American Journal of Applied Sciences

Original Research Paper

Using Crump Rubber (CR) of Scrap Tire in Hot Mix Asphalt Design

Omar Asad Ahmad

Department of Civil Engineering, Faculty of Engineering Technology, Zarqa University, Zarqa, Jordan

Article history
Received: 19-12-2015
Revised: 29-01-2017
Accepted: 07-02-2017

Email: support@thescipub.com

Abstract: Hot Mix Asphalt (HMA) design is one of the most important types of pavement used in highway construction. This research provided a hot mixture design method modifying with Crump Rubber Scrap Tire (CR) in order to develop and determining the optimum additive for hot mix asphalt design. All tests conducted to the raw material including specific gravity, compact test and absorption content to ensuring its quality. In this research, hot mix designed as a stander without any additives and with (4.5, 5, 5.5, 6, 6.5 and 7%) percent of asphalt content. All specimens of each asphalt percent content were tested after 24 h, according to AASHTO. The additives in this research were prepared by two methods (wet process and dry process). The results show that in dry process all additives cause a failure and the segregation was the major reason for failure. In wet process the selected wet process at 5.5% CR by weight of binder content was optimum were its raising the stability value to 65% of original stability in standard mix, which lead to decreasing the rutting effects.

Keywords: Rubber, Design, Modifier, Hot Asphalt, Stability, Flow

Introduction

Asphalt pavements are designed to resist rutting, fatigue cracking, low temperature cracking and other pavement distresses. Rutting and fatigue cracking are very known to be the most common distresses that occur in asphalt pavement. The rutting deformation occurs at high temperature and fatigue cracking which occurs at intermediate and low temperatures. These stresses reduce the design life of the pavement and increase the maintenance costs. This is due to the rapid growth of traffic volume and vehicle loads which led to unsatisfactory performance of asphalt binders (Cooley Jr *et al*., 2003). To minimize the structural damage of asphalt pavement and increase the durability of the pavement, the asphalt binder needs to be improved with regards to performance properties such as resistance against rutting and fatigue cracking (Cooley Jr *et al*., 2003; Martin *et al*., 2003).

Asphalt as a binder of aggregate has been widely used in road pavement. High-temperature cause rutting and low-temperature cause cracking of asphalt cement or coating layer due to the severe temperature and shortens its functional life. Therefore it is necessary to modify asphalt mix. Among the modifiers of asphalt, is Crumb Rubber (CR). The application of CRM asphalt is investigated by several researchers in the United States, Canada and other countries (Cheng, 2001; Magdy, 1997).

The previous research and application showed that CRM asphalt had many desirable effects such as improved resistance to rutting due to higher viscosity, higher softening point and better resilience, reduced fatigue/reflection cracking, reduced temperature susceptibility, improved durability and lower pavement maintenance costs. Another advantage for using CR is the reduction in waste by 7 recycling of waste tires and rubber which can have high cost to dispose of properly (Cheng, 2001). CR is the second used polymer to modify asphalt, following SBS (Yetkin, 2007).

The use of CRM asphalt is environmental friendly solution, since the use of this material partially reduces the need for new raw materials and improves the performances and life cycle of asphalt pavements (Miriam, 2009; Choubane *et al*., 1999). Several researchers studied the CRM asphalt. It is found that the improvement of CRM asphalt depended on many factors such as the particle size, the surface characteristics of CR, blending conditions, the manner in which CR devulcanizes, the chemical/physical properties of base asphalt, as well as its source and microstructure (Yetkin, 2007; Bahia and Davies, 1994; Navarro *et al*., 2004; Lee *et al*., 2008; Cao and Chen, 2008; Shi *et al*., 2005;

Science Publications

Xiang *et al*., 2009; González *et al*., 2012). Thodesena *et al*. (2009) developed an empirical model depicting the changes in values of G*/sin δ and failure temperatures. Liu *et al*. (2009) evaluated the performance of different modified binders with different CR contents, the particle size or type by using the analysis of variance method.

The crumb rubber is often sieved and separated in categories based on gradation to meet the requirements of a particular application or agency. Typically there are three classes of CR, mb rubber market, there are three main classes based on particle size: Grade A: 10 mesh coarse crumb rubber; Grade B: 14 to 20 mesh crumb rubber; Grade C: 30 mesh crumb rubber. Mesh size designation indicates the first sieve with an upper range specification between 5 and 10% of material retained.

Asphalt binder is the principal binding agent in Hot Mix Asphalt (HMA) and surface preservation treatments for flexible pavements such as fog seal, chip seal and crack sealing. Asphalt binder includes asphalt cement and any material added to modify the original asphalt cement properties. Some asphalt binders need modification to meet specifications. Modifiers can change the properties of the binder by: Lowering the viscosity at the construction temperature to facilitate pumping, mixing and compaction of HMA; increasing the viscosity at high service temperatures to reduce rutting and shoving; Increasing relaxation properties at low service temperatures to reduce thermal cracking; increasing adhesion between asphalt binder and aggregates in the presence of moisture to reduce or prevent stripping.

Crumb rubber can be used as an asphalt binder modifier to produce CRM modified Hot Mix Asphalt (HMA) concrete. HMA can be used in several pavement surface preservation or rehabilitation treatments, such as rubberized fog seal and rubberized chip seal.

Because of the complex nature of the rubber materials, their effect on the properties of the various types of asphalt binder and the HMA concrete mixtures are not always easy to predict without testing the modified binder (Roberts *et al*., 1996).

Materials and Methods

Crumb rubber was obtained from recycled tires. Crumb or ground rubber can be used either as fine aggregate in the mixture or as processed rubber added to the asphalt binder. To implement these two approaches, the dry process and wet process of using crumb rubber were developed.

The dry process is a method where granulated or Crumb Rubber Modifier (CRM) are added from scrap tires as a substitute for a percentage of the aggregate in the asphalt concrete mixture, not as part of the asphalt binder. The crumb rubber is mixed with the aggregate fraction before adding the asphalt cement. The resulting mix is often called rubber-modified asphalt concrete mixture. Different gradations or sizes of granulated or CRM can be used depending on the application or procedure. The percentage of the crumb rubber added in the dry process varies; Roberts *et al*. (1996) indicated that 3 to 5% of crumb rubber by weight of the aggregate is generally used (Navarro *et al*., 2004). The Asphalt Rubber Usage Guide refers to 1 to 3% of crumb rubber by weight of the aggregate in the asphalt concrete mixture (Roberts *et al*., 1996; Holikatti *et al*., 2012).

The wet process is a method of adding the asphalt binder with CRM from scrap tires before the binder is added to form the asphalt concrete mixture, the resulting product is called asphalt rubber or rubberized asphalt. The wet process requires thorough mixing of the CRM with the asphalt concrete and other components of the modified asphalt binder at temperatures between (190 to 224°C) and requires maintaining the blend at temperatures between (190 to 218°C) for a certain specified time, generally 45 min (Caltrans, 2006).

Laboratory Testing

The following tests were conducted.

Impact Test

Impact test designed to evaluate the toughness of stones i.e., the resistance of the fracture under repeated impacts may be called an impact test for road stones. The test sample consists of aggregates passing 12.5 mm sieve and retained on 10 mm sieve and dried in an oven for four hours at a temperature 1000 to 1100°C and cooled. Test aggregates are filled up to about one-third full in the cylindrical measure and tamped 25 times with rounded end of the tamping rod. An aggregate is then added up to two-third full in the cylinder and 25 strokes of the tamping rod are given. The measure is now filled with the aggregates to over flow, tamped 25 times. The surplus aggregates are stroked using the tamping rod as straight edge. The net weight of the aggregates in the measure is determined to the nearest gram and this weight of the aggregates is used. The hammer is raised to a distance of 380 mm from the lower face and allowed to fall freely on the aggregates. The test sample is subjected to a total of 15 blows, each being delivered at an interval of not less than one second. The crushed aggregate were then removed from the cup and the whole sample is sieved on the 2.36 mm sieve until all fine size passes. The fraction passing the sieve is weighed to the nearest 0.1 gm. The fraction retained on the sieve is also weighed and if the total weight of the fractions passing and retained on the sieve is added. The specific gravity and absorption for coarse aggregate and sand are listed in Table 1.

Table 1. Specific gravity and absorption for coarse aggregate and sand

Type	G APP	G bulk	Absorption%
19-12.5 mm	2.78	2.65	1.81
9.5-4.75 mm	2.73	2.64	1.24
2.63-0.085 mm	2.65	2.55	1.48
Sand	2.64	2.53	1.65

Penetration Test (AC 80/100)

The penetration test: Is most commonly-used tests on asphalt cements or residues from distillation of asphalt cutbacks or emulsions. It is an empirical test which measures the consistency (hardness) of asphalt at a specified test condition. In the standard test condition, a standard needle of a total load of 100 g is applied to the surface of an asphalt sample at a temperature of 25°C for 5 sec.

Ductility Test (106 mm)

Ductility Test: Test goal is to completely melt the bituminous material to be tested by heating it to a temperature of 75 to 100°C above the approximate softening point until it becomes thoroughly fluid. Assemble the mould on a brass plate and in order to prevent the material under test from sticking, thoroughly coat the surface of the plate and the interior surfaces of the sides of the mould with a mixture of equal parts of glycerin. While filling, pour the material in a thin stream back and forth from end to end of the mould until it is more than level full. Leave it to cool at room temperature for 30 to 40 min and then place it in a water bath maintained at the specified temperature for 30 min, after which cut off the excess bitumen using a hot, straight-edged putty knife or spatula, so that the mould is just level full. Place the brass plate and mould with briquette specimen in the water bath and keep it at the specified temperature for about 85 to 95 min. Then, briquette was removed from the plate; detached the side pieces and the briquette immediately (Bressette *et al*., 2007).

Softening Point Test

Ring and Ball Softening Point Test: The ring and ball softening point test measures the temperature at which asphalt reaches a certain softness. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed Upon the bitumen sample and the liquid medium is heated at a rate of 5°C per min. Temperature is noted when the softened bitumen touches the metal plate which is at a spaced distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates.

Marshall Test

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The test measures the maximum load supported by the test sample at a loading rate of 50.8 mm/min called (stability test). Load is applied to the sample until failure stage. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm, increments at the same time when the maximum load is recorded. The aggregate size distribution is shown in Tables 2 and 3.

Select 1200 gm of aggregates. Then heated bitumen to a temperature of 125°C with the different percentage of bitumen (4.5-7%) by weight of an aggregates. The mix is placed in a preheated mould and compacted by a hammer with 75 blows on both side at temperature of 145°C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably.

Stability and flow shown in Table 4 are the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain. While the stability test is in progress dial gauge is used to measure the vertical deformation of the sample. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall Flow value of the specimen. Properties of CR are discussed in Table 5.

The classification shown in Table 6 was used to select optimum binder content. So the optimum binder content is 5.5%.

The binder is considered because it improves the major properties stability and flow. CR can be calculated as a fraction of aggregates or bitumen. However different ways can be utilized to calculate rubber fraction from total weight.

The research present two methods of CR addition, first method by fraction of weight of aggregates and the second method by replacing binder content (5.5% in total mix) with different percentage of rubber.

Wet Process: Rubber is added to liquid asphalt before mixing at the hot plant, rubber is wet before mixing with aggregates. Dry Process: Rubber is added at the same time the asphalt and aggregate are mixed; rubber is dry before mixing with the aggregate.

Dry method was used for samples that have same weight of binder content with changing weight of aggregates replaced with the same size of rubber. For wet process the binder content is changed by weight by adding rubber weight of replaced aggregates. The rubber blending with bitumen first then aggregates added. Rubber is prepared to mixing in dry process by controlling its size to replace aggregates into two sizes by using sieves grader, because the size of pieces has not the same. The results are listed in Tables 7, 9, 12 and 15.

Table 2. Percentage of aggregate in used samples

Sieve (mm)	Percent of aggregate in sample %	Gb	Gapp	Average
25 -- 12.5	20	2.65	2.78	2.72
9.5 – 4.75	35	2.65	2.70	2.68
2.36 -- 0.85	27	2.55	2.65	2.60
0.5 -- 0.075	18	2.50	2.53	2.52

Table 3. Percentage of aggregate and different bitumen of 1200 g total sample weight

Sieve (mm)	Accumulative weight of 4.5% blinder	Accumulative weight of 5% blinder	Accumulative weight of 5.5% blinder	Accumulative weight of 6% blinder	Accumulative weight of 6.5% blinder	Accumulative weight of 7% blinder
25	0.00	0.0	0.00	0.00	0.00	0.00
19	34.38	34.38	34.02	33.84	33.66	33.48
12.5	229.20	228.0	226.80	225.60	224.40	223.20
9.5	343.80	342.0	340.20	338.40	336.60	334.80
4.75	630.30	627.0	623.70	620.40	617.10	613.80
2.56	802.20	798.0	793.80	789.60	785.40	781.20
0.85	939.72	934.8	929.88	924.96	920.04	915.12
0.5	1031.40	1026.0	1020.60	1015.20	1009.80	1004.40
0.15	1077.24	1071.6	1065.96	1060.32	1054.68	1049.04
0.075	1111.62	1105.8	1099.98	1094.16	1088.34	1082.52
Pan	1146.00	1140.0	1134.00	1128.00	1122.00	1116.00

Table 4. Stability and Flow results for different additives

Sample	Wdry	Wssd–Wsub	Stability reading	Flow reading
4.5%	1192	509.40	225	300
4.5%	1189.4	510.50	240	340
5.0%	1184	508.15	237	350
5.0%	1187	507.26	269	400
5.5%	1187.00	509.44	275	350
5.5%	1188	512.06	251	450
6.0%	1194	514.65	250	360
6.0%	1194	512.49	293	500
6.5%	1185	508.58	254	400
6.5%	1188.00	512.07	299	500
7.0%	1178	507.75	275	450
7.0%	1180	508.65	250	500

Table 5. Properties of samples with CR different additives

Sample	Gb Mix	Gapp Mix	Gb agg	Gapp Agg	AV %	VMA %	VFB %	Stability value	Flow reading
4.5%	2.33	2.45	2.22	2.63	4.82	15.32	68.56	604.5	12.59
5.0%	2.33	2.43	2.21	2.63	4.10	15.77	74.01	657.8	14.76
5.5%	2.33	2.43	2.20	2.63	3.59	16.40	78.08	683.8	15.74
6.0%	2.33	2.40	2.18	2.63	3.00	16.95	82.26	705.9	16.92
6.5%	2.32	2.38	2.17	2.63	2.32	17.43	86.67	718.9	17.71
7.0%	2.32	2.36	2.15	2.63	1.70	17.99	90.52	682.5	18.70

Table 6. Results of 5.5% CR additives

Stability Kg	683.8	Pass
Flow 0.25 mm	15.74	Pass
VMA%	16.40	Pass
VFB%	78.08	Pass
AV%	3.590	Pass

Table 7. Percentage of CR replacement of aggregate

Sieve mm	Return weight of 5.5% bitumen and 25% (4.75) rubber	Return weight of 5.5% bitumen and 35% (4.75) rubber	Accumulative weight of 5.5% bitumen and 50% (4.75) rubber
25	0.000	0.000	0.00
19	34.020	34.020	34.02
12.5	192.780	192.780	192.78
9.5	113.400	113.400	113.40
4.75 aggregate	212.625	184.275	141.75
4.75 rubber	70.875	99.225	141.75
2.36	170.100	170.100	170.10
0.85	136.080	136.080	136.08
0.50	90.720	90.720	90.72
0.15	45.360	45.360	45.36
0.075	34.020	34.020	34.02
pan	34.020	34.020	34.02

Table 8. Properties of samples with 5.5% bitumen and different CR

Sample	25%	35%	50%
Gb mix	2.07	1.99	1.87
Gapp mix	2.43	2.43	2.43
Gb agg	1.95	1.88	1.76
Gapp agg	2.65	2.65	2.65
AV %	14.80	18.10	23.00
VMA %	26.20	29.00	33.30
VFB %	43.40	37.70	30.90
Stability value	314.40	442.00	254.80
Flow value	28.00	38.00	39.00

Second try (9.5 mm)

Table 9. Percentage of 9.5 mm CR aggregate replacement

Sieve mm	Return weight of 5.5% bitumen 25% (9.5) rubber	Return weight of 5.5% bitumen 35% (9.5) rubber	Accumulative weight of 5.5% bitumen 50% (9.5) rubber
25	0.00	0.00	0.00
19	34.02	34.02	34.02
12.5	192.78	192.78	192.78
9.5 aggregate	85.05	73.71	56.70
9.5 rubber	28.35	39.69	56.70
4.75	283.50	283.50	283.50
2.36	170.10	170.10	170.10
0.85	136.08	136.08	136.08
0.50	90.72	90.72	90.72
0.15	45.36	45.36	45.36
0.075	34.02	34.02	34.02
Pan	34.02	34.02	34.02

Table 10. Properties of samples with 5.5% bitumen and different CR 9.5 mm

Sample	25%	35%	50%
Gb mix	2.22	2.21	2.10
Gapp mix	2.43	2.43	2.43
Gb agg	2.10	2.10	2.00
Gapp agg	2.65	2.65	2.65
AV %	8.6	9.00	13.50
VMA %	20.9	21.10	25.10
VFB %	58.5	57.60	46.10
Stability Value	494.0	421.00	551.20
Flow value	20.00	21.00	24.00

Table 11. Results of 9.5 mm CR modifying samples

	Modify sample				
Properties	25%	35%	50%	Standard sample	Result
% AV	8.6	9.0	13.5	3.59	Reject
% VMA	20.9	21.1	25.1	16.40	Reject
% VFB	58.5	57.6	46.1	78.08	Reject
Stability	494.0	421.0	551.2	683.08	Reject
Flow	20.0	21.0	24.0	15.74	Reject

Table 12. Percentage of 9.5mm and 4.75mm CR aggregates replacement

Sieve mm	Return weight of 5.5% bitumen 25% (4.5-9.5) rubber	Return weight of 5.5% bitumen 35% (4.75- 9.5) rubber	Accumulative weight of 5.5% bitumen 50% (4.75-9.5) rubber
25	0.000	0.000	0.00
19	34.020	34.020	34.02
12.5	192.780	192.780	192.78
9.5 aggregate	85.050	73.710	56.70
9.5 rubber	28.350	39.690	56.70
4.75 aggregate	212.625	184.275	141.75
4.75 rubber	70.875	99.225	141.75
2.36	170.100	170.100	170.10
0.85	136.080	136.080	136.08
0.50	90.720	90.720	90.72
0.15	45.360	45.360	45.36
0.075	34.020	34.020	34.02
Pan	34.020	34.020	34.02

Table 13. Properties of samples with 5.5% bitumen and different CR 9.5 and 4.75 mm

Sample	25%	35%	50%
Gb mix	2.02	1.85	1.74
Gapp mix	2.43	2.43	2.43
Gb agg	1.91	1.75	1.64
Gapp agg	2.65	2.65	2.65
AV %	16.90	23.70	28.40
VMA %	21.40	27.90	32.40
VFB %	21.30	15.10	12.20
Stability Value	543.40	286.00	247.00
Flow value	31.00	33.00	43.00

Table 14. Results of 9.5 and 4.75 mm CR modifying samples

	Modify sample				
Properties	25%	35%	50%	Standard sample	Result
% AV	16.9	23.7	28.4	3.59	Reject
% VMA	21.4	27.9	32.4	16.40	Reject
% VFB	21.3	15.1	12.2	78.08	Reject
Stability	543.4	286.0	247.0	683.08	Reject
Flow	31.0	33.0	43.0	15.74	Reject

Table 15. Results of CR weight for different additives

Percent of rubber	Binder weight	Rubber weight
3.5%	63.69 g	2.31 g
4.5%	63.03 g	2.97 g
5.5%	62.37 g	3.63 g
6.5%	61.71 g	4.29 g
7.5%	61.05 g	4.95 g

Most of rubber size was (4.75 and 9.5 mm), so we select this size to testing in same processor of standard mix design by adding percentage (25, 35 and 50%) by weight of aggregates 4.75 mm, (25, 35 and 50%) by weight of aggregates 9.5 mm and (25, 35 and 50%) of both 4.75 and 9.5 mm aggregates size. The properties of sample such as (stability, flow, voids filled with bitumen and air voids), Must be improved and any losses in quality in standard mix after adding rubber leading to reject the method, where the results reported in Tables 8, 10, 11, 13 and 14.

Results and Discussion

The aim of this research is to improve the major properties of Asphalt mix including stability and flow by selecting 5.5% of binder content and different rubber percentages. However, adding rubber was calculated by two methods, by total weight, replaced fillers aggregate with rubber and by replacing bitumen percentage with rubber percentage. In Table 9, the addition method involve adding different percent by weight of aggregates and by replacing fixed percentages of binder content (5.5% in total mix) with different percentage of rubber. First test (4.75 mm): In this test the selected percentage was removed from aggregates and replaced with rubber at same percent as removed.

In wet process method CR is added to liquid asphalt at temperatures around 110 to 155°C and we select small percent to adding (3.5, 4.5, 5.5, 6.5 and 7.5%). Only, small fraction additions are used since large percentage may cause segregation.

The addition method is by substituting the selected percent of rubber from optimum binder content as standard mix (5.5%). This percent equal 66 g which should be removed to add 3.5% and the weight removed was 2.31 g. However; this rubber quantity is added to liquid and it is completely mixed and fully suspended.

To prepare the samples same way in the standard method, rubber was cut to small size to make it easier to melt. The mix has 1134 gm of aggregates and 66 gm of bitumen in standard mix, Table 15 describe the weight of bitumen and rubber to add for fixed weight of aggregates.

Tables 15 and 16 summarize laboratory test results for all rubber percentages. Tables 15 and 16 shows acceptable values (except 3.5% failure in air voids percent). The percentage falls within general classification when the air void has a range between 3 and 5% maximum and the percent of void of mineral aggregates not less than 15%. Then we observed that voids filled with bitumen specified between 75 and 85%. Generally, the stability and flow was within general classification when stability was not less than 600 kg for wearing layer at heavy traffic and the flow was between 8% and 16% maximum. This classification is not considered in our study for wet process, because standard mix is selected for reference and it show improved mix.

Bulk specific gravity is directly proportional with quantity of rubber and rubber size as shown in Fig. 1. This trend is caused by changes in volume liner relation with additional rubber, rubber has lower density than aggregates, so we need to increase quantity to gets the needed weight.

However, density of sample will decrease as rubber increase, for example if we have 1200 gm at standard state and the volume is around 508 cm^3 and the density calculated as dividing the weight by volume will be 2.36 gm/cm^3. At 4.75 maximum densities recorded 2.07 g/cm^3 comes from adding 70.875 gm of rubber and 28.35 gm of 9.5. We observed that density go up to 2.22 at 9.5 mm, because the quantity is small. The bulk specific gravity decrease and this trend are related to high quantity of CR added and a volume increase of (56.7 g) was reported. So when rubber added, the volume will increase and the density go smaller.

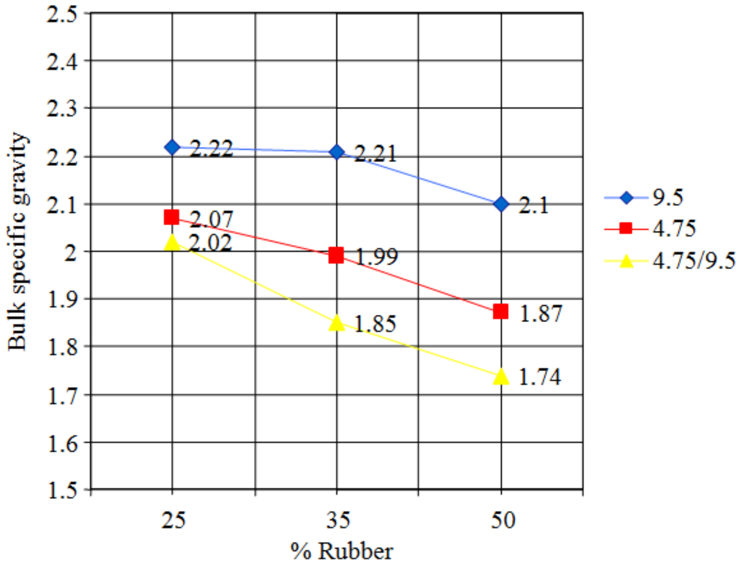

Fig. 1. Variations of bulk specific gravity with variety of % CR

For AV property, we observed a highest value for the mix contain both size of rubber (4.75 and 9.5) as shown in Fig. 2, because of non-equal distribution of temperature on all rubber pieces. So, some of the particles stay in solid state (at least in inner body). So when heating and mixing finished and compacted step is done. The rubber after cooling and decreasing pressure will solidify again. This behavior leads to changing in volume of rubber particle from large size to small size to make gaps between an aggregate. This is shown in 9.5 mm of rubber, because the quantity is less; the heating and mixing was more homogeneous, so the rubber transformed from solid stage to semi liquid state and this lead to distribution of all melting rubber around all aggregates and filling the small gabs. For 4.75 at (25%) and that means increasing in Gb leads to decease the Air voids.

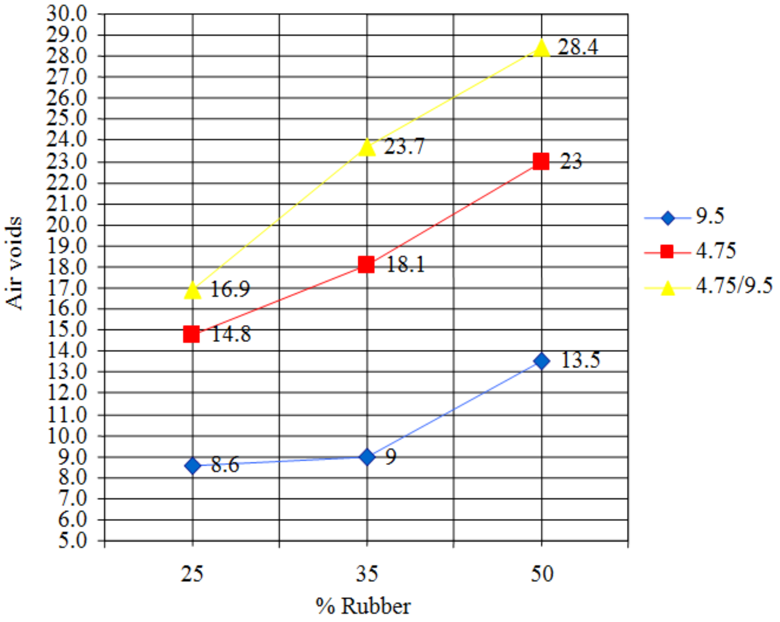

Fig. 2. AV changes in samples with variety of % CR

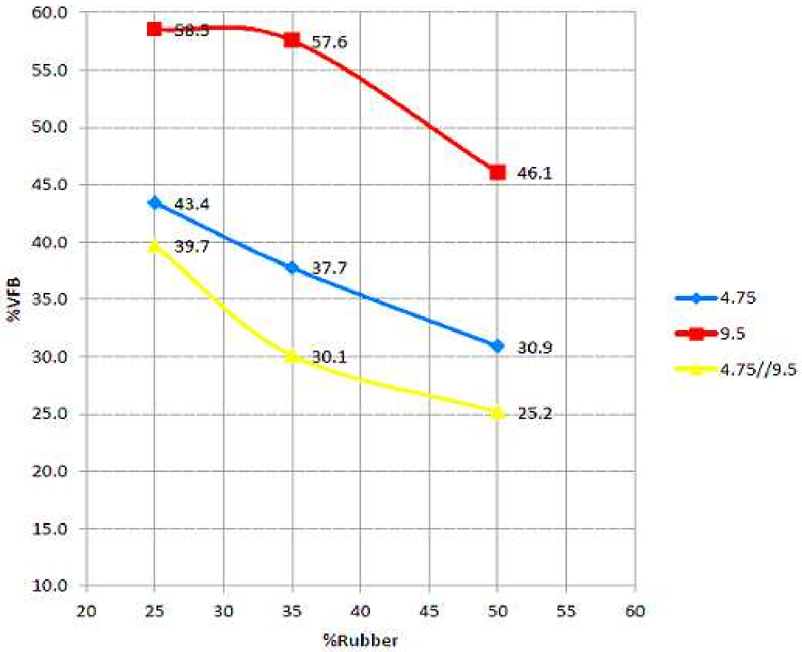

Fig. 3. VFB changes in samples with variety of % CR

VFB property changes when quantity of rubber is large as shown in Fig. 3, the voids filled with bitumen decrease, this can be referred to rubber has not fully melted and some parts remain in solid state. This is because rubber resists motion with bitumen. Finally liquid network (rubber plus bitumen) has high viscosity which would not fill all voids.

Flow properties show failure in stability as shown in Fig. 4 and Fig. 5 and this failure is caused by segregation in the sample, because the rubber when its added to the mix at large amount cause segregation between aggregates and bitumen. This is because rubber attach to aggregates when it's fully melted. If rubber is not fully melted it will not attach with bitumen.

Air voids increase linearly with rubber content as shown in Fig. 6 where more voids are added to bitumen which cause an increase in mixing liquid viscosity. But it is improving the mix by increasing this value from 3.59% in standard mix to 4.5 in the mix with rubber. However; the best value of air voids falls at 4% average of classification acting between (3 and 5%) and it falls at this around 6.5% rubber with 4.3% air voids.

VFB curve decreases with increasing rubber content as shown in Fig. 7, but it is improving the percent of voids filled with liquid (bitumen and rubber); the standard mix have VFB of 78.08% as the rubber raise, also VFB increase to 81.12 at 3.5% rubber and VFB of 80.6 at 4.5% of rubber and VFB of 79 at 5.5% of rubber. So we improve this property without adding more asphalt.

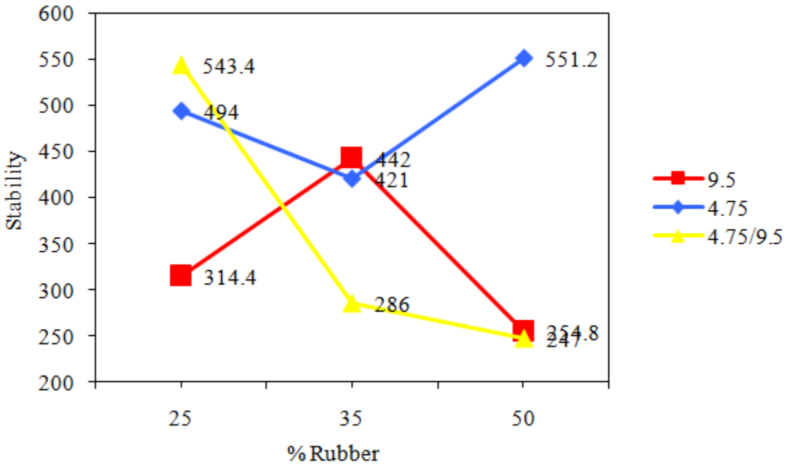

Fig. 4. Stability variations in samples with variety of % CR

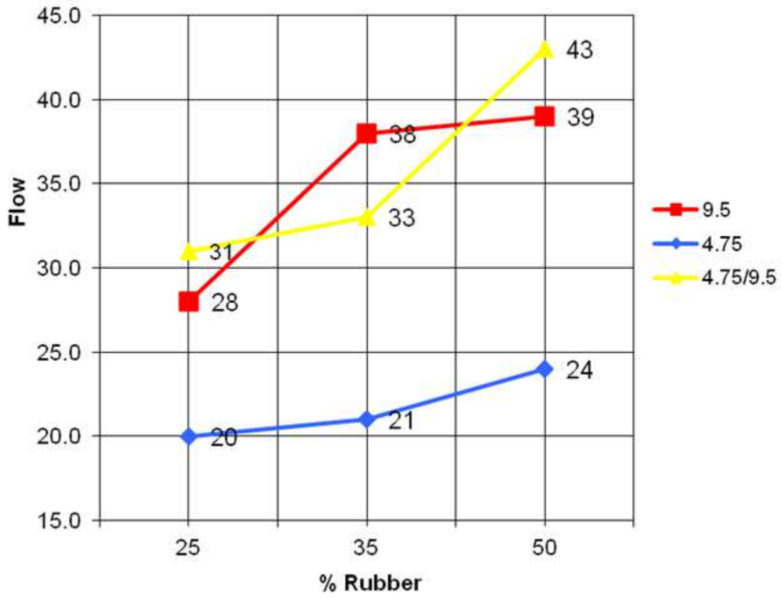

Fig. 5. Flow changes in samples with variety of % CR

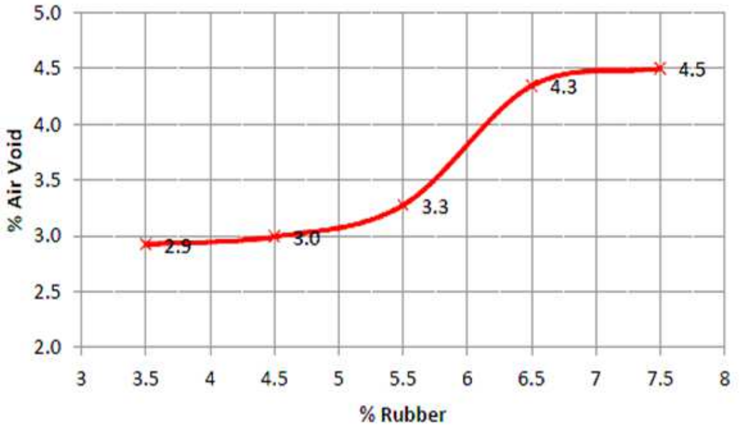

Fig. 6. Air Voids changes in samples with variety of % CR

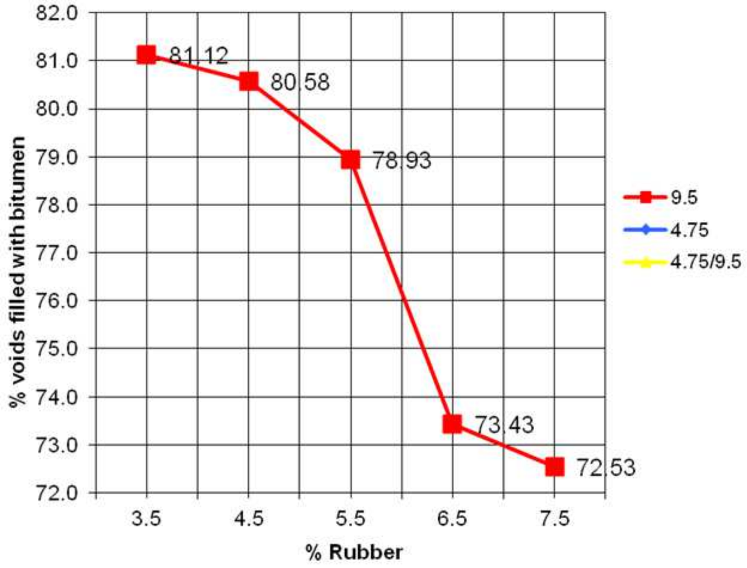

Fig. 7. Percentage of changes in voids with variety of % CR

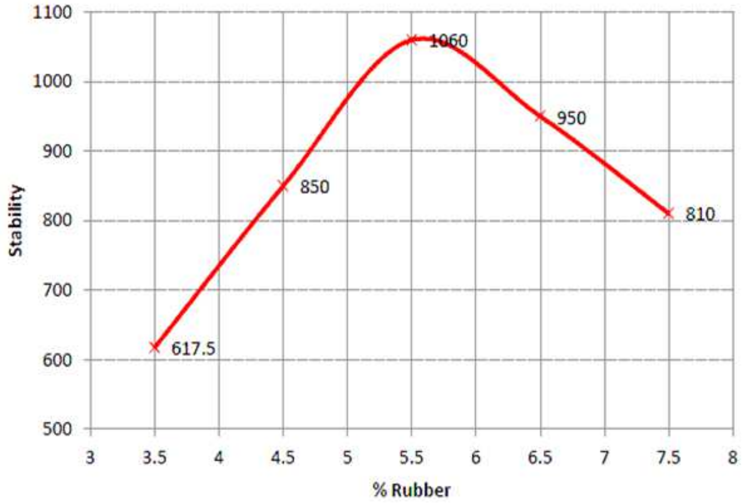

Fig. 8. Stability changes in samples with variety of % CR

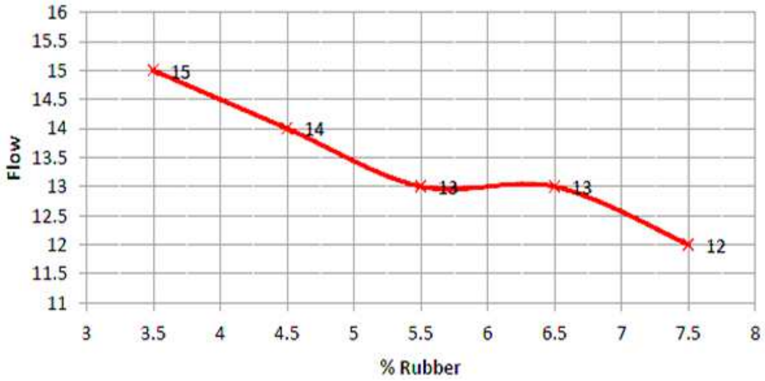

Fig. 9. Flow changes in samples with variety of % CR

Table 16. Results of stability and flow for % CR

%Rubber	Gb of mix	% AV	% VMA	% VFB	Stability	Flow
3.5%	2.365	2.9	15.48	81.12	617.5	15
4.5%	2.366	3.0	15.41	80.58	850.0	14
5.5%	2.361	3.3	15.55	78.93	1060.0	13
6.5%	2.337	4.3	16.36	73.43	950.0	13
7.5%	2.335	4.5	16.39	72.53	810.0	12

Stability trend is shown in Fig. 8, it indicates an increase in stability such as at 5.5% of rubber has stability value 1065 kg, when the value at standard mix was 683.08 kg a segregation in mix was observed. Stability increased incrementally up to 5.5% and is reduced after 5.5%.

The value of flow decreased from 15.75 at standard mix to 12 min and this referred to extra rubber additives to bitumen that decreasing flow indexes in the mix as shown in Fig. 9.

Conclusion

Air voids in compacted paving mixture consist of the small air spaces between the coated aggregate particles. The small space allow moving a bitumen through as a loads (vehicle) moves on road. That mean, it's very important property in the mix, because if no air spaces in the mix the bitumen will moving to the lowest pressure point.

This point at a surface or nearly cracks acting in the pavement. This observation leads to bleeding in the bitumen on the surface. However; in wet process the best percentage at 5.5% rubber content equal 3.3%. May we can select 4.3 at 6.5% rubber content, but it’s nearest for limitation.

Voids filled with Bitumen in the compacted paving mixture consist of the bitumen content can fill large gap between aggregates. See at 4.5% rubber content the VFB was 80.6% with 63.03 g bitumen and for 6.5% rubber content the VFB was 73.4% with 61.7 g bitumen content. But at 5.5% rubber content, the VFB is around 79% more than 6.5% rubber content and low than 4.5% rubber content around 1% VFB. At 62.3 g bitumen content, whilst the 4.5% rubber content with 63 g.

Stability and flow tests indicate the ability of asphalt paving mixture to resist deformation due to loads, unstable pavement are marked by channeling or rutting. However; the recommendation is to select 5.5% rubber content of 1060 kg. These means increasing of interlock between aggregates and resist the fraction.

Acknowledgment

This research is funded by the Deanship of Research and Graduate Studies in Zarqa University/Jordan-Zarqa.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

Bahia, H.U. and R.R. Davies, 1994. Effect of Crumb Rubber Modifiers (CRM) on performance related properties of asphalt binders. J. Assoc Asphalt Pav. Technol., 1: 414-420.

Caltrans, 2006. Use of rubberized asphalt concrete for new construction. Memorandum, Caltrans, Sacramento, CA.

Cao, R.J. and R.S. Chen, 2008. Laboratory study on process parameters of asphalt rubber and their effects on performance. J. Southeast Univ., 38: 269-273.

Cheng, Y., 2001. Prospect for application of waster rubber powder. China Synthetic Rubber Ind., 24: 65-66.

Choubane, B., G.A. Sholar, J.A. Musselman and C.C. Page, 1999. Ten-year performance evaluation of asphalt-rubber surface Mixes. Trans. Res. Rec., 1681: 10-18. DOI: 10.3141/1681-02

Cooley Jr, L.A., B.D. Prowell and M.R. Hainin, 2003. Comparison of the saturated surface-dry and vacuum sealing methods for determining the bulk specific gravity of compacted hma (with discussion and closure). J. Assoc. Asphalt Pav. Technol., 72: 56-96.

González, V., F. Martínez-Boza, C. Gallegos, A. Pérez-Lepe and A. Páez, 2012. A study into the processing of bitumen modified with tire crumb rubber and polymeric additives. J. Fuel Process. Technol., 95: 137-143. DOI: 10.1016/j.fuproc.2011.11.018

Holikatti, S., H. Zhou and P. Vacura, 2012. Seven year itch-evaluation of Caltrans full scale experiment on asphalt rubber modified pavements. Rubberized Asphalt Foundation.

Lee, S.J., C.K. Akisetty and S.N. Amirkhanian, 2008. The effect of Crumb Rubber Modifier (CRM) on the performance properties of rubberized binders in HMA pavements. Construct. Build. Mater., 22: 1368-1376. DOI: 10.1016/j.conbuildmat.2007.04.010

Liu, S.T., W.D. Cao, J.G. Fang and S.J. Shang, 2009. Variance analysis and performance evaluation of Different Crumb Rubber Modified (CRM) asphalt. Construct. Build. Mater., 23: 2701-2708. DOI: 10.1016/j.conbuildmat.2008.12.009

Magdy, A.A., 1997. Engineering characterization of the interaction of asphalt with crumb rubber modifier. J. Sci. Eng., 57: 51975179.

Martin, J., L.A. Cooley Jr. and H.R. Hainin, 2003. Production and construction issues for moisture sensitivity of hot-mix asphalt pavements. Proceeding of the Transportation Research Board National Seminar, Feb. 4-6, San Diego, California, pp: 209-222.

Miriam, E., 2009. Use of coupling agents to stabilize asphalt–rubber–gravel composite to improve its mechanical properties. J. Clean. Product., 17: 1359-1362. DOI: 10.1016/j.jclepro.2009.04.002

Navarro, F.J., P. Partal, F. Martinez and C. Gallegos, 2004. Thermo-rheological behaviour and storage stability of ground tire rubber-modified bitumens. Fuel, 83: 2041-2049. DOI: 10.1016/j.fuel.2004.04.003

Roberts, T.J., J.M. Weber, H. Hoppeler, E.R. Weibel and C.R. Taylor, 1996. Design of the oxygen and substrate pathways. II. Defining the upper limits of carbohydrate and fat oxidation. J. Exp. Biol., 199: 1651-1658. PMID: 8708572

Shi, H.B., M.X. Zou and K.J. Liao, 2005. Research progress of ground tire rubber modified pavement asphalts. J. Chem. Indus Eng., 26: 27-30.

Bressette, T., H. Zhou and A. Stonex, 2007. Asphalt rubber and its potential use in China. Proceedings of the 7th International Conference of Chinese Transportation Professionals, (CTP' 07), Shanghai.

Thodesena, C., K. Shatanawia, S. Amirkhaniana and W. Bridges, 2009. Development of an empirical model for determining G*/sin δ in crumb rubber modified binders. Construct. Build. Mater., 22: 1922-1927. DOI: 10.1016/j.conbuildmat.2008.09.002

Xiang, L., J. Cheng and G.H. Que, 2009. Microstructure and performance of crumb rubber modified asphalt. Construct. Build. Mater., 23: 3586-3590. DOI: 10.1016/j.conbuildmat.2009.06.038

Yetkin, Y., 2007. Polymer modified asphalt binders. Construct. Build. Mater., 21: 66-72. DOI: 10.1016/j.conbuildmat.2005.07.007