STUDY OF CRUMB RUBBER AS BINDER MATERIAL IN ASPHALT

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ABSTRACT

Asphalt is a mixture of aggregates, bitumen, quarry dust, and cement. As an addition in hot mix asphalt mixtures, recycled tire rubber known as "crumb rubber" is regarded as an environmentally friendly building practice. The laboratory hot mix asphalt design tests were conducted according to Marshall method procedure. In this study, three different crumb rubber contents (10%, 15%, and 20% by weight of bitumen), and three different bitumen contents (4%, 5%, and 6%) with a penetration grade 60/70 were investigated. The Marshall stability value and durability properties were taken into account in a comparison study between the standard and modified asphalt concrete mixtures. The strength and performance of asphalt mixtures tended to improve with the addition of crumb rubber. As some of the test results were within the acceptable range, the findings indicated that crumb rubber is advised for use as an addition in asphalt mixtures. Besides, the durability of asphalt mixtures also needed to be concerned.

Keyword: *Asphalt, crumb rubber, durability, Marshall stability*

1. INTRODUCTION

The road is one of the popular modes of transportation. Road plays an important role in integration of a nation's economy and socio-cultural in a country. The road is constructed to facilitate smooth traffic flow and can support the load of the vehicle thereby reducing the severity of traffic accidents. Not all paths, though, are meant to last. The process for constructing the most cost-effective combination of pavement layers focuses primarily on the design of material mixtures and pavement layer thicknesses. The use of secondary material consumption is one of main indicators for assessing the sustainability of a project as a result of substituted for primary material (Bressi et al., 2019). Weather changes, especially during the rainy season, may weaken the pavement structure and drainage system, causing water stagnate and seep into the pavement. It can also be damaged by an imperfect premix mix and quality of the pavement process. These distresses can decrease the service period and decrease the quality of asphalt pavement with increased maintenance costs. According to (Mashaan et al., 2014), the study of various types of bitumen modifiers to change the properties of pavement performance affected by the binding properties of bitumen; where conventional bitumen has a limited range of rheological properties and durability that is not enough to withstand pavement pressure (Shaari & Buhari, 2023).

An enormous quantity of scrap tires is a major environmental concern for the future. This burden is increasing with the rapid increase in the number of vehicles on the roads today due to economic growth (Khiong et al., 2021). The impact of the increased quantity of scrap tires stored or landfilled that can threaten human health and the environment near the landfill area (Shaari & Buhari, 2023). Therefore, standard asphalt has been modified with the addition of crumb rubber as a binder in asphalt in road construction is considered a sustainable way of dealing with these issues.

Considering their deterministic role, this study was focused on the effects of strength (stability, flow, and density) and durability (void in total mix and void filled with bitumen) by conducting the Marshall stability test. Lastly, modified asphalt will be compared to standard asphalt according to specification limits. This study is crucial in finding out the extent to which recycled tire rubber crumb acts as an asphalt binder to increase the strength and durability of asphalt (Wulandari & Tjandra, 2017), and so on to extend premix life and save maintenance costs (Almusawi et al., 2020). In addition, it is believed that recycling tire rubber can help to lessen the impact on the environment.

2. METHODOLOGY

Three samples shall be prepared for each different ratio of crumb rubber and bitumen content within the range at increments of 0.5 percent, according to ASTM D 1559 using 75 blows/face compaction standard as shown in Figure 1. All bitumen contents shall be in percentage by weight of the total mix. As soon as the freshly compacted samples have cooled to room temperature, the bulk specific gravity and density of each test sample shall be determined according to ASTM D 2726. Then, the stability and flow value of each sample have to be tested according to ASTM D 1559. Figure 2 shows the Marshall testing machine used.

Materials used are bitumen with a 60/70 penetration grade, aggregate, and crumb rubber. All these materials are supplied from laboratory tests of Centre for Engineering Services, IKRAM. The combined grading of aggregate is quarrying dust and ordinary Portland cement as a filler. The size of the aggregate used is 14.0 mm and 10.0 mm. The mixture comprises sufficient aggregate, quarry dust, and cement to produce a sample of approximately 1120g. The contents of crumb rubber in the form of a powder that was selected in this study are 10%, 15%, and 20% by weight of bitumen. The contents of bitumen are 4%, 5%, and 6%. Thus, the ratio of asphalt mixtures mixed with crumb rubber is shown in Table 1.

Figure 1. Samples of asphalt mixture

Figure 2. Marshall testing machine

Table 1. Ratio of asphalt mixture mixed with crumb rubber

Group	Sample	Ratio					
		Aggregate (14.0 mm)	Aggregate (10.0 mm)	Quarry Dust	Cement	Bitumen	Crumb Rubber
A	A1	291.2g (26%)	268.8g (24%)	537.6g (48%)	22.4g (2%)	46.7g (4%)	4.67g (10%)
	A2						7.005g (15%)
	A3						9.34g (20%)
B	B1	291.2g (26%)	268.8g (24%)	537.6g (48%)	22.4g (2%)	58.9g (5%)	5.89g (10%)
	B2						8.84g (15%)
	B3						11.78g (20%)
C	C1	291.2g (26%)	268.8g (24%)	537.6g (48%)	22.4g (2%)	71.5g (6%)	7.15g (10%)
	C2						10.73g (15%)
	C3						14.30g (20%)

3. RESULTS AND DISCUSSION

Specification limit

Specification limits as seen in Table 2 are guidance to determine the strength and durability of the pavement. The strength of asphalt is related to values of stability, flow, and density. The durability is related to voids in asphalt such as voids in total mix and voids filled with bitumen. The higher stability value shows the pavement has more stiffness and strength to resist cracking, while the lower stability value can cause cracking and potholes in the pavement due to heavy moving loads. A decreasing flow value of the specification limit indicates insufficient asphalt thickness and lack of compaction which can cause rutting in the pavement. While the flow value is in the range of the specification limit can make the asphalt stiffer which can improve rutting resistance.

The void in the total mix shows the air void content. The higher air voids content can decrease the durability which can cause bleeding in the pavement. The decrease in void filled bitumen indicates a higher air void between aggregate and bitumen which results in lower durability and can cause raveling in the pavement. According to generally held beliefs, the lifespan of a pavement may be reduced by 10% for every 1% increase in air spaces. That's because a pavement's longevity, resistance to raveling, and susceptibility to bleeding are all compromised the more air voids a pavement has. It can be proved that the durability of asphalt depends on the values of void in total mix and void filled bitumen. Meanwhile, for the density test, the increasing density value can strengthen the asphalt mixture and make the pavement last longer. Addition of crumb rubber to the bitumen significantly improved the performance of the produced binder (Ahmed et al., 2020). However, according to (Altieb et al., 2016) various mixes Marshall results of do not give a clear indication of the relative performance.

Table 2. Specification limit for properties of the Marshall test

Marshall Stability (N)	Flow Value (mm)	Void in Total Mix (%)	Void Filled Bitumen (%)	Density (g/cm³)
>13000	2.0 – 5.0	3.0 – 5.0	70 - 80	>1.8

[Source:(Malaysia, 2004)]

Stability

Referring to Figure 3, the stability of samples with 20% crumb rubber will be decreased when increasing of the percentage of bitumen mixed. In the meantime, samples with 10% and 15% crumb rubber present a similar graph trend where the value of stability is increasing from 4% to 5% of bitumen and decreased when 6% of bitumen is added. Samples B1 and B2 of 5% bitumen with 10% and 15% crumb rubber respectively are closest to the stability limit. However, the value of stability of all the samples is below the limit given. It means that pavement with all the ratios of additional crumb rubber and bitumen suggested is not enough strength to resist cracking. According to (Mu et al., 2020), this characteristic is mostly caused by the fatigue performance of crumb rubber at high temperature. According to (Ogundipe, O. M., Aboloye, O. C., & Fatuase, 2020) & (Siswanto et al., 2017) findings, bitumen content and crumb rubber combination enhance the stability of asphalt concrete. However, (Cao, 2007) found that crumb rubber's higher elasticity and lower compressive strength result in a decline in stability and flow as rubber content is increased.

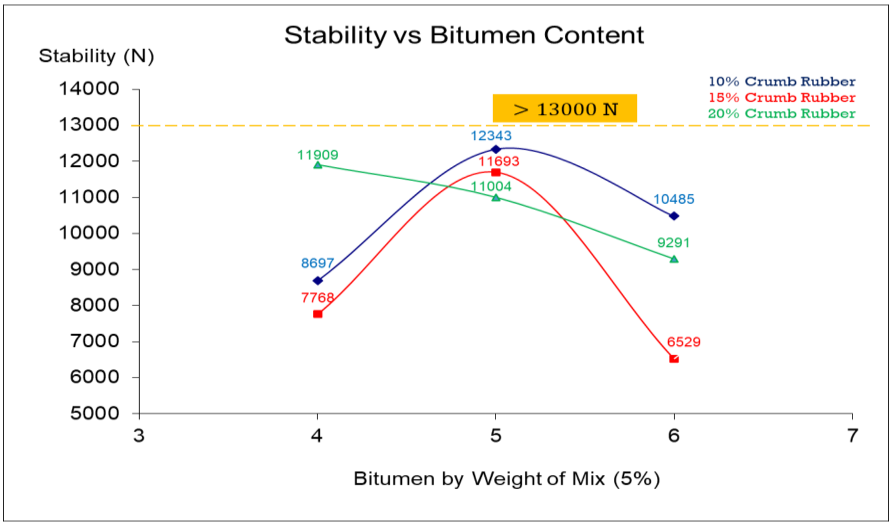

Figure 3. Stability with different percentages of crumb rubber and bitumen content

Flow

Figure 4 shows all the samples of different percentages of crumb rubber have a similar trend with 4%, 5%, and 6% bitumen content. However, samples A1, B1, and C1 were most likely to have better flow when adding 4% of bitumen content compared to 5% and 6% of bitumen content. Due to the good interaction between crumb rubber and bitumen, all samples reached the specification limit for showing a good flow. It means can make the asphalt stiffer which improves rutting resistance in the pavement. This result is consistent with (Ogundipe, O. M., Aboloye, O. C., & Fatuase, 2020) that found the addition of crumb rubber content also increased with the flow up to 7% of Marshall tests. According to (Turbay et al., 2022) crumb rubber content improves the rheological performance due to higher values of the super pave parameter. As a result, according to (Wulandari & Tjandra, 2017), adding crumb rubber to an asphalt mixture tends to improve its strength and quality. An increase in stability and a decrease in flow serve as indicators.

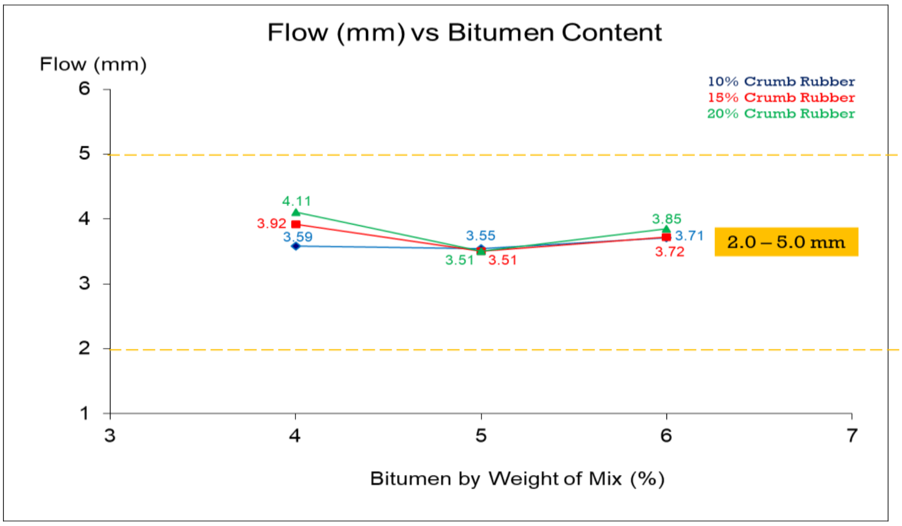

Figure 4. Flow with different percentages of crumb rubber and bitumen content

Void in Total Mix (VTM)

Figure 5 represents the percentage of void in total mix affected by the percentage of bitumen and crumb rubber added. From the graph, sample A shows the highest percentage of VTM compared to the other samples with values ranging from 9% to 12% for all 10%, 15%, and 20% of crumb rubber which is very high from the specification limit. This shows that 4% bitumen mixed with asphalt had created poor interaction between crumb rubber to asphalt. However, the trend of the graph decreases over the increasing percentage of bitumen to 5% represented by sample B. This proves that additional bitumen helped to reduce the number of air voids inside the asphalt mixed with crumb rubber by filling up the void. Besides that, sample C shows the lowest percentage of VTM compared to the others with a value of 6% to 7% nearest to the specification limit of 3% to 5% especially for sample C1 with 10% of crumb rubber. At 6% bitumen, the VTM will be decreased when the additional percentage of crumb rubber also decreased. It shows that the lower content of crumb rubber reacts as a binder and fulfilled the air void in the asphalt mixture. According to (Ahmed et al., 2020), the increase in crumb rubber percentage can be a factor in the lack of full blending between the crumb rubber particles and the binder's bulk. Low VTM content reduces the aging effect of the asphalt film and also minimize the potentiality of the water to penetrate through the asphalt mixture (Almusawi et al., 2020).

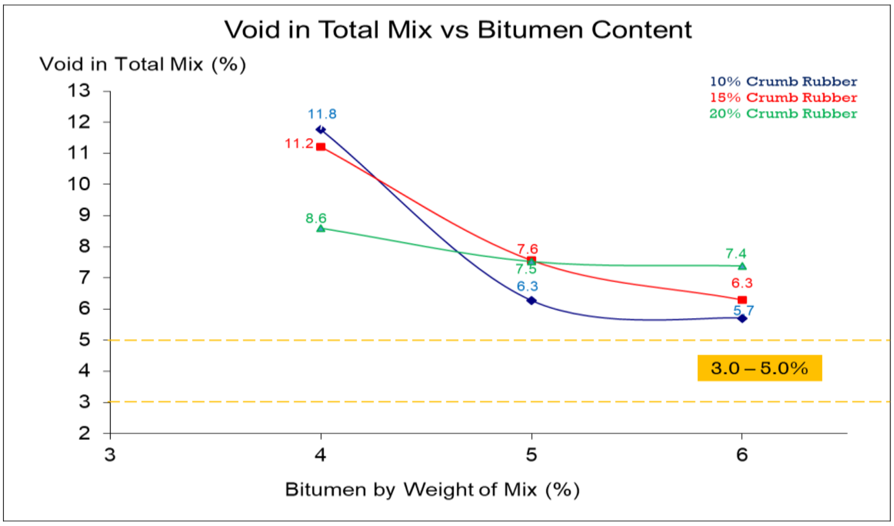

Figure 5. Void in total mix with different percentages of crumb rubber and bitumen content

Void Filled Bitumen (VFB)

Figure 4 shows all the samples of different percentages of crumb rubber have a similar trend with 4%, 5%, and 6% bitumen content. However, samples A1, B1, and C1 were most likely to have better flow when adding 4% of bitumen content compared to 5% and 6% of Figure 6 shows that sample A1 has the lowest percentage of VFB while sample C1 has the highest percentage of VFB. The increasing trend has proven that the addition of crumb rubber to a higher percentage of bitumen content can increase the VFB percentage. This is because the addition of crumb rubber which in irregular shapes had a relatively high surface area and was more likely to react with bitumen and produced a modified binder that increases the VFB % value. Besides, according to (Almusawi et al., 2020), the VFB is sensitive to the bitumen content in which any increase in the bitumen content will increase the VFB and vice versa. In this study, the specification limit for void filled bitumen is 70 - 80%. From the graph, it can be concluded that sample C1 of 10% crumb rubber with 6% bitumen is the best mixture with a VFB value of 80% due to the lowest number of crumb rubber being easily integrated into the high percentage of bitumen. Crumb rubber gradations could significantly affect the binders' properties and resistance to distress (Venudharan & Biligiri, 2017).

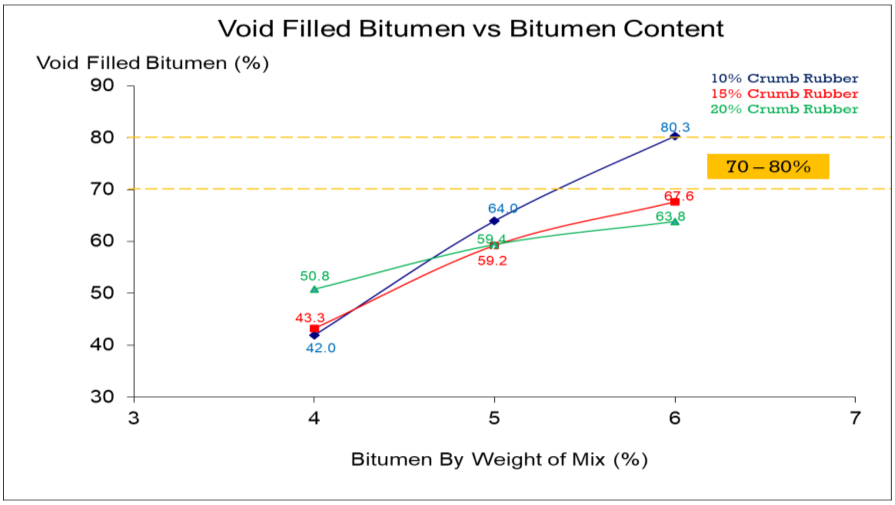

Figure 6. Void filled bitumen with different percentages of crumb rubber and bitumen content

Density

The effect of different percentages of crumb rubber and bitumen showing a similar value of density results as presented in Figure 7. All the samples have a density more than the limit of 1.8g/cm³. These results showed that the density of asphalt would not be affected by using different percentages of crumb rubber and bitumen content, but the addition of crumb rubber can strengthen the asphalt mixture and make the pavement last longer. Noticed that increasing the bitumen content will increase the mixture density until it reaches the peak value and then starts to decrease. This is attributed to the asphalt film thickness developing around the aggregate particles (Almusawi et al., 2020). According to (Sierra-Carrillo de Albornoz et al., 2022), the density of the surface layers was not affected regardless of the type of asphalt binder used.

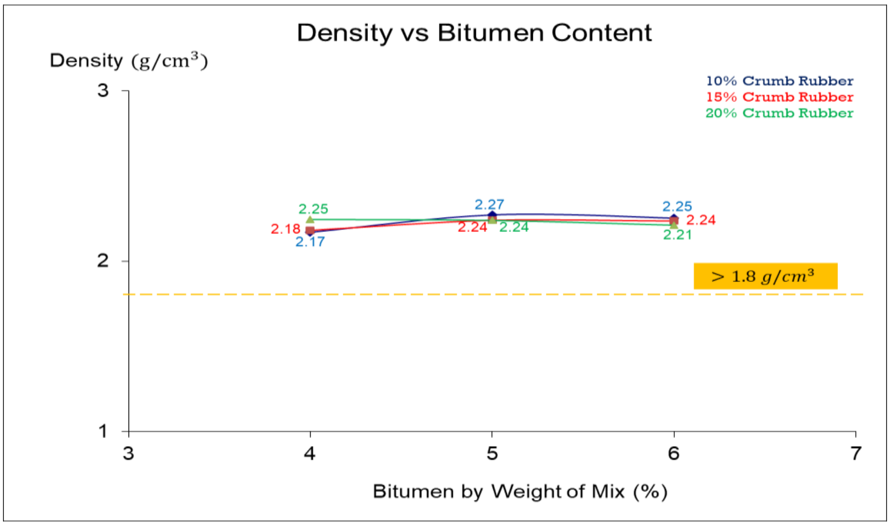

Figure 7. Density with different percentages of crumb rubber and bitumen content

4. CONCLUSION

From this study, the presence of 10% crumb rubber mix with 5% bitumen content of sample B1 shows good behavior which tends to increase the strength and quality of the asphalt mixture. It is shown by the value of stability and flow reaching the specification limit. Meanwhile, sample C1 of 10% crumb rubber with 6% bitumen content reaches the specification limit of void in total mix and void filled bitumen. However, sample C1 which is 10% crumb rubber with 6% bitumen was selected and recommended for this study because it shows good behavior in stability, flow, void in total mix, void filled bitumen, and density compared to other samples. Crumb rubber modified asphalt mixture needed high bitumen content to decrease the air void in asphalt. As air void increases, asphalt mixture becomes less durable and susceptible to bleeding and raveling in asphalt. Different sizes and percentages of crumb rubber used had a considerable effect on Marshal test parameters and also influences the optimum binder content estimates (Almusawi et al., 2020). In general, the cost of crumb rubber modified asphalt mixture is relatively high, but the extension of the service life has saved the cost of maintenance in the long term (Almusawi et al., 2020). It is also provide considerable structural and financial enhancements to the construction (Hashim et al., 2023). Therefore, when using this method to save the environment, it will benefit the economy and quality structure on road pavement.

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