The Effect of Crumb Rubber on Asphalt Concrete

Asmaa Abdulmajeed Mamhusseini[1]

[1]Civil Engineering Department, Faculty of Engineering, Tishk International University, Erbil, Iraq
Correspondence: Asmaa.Abdulmajeed Mamhusseini, Tishk International University, Erbil, Iraq.
Email: Asmaa.abdulmajeed@tiu.edu.iq

Doi: 10.23918/eajse.v6i2p53

Abstract: One of the major problems caused by environmental pollution in the world is waste tires (tyres). Millions of waste tires are stockpiling each year in the world. In order to minimize this pollution, a method applied to reuse these waste materials in hot mix asphalt to improve the properties of asphalt concrete. The purpose of this study is to investigate the effects of Crumb Rubber (CR) obtained from the waste tires on the properties of the mixes as an additive. This material (Rubber) which is made from the scrap tyres, usually known as Crumb Rubber, can be used in the asphalt mixture processes either wet process (as binder modifier) or dry process (as a fine aggregate replacement). In both processes (wet and dry), at high temperature rubber particles and bitumen react with each other. Also 50/70 penetration asphalt was modified in this study by mixing with (2,4,6,8 and 10) % of Crumb Rubber by weight of the bitumen using the dry process method. In order to investigate the effects of Crumb Rubber on the physical properties of the bitumen, Ductility, Softening Point, Penetration and Elastic Recovery tests were performed on the bitumen modified with Crumb Rubber. Marshall Design Method was used to determine the optimum bitumen content. The stability value of the specimen with 4 % of Crumb Rubber was found to be the maximum.

Keywords: Crumb Rubber, Asphalt Mixture, Dry Process, Waste Tires

1. Introduction

The Crumb Rubber is a waste which is acquired from the use of tyres or (tires) that has been discarded and no more needed to use. By means of crumb rubber produced from scrap tyres of most vehicles like cars, trucks, buses, automobiles etc. In recent years scrap tyres has become a serious trouble which threatens the community health, and they have become the source of environmental issues and air pollution. As well as they are the base of growth and developing ground for mosquitoes to transmit diseases from a place to another, especially in places with hot climates faces more than other cold climates to catching different diseases, like Dengue fever, which leads sudden fever and strong pains in the joints besides of being a major annoyance. The idea of modifying asphalt is not something new; in real, throughout the past 20 years there have been various attempts to modify asphalt to get a better quality of performance and getting better asphalt mixtures. Jiang (2005) stated that with the rapid development of the automobile industry and higher standard of living of people in the world and China as an example, the quantity of autos increased sharply, China is facing the environmental problem related to the disposal of large-scale waste tires. In accordance with the statistical data, 80 million scrap tires were produced in 2002, and with 12% of growth rate every year, the total number of abandoned tires will be expected to reach 120 million in 2005 and 200 million in 2010.

Received: September 15, 2020
Accepted: November 19, 2020
Mamhusseini, A.A. (2020). The Effect of Crumb Rubber on Asphalt Concrete. *Eurasian Journal of Science & Engineering,* 6(2), 53-63.

How to deal with the huge number of waste tires has become an urgent problem of environment in the world.The disposal of waste tires in the world primarily has three ways to deal with such as landfill, burning and recycling. Recycled tire rubber applied to pavement may be the best way to reduce waste tires in large quantities and, at the same time, improve some engineering properties of asphalt mixtures. Sufian & Mustafa (1997) surveyed this phenomenon in Malaysia, the use of crumb rubber as an additive for road pavement construction supposedly started in the 1940s, but there has not been any official record of such practices. The first recorded trial using rubberized bitumen technology was reported in 1988, and the wet mix process was used with the mix of rubber additives in the form of latex into bitumen binder. Before Sufian and Mustafa, (Samsuri, Hasshim, Harun and Dewa, 1995) showed that in 1993, another rubberized road trial using waste gloves and natural rubber latex was carried out in Negeri Sembilan.

In addition, Mashaan, Ali, Karim and Abdelaziz, (2011) showed that Malaysia's production of scrap tyres is about 10 million pieces per annum, and unfortunately, they are being disposed in an environmentally unfriendly manner. To minimize the damage of pavement such as resistance to rutting and fatigue cracking, asphalt needs to be modified with selected polymer such as crumb rubber modifier (CRM), and it will definitely be environmentally beneficial as well as improve the bitumen properties, durability, and reduces cost of rehabilitation. Crumb rubber can be incorporated by a wet process or dry process. In 1989, (Roberts, Kandhal, Brown and Dunning) stated that wet process refers to modification of asphalt cement binder with 5–25 wt% of fine tire rubber crumb modifier (CRM) at an elevated temperature. The dry process includes mixing the rubber particles with aggregates prior to addition to asphalt. The main differences between the two processes consist in rubber particle size, rubber amount, rubber function, and incorporation facility.

2. Materials Used

2.1 Aggregate

Aggregate is a collaborated term for the mineral materials such as sand, gravel and crushed stone in which they are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.). 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.

2.2 Bitumen

The bitumen type used in this research was PGB 50/70 which is a standard Penetration Grade Bitumen (PGB), generally used as a Paving Grade of Bitumen which is suitable for road constructions and for producing of asphalt pavements with superior and better properties. Table 1 shows the characteristics and specifications of PG 50/70.

Table 1: Characteristics and specifications of PG 50/70

Characteristic	Test Method	Unit	Min.	Max.
Penetration at 25 °C, 100 g, 5 s	EN 1426	mm	50.0	70.0
Softening Point (Ring & Ball)	EN 1427	°C	46.0	56.0
Flashpoint (Cleveland Open)	EN 2592	°C	230.0	-
Kinematic Viscosity @ 135 °C	EN 12595	mm²/s	295.0	-
Solubility	EN 12592	%	99.0	-

2.3 Crumb Rubber Modifier (CRM)

The CR used in this research is 100 % of Turkish sources and 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 CR and it is declared that this type of CR retains on sieve no. 0.125 mm and 0.075 mm respectively, with having a little among passing sieve no 0.075.

Figure 1: Ground or Fine CR

Figure 2: A set of sieves

3. Tests and Experimental Work

3.1 Aggregate Tests

3.1.1 Sieve Analysis Test

The sieve analysis test is applied to divide or separate the aggregate into different sizes of sieves, by passing the aggregate downward through a series of standard sieves, from bigger sizes to smaller. Opening sizes the aggregates are separated into several groups, each of which contains aggregates in a particular size range. Either the hand or mechanical method of sieving can be used.

3.1.2 Specific Gravity and Absorption of Coarse Aggregate Test

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water at nearly 23°C. The standards for determining the specific gravity and absorption of coarse aggregate is given in AASHTO T 85. This method envelopes the determination of specific gravity and absorption of coarse aggregate. Some deleterious particles are lighter than the good aggregates. Specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used during production to separate the deleterious particles from the good using a heavy media liquid.

3.1.3 Specific Gravity and Absorption of Fine Aggregate Test

This method envelopes the determination of bulk and apparent specific gravity, and absorption of fine aggregate. Bulk specific gravity is the characteristic generally used for calculations of the volume occupied by the aggregate in asphalt mixes. It is the same as specific gravity of coarse aggregate, the standards are determined in AASHTO T 84.

3.1.4 Specific Gravity of Filler by Pycnometer Method

This method is used to determine the specific gravity of filler by Pycnometer method. The standards are given in ASTM D 70.

3.1.5 Los Angeles Abrasion Test (L.A.A.T)

The aim of this test is to measure the hardness or toughness of coarse aggregate and to find the Los Angeles Abrasion Value (L.A.A.V). The standards for this test are ASTM C 131 – 69, ASTM C 535 – 69, AASHO T 96. Los Angeles abrasion test shows all possible reasons causing wear. Los Angeles Abrasion test is convenient for coarse aggregate of having different sizes and it is not used for fine aggregate.

3.1.6 Flakiness Index Test

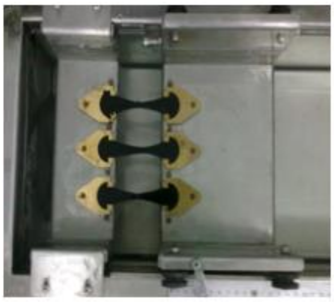
This test method is used to determine the percentage of particles in a coarse aggregate which have a thickness (smallest dimension) of less than one-half of the nominal size. The Flakiness Index of a coarse aggregate is the mass of particles in that aggregate, expressed as a percentage of the total mass, which pass the slots of specified width for the appropriate size fraction. The width of the slots is half those of the sieve openings through which each of the fractions passes (Tex-224-F).

3.2 Bitumen Tests

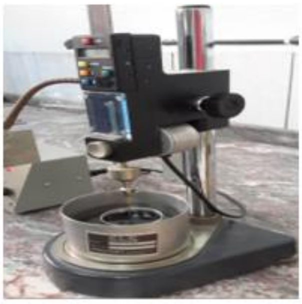
In this research four bitumen tests such as: Ductility Test, Penetration Test, Softening Point Test and Elastic Recovery Test are conducted for both modified and unmodified asphalt and making comparison between them.

- Needed information for mixing process:
  - Time for mixing bitumen with CR = 30 min.
  - Temperature for mixing bitumen with CR = 170 ^{0}C
  - % of CR mixed to bitumen = 2 %, 4 %, 6 %, 8 % and 10 %
- Time & temperature for bitumen tests:
  1. Ductility Test:
     - Bitumen Softening temp. = 160 °C
     - Time cooled in room temp. = 30 min.
     - Time placed in water bath = 2 ½ hrs.
     - Temp. of water bath = 25 ± 0.5°C
     - Elongation Speed = 5 cm/min

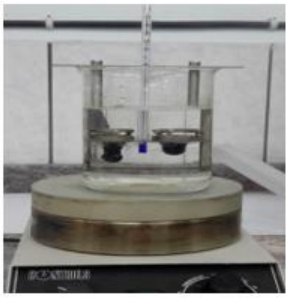
2. Penetration Test:
   Bitumen Softening temp. = 160 °C
   Time cooled in room temp. = 75 min.
   Time placed in water bath = 75 min.
   Temp. of water bath = 25 ± 0.5°C
3. Softening Point Test:
   Bitumen Softening temp. = 160 °C
   Time cooled in room temp. = 60 min.
   Recording temp. to for 5^0C/min = Table 4.3
4. Elastic Recovery Test:
   Bitumen Softening temp. = 160 °C
   Time cooled in room temp. = 30 min.
   Time placed in water bath = 2 ½ hrs
   Temp. of water bath = 25 ± 0.5°C
   Time left to recover = 60 min
   Elongation Speed = 5 cm/min



a. Ductility test



b. Penetration test



c. Softening Point test

d. Elastic Recovery test

Figure 3: Bitumen tests

3.3 Marshall Stability and Flow test

One of the most widely used method of bituminous mix design is the Marshall method developed by Bruce Marshall & the U.S. Corps of Engineers. Stability and flow, together with density, voids and percentage of voids filled with binder are determined at varying binder contents to determine an 'optimum' for stability, durability, flexibility, etc. The purpose of this test is to determine.

a. All Marshall test characteristics such as: Stability, Flow Value, Air Void Ratio, VMA, Specific Gravity and VFA.

b. The Optimum Binder Content for a specified aggregate blend and asphalt to be used.

The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. Strength is measured in terms of the 'Marshall's Stability' of the mix following the specification ASTM D 1559. The *Flow value* is the deformation that the test specimen undergoes during loading up to the maximum load, it is measured in 0.25 mm units. The flexibility is measured in terms of the 'flow value'. The associated plastic flow of specimen at material failure is called flow value.

a. Pedestal, hammer and mold

b. Aggregate specimens

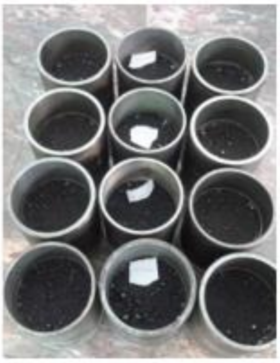
c. Placing agg. in oven

d. Adding CRM to agg.

e. Mixer machine

f. Compaction mold

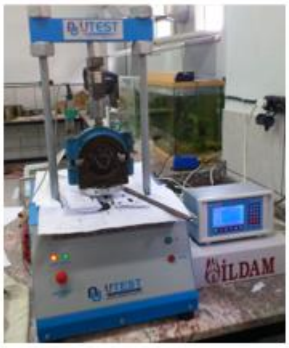
g. Marshall compaction machine



h. Molds left to cool

i. Extractor machine

j. Water bath



k. Stability and Flow testing machine

Figure 4: Apparatus used in materials used in Marshall Mix Design

4. Results

4.1 Aggregate Test Results

The results for physical property of aggregate are summarized in Table 2. These are according to GDH of Turkey Standards for use in Surface Course Pavements. In general, aggregate particles have physical and chemical properties which make the aggregate convenient or non-convenient for specific uses and conditions. The physical properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate. These properties are: Absorption, Porosity, Permeability, Surface Texture, Strength, Elasticity, Density, Hardness, Aggregate, Voids and Specific Gravity.

Table 2: Aggregate Test Results

Agg. Designation	Sp. Gr. (gr/cm^3)	Absorption, %	App. Sp. Gr. (gr/cm^3)	Los Ang. Ab, %	NaSo4 Soundness, %	Flakiness Index
Coarse Agg.	2.672	1.343	2.771			18
Fine Agg.	2.674	0.606	2.718	26.12	4.05	-
Filler	2.75	-	-			-
Limits	-	< 2		< 27	< 16	< 25
Standards	ASTM C 127, ASTM C128			ASTM C 131	ASTM C 88	BS 812-105.1

4.2 Bitumen Test Results

Test results are summarized in Table 3 below.

Table 3: Bitumen test results

% Modifier (CR)								
Tests	0%	2%	4%	6%	8%	10%	Standards	Limits
Ductility (cm)	100.0	26.5	23.5	19.8	18.9	18.5	ASTM D113	-
Penetration (mm)	69.1	62.3	59.8	53.3	51.9	50.7	EN 1426	50 - 70
Ring&Ball Softening Point (^{0}C)	51.3	50.5	53.0	53.5	55.5	57.8	EN 1427	46 - 56
Elastic Recovery (%)	13.0	15.2	35.0	37.8	38.6	41.0	ASTM D113 - 86	-

The ductility values as shown in Table 3 are decreased with increasing the amount of CR, it decreases from 100 cm for neat bitumen to 18.5 cm for 10% of CR. The binders having that the ductility less than 50 should not be used in road constructions, but it can be used as crack or joint filler material, having high ductility value describe a good cementing quality in road surfaces and it will adhere good with aggregate. Through which the cracks are starting at the surface of the roads, the bitumen loses its oil by evaporation and it oxidized. These changes make the road to be hard and brittle. Adding CR to the asphalt binder changes the consistency due to increase of viscosity. The increasing amount of CR has a great effect on modified bitumen binder, and it shows a linear increase of elastic recovery value. Increasing the binder mass makes the binder to be more elastic, stiff, and high resistance to pavement rutting. However, due to the fact that rubber - modified asphalts break before reaching this standard length (20) cm. Penetration value decreases with increasing the amount of CR; this is indicating the improvement in their temperature susceptibility and resistance characteristics as well as increases the stiffness of the binder. The increase in stiffness makes the viscosity to be increased at the same time makes to be more resistance against deformation. The variation in softening point due to varied CR content showed significant results for all modified samples. When the amount of CR increases, the softening point also increases, it's because of the bitumen becomes more viscous as the temperature increases in which from 2% to 8% are according to specifications (EN 1427).

4.3. Marshall Stability and Flow Test Results

Mixing CR with the asphalt binder makes the binder more viscous and stiffer to blend. The figures above indicate that as the CR modified asphalt content increases:

- The Stability increases, by adding 2% and 4% of CR, 4% of CR gives the maximum value of (1464.92) kg. While it decreases by adding 6%, 8% of CR and sudden increase at 10%, see Figure 6.
- The Flow, V_a and VMA increases by adding CR modifier to the asphalt binder. The flow value from 2% to 10% is within the specification range of (2-4) mm (AASHTO T 245), see Figure 5, Figure 7, Figure 10 respectively.

- The bulk specific gravity of bituminous mixture decreases with increasing CR content. Adding CR reduces the specific gravity of asphalt binder as compared to the control mixture. All the results are within the specification range which also supports the use of these additives. Increasing the CR content reduces VFA, see Figure 9.

Table 4: Results of Marshall Stability for CRM Asphalt

PG 50-70 %	BC (%)	VMA (%)	VFA (%)	V_a (%)	G_{mb} (gr/cm^3)	Stability (kg)	Flow (mm)	MQ (kg/mm)
0	5.2	14.53	79.17	3.04	2.41	1446.86	2.065	701.78
2	5.2	14.56	78.99	3.08	2.41	1463.97	2.040	717.69
4	5.2	14.68	78.20	3.22	2.40	1475.51	2.201	669.42
6	5.2	14.96	76.51	3.55	2.40	1443.89	2.029	712.33
8	5.2	15.32	74.37	3.96	2.39	1442.71	2.152	671.25
10	5.2	15.42	73.83	4.07	2.38	1475.88	2.074	715.38

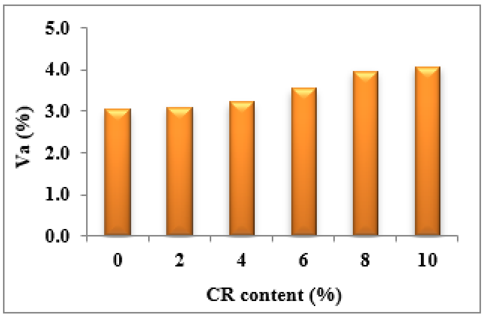


Figure 5: Variation of Air Void vs. CR Content

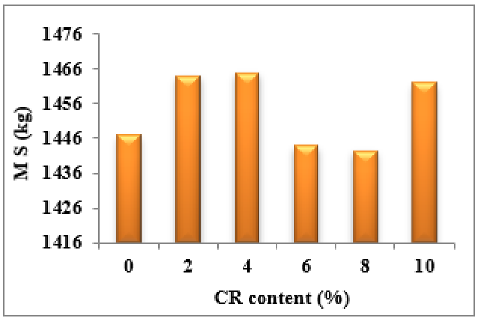


Figure 6: Variation of Marshall Stability vs.CR Content

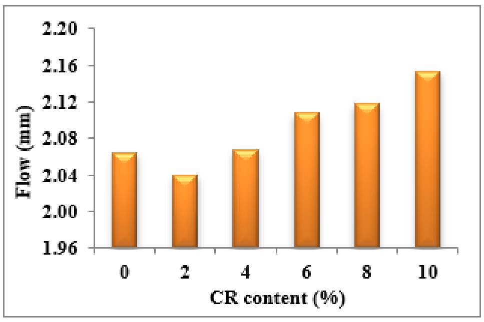


Figure 7: Variation of Flow vs. CR Content

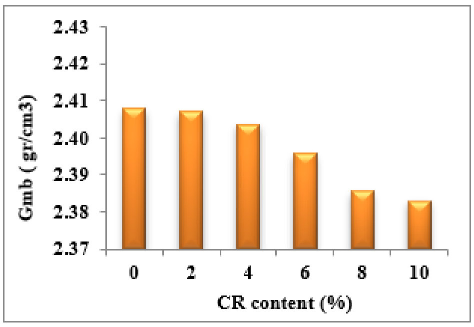


Figure 8: Variation of Specific Gravity vs. CR Content

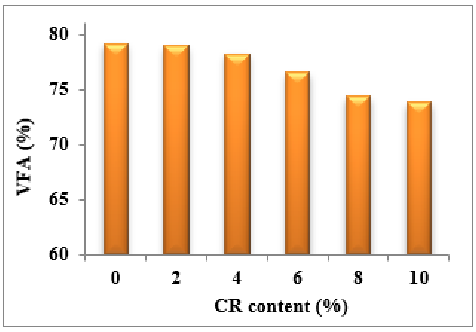


Figure 9: Variation of VFA vs. CR Content

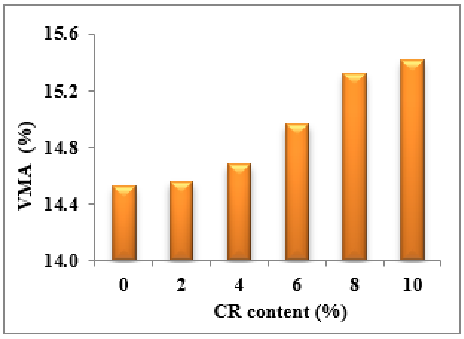


Figure 10: Variation of VMA vs. CR Content

5. Conclusions

The ductility is decreasing when the amount of CR is increasing and it's the normal phenomena happening when adding CR to asphalt binder, for this reason the binders having the ductility less than 50 should not be used in road constructions, but it can be used as crack or joint filler material. Having high ductility value is described good cementing qualities in road surfaces and it will adhere good with aggregate. Increasing amount of CR has a great effect on modified bitumen binder, and it shows a linear increase of Elastic Recovery by increasing the binder mass make the binder more elastic, stiff and high resistance to pavement rutting. However, rubber-modified asphalts break before reaching this standard length (20 cm).

Penetration value decreases with increasing the amount of CR, which is indicating the improvement in their temperature susceptibility and resistance property as well increase in the binder's stiffness. The increase in stiffness makes the viscosity higher, at the same time makes more resistance against deformation. All of the results from 2% to 10% are within the specification limits. The variation in Softening Point due to varied CR content showed significant results for all modified samples. These significant results are obtained by increasing the amount of CR and it found that the softening point also increases. It is because of more viscous bitumen as the temperature, and softening point values are within the specification limits for 2% to 8% CR content.

The test results show that air void increases after adding CR into bituminous mixtures. However, the air voids of mixtures are located within the specification range of 3% to 5% (AASHTO T 312) which support the use of these additives. All the percentages of CR from 2% - 10 % are within the specification limits. The Stability value increases, by adding 2%, 4% of CR content and here 4% of CR gives the maximum value of (1464.92) kg. While it decreases by adding 6% and 8% of CR, the Flow, V_a and VMA increases by adding CR modifier to the asphalt binder. The flow value from 2 % to 10% is within the specification range of (2 - 4) mm (AASHTO T 245).

References

Ali, A.H., Mashaan, N.S., & Karim, M.R. (2013). Investigations of physical and rheological properties of aged rubberized bitumen. *Advances in Materials Science and Engineering*, 1-7.

Jiang, Z. (2005). The status and development of waste tire resources recycling in China. *Chinaire Resource Recycling*, 6–8.

Mashaan, N.S., Ali, A.H., Karim, M.R., & Abdelaziz, M. (2011). Effect of crumb rubber concentration on the physical and rheological properties of rubberised bitumen binders. *International Journal of Physical Sciences,* 6(4), 684–690.

Roberts, F.L., Kandhal, P.S., Brown, E.R., & Dunning, R.L. (1989). Investigation and evaluation of ground tire rubber in hot mix asphalt. *National Center for Asphalt Technology, NCAT Report No*, 83-3.

Samsuri, A., Hasshim, S., Harun, M.H., & Dewa, A.L. (1995). Rubberised bitumen for road construction. *Proceedings of the International Conference on the Usage of Rubber in Engineering Technology, Kuala Lumpur, Malaysia.*

Sufian, Z., & Mustafa, M.S. (1997). Prospects of rubberised bitumen pavement Malaysia roads and highways. *Proceedings of the Conference on the Use of Rubberised Bitumen in the Road Construction, Selangor, Malaysia.*