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Effects of Crumb Rubber at Different Sizes in Asphalt Mixtures on Mechanical Properties

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Abstract. High vehicles loads due to increasing the road users are one of the main issues affecting the asphalt pavement surface and its performance by resulting various problems such as fatigue cracking and other deformations due to road overloading caused by vehicles loads. The use of crumb rubber in asphalt pavements has attracted increasingly growing attention and become one of the factors that increase the strength of the pavement. Crumb rubber is used to improve asphalt binder properties and pavement performance since it contributes as an additive material in the structural applications and reducing the environmental problem. The main contribution and purpose of this research is to investigate the effectiveness of adding crumb rubber into the asphalt by using the wet method. There were two different amounts of crumb rubber content used in this study (2.5 % and 3.5 % of the overall asphalt mixture weight) and two different crumb rubber sizes (0.6 mm and 0.3 mm) that were examined in this study. In addition to this study, asphalt grade 60/70 penetration grade. The performance of the modified binder is comparatively evaluated with an unmodified binder to find the best modifier. The evaluation is done through conducting the comparison between results obtained from modified and unmodified asphalt samples using Marshall stability, flow and resilience modulus test. The results from this study shows crumb rubber is an efficient material to be used as an additive to asphalt binder since it contributes in better performance by increasing the strength and stiffness of pavement and can be used for future development.

1. Introduction

Asphalt pavement is a large road leading through one place to another, specifically with a prepared road that can be used by vehicles. Roads play a significant role with in social and economic growth of a nation. Thus the, road pavement needs to be maintained from time to time to accomplish its goal and lead to the convenience of road users [1]. The primary function of asphalts in a transportation is to give a safe, monetary and agreeable course for moving individuals and merchandise. With time, asphalts pavement, also called adaptable asphalts, are liable to various sorts of misery. The Strategic Highway Research Program (SHRP) showed three primary sorts of asphalt failures, such as rutting, fatigue cracking and cracking. Extensive fatigue cracking reduces asphalt life, requiring continuous restoration and maintenance activities to re-establish the asphalt to its underlying protected and proficient conditions. Expanding asphalt life by preventing or diminishing fatigue cracking may carry critical investment funds and advantages to public agencies and roadway clients. Modern tires are manufactured to last a long time, withstand harsh environments and changes in weather conditions. Therefore, to deal with these conditions, tires are made from rubber, steel wire and fibre, and other ingredients. However, the end use of tires remains an essential concern for environmentalists. So, the process of recycling scrap tires either by cutting, shredding or breaking them down into small pieces



even though they are expensive and lengthy processes [2]. As the rapidly growing number of vehicles in Malaysia, misuse of rubber tires becomes a major natural concern. The use of crumb rubber, which is the reused tires rubber as an added material in asphalt mixtures is considered a safe method of construction since several studies on crumb rubber adjusted asphalt mixtures have been performed. Adding crumb rubber to the bitumen binder boosted the mechanical properties of the rubberised bitumen binder by reducing ductility and penetration [3]. The rubber particle is inspected and identified by the mesh screen or sieve size that it passes through during the manufacturing process in different sizes and shapes to deliver crumb rubber, for the most part, it is essential to lessen the size of the tires. Thus, once the Crumb Rubber Modifier CRM is mixed and heated with asphalt, the results will have significant changes in the properties than the original results of asphalt [4]. There are two different percentages content of crumb rubber that were used in this research which are (2.5% and 3.5% from the total weight of asphalt mixture) and two different crumb rubber sizes that were investigated in this research which are (0.6 mm and 0.3 mm). In this study, the number of samples were used for each test are 15 sample, three which were representing the control (the unmodified asphalt) and the others 12 samples were representing the modified asphalt with different percentages content and different sizes of crumb rubber.

2. Materials

Pavement is a road structure that forms of arranged layers of structural material above the soil layer are graded as surface courses, base courses, sub-base courses and sub-grades. Therefore, the surface course should be solid enough to withstand with external forces such as vehicles loads, to achieve a solid pavement. Thus, crumb rubber is purposed to be incorporate with surface course layer in order to protect the other layers by rising its stiffness. [5].

2.1. Crumb rubber modifier

Crumb Rubber Modifier is a general term for the identification of a group of concepts which incorporate scrap tire rubber into pavement materials. Crumb rubber can be divided into four assemblies: coarse, 9.5-6.3 mm; mid-range, 2-1 mm; fine, 0.4-0.2 mm; and superfine, 0.15-0.075 mm. Methods allocate the size of the crumb rubber to a job it is passed through during its production [5]. Crumb rubber is produced through refining the scrap tires of cars, trucks, busses and other transporter tires, steel and synthetic fibers, which account for approximately 40 percent of the structure of the tyres are extracted via a magnetic system and an air gravity system. In general, crumb rubber modifier (CRM) innovation can be separated into two classifications whereas these classes characterize the essential procedure used in order to add the crumb rubber into the material of asphalt pavement. They are two procedures, the wet procedure and the dry procedure. The term of wet procedure characterizes any technique that mixes the crumb rubber with the asphalt before consolidating it with aggregate and it is concluded that the wet procedure is more extra efficient in improving the pavement of an asphalt combination [6]. While the term of dry procedure characterizes those strategies that indicating mixing the crumb rubber with the aggregate and asphalt at the same time. Which means, in the dry process, the crumb rubber is inserted directly into the mix. In this study, wet process was used in order to get better performance of the pavement. The utilization of crumb rubber, which is the reused tires rubber as an added substance in asphalt mixtures is considered as a sustainable construction method [7]. Using tire scrap rubber as an asphalt additive can not only improve the strength of asphalt, but can also be an efficient solution to a waste disposal problem and environmental contamination [8]. In fact, applying crumb rubber to the asphalt mixture implies an increase in the rigidity and strength of crumb rubber asphalt pavement [9].

2.2. Tires

Nowadays tires are fabricated to keep going quite a while, withstand brutal situations and changes in climate conditions. To manage these conditions, tires are produced using rubber, steel wire, fibbers, and different components. However, the end utilization of tires remains an essential concern for environmentalists to reduce the environmental impact of tires after using them (Fadiel, A., 2013).

Tires still exist in landfills which is threatening human life and might create new diseases also, scrap tires form a fire hazardous since tires are designed tolerate high temperature caused by friction between a tire and an asphalt. Despite when a tire is presented to fire, it ends up hard to put that fire out, because of the tire elements. So, recycling scrap tires will be able to prevent and reduce the mentioned issues by using it in another resources such as asphalt improvements [10].

2.3. Aggregate

The aggregate type was used in this study is AC14. The aggregate gradient is the distribution of different particle sizes. The gradient size significantly affects the performance of AC pavements including stability and resistance to distresses. Therefore, asphalt mix designs require an appropriate distribution of aggregate sizes for certain environmental conditions, load, material and conditions of the desired AC layer. In common, aggregate constitute approximately 90 to 95% of asphalt mixes. These aggregates are intensely capable for the load carrying capacity of the AC asphalts. Hence, structure and properties of aggregates play an imperative part within the execution of asphalt mixtures. Furthermore, sieve analysis in this experiment was used according to ASTM standards starting with 14mm and ending by 0.075mm with different weight for each sieve size whereas the total size of aggregate is used in this study was 1200g after conducting the sieve analysis. The aggregates were sieved and weighted then it was putted in containers as shown in the Figure (1) and (2) then the aggregate was heated in the oven for minimum two hours in order to make the aggregate homogenous within mixing other materials with temperature degree located between 130-140 °C.



Figure 1. Sieve analysis



Figure 2. Weighing aggregate

2.4. Asphalt

Asphalt is described as a substance of sticky and black color extracted from petroleum products, exist in nature asphalt, fully or almost fully dissolve in high temperature, and quite viscous or almost solid at lower temperatures. Currently, asphalt is essentially obtained by the distillation of crude oil and only one of the most available Crude oil is found suitable for yielding. Sufficient amounts of asphalt, the heavier the crude oil and the higher its asphalt yield. The percentage of asphalt content was used in this study is 6% with AC14 of aggregate type and the bitumen grade was obtained according to a specific requirement of this research with asphalt binder (PEN 60/70) penetration grade from university Malaysia Pahang laboratory which is highly used grade in Malaysia.

3. Sample Preparation and Test

In this research, Marshall and resilient modulus were conducted in the laboratory to investigate the characteristic and mechanical properties of different asphalt mixture by using Marshall mix design. The number of samples were used for each test are 15 sample, three which were representing the control (the unmodified asphalt) and the others 12 samples were representing the modified asphalt with different percentages content and different sizes of crumb rubber. In addition, there were two

different crumb rubber percentages content and two different crumb rubber sizes were used in the asphalt mixture. The percentage content of crumb rubber used were 2.5% and 3.5% from the total weight of the mixture. Furthermore, the crumb rubber sizes were used are 0.6mm and 0.3mm by using ASTM standards of sieve analysis to get the actual sizes of crumb rubber.

3.1. Marshall mix design procedures

In this study, Marshall mix design method was applied for modified and unmodified asphalt concrete mixture. This mixing technique is used in the designing and evaluation of bituminous pavement mixtures and is commonly used in routine test programs for asphalt pavement. The dimensions of the specimens for this mix design are (101.6 mm) of diameter and (63.5 mm) of height. The following steps are the steps for preparing Marshall mix based on the wet process:

- Approximately 1200 grams of aggregate with different gradient were required for each specimen then putted in drying oven.
- Then the bitumen with grade 60/70 was heated to temperature of (140°C) prior mixing with crumb rubber
- Then crumb rubber was mixed with asphalt mixture based on wet method with different crumb rubber sizes and percentage content.
- During mixing crumb rubber with asphalt, the temperature was kept between 100-130°C and the mixing behavior was done manually until it become homogenous mix, then mixed with aggregate until all materials become homogenous.
- After that, the specimens were compacted with a base plate and collar in the heated moulds with 25 blows manually on each side of the specimen, then they were compacted mechanically with about 75 blows with temperature degree was kept about 100-130°C.
- Once the samples were done of compaction process, then they were extruded from the compaction moulds for volumetric measurement and testing completion.

3.2. Warm mix asphalt

In this study warm mix asphalt was used. Warm mix asphalt (WMA) was introduced in the previous years and has received enormous utilization in road construction since it attracted a great interest of the toll road engineering community because of its advantages over both HMA and cold combine asphalt. The degree of mixing of WMA is kept between 100-150 °C and compacted at 100-130 °C [11].

3.3. Compaction process

For the preparation of the specimens, compaction is a very important process to prevent air voids that could take a place in the pavement and cause deformations such as settlement [12]. When performing Marshall stability and flow tests, compaction helped to determine the actual mass and height of the specimen. Once the mixes were placed in the moulds, then they were compacted by spatula with fifteen times around the perimeter and ten times in the middle. Then every specimen was instantaneously compacted mechanically with the constructed number of blows representing 75 blows. Then the moulds were removed immediately, and pulled over to be cooled to room temperature and conducting the required tests (Figure 3 and 4).



Figure 3. Compaction machine



Figure 4. Drying oven

3.4. Marshall test

The stability, flow, asphalt filled voids and bulk density were performed in the Marshall test. The stability section of the test represents the overall load of the test specimen at a load rate of 50.8 mm / min (2 inches / minute). Marshall stability load was applied to the sample until failure occurs, which is the maximum level, and the maximum load is described as stability, which is the peak resistance load during a constant rate of deformation. Loading sequence describes Marshall flow is an elastic plus plastic deformation function of the asphalt mix as calculated during the stability test. The test determined the stability and flow of compacted asphalt samples and the optimum stability to flow ratio. In addition, before implementing the experiment, all the samples were immersed in a bathtub with temperature of 60°C and kept between 30 and 40 minutes as shown in Figure 5 and the immersed samples were not exceeded 60 minutes in order to conduct the test with limits of marshall test. In other hand, if the samples exceeded 60 minutes inside the hot tub, the extra duration inside the hot bath might affect the samples and make them very loose which is not suitable to be conducted for the test. In this study, the number of samples were used for Marshall test are 15 sample, three which were representing the control (the unmodified asphalt) and the others 12 samples were representing the modified asphalt with different percentages content and different sizes of crumb rubber.



Figure 5. Immersed samples

3.5. Resilient modulus test

Resilient modulus is the most important variable for materialist design concepts to asphalt structures. It is a method of measuring of the asphalt response in relation to dynamic stresses and corresponding strains. The main purpose of the resilient modulus test results analyses was to evaluate if the addition of crumb rubber has resulted to any dramatic improvement in the stiffness properties of the modified mixtures. Dynamic Stress is representing the load coming from the vehicles into asphalt surface which

is the ratio of force to the area. Whereas, strain in resilience modulus test represent the ability of the asphalt pavement to return to its original shape without any deformation such as rutting after the load is applied. The test was implemented by applying sequences of vertical loads into specimen. The stress dynamic load of 68 kg was applied and halted after 100 repetitions of the load with temperature of 25°C for all 15 samples.

4. Results and discussion

4.1. Sieve analysis and aggregate gradation

Determination of the size of the aggregate is very critical in pavement work, as the size of the sample defines the potency of the final product. Sieve analysis of aggregate was performed in accordance with ASTM requirements, while the aggregate form used was AC14 and the total aggregate quantity for each sample used was 1200g with different gradation as shown in the Figure 6.

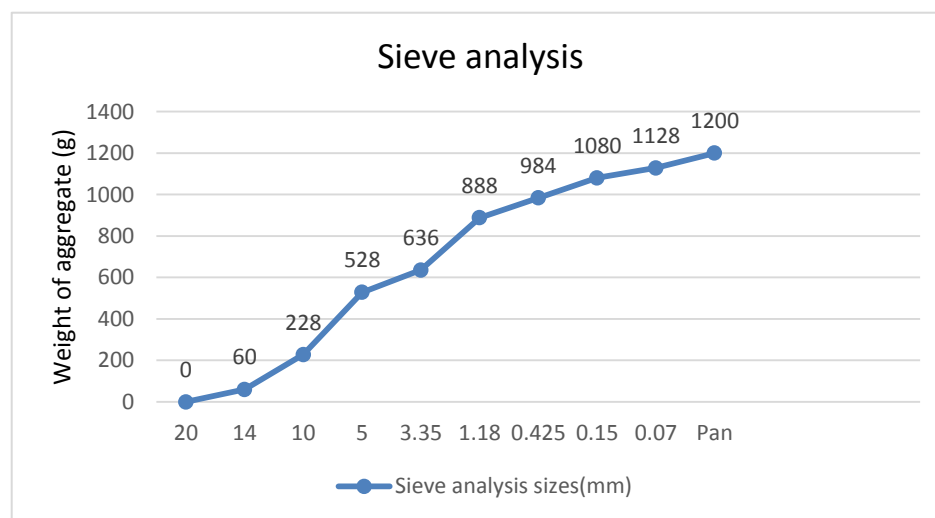


Figure 6. Sieve analysis data

4.2. Marshall stability and flow results

As shown in the following table (1), modifier (3.5% with 0.3mm) had the highest value of stability (15.36 kN) and the smallest value of flow (2.66mm), therefore getting higher value in the stiffness. Marshall stability and flow had proven that the best modifier is (3.5% with 0.3mm) comparing with other mixes and control mix. Thus, having less value of flow is indicating that the asphalt has insufficient amount of bitumen percentage content therefore the asphalt pavement is stiffer [13]. In the following Figure 7, Marshall stiffness was calculated from the ratio of stability/flow. The highest value of stiffness was 5.77 kN with modifier of 3.5% percentage content and 0.3mm crumb rubber size. Increasing the stiffness value indicates the increasing of pavement strength against asphalt deformations such as fatigue cracking.

Table 1. Marshall stability and flow data

Samples	Stability(kN)	Flow(mm)
Control	10.32	4.12
Modified (2.5%, 0.6mm)	11.02	3.93
Modified (2.5%, 0.3mm)	12.98	3.74
Modified (3.5%, 0.6mm)	14.22	2.91
Modified (3.5%, 0.3mm)	15.36	2.66

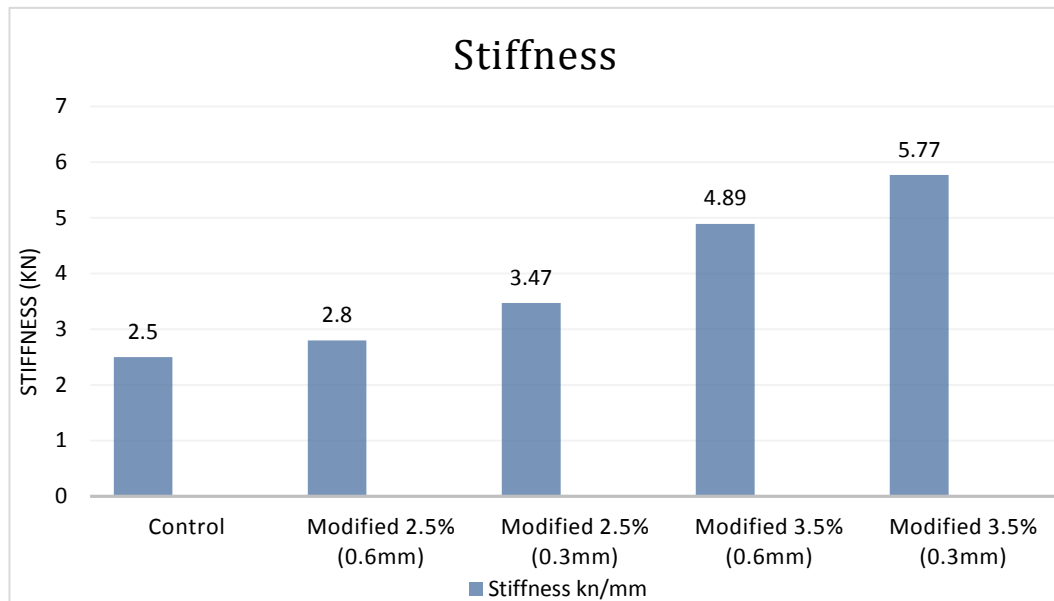


Figure 7. Stiffness data

4.3. Bulk density and void fill with asphalt VFA

In order to obtain asphalt pavement with high strength and resistance against other deformation such as settlement, bulk density and void fill asphalt VFA must be decreased and allocated in the range [14]. Based on the results obtained in the following table 2, modified bulk density results decreased compared with unmodified bulk density. For modified asphalt of 2.5% of crumb rubber content with 0.6mm crumb rubber size the bulk density decreased slightly with 2.23g/cm^3 compared with control mix of 2.23g/cm^3 . Whereas, modifier (2.5%, 0.3mm) and (3.5%, 0.3mm) contributed satisfier results of 2.09g/cm^3 and of 2.00g/cm^3 respectively as the best modifier compared with other mixes since it has smaller crumb rubber sizes. Indeed, the data of modified void fill asphalt was dropped dramatically to 72.94% with modifier (2.5%, 0.3mm) compared with control mix 89.34%, especially by using more crumb rubber content and small crumb rubber size. Therefore, it contributed in percentage reduction of void fill asphalt in modified asphalt pavement thus it reduced the possibilities of settlement and other structural deformation. In conclusion of bulk density and VFA results, the best result was obtained once modified asphalt had higher crumb rubber content of 3.5% and finer crumb rubber size of 0.3mm.

Table 2. Bulk density and void fill with asphalt VFA data

Samples	Bulk density(g/cm^3)	VFA(%)
Control	2.23	89.34
Modified (2.5%, 0.6mm)	2.20	86.63
Modified (2.5%, 0.3mm)	2.09	77.39
Modified (3.5%, 0.6mm)	2.11	79.23
Modified (3.5%, 0.3mm)	2.00	72.94

4.4. Resilient modulus test

Resilient modulus for asphalt structures is the most important aspect to mechanistic design approaches [15]. According to the results obtained in Figure 8, modifier (3.5% with 0.3mm) which contains a higher crumb rubber percentage content and finer crumb rubber size resulted as the highest resilient modulus value of (3253Mpa) that contribute to give a higher performance against heavy loads comparing with modified mixes and control mix. As well as, it's the same for peak loading force as

shown in Figure 9, the data is clearly raised with modifier (3.5% with 0.3mm) in the peak loading force comparing between the control mix and modified mixes.

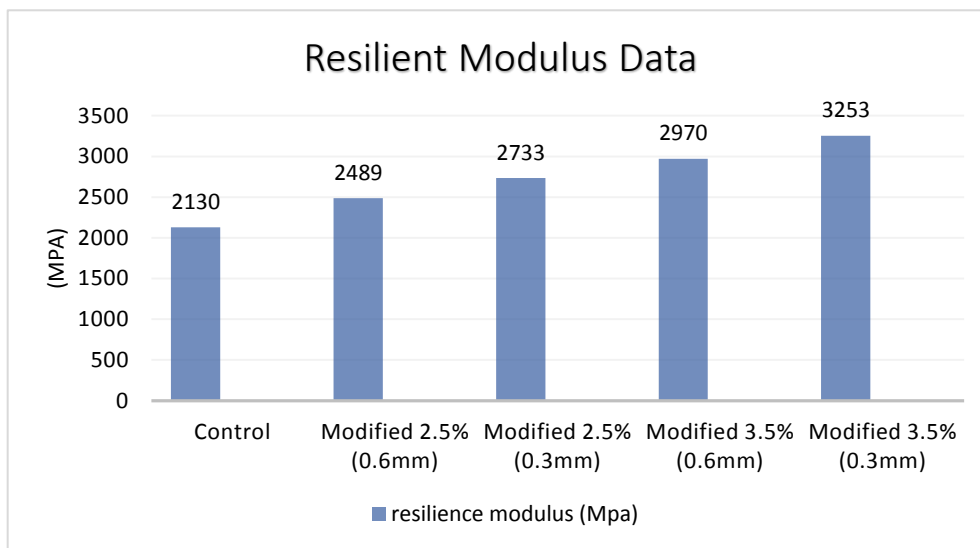


Figure 8. Resilient modulus data

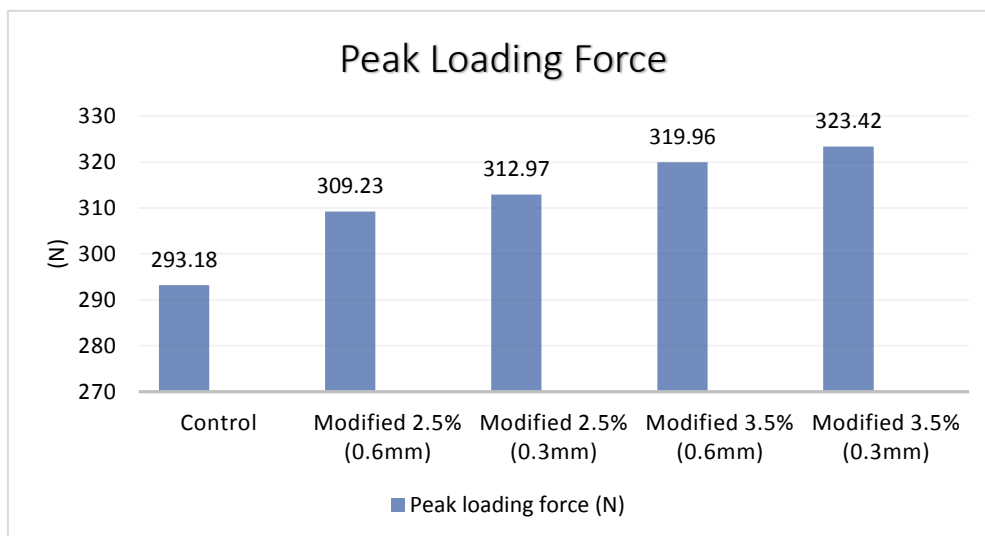


Figure 9. Peak loading force

5. Conclusion

In conclusion, based on the results of the analysis that were conducted in this study, addition of different crumb rubber sizes and percentage capacities evaluated clearly differences on the mechanical properties of asphalt pavement. Variety of crumb rubber sizes mainly influenced the mechanical properties of modified asphalt and produced better performance in the results of resilient modulus and peak loading force test. Modifier of (3.5% with 0.3mm) contributed to increase the stability value and decreasing the flow value therefore getting better stiffness value of Marshall test and resilient test. Crumb rubber is considering an excellent modifier in improving mechanical properties of asphalt pavement by improving the strength against deformation caused by heavy loads. Moreover, the usage of crumb rubber as an additive material is an effective way to solve waste disposal issues of scrap tires accumulated in landfill, thus reduce scrap tires volumes in landfill and decrease the contamination of weather resulted of burning the tires in some areas

6. References

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