LABORATORY EVALUATION OF ITS TEST ON ASPHALT MODIFIED WITH VARIOUS RANGES OF CRUMB RUBBER

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ABSTRACT

The rubber which is generated from scrap tyres (tires), identified by crumb or powdered rubber. Day after day, discarded or scrap tyres create huge environmental problems. As long as the scrap tyres are regarded as a non-decade material those disrupt the clean environment. Using this rubber in pavement and asphalt has become a great interest and proposal for researchers for overcome this issue in recent years. Researchers and engineers discovered another way to improve asphalt concrete, by adding crumb rubber (CR) into asphalt concrete. This is done by two methods; first method rubber placed in bitumen and completely or partially reacted with bitumen, this will become binder modifier (wet process). Second method replacing this rubber with fine aggregates which are not dissolved completely with bitumen (dry process). In this study crumb rubber is added into mixture initially by substituting rubber with amount of fine aggregate. Thereafter laboratory tests; penetration, ductility, softening point, elastic recovery and moisture susceptibility test were conducted. These tests were performed, investigated and compared to evaluate the effect of indirect tensile strength (ITS) on asphalt concrete modified with several ranges of crumb rubber. It has been shown that (0%) is control sample, while (2, 4, 6, 8 and 10) are percent of rubber by the total weight of aggregate. One of the critical issues in asphalt pavement is moisture damage. The existence of moisture play a great role in reducing the stiffness of the asphalt mix as well as makes the chance for stripping of the asphalt from the aggregate. This study evaluates the strength loss by comparing two methods of ITS test, which are conditioned (tested in saturated state) and unconditioned (tested in dry state) samples. Marshall Mix method was applied for preparation of total 24 samples for both states of ITS. The results show that for conditioned samples 6% of CR gives the highest value of tensile strength, (892) Kpa. While in unconditioned samples, 10% of CR gives even higher value of strength, compared to conditioned and control sample, (933) Kpa. According to AASHTO T 283-14, the tensile strength ratio (TSR) results of all samples are within the standards, using the minimum value of 80%. For asphalt modified with (2, 4, 6, 8 and 10) % of CR, the TSR values are (95.3, 97.7, 97.4, 93.6 and 90.9) % respectively. Moreover the results are discussed in detail in this study. As summary, the optimal dose of CR is 4% which gives better performance for penetration, softening point, elastic recovery and tensile strength ratio.

Contribution/Originality: This study contributes in the existing literature, to investigate the binding medium between concrete asphalt with crumb rubber. This study uses new methodology which is called Wet Process, mixing crumb rubber with asphalt prior to the aggregate. This study originates new formula to improve asphalt and
asphalt concrete. This study is one of very few studies which have investigated tensile strength ratio (TSR) by using Indirect Tensile Strength Test, and elastic recovery for conventional mixture.

1. INTRODUCTION

Rubberized asphalt binder involves the mixture of normal asphalt binder with crumb rubber resulting from vehicles and automobile tires. With the rapid increase in development of the vehicle industry and factory, the number of individual that possess a car is growing and increasing each year. This huge amount of scrap and unwanted tires are indications for facing and dealing with a serious problem nowadays and in future [1]. Old tires actually do not decay and are permanent environmental matter. Unfortunately, tires are intended to be firm and are characterized by their chemical, biological, and physical resistance, which make them difficult to resolve [2]. Referring to the total weight of tires, there are three main components of tires: 22% almost synthetic fiber, 18% steel wire, and 60% rubber. As well as there are two procedures for pulverizing scrapping tires into crumb rubber: the ambient or cryogenic grinding procedures are used [3].

Recycling and repurposing are two thinkable approaches for disposing discarded tires. Yearly almost 80% of scrap tires have been recycled or repurposed, since 2003 Rangaraju [1]. There are various techniques to reuse these scrap tires, most common method is to apply in civil engineering applications [4]. Numerous investigations have studied the performance of asphalt mixtures that use crumb rubber obtained from squander tires. Studies have found adding crumb rubber into asphalt mixture has many advantages, reutilizing the rubber of scrap tire facilitate the pressure on atmosphere and enhance the performance of asphalt. Due to this, the performance of pavements depend on bituminous mixture, external and environmental factors such as heavier loads, higher traffic volume, higher tire pressure and climate circumstances like high or low temperature [5]. In addition, there is another serious distress in pavements which is moisture damage in bituminous mixtures. Moisture may harm and damage asphalt concrete by three behaviors. Initially, the loss of cohesion of the asphalt layers which is caused by merging the moisture with asphalt. Secondly, the reason behind the bond failure at the asphalt aggregate interface is water. Lastly, the effect of moisture in the asphalt concrete may result in disintegration of the aggregate in the concrete. These defects in concrete are known as stripping. Stripping in asphalt pavements can lead to early destruction of the pavement structure [6].

Crumb rubber is antistripping agent. Assists the flexible pavement to improve the binder stability at high temperature, crack resistance at low temperatures and fatigue resistance [1]. Regardless of its many advantages, hot mixed asphalt that contain crumb from waste tires are infrequently recycled in some countries [2]. Iraq is an example, possibly because of the lack of researches that focuses its benefits in Iraq circumstance.

The scope of this study is to determine the tensile strength ratio (TSR) and elastic recovery for conventional mixture then compare them with crumb rubber modified asphalt (CRMA) with different percentages of rubber. Also the laboratory evaluation focuses on asphalt mixture tests for instance; penetration, ductility and softening point. In addition, Marshall Mix design was conducted to determine Optimum Bitumen Content (OBC) which was 5.2% of the total weight of the aggregate. 4% is the optimal CR content which was added to the mixture as additive.

2. MATERIALS AND EXPERIMENT PREPARATIONS

2.1. Aggregate

The aggregates used in the tests were from the type of lime aggregate and they are of various sizes from the biggest size 38 mm to smallest size of 0.075 mm. Gradation of aggregate used in this test is according to GDH of Turkish Highway Construction Specification Standards for use in surface course pavements. The physical properties of aggregate are summarized in Table 1.
Table 1. Physical properties of aggregate used in this study

| Properties                                      | Test Results | Standards     |
|------------------------------------------------|--------------|---------------|
| Specific Gravity of coarse aggregate, 25°C, gr/cm³ | 2.672        | ASTM C127-07  |
| Water Absorption of coarse aggregate, %         | 1.343        | ASTM C127-07  |
| Specific Gravity of fine aggregate, 25°C, gr/cm³ | 2.674        | ASTM C128-07a |
| Water Absorption of fine aggregate, %           | 0.606        | ASTM C128-07a |
| Specific Gravity of filler, 25°C, gr/cm³        | 2.75         | ASTM C128-07a |
| Los Angeles test, %                             | 26.12        | ASTM C535-09  |
| NaSO₄ Soundness, %                              | 4.05         | ASTM C 88     |

2.2. Bitumen

The bitumen type used here was the PGB 50/70 which is a standard Penetration Grade Bitumen (PGB). Commonly used as a paving grade of bitumen, this is proper for road constructions mostly for wearing courses as well as for manufacturing of asphalt pavements with greater and better properties. The properties of neat bitumen are shown in Table 3.

2.3. Crumb Rubber

The CR used in this research is 100% of Turkish sources it is taken from (Akyüz İnovasyon ve Geri Dönüşüm Teknolojileri San.Ve Tic.A.Ş) in Istanbul city, Turkey. Its trademark is registered as CRM 300. It’s also called fine crumb rubber because by making sieve analysis, particles retains on sieve no. 0.125 mm and 0.075 mm respectively.

Table 2. Sieve Analysis for crumb rubber

| Sieve Size (mm) | Retained (gm) |
|-----------------|---------------|
| 25              | 0             |
| 19              | 0             |
| 12.5            | 0             |
| 9.5             | 0             |
| 6.3             | 0             |
| 4.8             | 0             |
| 2               | 0             |
| 1               | 0             |
| 0.25            | 245           |
| 0.125           | 56.5          |
| 0.075           | 2.5           |
| filler          |               |

Fig-1. Sieve analysis for CR

Fig-2. Crumb Rubber

Table 3. Properties of neat bitumen with crumb rubber modified asphalt

| Properties                      | Values | Standards     |
|---------------------------------|--------|---------------|
| Penetration at 25°C, 1/10 mm    | 69.1   | EN 1426       |
| Ductility at 25°C, cm           | 100    | ASTM D 113    |
| Softening Point, ºC             | 51.3   | EN1 27        |
| Elastic Recovery, % (25°C)      | 15     | STM D 6084    |
|                                 | 15.2   |               |
|                                 | 35     |               |
|                                 | 37.8   |               |
|                                 | 38.6   |               |
|                                 | 41     |               |
2.4. Mix Design Method

Marshall Design Method was used to prepare the samples for I.T.S. which was conducted according to ASTM D 6931 standard. Specimens were left to cool in a controlled temperature cabinet at 25°C for at least 3 hours. For pavement engineers, the tensile properties are of great interest for bituminous mixtures, because of the problems related to cracking [6].

24 specimens were prepared for each additive (0-2-4-6-8-10) %; they divided into two groups (12 specimens each). The first 12 samples were submerged in a water bath at 60°C, for 24 hours (conditioned sample). The samples are then removed from the water bath and kept at a temperature of 25°C for a period of 2 hours. Other set of samples (unconditioned sample) were kept at a temperature of 25°C for a period of 2 hours without submerging in a water bath. Then these samples were mounted on the conventional Marshall testing apparatus and loaded at a deformation rate of 51mm/min and the failure load is recorded at each case. Then the tensile strength of conditioned as well as unconditioned specimen for each additive stabilized mixture is determined. The following is the detail for Marshall Preparation.

3. RESULTS AND DISCUSSIONS

3.1. Indirect Tensile Strength

The ITS of bituminous blends is performed by loading a cylindrical specimen laterally by vertical diametric plane at a specified rate of deformation.

Two types of HMA samples are subjected to a moisture susceptibility test (usually called as Indirect Tensile Strength test (ITS). One type is used as a control (unconditioned) by leave it in room temperature at 25 °C. The other type is conditioned by saturating with water, soaking in water for 24 hours. Tensile Strength Ratio (TSR) is defined as the ratio of the average tensile strength of the conditioned samples over the average tensile strength of the unconditioned (control) samples.
Fig-7. Loads acting vertically on compacted specimen

Fig-8. Schematic represents ITS test

Samples prepared by Marshall Mix Design

Samples placed in distilled water

Sample during ITS test

Fig-9. Indirect Tensile Test

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Moisture Susceptibility Test (Indirect Tensile Strength) Test

Preparing samples by Marshall Design Method

1. Aggregate total weight = 1150 grams.
2. Bitumen Content (BC) % = (4 – 7) %, 0.5 % increment value.
3. Number of blows = 50 blows for medium traffic.
4. AC specimens dia. = 4 in., h = 2.5 in.
5. Marshall Hammer = weight 10 lbs. (4.5) kg, free fall 18 in. (45.7) cm.
6. Specimen compacting temperature = (145 – 150) °C.
7. Heating temperature of aggregate before starting the test = 160 °C.
8. Marshall testing apparatus, loaded at a deformation rate of 51mm/min.
9. The Optimum Bitumen content (OBC) for the mixture is determined to be 5.2 % (by weight of total mix).
Preparation of samples for ITS test (wet state)
1. Twelve Marshall samples were prepared and compacted with Marshall hammer.
2. Samples were left to a room temperature for some hours between (3-4) hours to cool.
3. Samples were placed and were left in a water bath in which the container is
   prefilled with water until the sample is
   covered by 1 inch (25 mm) of water.
4. The bulk specific gravity (G_mm) and the SSD
   mass were calculated and determined for
   comparing the volume of absorbed water.
5. The degree of saturation is determined by
   comparing volume of absorbed water with
   volume of air voids (V_a).
6. Indirect tensile test is run on each sample by
   placing the sample between the two bearing
   plates in the testing machine and applying the
   load at a constant rate of 2 inches/minute
   (50 mm/min).
7. The tensile strength values are recorded.

Preparation of samples for ITS test (dry state)
1. Twelve Marshall samples were prepared and compacted with Marshall hammer.
2. The bulk specific gravity (G_mm) and the SSD
   mass were calculated and determined for
   comparing the volume of absorbed water.
3. The degree of saturation is determined by
   comparing volume of absorbed water with
   volume of air voids (V_a).
4. Indirect tensile test is run on each sample by
   placing the sample between the two bearing
   plates in the testing machine and applying the
   load at a constant rate of 2 inches/minute
   (50 mm/min).
5. The tensile strength values are recorded.

3.2. Indirect Tensile Strength for Conditioned Samples
The results for ITS of conditioned samples, inverses with dry stated samples, as shown in table 4. By adding (2, 4, 6)% of CR to the bitumen binder, the strength increases and reaches the maximum value by adding 6% of CR as compared to control mix. But a sudden decrease can be seen by adding 8% and 10% of CR by 857.722 kpa to 847.997 kpa respectively.

Table 4. Indirect tensile strength results for conditioned samples

| No | h1 (mm) | h2 (mm) | h3 (mm) | hav (mm) | Wair (gr) | Wwater (gr) | Gmm | Gmb | Va | P Load (kN) | P Load (N) | Tensile Strength (MPa) | Tensile Strength (kPa) |
|----|---------|---------|---------|----------|-----------|-------------|------|------|----|--------------|-------------|----------------------|----------------------|
| 1  | C1      | 61.68   | 61.70   | 61.78   | 61.72     | 1194.9      | 698.1 | 2.405 | 2.484 | 8.692        | 8692        | 0.882                | 882.428               |
| 2  | C2      | 62.17   | 62.19   | 62.21   | 62.19     | 1196.6      | 699.8 | 2.409 | 2.484 | 8.563        | 8563        | 0.863                | 862.762               |
| 3  | R1      | 62.30   | 62.26   | 62.30   | 62.29     | 1192.6      | 695.8 | 2.401 | 2.485 | 8.567        | 8567        | 0.862                | 857.619               |
| 4  | R2      | 62.62   | 62.69   | 62.53   | 62.61     | 1191.6      | 696.3 | 2.406 | 2.485 | 8.546        | 8546        | 0.855                | 855.227               |
| 5  | R3      | 62.45   | 62.45   | 62.45   | 62.45     | 1192.1      | 696.1 | 2.403 | 2.485 | 8.557        | 8557        | 0.859                | 858.505               |
| 6  | R4      | 62.40   | 62.37   | 62.55   | 62.57     | 1194.8      | 698.3 | 2.408 | 2.486 | 8.746        | 8746        | 0.879                | 878.610               |
| 7  | R5      | 62.49   | 62.36   | 62.47   | 62.44     | 1197.0      | 700.8 | 2.412 | 2.486 | 8.771        | 8771        | 0.880                | 880.180               |
| 8  | R6      | 63.41   | 63.57   | 63.64   | 63.41     | 1195.7      | 699.6 | 2.410 | 2.486 | 8.759        | 8759        | 0.879                | 879.395               |
| 9  | R7      | 62.96   | 62.95   | 62.96   | 62.96     | 1195.9      | 697.3 | 2.389 | 2.486 | 8.762        | 8762        | 0.877                | 876.703               |
| 10 | R8      | 62.10   | 62.02   | 62.04   | 62.05     | 1197.0      | 700.8 | 2.412 | 2.486 | 8.987        | 8987        | 0.907                | 907.476               |
| 11 | R9      | 62.34   | 62.34   | 62.34   | 62.34     | 1196.5      | 699.1 | 2.405 | 2.486 | 8.875        | 8875        | 0.892                | 892.089               |
| 12 | R10     | 62.27   | 62.42   | 62.34   | 62.34     | 1186.3      | 690.8 | 2.394 | 2.487 | 8.352        | 8352        | 0.839                | 839.433               |
| 13 | R11     | 62.74   | 62.84   | 62.76   | 62.78     | 1192.1      | 694.4 | 2.385 | 2.487 | 8.777        | 8777        | 0.876                | 876.012               |
| 14 | R12     | 62.56   | 62.56   | 62.56   | 62.56     | 1189.2      | 692.6 | 2.395 | 2.487 | 8.777        | 8777        | 0.876                | 876.012               |
| 15 | R13     | 63.13   | 63.11   | 63.16   | 63.13     | 1200.5      | 697.4 | 2.386 | 2.488 | 8.863        | 8863        | 0.880                | 879.645               |
| 16 | R14     | 63.31   | 63.42   | 63.24   | 63.32     | 1198.5      | 695.7 | 2.384 | 2.488 | 8.250        | 8250        | 0.816                | 816.348               |
| 17 | R15     | 63.23   | 63.23   | 63.23   | 63.23     | 1199.5      | 696.6 | 2.385 | 2.488 | 8.557        | 8557        | 0.848                | 847.997               |
3.4. Indirect Tensile Strength for Unconditioned Samples

ITS of Unconditioned samples decreases by adding (2, 4 and 6) % of CR as compared to control mix which has greater value of 912.531 KPa, as shown in Table 5. But there is a sudden increase by adding 8% and 10% of CR by 916.350 kpa and 933.390 kpa respectively can be seen. At last a concaved up curve will be achieved.

Table 5. Indirect tensile strength results for unconditioned samples

| CR % | $H_c$ (mm) | $W_{ce}$ (gr) | $W_v$ (gr) | $G_{cm}$ | $G_{ab}$ | $V_c$ | $P$ (kN) | Tensile Strength (MPa) | Tensile Strength (KPa) |
|------|------------|---------------|------------|---------|---------|------|--------|-----------------------|----------------------|
| 0    | 61.96      | 1195.8        | 699.0      | 2.407   | 2.484   | 3.1  | 8.628  | 0.863                 | 872.595              |
| 2    | 62.45      | 1192.1        | 696.1      | 2.403   | 2.485   | 3.3  | 8.557  | 0.859                 | 858.526              |
| 4    | 62.41      | 1195.7        | 699.6      | 2.410   | 2.486   | 3.1  | 8.750  | 0.879                 | 879.395              |
| 6    | 62.34      | 1196.5        | 699.1      | 2.405   | 2.486   | 3.2  | 8.875  | 0.892                 | 892.089              |
| 8    | 62.56      | 1189.2        | 692.6      | 2.395   | 2.487   | 3.7  | 8.565  | 0.858                 | 857.722              |
| 10   | 63.23      | 1199.5        | 696.6      | 2.385   | 2.488   | 4.1  | 8.557  | 0.848                 | 847.997              |

Fig-10. ITS values of conditioned samples vs. CR content

Fig-11. ITS values of unconditioned samples vs. CR content
3.5. Tensile Strength Ratio

Tensile Strength Ratio (TSR) is the last step for this test can be found by calculating tensile strength ratio (TSR) before and after conditioning. In Fig 12. TSR value results are shown and a half concaved down curve is achieved. There is a very important point should be discussed which is moisture damage; it is the result of moisture interaction with the asphalt binder - aggregate adhesion within a HMA mixture.

The ITS test is a performance test which is often used to evaluate the moisture susceptibility of a bituminous mixture. Tensile strength ratio (TSR) is a measure of water sensitivity. It is the ratio of the tensile strength of water conditioned specimen, (ITS wet, 60˚C, and 24 h) to the tensile strength of unconditioned specimen (ITS dry) which is expressed as a percentage. A higher TSR value typically indicates that the mixture will perform well with a good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water soaking condition, or the more water-resistant it will be [6].

![Fig-12. TSR values vs. CR content]

Table-6. Tensile strength ratio results

| CR (%) | Dry State (Unconditioned) | Wet state (Conditioned) | Tensile Strength Ratio (TSR) (%) |
|--------|--------------------------|-------------------------|----------------------------------|
| 0      | 912.531                  | 872.595                 | 95.6                             |
| 2      | 900.998                  | 858.526                 | 95.3                             |
| 4      | 900.144                  | 879.395                 | 97.7                             |
| 6      | 895.356                  | 872.089                 | 97.4                             |
| 8      | 916.350                  | 857.722                 | 93.6                             |
| 10     | 933.390                  | 847.997                 | 90.9                             |

\[
TSR = \frac{S_1}{S_2} \times 100
\]

Where:

- \( S_1 \) = Average tensile strength of unconditioned samples
- \( S_2 \) = Average tensile strength of conditioned samples

4. CONCLUSION

Based on the results in this laboratory evaluation, the conclusions of this study are summarized as the following:

1. Crumb rubber is proposed by many scholars as asphalt additive, moreover the results are within the standard requirements.

2. By increasing the addition amount of CR to asphalt, penetration, ductility, softening point and elastic recovery values will change. Compared to the control mix sample 0%, penetration and ductility values decrease by increasing the amount of CR. Meanwhile softening point and elastic recovery will increase as shown in table 3. Most significant improvement noticed in this study is higher elastic recovery values.
From the addition of 10% of CR to the asphalt binder, the elastic recovery value gave highest value of 41% as compared to conventional sample 0% which was 13%.

3. ITS of Unconditioned samples decreases by adding 2%, 4% and 6% of CR modifier as compared to control mix which has value 912.531 kpa, 900.098 kpa, 900.144 kpa and 881.356 kpa respectively. But there is a sudden increase by adding 8% and 10% of CR by 916.350 kpa and 933.390 kpa respectively. ITS of Conditioned samples, as it inverses with unconditioned samples, by adding the amount 2%, 4%, 6% of CR to the bitumen binder it increases the tensile strength value up to 6% as compared to the control mix, from 913.252 kpa to 858.526 kpa, 879.395 kpa and 892.089 kpa respectively. But a sudden decrease can be seen by adding 8% and 10% of CR by 857.722 kpa and 847.997 kpa respectively.

4. As summary the scope of this study is to determine the tensile strength ratio (TSR) and elastic recovery for conventional mixture. Later step is to compare them with crumb rubber modified asphalt (CRMA) with different percentages of rubber. Also the laboratory evaluation focuses on asphalt mixture tests for instance; penetration, ductility and softening point. In addition, Marshall Mix design was conducted to determine Optimum Bitumen Content (OBC) which was 5.2% of the total weight of the aggregate. 4% is the optimal CR content which was added to the mixture as additive.

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