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Investigation Moisture Damage Resistance of Asphalt Mixture Containing Crumb Rubber

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Abstract: Moisture content in pavement or asphalt mixture was commonly can cause major defect at the road such as potholes that can be dangerous to the road users. The dry process and wet process were the two conventional ways of incorporating the crumb rubber into asphalt mixtures. Dry process got more advantages rather than wet process. This study aims to determine the Optimum Bitumen Content (OBC) and also the Indirect Tensile Strength (ITS) of rubberized asphalt mixture. 1%, 2% and 3% of crumb rubber mixes were added by weight of aggregate The test that involve were air void density, specific gravity, penetration, softening and volumetric test to determine the Optimum Bitumen Content (OBC). For the performance test, ITS were conducted which was dry and wet method to produce ITSr to analysis the resistance of moisture content. The expected result was showed that the less of CR powder was the higher resistance of moisture content in the mixture. The amount of OBC that were achieved was 5.5% by weight if aggregate. The result for ITS by adding 1%, 2% and 3% of CR were 1139.72kN, 846.06kN and 778.79kN for dry sample and 1068.07kN, 711.69kN and 575.2kN. The ITSr result was increasing from 86.11% to 98.71% and then decreasing to 84.12% and 73.87% for the percentage of crumb rubber 2% and 3%. The Amount of CR powder effect the moisture content resistance. The more the CR in the asphalt mixture, the less strength it can bear.

Keywords: Moisture Content, Optimum Bitumen Content, Strength, Crumb Rubber

1. Introduction

As world were now having problem on managing waste non-degradable products materials such as plastic, and rubber tyre that will damage the environment [1]. The use of this materials mostly waste tyre rubber or crumb rubber particles has been suggested as recycle material for building and road construction. Crumb rubber (CR) was commonly used in construction to conserve the road construction materials and also reducing waste space to minimise environmental effects [2]. Many researchers came to the conclusion that crumb rubber modified (CRM) binders would create asphalt pavements with less noise pollution, lower maintenance or correction costs, and better fatigue and cracking resistance [3]. Crumb rubber in asphalt mixture was begun in Malaysia since 1940s, though there was no official

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record of such operations. Moisture damage which also known as moisture induced damage in bitumen aggregate systems was characterized as defect due to the water or moisture which can appear as a lack of bonding or cohesion [4]. Porthole was caused by moisture effect damages that also caused by rutting and cracking [10]. Rubber as an additive for road pavement material. Alternatively, crumb rubber that can be used in the road pavement due to its ability to reduce rubber waste also, reported can improve the asphalt mixture on reducing road damages. As discovered by the previous researchers, the physical properties of the rubber such as its type, quantity, shape, and grading were said to influence the efficiency of the rubber modified asphalt mix [5]. The paving industry was interested in the use of crumb rubber in asphalt substances because of the crumb rubber has an elastic property that has the ability to increase the skid-resistance and toughness of asphalt. Crumb rubber includes synthetic rubber, natural rubber, complete rubber hydrocarbon, and acetone extractable components, resulting in a crumb rubber of high toughness, viscosity, softening point, and resilience.Mainly, Dry Process (DP) and the Wet Process (WP) were the two methods of adding Crumb Rubber Modified (CRM) to hot mix asphalt concrete [6].

Using the crumb rubber as additive to the pavement road also reduce the disadvantages of the bitumen which was potholes and also increasing the lifespan of the pavement [7]. However, the issue of early pavement degradation, as well as the gradual rise in used tyres, caused road planners to integrate new rubber tyres into asphalt mixtures to avoid pavement distresses caused by overloads and environmental causes. This concept improves asphalt consistency and aids in the disposal of large amounts of excess tyres while still being environmentally safe. Many good characteristics have reported by the researches and applications of use the CR in the reinforcement of binders. But a few, improved resistance to surface initiated, improved durability, improved resistance to rutting, better resilience and high softening point, reduction in pavement maintenance costs, minimize temperature susceptibility, reduce fatigue cracks and saving energies and natural resources by using waste products [12].The objective of this study were to determine the Optimum Bitumen Content (OBC) and evaluate moisture damage resistance of rubberized asphalt mixture. This study focusing on moisture damage resistance of asphalt concrete mixture containing crumb rubber powder. Crumb rubber, with particles using sieve 0.150 mm and 0.425 mm was applied directly to the mixing phase to add 1%, 2% and 3% as additive [9]. Next, before undergoing the Modified Lottman test, the optimum content had been obtained.

2. Materials and Methods

This part outline and explained the framework and test methods that was conducted evaluate the resistance rubberised asphalt mixture on moisture using Indirect Tensile Strength. Besides that, the OBC was determined using Marshall and volumetric design.

2.1 Materials

To achieve specific objectives for this study, the aggregate, bitumen, filler and crumb rubber powder was prepared for the asphalt mixture [8]. Aggregate qualities were critical to roadway construction [13].the asphalt binder PG 70 was applied in this research for the production of HMA samples by using Marshall Mix Design method. Quarry Minyak Beku Sdn Bhd, Batu Pahat Johor, provided granite aggregate for this study. Crushed aggregate was dried for 24 hours before sieving into a size range according on the asphaltic concrete ACW14 gradation limit.

2.2 Sample Preparation

To examined the impact of the curing procedure, four type of specimen was generated which were different amount of crumb rubber to the sample. Each of the type of sample consist of 5 sample to be averaged. The percentage of crumb rubber that were generated was 0%, 1%, 2% and 3% which the crumb rubber were additive to this asphalt mixture [9]. For OBC, the aggregate were weighted which was 1200g used and add 2% of Portland cement by weight of the filler which was 24g [11].

The aggregate mixture were heated for 2-4 hours and bitumen 60/70 were heated 1 hour before mixing with temperature of 165°C. Mix the aggregate that had been heated up with bitumen for 120s. The sample need to be compact with 75 blow for both side with compactor machine. Then, the sample were cooled up for 24 hours before removing it from the mould.In addition, the size of filler was passing sieve size (0.075mm) and the crumb rubber size was 0.150mm and 0.425mm. The amount of crumb rubber that were used in the mixture was 1%, 2% and 3% which was 12.83g, 25.915g and 39.273g. Besides, after the sample had been prepared it need to undergo material testing and also advanced testing for the mixture.

2.3 Determination of Optimum Bitumen Content (OBC)

The percentages of bitumen employed in the Marshall Mix design approach to get OBC was 4.0 % to 6.0%. The value that was determined were also been used for performance test.

2.3.1 Air Voids

Air voids were defined as the air gap between the binder-coated asphalt aggregate particles for compacted mixes. The percentage of air vacuums in a compact pavement mix was estimated by calculating the bulk specimen gravity AASHTO T 166, but the recommended design of air voids was four percent for all levels of traffic and by calculating the theoretical highest species gravity AASHTO T 209 using equation:

$$Va = 100\,[(G_{mm} - G_{mb})/\,G_{mm}] \quad (1)$$

Where:
Va = Residual voids as a percentage of the total volume in a compact specimen
G_{mm} = Maximum Specific Gravity of paving mixture
G_{mb} = Bulk specific gravity of compacted mixture.

2.3.1 Air Voids in Mineral Aggregate

The intergranular void space between aggregate particles in compacted pavement mixtures was known as voids in mineral aggregate (VMA). The following equation demonstrates how to calculate:

$$VMA = 100 - (Gmb \times ps/Gsb) \quad (2)$$

Where;
Gsb = bulk specific gravity of total aggregates
Gmb = bulk specific gravity of compacted mixture
Ps = aggregate content, percent by total mixture

2.3.2 Voids Filled with Asphalt

The percentage of voids in mineral aggregate that were filled with asphalt was known as Voids Filled with Asphalt (VFA). The following equation demonstrates how to calculate:

$$VFA = 100 \times ((VMA - Va)/VMA) \quad (3)$$

2.4 Specific Gravity Test

The specific gravity test procedures start with fill one of the bottles with distilled water and place them on the stopper. Next set a bottle in a beaker of distilled water under its neck for at least 30 minutes at 27°C so that specific gravity can be determined. Remove the water bottle and remove the extra moisture outside the bottle which the bottle weight were state as *b*. Next, by using the heat the bitumen specimen will in a fluid condition. In a clear, dry, gravity container, pour the bituminous sample to half.

After that, let the bottle be partially fill at a temperature 60-70 so that the air bubbles can escape if they exist. Let the bottle cool down and weigh up to the appropriate temperature and this as *c* as weight. Air bubbles in the bottle were prevented. In the water bath, place the specific gravity bottle and fix it tightly for at least 30 minutes and then take the bottle from the water bath and wipe the excess humidity of a dry cloth put on the surface of the bottle. Again, measure the bottle weight. Note the weight down as d.

$$\text{Specific Gravity} = (c-a) / (b-a) - (d-c) \quad (4)$$

a = weight of that certain bottle of gravity
b = the specified bottle of gravity weight + the distilled water weight
c= weight of the particular gravity bottle + weight of the half-filled bottle specimen
d = weight of the specific gravity bottle + weight of half-filled specimens + weight of the filled water for the rest of the bottle

2.5 Penetration Test

The Penetration Test used to assess bitumen consistency by measuring the distance between the standard needle (reported in 10/mm) and the sample. In accordance with certain terms which was 100g loading, 25°C temperature, and five seconds for the time. In a penetrating cone, the heated bitumen sample was positioned so that the sample profile was 10mm larger than the predicted penetration when cooled. 3 sets of cones with a bitumen sample have been produced for this experiment. After that, the temperature of the bitumen in the bath was lowered down to keep at 25°C.

Before starting the penetration, the load was set at 100g before the needle was allow to penetrate the bitumen and the test was stop after 5 seconds. The findings of the diameter were recorded in which a penetration of 1 dcm or 0.1 mm equals. In order to validate the correctness of the result three 3 or more readings were obtained per cone.

2.6 Softening Test

The 60/70 sample penetration was heated to a pouring condition between 75°C and 100°C. The sample was then moved to eliminate bubbles of air. After that, underneath the ring were a series of brass rings heated and greased. The sample has been poured into the ring and cooled for 30 minutes also with a preheated sharp knife, excess samples were taken.

Next, the devices were put in position and placed within a beaker with distil water chill down to ice cubes, which were fill with distil water, up to 5.0 °C ± 0.5 °C. The device was left at temperature sustained for 15 minutes. After that, the heat was continued until the sample was softened and the ring was permitted. The ball's temperature contacts the bottom of the sample as the temperature at the softening point. This test shows how hard bitumen was.

2.7 Indirect Tensile Strength (ITS)

There were two subset specimens prepared: moist and dry subset specimens. The dry subset specimens were kept at room temperature for 24 hours, while the wet specimens were immersed in a 60°C water bath. The wet specimens were then immersed in water and subjected to 50 kPa vacuum pressures to achieve saturation levels of 70% to 80%.The wet and dry subsets were then conditioned for 2 hours at 25°C before being evaluated for indirect tensile strength (ITS). The specimens were put between steel load strips and a force of 50.8 mm/min was applied. The final result was an average of 5 specimens with about the same length and circumstances. The Equation was computed for the horizontal tensile strength as below:

$$\sigma = 2000F / \pi td \qquad (5)$$

Which:
σ = horizontal tensile strength (Kpa)
P = apply load (kN)
t = tested specimen thickness (mm)
d = specimen diameter (mm)

To assess moisture resistance, the results of ITS conditioned specimens were compared to those of unconditioned (dry) specimens. The moisture damage was targeted at least 80% according to the AASHTO T283 method, 36 specimens were produced and afterwards split into 2 groups with about the same average percentage of air spaces. Then, the tensile strength was tested in a set indirectly in dry, ITSd. After saturating vacuum conditioning and a warm bath between 40°C and 60°C, ITSw the indirect tensile strength of the other set was measured. The ITSR, defined as the ratio of the ITSw-ITSd averaged. The Equation was compute for the horizontal tensile strength as below:

$$ITSr = (ITS\ wet / ITS\ dry) \times 100 \quad (6)$$

Which;
ITSr = Indirect tensile strength ratio (%)
ITS wet = Average indirect tensile strength of the wet group (Kpa)
ITS dry = Average indirect tensile strength of the dry group (Kpa)

3. Results and Discussion

The findings of a variety of laboratory tests were presented and discussed in this Section. The aggregate, binder testing, (OBC), and indirect tensile test (ITS) were the first steps in the process.

3.1 Sieve Analysis Test

The sieve analysis test was crucial in mix design because it has an impact on the aggregate outcome and the binder mixing process. Furthermore, aggregate gradation has an impact on the road layer's performance. This test was referred to Marshall Gradation limit AC14. The size of the sieve that were used were 14mm, 5mm, 3.35mm, 1.18mm, 0.425mm, 0.150mm, 0.075mm, and the pan as the filler. The aggregate size distribution criteria were shown in the table below, and the sieve distribution curve for aggregate was shown in figured below:

Table 1: Marshall Design's aggregate size distribution criteria.

Sieve Size	Limit	Passing (%)	Retained (%)	Weight of Sample (g)
14	90-100	95	5	60
10	76-86	81	14	168
5	50-62	56	25	300
3.35	40-54	47	9	108
1.18	18-34	26	21	252
0.425	12-24	18	8	96
0.150	6-14	10	8	96
0.075	4-8	6	4	48
Pan	-	-	6	72
		Total	100	1200

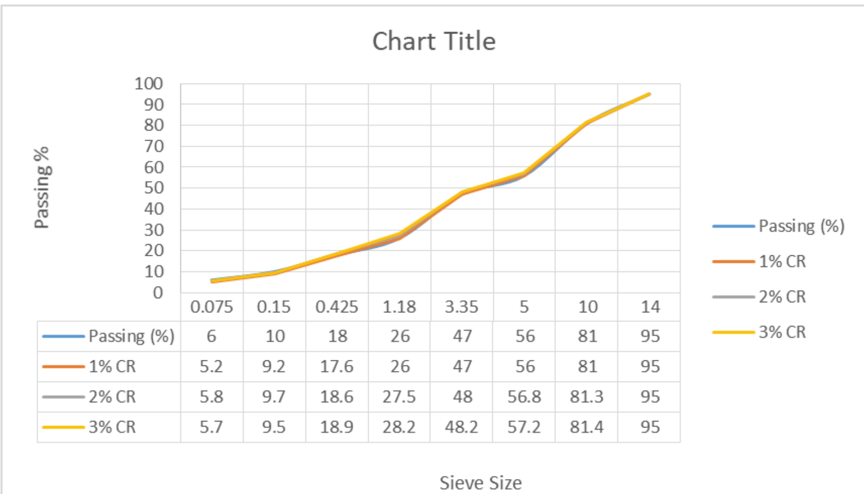

Figure 1: Sieve distribution curve aggregate.

3.1 Asphalt Binders Properties

The physical properties of control bitumen were determined by penetration tests and all results obtained must adhere to the standard. The bitumen that applied in this investigation was grade 60/70, which implies the penetration ranges from 60 to 70, and the penetration values were acquired. The penetration results for the control asphalt and modifying binder were 67.73 in average.

The softening point test was used to determine the temperature at which bitumen begins to melt. The result of this softening point for testing 1 and 2 does not had a big differences which were 55.1°C and 55.8°C. This shows a positive result, because the difference between the test 1 and 2 should not more that ±1°C. The result of softening point was 55.45°C in average for the two number of test.

3.3 Determining the Optimum Bitumen Content (OBC)

The Marshall Design test method was used to assess specimens with bitumen content of 4%, 4.5%, 5%, 5.5% and 6%. The tools and procedures for processing the samples in this study were based on ASTM D6927. The aggregate that were used was 1200g in weight. The results of a Marshall test on a combination with various binder contents were displayed. Result will show the correlations between binder content and mixture parameters such as stability, flow, V.F.B, V.I.M, and bulk density [14]. There were 25 samples of each sort of bitumen percentage (4%, 4.5%, 5%, 5.5% and 6% by total weight of aggregate) each weighing 1200g. In order to evaluate the appropriate bitumen content, a compactor was used with 75 blows for each face of the specimens at compaction temperature.

The ideal bitumen percentage was found to be 5.5% of the whole mix, calculated as the average of bitumen content values corresponding to maximum stability, maximum density, and median of the air voids, with a flow of 3mm and a VIM of 4%. 5.5% of bitumen content was about 69.84 gram of bitumen by weight of the sample. The Marshall result was all good based on the specification OBC value below:

Table 2: Marshall Result and Specification at OBC Value

Parameter	Test Value	Specification (JKR, 2008)	Condition
Stability (N)	15000	> 8000	OK
Flow (mm)	2.98	2.0 - 4.0	OK
Stiffness (N/mm)	5100	> 2000	OK
VIM (%)	4.4	3.0% – 5.0%	OK
VFB (%)	74.0	70% – 80%	OK

3.4 Indirect Tensile Strength (ITS) Test

Trial sample were made to identify how much blow in the compacter used to get 7.0% air void in the sample. They were five type of blows that were made which were 30, 40, 50, 60 and 70 blows. The result of the trial sample to get 7.0% of air void in the sample as below:

Table 3: Void in Mixture for each type of blows

Blows	Theoretical Specific Gravity, Gt	Bulk Specific Gravity, Gm	Void In Mixture, VIM
30	2.461	2.255	8.376
40	2.461	2.297	6.668
50	2.461	2.312	6.070
60	2.461	2.341	4.882
70	2.461	2.340	4.943

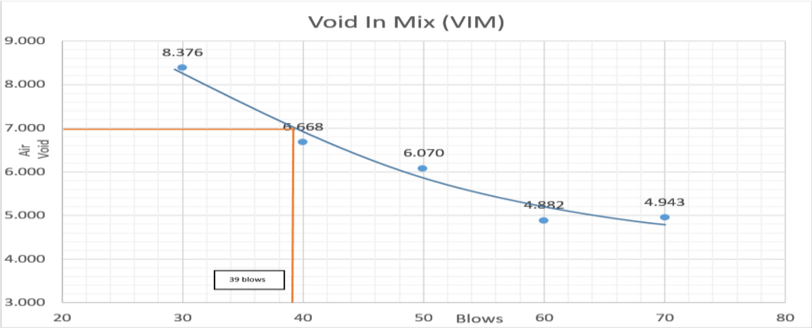

Figure 2: Number of blows for 7.0% air void

From this result, the number of blows for the compacter were 39 blows to get 7% of air void in the sample. After the number of air void have been determined, the test for determined the Indirect Tensile Strength can be performed. It can be seen also that the less the blows for compact at sample, the more the air void in the sample acquire.

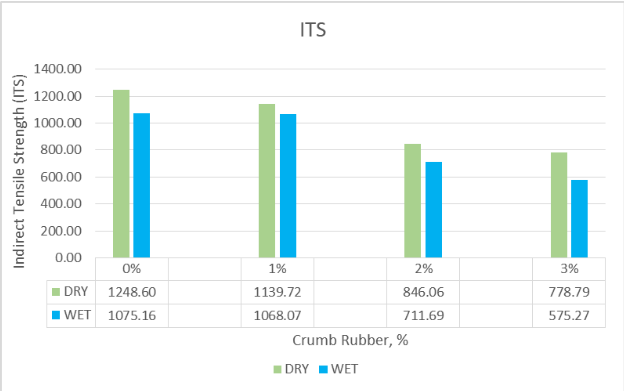

Figure 3: Comparison of Indirect Tensile (ITS) by crumb rubber percentages

The bar chart shows that as the percentage of crumb rubber increases, the ITS value drops. Increased crumb rubber percentages, on the other hand, reduce the ITS value for all types of blends. By adding 1%, 2% and 3% the ITS values for the sample decrease to 1139.72kN, 846.06kN and 778.79Kn for Dry sample. Meanwhile for wet sample also was the same, the value of ITS decreases to 1068.07kN, 711.69kN and 575.27kN along with the addition of crumb rubber. The percentage for dry sample were decreasing to 91%, 68% and 62%. Meanwhile for wet sample decreasing from 99%, 66% and 54%.

3.4 Indirect Tensile Strength ratio (ITSr)

The 1% crumb rubber added shows increasing from 86.11% to 98.71% and then decreasing to 84.12% and 73.87% for the percentage of crumb rubber 2% and 3%. The result can be shown in the below:

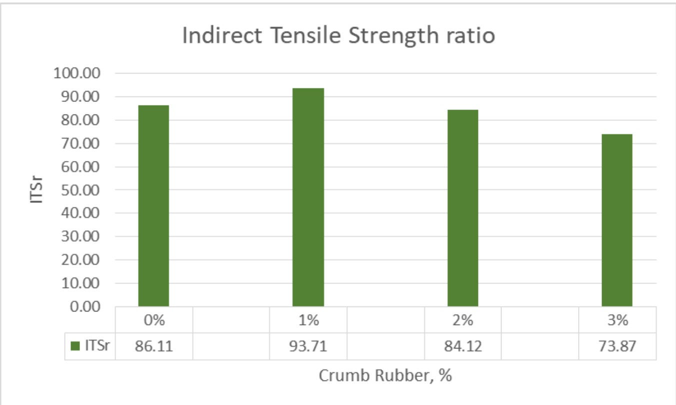

Figure 4: Comparison of resistance of moisture sensitivity of different percentage of crumb rubber

Although the crumb rubber can increase the percentage of ITSr, it also can decrease the percentage if the amount of crumb rubber added to the asphalt mixture was too big which can be picture by the result of 1%, 2% and 3% amount of crumb rubber. It could related to the compaction of the mixture, that resulting tensile strength values may decrease as the amount of crumb rubber was increased. Crumb rubber may create larger air gaps in the mixture, resulting in decreased cohesion and a poor response to moisture action (Moreno et al. 2012).

4. Conclusion

The moisture susceptibility features of asphalt concrete with crumb rubber were studied in this study utilising ASHTO T283 tests. As an additive, 1% 2%, and 3% crumb rubber powder with sizes of 0.150 and 0.425mm were added to the aggregate mixture. The aggregate that was used came in a variety of gradations, and the Marshall Mix Design standard gradation limit was followed.

The first objective was achieved which was to determine the Optimum Bitumen Content (OBC) of rubberised asphalt mixture. 18 sample were made to determine the OBC. The amount of bitumen that were used were 4%, 4.5%, 5%, 5.5% and 6% by weight of the aggregate which was 1200g and each type of sample had 4 sample to be averaged. The type of bitumen that had been used was 60/70. The bitumen result for the penetration test and softening point was improved and it shown that the bitumen was stiffness and good temperature susceptibility which still in specification bitumen for grade 60/70 or PG70. After all the Marshall Mix Design testing which were stiffness, flow, specific gravity, stiffness, VMA and VFB were done, the OBC value of 5.5% which 69.84g of bitumen were get.

The second objective was to evaluate moisture damage resistance of rubberised asphalt mixture also achieved. The strength of the compacted specimens was tested using water immersion and unconditioned specimens which was dry and wet. The percentage for dry sample was decreasing to 91%, 68% and 62%. Meanwhile for wet sample decreasing from 99%, 66% and 54%.It can be determined that the crumb rubber percentages have an effect on the tensile strength value. For ITS it can be seen that adding to much amount crumb rubber in the mixture can lead to decreasing the strength of mixture. For 1% crumb rubber in ITSr the strength decrease just a few but adding more which were 2% and 3% can lead to decreasing ITSr. For ITSr the ideal amount was in 80% which 3% of crumb rubber was excluded.In conclusion, the two objective were achieved and increasing the rubber content decreased the tensile strength of the mixtures, indicating that the rubberized mixtures' structural capabilities had been negatively impacted.

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