cm)	D113	not less than 100	not less than 100

Figure 5: Bitumen Properties [5]

2.4 Marshall Stability Test

This testing is an attempt to get the optimum bitumen content for the modified pavement. There are a few parameters used in this study, such as stability, flow, and stiffness. Thus, the testing is used

to determine the maximum load carried by the mixture, predict the deformation of the specimen, and discover the mixture's performance. Hence, the stability and flow test results are taken from the previous study. Instead, the stiffness data calculated using Equation 1 below.

$$Stiffness = \left(\frac{Marshall\ Stability}{Marshall\ Flow} \right) \quad Eq.1$$

Once the Marshall Test is being performed, the data illustrated and analyzed by comparing with JKR specification, as shown in Table 1.

Table 1: Marshall Test Specification [5]

Parameter Name	Wearing Course	Unit or Dimension
Stability, S	> 8000	Newton (N)
Flow, F	2.0 – 4.0	Millimeters (mm)
Stiffness. S/F	> 2000	Newton per millimeter (N/mm)

2.5 Indirect Tensile Strength Test

The indirect tensile test (IDT) is a practical test to predict pavement performance in terms of strength and distress [6]. This IDT has tested the samples from the previous studies. At the end of testing, the maximum pressure at the failure of the sample will be determined. Therefore, Table 2 indicates the Indirect Tensile Strength Test based on the JKR standard parameter.

Table 2: Indirect Tensile Strength Test Parameter [5]

Parameter Name	Specification
Total Resilient Modulus	> 2500 Mpa
Test Temperature	25°C
Applied Load	20 N/mm of specimen thickness (max. 1500 N)

3. Results and Discussions

The data test is collected for this study using different crumb rubber percentages and bitumen grades, as shown in Table 3. Three main tests, bitumen test, Marshall Test, and Indirect Tensile Strength test focused on determining crumb rubber performance in asphalt pavement. The data used in this testing collected from six previous studies performed all testing except Journal 7 and 8 only used for Indirect Tensile Strength Test.

Table 3: Parameter from previous studies

Parameter	Reference	PEN Grade	Crumb Rubber Percentage
Journal Paper 1 [7]	Manoharan et al. (2020)	70-80	8%
Journal Paper 2 [8]	Al Qudah et al. (2018)	60-70	10%
Journal Paper 3 [9]	Issa (2016)	70-80	10%
Journal Paper 4 [10]	Alhaddad (2017)	80-100	10%
Journal Paper 5 [11]	Irfan et al. (2017)	80-100	12%
Journal Paper 6 [12]	Mashaan et al. (2013)	80-100	12%
Journal Paper 7 [13]	Celtin (2013)	50-70	10%
Journal Paper 8 [14]	Bakheit & Huang (2019)	80-100	12%

3.1 Bitumen Test

Three methods of bitumen testing, penetration, softening, and ductility take place to evaluate related properties. Table 4 shows the comparison between penetration, softening, and ductility tests.

Table 4: Comparison of Bitumen Test

Journal	Penetration (mm)	Softening (°C)	Ductility (cm)	Results
1	37.4	57.5	47.4	Fail
2	63	52	110	Pass
3	78.1	52.3	-	Pass
4	61	48.9	150	Pass
5	42	56	18	Fail
6	88	47	120	Pass

Four research papers showed that all data obtained passed the JKR requirement. While Journal Paper 1 and 5 failed as recorded the low value of ductility. Both the journal data cannot be accepted because the bitumen must be hardened enough to preserve the pavement. Overall, the most suitable bitumen grade for road pavement is 60-70 with 10.00 % of crumb rubber as it is appropriate to use enduring the weather in Malaysia.

3.2 Marshall Test

In this study, three methods are analyzed to determine the mechanical properties of pavement in load resistance and fatigue properties. The stability test indicates that the modified pavement containing 10.00 % of crumb rubber in Figure 6 showed a high strength value. The value is increasing despite the difference in bitumen grade used. The data is inconsistent may come from the addition of crumb rubber changes the flexibility and compression strength of the road surface [7].

As the stability test is carried out, the flow value is recorded when vertical deformation happens as the dial gauge measure the specimen's plastic flow to the applied flow. The flow rate shown in Figure 7 has met the JKR requirement except for journal paper 5. The road pavement may have problems such as rutting, upheaval if the flow rate exceeds or too low from the limits (2 mm – 4 mm).

Lastly, the stiffness is related to each stability and flow value because the value of stiffness is obtained when the stability value is divided by flow rate. The stiffness value is crucial as it can decide the performance of asphalt. The higher number of stiffness can protect the pavement by spreading the applied load and resistance relatively [8]. Figure 8 shows that the highest value is from journal paper 2 due to the high value in marshall stability. So, when a certain amount of crumb rubber can improve the performance of the modified pavement.

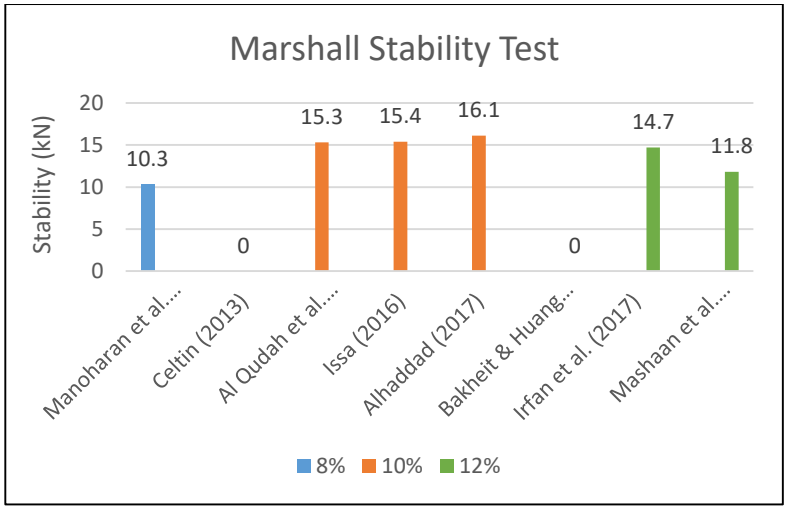

Figure 6: Marshall Stability Test

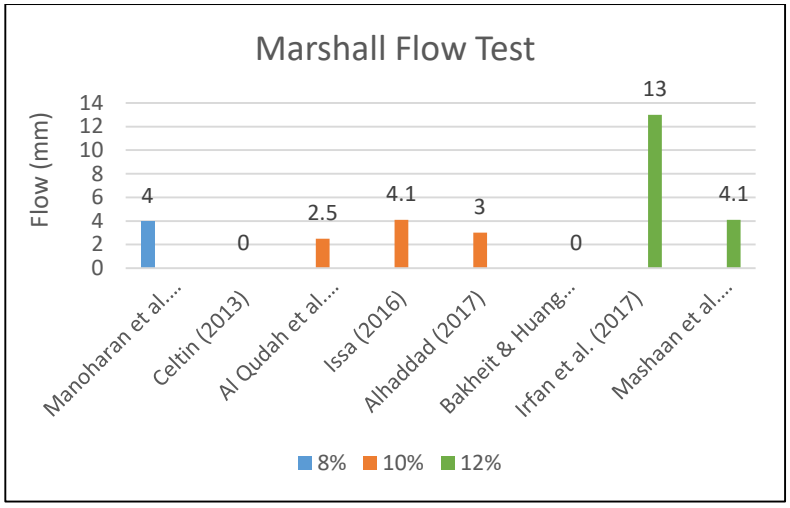

Figure 7: The marshall flow test

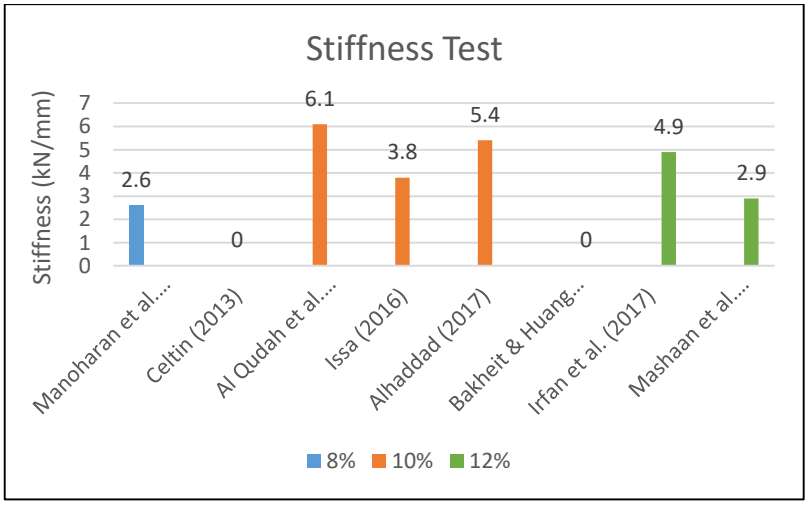

Figure 8: The result of stiffness test

3.3 Indirect Tensile Strength Test

The indirect tensile strength test is beneficial in predicting pavement performance in terms of strength and distress. By referring to Figure 9, a higher value was developed by journal paper 2 compared to the value obtained by journal paper 8. The difference between the study is crumb rubber percent used in pavement mixture. Although journal paper 7 and 2 use the same percent of crumb rubber, the massive difference has occurred as it uses different crumb rubber sizes. Thus, the usage of 10% of coarse crumb rubber given a better performance. Therefore, the service life of pavement can increase using modified pavement proved through this testing.

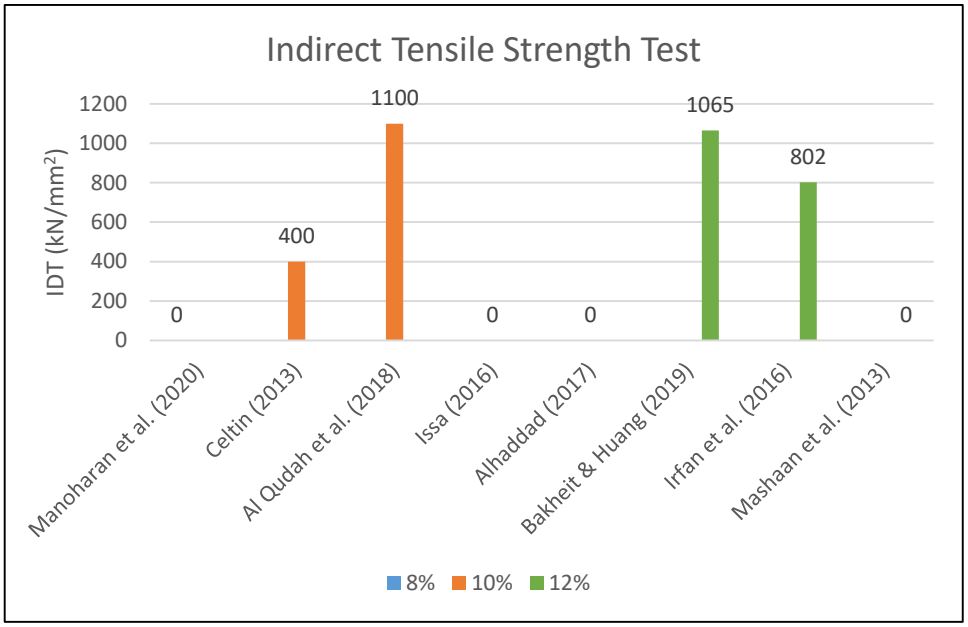

Figure 9: The indirect tensile strength test

4. Conclusions

This study aims to help the problem faced by conventional road conditions such as cracks, potholes, and other deterioration of the pavement. For that reason, the modification to the pavement is required. This study aims to review the performance of crumb rubber in asphalt pavement, study the mechanical properties of crumb rubber, and determine the optimum percentage of crumb rubber by comparing the data from the previous study that has been successfully achieved. The results from all testing show 10.00 % of crumb rubber is the optimum percentage to be added in asphalt pavement as all the data passed the JKR specification.

Without a doubt, the maximum results of 1100 kN/mm^2 obtained from the Indirect Tensile Strength Test, compared to JKR specification have concluded that the addition of crumb rubber in road pavement improved the long-term pavement performance. Thus, the usage of crumb rubber as a modifier can be applied in Malaysia because it improved the life cycle and quality of the road.

It is recommended to do further research for this topic by performing the actual laboratory testing for each sample using the specific size of crumb rubber. It is for proving the actual optimum percentage for the exact crumb rubber size. The future researcher also can focus more on the indirect tensile strength test because it can predict the potential for pavement stress. Lastly, compare the modified pavement result with conventional to see the ability of crumb rubber as a modifier in asphalt pavement.

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