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Improvement the Durability of the Hot Mix Asphalt by using Crumb Rubber

Amani Soud Altaamseh
Department of Civil Engineering, Faculty of Engineering Technology, Al-Balqaa' Applied University, Amman, Jordan

Key words: Crumb rubber modifier, hot mix asphalt, optimum content, viscosity, resistance

Corresponding Author:
Amani Soud Altaamseh
Department of Civil Engineering, Faculty of Engineering Technology, Al-Balqaa' Applied University, Amman, Jordan

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Abstract: With the rapid economy growth and continuously increased consumption, a large amount of tire waste materials is generated. This study attends to test the performance of asphalt concrete mix with adding the Crumb Rubber Modifier (CRM) of 5, 10, 15, 20 and 25% as percentage of Asphalt Cement content (AC) in order to develop and determining the optimum CRM for hot mix asphalt design. The Marshall design was used to examine the influence of the optimum CRM content. The CRM is blended with AC using wet process. Subsequently, by obtaining low price and economic mixes that will reduce the optimum asphalt content OAC.

INTRODUCTION

The tire waste problem: Damaged tires represent one of the most dangerous types of waste according to experts in the environment because of the disposal difficulty and the absence of effective laws explain how to deal with them in ways not harmful to the environment. Damaged tires are an environmental burden for all consuming countries because they do not decompose for up to hundreds of years and are a bad health environment if they are burned to get rid of them. Many toxic gases such as sulfur oxides, carbon and lead will be released in air[1]. Also the use of accumulated waste materials in third world countries is still in its early phases. It will take courage for contractors and others in the construction industry to recycle selected types of waste materials in the concrete mixes[2].

The problem in the Arab countries with the huge numbers added to it each year. A country like Saudi Arabia consumes 23 million tires per year while Egypt consumes 20 million. A country like Kuwait consumes about 1 million tires/year. The total number of tires consumed in the Arab world is 170 million per year. While in Jordan, May reach >30 tons per year. Waste tires are a major cause of environment pollution in Jordan. One possible potential to minimize this pollution and to possibly improve the properties of asphalt mixtures is to utilize this waste material in modifying the asphalt used in preparing asphalt mixtures[3].

That the old tires are a big problem for all countries, especially, that consume a large number of tires in the US it is estimated that one scrap tire is produced annually for each person which is approximately 300 million tires (3.6 million tons), some of them are buried.

In USA280 million tires are buried each year which is considered an impractical solution because these tires may need up to 600 years until degradation because of their sulfur content, giving them cohesion and non-biodegradable[4]. In the case of burning, even if it is to obtain energy where carcinogenic substances are emitted as a result of combustion of polycyclic aromatic hydrocarbons other than carbon monoxide, nitrogen oxides and sulfur which have direct and indirect effects on water, soil and air and human which affects asthma, cancer and allergies and causes pneumonia and shortness of breath and it is also harmful to heart patients, especially, the elderly[1]. The industries involved in tire recycling are the manufacture of marine barriers made of recycled rubber. Synthetic rubber can be extracted from recycled products. There is also the production of rubber powder produced from the recycling of rubber and the most important use in the field of roads is the use of asphalt mixtures which used in paving. For example, approximately 31% of all Hot Mix Asphalt (HMA) placed by Caltrans (California Department of Transportation) was rubberized HMA, roughly 1.2[4]. The use of tires rubber as a 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[5, 6].

CRM : All tires of automobiles, trucks, buses, airplanes, etc. are made from rubber due to its unique properties. Rubber is related to thermo-plastic-elastic materials and is turned to thermosetting on vulcanization during manufacturing of rubber products or tires. This occurs as a result of the formation of three-dimensional structure due to the presence of the so-called vulcanizing system in rubber mixes[7]. The asphalt rubber can be used in four different applications. Listed in order of their volume of asphalt rubber consumption, these are chip seal or Stress-Absorbing Membrane (SAM) construction, Stress-Absorbing Membrane Interlayer (SAMI) construction crack or joint sealing and hot-mixed asphalt concrete pavement construction (on a very limited experimental basis)[8].

The use of scrap tire rubber as a modifier for asphalt cement has been developing for >25 years. However, since, the late 1980's, the emphasis for this engineering technology began to focus on its potential as a solution to an environmental solid waste problem. Pavement performance is a key component in determining if the use of scrap tire rubber is cost-effective. Because of the variable conditions that affect pavement performance, it is probable that some areas of such country will not benefit from this technology[8, 9].

Of the available expanding markets for scrap tires, only two have shown the potential to use a significant number. They are fuel for combustion and Crumb Rubber Modifier (CRM) for asphalt paving. Combustion already plays a major role, consuming about 9% of tires annually. Combustion facilities have the potential to use 0.5-10 million scrap tires per facility per year. In comparison, the second potential new market, CRM, presently consumes 1-2 million tires par year where 15-20% rubber asphalt ratio is proposed for the production of CRM binder[10].

The CRM technology can incorporate the rubber from 2-6 tires into a metric ton of Hot-Mix Asphalt (HMA) paving material. To recycle 10 million scrap tires annually as CRM, 2-5 million metric tons of HMA material would require modification[9]. The principal source of raw material for producing CRM is scrap tire rubber. In general, a scrap tire weighing approximately 9 kg (20 lb) will produce 4.5-5.5 kg (10-12 lb) of CRM. The remainder of the tire is fiber, steel and any rubber removed with the fiber and steel. Now, the millions of new passenger tires wear are available for reprocessing into CRM which ultimately can be used in asphalt rubber. The passenger tires are composed of in total about 70% rubber. The rubber is composed of synthetic rubber (27%), natural rubber (15%) and carbon black (28%). Other components include 15% steel and 16% fabric. Scrap tire rubber can be delivered to the processing plant as whole tires, cut tire, shredded tire or retread buffing waste. Shredded tire rubber is the preferred and logical alternative as a raw material for producing CRM. The type of scrap tire raw material and the quality of that material are generally the responsibility of the CRM processors. The capability of the processing plant and the buyer's specified CRM properties will direct the processor's operation[9]. There are three methods currently used to process scrap tire rubber into CRM. The cracker mill process is the most common method. The cracker mill process tears apart scrap tire rubber, reducing the size of the rubber by passing the material between rotating corrugated steel drums. The granul at or process shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance. The micro-mill process further reduces a crumb rubber to a very ground particles. The cracker mill process produces an irregularly shaped torn particle with a large surface area. The particles can be produced over a range of sizes from 4.75 mm to 425 μm (No. 4-40) sieve. These particles are commonly described as a ground CRM. The granulat or produces a cubical, uniformly shaped cut particle with a low surface area. The particles can be produced over a range of sizes, typically 9.5 mm down to 2.00 mm (3/8 in. to No. 10) sieve. This material is called a granulated CRM. The micro-mill process produces a very fine ground CRM. The particles can be reduced to a range of sizes from 425 μm down to 75 μm (No. 40-200) sieve[11].

The CRM has two main process of construction the wet process and the dry process. The wet process defines any method that adds the CRM to the asphalt cement before incorporating the binder into the asphalt paving project. This process is used to produce the asphalt rubber product. There are three elements to the equipment necessary to achieve the wet process. They include blending the CRM and asphalt cement, reacting the two materials and transferring the asphalt rubber product to the desired project application. Special pumps and frequent calibration are essential to ensure that a uniform accurate application of the modified binder is achieved[12]. The dry process defines any method of adding CRM directly into the HMA mix process, typically pre-blending the CRM with the heated aggregate before charging the mix with asphalt the dry process has been reported to have limited success in the past[13, 14]. The limitation is because of that in dry process all additives cause a failure and the segregation was the major reason for failure[15].

Asphalt rubber: According to the ASTM definition, Asphalt Rubber (AR) is "a blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. By definition, asphalt rubber is prepared using the "wet process." Physical property requirements are listed in ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," located in Vol. 4.03 of the Annual Book of ASTM Standards 2001 and in Caltrans Standard Special Provisions for Asphalt Rubber Binder. The asphalt rubber is produced at elevated temperatures (≥177°C), under high agitation to promote the physical interaction of the asphalt binder and rubber constituents and to keep the rubber particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, to facilitate spray applications and to promote work ability.

The asphalt rubber is the result of asphalt rubber reaction which is affected by a number of variables. Specifically, by the temperature at which the blending-reaction occurs, the length of time the temperature remains elevated the type and amount of mechanical mixing energy, the size and texture of the CRM and the aromatic component of the asphalt cement[16]. As CRM reacts with asphalt cement, it also swells and softens. The viscosity of the asphalt-CRM blend is used to monitor the reaction. Asphalt cement modified with 15% CRM can increase the binder's high temperature viscosity by a factor of 10 or more[9].

The surface area can be increased by reducing the size and specifying a crackermill process. The specified reaction time should be the minimum time (at a preset temperature) required to stabilize the binder viscosity[11]. The asphalt is paving grade asphalt and it is heated to about 375°F (190°C). Crumb rubber at ambient temperature is added to the hot asphalt and thoroughly mixed. The resultant asphalt-rubber is pumped into a holding tank where the asphalt-rubber is kept to a temperature of at least 350°F (177°C) for a period of 45-60 min.

Problems of using AR asphalt rubber that have been documented typically have been construction issues related to cold temperature paving or late season construction. This indicates that temperature was a major contributing factor. Temperature also affects placement and compaction of conventional mixtures but is more critical when working with materials that have been modified to increase high temperature stiffness (such as asphalt rubber and polymer modified performance based asphalt, PBA) and are being placed in thin lifts. Asphalt rubber paving materials should not be placed in rainy weather, cold weather with ambient or surface temperatures <13°C, over pavements with severe cracks more than 12.5 mm wide where traffic and deflection data are not available, areas where considerable handwork is required and where haul distances between AC plant and job site are too long to maintain mixture temperature as required for placement and compaction.

Expected effects of rubber on asphalt cement: 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 and many effects can improve the performance of binder[10].

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[17, 18].

The nature of the interaction process between asphalt cement and Crumb Rubber Modifier (CRM) has not been fully understood. Two main types of mechanisms that affect the produced binder properties are reported: particle swelling and degradation[19]. But the previous researches and applications 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 and reflection cracking, reduced temperature susceptibly and improved durability and lower pavement maintenance costs due to aging resistance[20]. Using CRM will reduce the waste by recycling of waste tires and rubber which can have high cost to dispose[14]. Logically, the rubber should impart desirable characteristics that improve the life of the pavement. The changing in the viscosity of the binder over the normal range of operating and mixing temperatures indicates that the addition of CRM flattens the temperature-viscosity curve and will reduce the binder's temperature sensitivity. Properly proportioned asphalt-rubber binders can be used in dense, gap or open-graded friction course mixtures without any significant effect on conventional mix production operations. However, standard asphalt metering pumps on asphalt hot mix plants may not be adequate to handle the higher viscosity binders. Plants with asphalt weigh buckets will generally operate without any problems provided that the spray bar orifices do not restrict flow. And because the crumb rubber does not dissolve into the asphalt cement, the swollen rubber particles in the binder can affect the consistency of the binder during a particular test. In simple terms, modifying the asphalt binder with CRM will requirean increase in the binder content. This affects the paving material's cost, potential to flush-bleed and may cause tracking. Finally, the ability of CRM to enhance the properties of the binder hinges on the compatibility between the asphalt cement and the CRM[9, 11, 12].

MATERIALS AND METHODS

Laboratory test

Material selection

CRM: Conventional Marshall mix design procedures have been used. One concern regarding the HMA with the wet process is the required batching and reaction time associated with blending CRM and asphalt cement to produce asphalt rubber[21].

As previously discussed, the time required to react these materials is dependent on a number of factors including the size of the CRM. Table 1 shows the course, fine and medium gradation of the CRM. For this study the passing No. 20 gradations (medium) is choosing to be blending with asphalt cement using the wet process in order to prepare the asphalt rubber. Table 2 shows all other specifications of the used CRM.

Aggregate: The amount and fineness the CRM to be used in asphalt-rubber blends is based on the aggregate application. In dense-graded friction course mixtures, 5% of CRM passing the No. 50 sieve (e.g., a maximum nominal 80 mesh) is recommended. In open-graded friction courses, 12% of CRM passing the No. 30 sieve (e.g., a maximum nominal 40 mesh) is recommended to be blended with the asphalt cement. Open-graded mixtures are more tolerant of larger rubber particulate size and greater CRM contents. And it was found that the calculations for blending are simplified if the amount of CRM is specified as a percentage of the asphalt cement rather than of the total binder mix. For this study Table 1-7 shows the characteristics of the chosen aggregate and Fig. 1 shows the gradation of aggregate.

Asphalt cement: For this study the AC (60-70) is used. Table 8 shows the tests and specification of the asphalt cement and the asphalt rubber concrete.

Testing method: As previously mentioned the Marshall mix design method will be used to prepare HMA with CRM. The Marshall stability and flow test provides the performance prediction measure for the Marshall mix

Table 1: Gradation of CRM

Sieve size passing (%)	Fine	Medium	Course
10	-	-	100
20	-	100	85-100
30	-	95-100	40-65
40	100	85-100	20-45
60	98-100	30-60	-
80	90-100	15-40	5-20
100	70-90	5-25	-
200	35-60	-	-

Table 2: The CRM specification

The specification	The requirements
General	The GTR should be produced by ambient grinding methods. It should be sufficiently dry, so that, it is free flowing and foaming is prevented when it is mixed with asphalt cement. The rubber should be substantially free from contaminants including fabric, metal, mineral and other non rubber substances. Up to 4% (by weight of rubber) of talc (such as magnesium silicate or calcium carbonate) may be added to prevent sticking and caking of the particles
Physical requirements	Gradation: when tested in accordance with ASTM C-136 using a 50 g sample, the resulting rubber gradation should meet the gradation limits shown in Table 3 for the type of rubber specified. Specific gravity of the rubber as determined by ASTM D-297, pycnometer method, should be 1.15±0.05. Moisture content: maximum 0.75% by weight as determined by AASHTO T 255 using a controlled oven temperature of 140°F and a 50 g sample. Mineral contaminants: maximum 0.25% by weight
Chemical requirements	Acetone extract: maximum 25%. Rubber hydrocarbon content: 40-55%. Ash content: maximum 10%. Carbon black content: 20-40%

Table 3: The cold bin testing

Aggregate identification	Test result passing by weight (%)				Cold bin
Sieve analysis/Test name	Coarse aggregate (Basalt)	Medium aggregate (Basalt)	Fine Agg.1 (Basalt)	Fine Agg. 2 (limestone)	Test standard
Sieve No. (Size, mm)					
1" (25.4)	100	100	100	100	AASHTO 27-14,
¾ (19.0)	100	100	100	100	
½ (12.7)	40	100	100	100	
3/8 (9.5)	4	73	100	100	
No. 4 (4.75)	1	3	97	99	AASHTO T11-05 (2013)
No. 8 (2.36)	1	1	63	86	
No. 20 (0.85)	1	1	42	40	

Table 3: Continue

Aggregate identification Sieve analysis/Test name	Test result passing by weight (%) Coarse aggregate (Basalt)	Medium aggregate (Basalt)	Fine Agg.1 (Basalt)	Fine Agg. 2 (limestone)	Cold bin Test standard
No. 50 (0.30)	1	1	27	30	
No. 80 (0.18)	1	1	18	25	
No. 200 (0.075)	0.5	0.6	12	19	
Specific Gravity (SG):					
Bulk SG (Oven Dry)	2.745	2.744	2.842	2.505	AASHTO T84-13,
Bulk SG (SSD)	2.798	2.799	2.907	2.588	AASHTO T85-14
Apparent SG	2.899	2.903	2.041	2.731	
Water absorption (%)	1.9	2.0	2.3	3.3	
Atterberg limits					
Liquid limit		-	-	16	AASHTO T89-13,
Plastic limit		-	-	14	AASHTO T90-16
Plasticity index	-	N.P	2	2	BS812:Part105.1,1989
Flakiness index	8	15	-	-	BS812:Part105.2,1990
Elongation index	19	17	-	-	AASHTO T96-02 (2015)
Abrasion loss (500 cycles%)	23	24	-	-	
Ratio of wear loss (100/500%)	19	22	-	-	
Clay lumps (%)	0.18	0.37	0.37	0.69	AASHTO T112-00 (2012)
Fractured faces (at least two%)	100	100	--	-	AASHTO T335-09 (2013)

Table 4: Hot bin testing

Aggregate identification Sieve analysis/Test name	Test result passing by weight (%) Coarse aggregate (Basalt)	Medium aggregate (Basalt)	Fine aggregate (Mix)	Cold bin Test standard
Sieve No. (Size, mm)				
1” (25.4)	100	100	100	AASHTO 27-14,
¾ (19.0)	100	100	100	AASHTO T11-05 (2013)
½ (12.7)	32	100	100	
3/8 (9.5)	7	71	100	
No. 4 (4.75)	1	4	97	
No. 8 (2.36)	1	1	70	
No. 20 (0.85)	1	1	40	
No. 50 (0.30)	1	1	25	
No. 80 (0.18)	1	1	18	
No. 200 (0.075)	0.7	1.0	10.9	
Specific Gravity (SG):				
Bulk SG (Oven Dry)	2.765	2.756	2.787	AASHTO T84-13,
Bulk SG (SSD)	2.813	2.806	2.839	AASHTO T85-14
Apparent SG	2.904	2.902	2.941	
Water Absorption, %	1.7	1.8	1.9	
Atterberg limits				
Liquid limit	-		-	AASHTO T89-13,
Plastic limit	-		-	AASHTO T90-16
Plasticity index	-		NP	
Sand equivalent	-		73	AASHTO T176-08 (2013)
Static stripping, coated (%)	>95%		-	AASHTO T182-84 (2002)
Dynamic stripping, coated (%)			-	
Without filler	50			
With filler	70			

Table 5: The aggregate specifications of by the Ministry of Public Works and Housing

Specification of materials used in asphalt mixtures Sieve analysis	Binder mix	Wearing mix
Plasticity index fine aggregate	4.0 Max.	
Flakiness index	30 Max.	25 Max.
Elongation index	30 Max.	25 Max.
Abrasion (%)	35 Max.	
Wear loss (100/500) (%)	25 Max.	
Sand equivalent	50 Min.	
Clay lumps	1.0 Max.	
Resistance to stripping (%)		
Static	95 min. coated particles	
Dynamic	50 min. coated particles	

Table 6: The aggregate proportions

Hot bin components	Hot bin proportions (%)
Coarse aggregate (hot bin) 1	24
Medium aggregate (hot bin) 2	30
Fine aggregate (hot bin) 3	46
Fine aggregate (basalt)	
Fine aggregate (limestone)	

design method. The test measures the maximum load supported by the test sample at a loading rate of 50.8 mm min^{-1} 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

Table 7: Aggregate gradation

Sieve No.	Weight of retained (g)	Passing (g)	Weight of retained (%)	Cumulative passing (%)	Specification limits	Test standards
1”	0	2000	0.0	100.0	100	ASTM C136/C136M-14
¾”	0	2000	0.0	100.0	70-100	
½”	326	1674	16.3	83.7	53-90	
3/8”	294	1380	31.0	69.0	40-80	
No. 4	458	922	53.9	46.1	30-56	
No. 8	268	654	67.3	32.7	23-38	
No. 20	276	378	81.1	18.9	13-27	
No. 50	138	240	88.0	12.0	5-17	
No.80	64	176	91.2	8.8	4-14	
No. 200	66	110	94.5	5.5	2-8	ASTM D1140-17
Pan	110					
Total weight	2000 g					

Table 8: The tasting and specification of asphalt cement

	Penetration (mm)				
Rubber (%)	Specimen 1	Specimen 2	Specimen 3	Average	Test standard
AC(0)	5.35	5.53	5.54	5.47	ASTM D5/D5M-13
5	5.18	5.04	4.78	5.00	
10	4.94	4.81	4.47	4.74	
15	2.51	2.36	2.15	2.34	
20	2.43	2.54	2.72	2.56	
25	0.92	0.63	0.42	0.66	
Softening temperature (°C) (%)					
AC(0)	48	50	49	49	ASTM D36/D36-14^{e1}
5	53	55	54	54	
10	63	65	64	64	
15	68	70	69	69	
20	82	80	81	81	
25	93	95	94	94	

Rubber (%)	Flash point	Fire point	Test standard
AC(0)	240	244	ASTM D92-16
5	260	265	
10	277	279	
15	259	261	
20	220	225	
25	217	219	

Table 9: The HMA layers

Type of mix	Wearing course	Binder course	Standards
Thickness of course (mm)	40-65	50-100	BS W3B wearing course (PWD 1992) mix specification
Max. size of stone (mm)	19	38	B.S W3B wearing course (PWD 1992) mix specification
Sieve size	Passing (%)	Passing (%)	
1½” (38.1 mm) 1” (25.4 mm) ¾” (19.0 mm) ½” (12.7 mm) 3/8” (9.5 mm) No. 4 (4.75 mm) No. 8 (2.36 mm) No. 20 (0.85 mm) No. 50 (0.3 mm) No. 80 (0.18 mm) No. 200 (0.075 mm)	According to combined aggregate gradation	According to combined aggregate gradation	ASTM MS-2 mix specification
Soluble bitumen (%) (60/70 penetration grade) (by mass of total mix) (%)	5±0.5	5±0.5	B.S W3B wearing course (PWD 1992) mix specification

(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 control mixture contained an optimum 4.4% of AC-60 asphalt cement

Table 10: Marshall results for HMA without rubber

Test certificate for uncompacted bituminous paving mixtures

Asphalt work

Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 4/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	0.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17[e1]
Bulk specific gravity				
Wt. in air dry (g)	1198.1	1201.4	1191.7	ASTM D2726-17
Wt. in surface dry, SSD (g)	1206.5	1210.2	1199.8	
Wt. in water (g)	731.3	734.4	727.7	
Volume (cm^3)	475.2	475.8	472.1	
Bulk specific gravity, Gmb (gcm^{-3})	2.521	2.525	2.524	
Average		2.523		
Maximum theoretical density, Gmm (gcm^{-3})	2.656			ASTM D2041-11
Air Voids, AV (%)	5.0			ASTM D3203-17
Voids in mineral aggregate, VMA (%)	13.0			ASTM D6995-13
Void Filled, VFB (%)	61.5			ASTM D6927-15
Marshall stability after 30 min/Reading	70	69	70	ASTM D6927-15
Dial factor	24.01	24.01	24.01	
Measured stability (kg)	1680.7	1656.7	1680.7	
Correction factor	1.14	1.14	1.14	
Corrected stability (kg)	1916	1889	1916	
Average corrected stability after 30 min	1907			
Average corrected stability after 24 h	1623			
Loss of stability (%)	14.9			
Marshall flow (mm)	2.30	2.40	2.35	ASTM D6927-15
Average		2.35		
Marshall stiffness ($kgmm^{-1}$)	811			ASTM D1559-89
Gsb of aggregate (gcm^{-3})	2.772			ASTM C127-15
Gse of aggregate (gcm^{-3})	2.877			ASTM C127-15
Bitumen specific gravity (gcm^{-3})	1.019			ASTM D70-18
Rubber specific gravity (gcm^{-3})	0.911			ASTM D792-13

Table 11: Marshall results for HMA with 5% rubber

Test certificate for uncompacted bituminous paving mixtures

Asphalt work

Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 10/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	5.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17[e1]
Bulk specific gravity				
Wt in air dry (g)	1188.8	1195.6	1190.2	ASTM D2726-17
Wt in surface dry, SSD (g)	1197.1	1204.4	1198.6	
Wt in water (g)	724.4	727.7	723.8	
Volume (cm^3)	472.7	476.7	474.8	
Bulk specific gravity, Gmb (gcm^{-3})	2.515	2.508	2.507	
Average		2.510		
Maximum theoretical density, Gmm (gcm^{-3})	2.637			ASTM D2041-11
Air Voids, AV (%)	4.8			ASTM D3203-17
Voids in Mineral Aggregate, VMA (%)	13.4			ASTM D6995-13
Void Filled, VFB (%)	64.2			ASTM D6927-15
Marshall stability after 30 min/Reading	72.5	70.0	72.4	
Dial factor	24.01	24.01	24.01	ASTM D6927-15
Measured stability (kg)	1740.7	1680.7	1738.3	
Correction factor	1.14	1.14	1.14	
Corrected stability (kg)	1984	1916	1982	
Average corrected stability after 30 min	1961			
Average corrected stability after 24 h	1686			
Loss of stability (%)	14.0			
Marshall flow (mm)	2.30	2.35	2.35	ASTM D6927-15

Table 11: Continue

Test certificate for uncompacted bituminous paving mixtures		
Asphalt work		
Layer type: wearing mix	Location: mix design (Trial No. 2)	Date: 10/7/2018
Average	2.33	
Marshall stiffness (kg mm^{-1})	842	ASTM D1559-89
Gsb of aggregate (g cm^{-3})	2.772	ASTM C127-15
Gse of aggregate (g cm^{-3})	2.847	ASTM C127-15
Bitumen specific gravity (g cm^{-3})	1.019	ASTM D70-18
Rubber specific gravity (g cm^{-3})	0.911	ASTM D792-13

Table 12: Marshall results for HMA with 10% rubber

Test certificate for uncompacted bituminous paving mixtures				
Asphalt work				
Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 15/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	10.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17^{e1}
Bulk specific gravity				
Wt in air dry (g)	1199.6	1201.4	1193.5	ASTM D2726-17
Wt in surface dry, SSD (g)	1209.1	1211.2	1202.3	
WT in water (g)	727.1	728.3	724.1	
Volume (cm^3)	482.0	482.9	478.2	
Bulk specific gravity, Gmb (gcm^{-3})	2.489	2.488	2.496	
Average		2.491		
Maximum theoretical density, Gmm (gcm^{-3})	2.611			ASTM D2041-11
Air Voids, AV (%)		4.6		ASTM D3203-17
Voids in mineral aggregate, VMA %	14.1			ASTM D6995-13
Void Filled, VFB (%)	67.4			ASTM D6927-15
Marshall stability after 30 min/Reading	74.0	73.0	72	ASTM D6927-15
Dial factor	24.01	24.01	24.01	
Measured stability (kg)	1776.7	1752.7	1728.7	
Correction factor	1.14	1.14	1.14	
Corrected stability (kg)	2025	1998	1971	
Average corrected stability after 30 min	1998			
Average corrected stability after 24 h	1728			
Loss of stability (%)	13.5			
Marshall flow (mm)	2.25	2.30	2.25	
Average		2.27		ASTM D6927-15
Marshall stiffness ($kgmm^{-3}$)	880			ASTM D1559-89
Gsb of aggregate (gcm^{-3})	2.772			ASTM C127-15
Gse of aggregate (gcm^{-3})	2.817			ASTM C127-15
Bitumen specific gravity (gcm^{-3})	1.019			ASTM D70-18
Rubber specific gravity (gcm^{-3})	0.911			ASTM D792-13

Table 13: Marshall results for HMA with 15% rubber

Test certificate for uncompacted bituminous paving mixtures				
Asphalt work				
Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 22/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	15.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17^{e1}
Bulk specific gravity				
Wt in air dry (g)	1190.7	1194.3	1192.9	ASTM D2726-17
WT in water (g)	1199.0	1202.9	1201.3	
Wt in surface dry, SSD (g)	719.5	721.3	719.7	
Volume (cm^{-3})	479.5	481.6	481.6	
Bulk specific gravity, Gmb (g cm^{-3})	2.483	2.480	2.477	
Average			2.480	
Maximum theoretical density, Gmm (g cm^{-3})	2.602			ASTM D2041-11
Air voids, AV (%)		4.7		ASTM D3203-17
Voids in Mineral Aggregate, VMA (%)	14.5			ASTM D6995-13

Table 13: Continue

Test certificate for uncompacted bituminous paving mixtures				
Asphalt work				
Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 22/7/2018
Void filled, VFB (%)	67.6			ASTM D6927-15
Marshall stability after 30 min/Reading	72.0	72.0	71.0	ASTM D6927-15
Dial factor	24.01	24.01	24.01	
Measured stability (kg)	1728.7	1728.7	1704.7	
Correction factor	1.14	1.14	1.14	
Corrected stability (kg)	1971	1971	1943	
Average corrected stability after 30 min	1961			
Average corrected stability after 24 h	1706			
Loss of stability (%)	13.0			
Marshall flow (mm)	2.20	2.15	2.25	ASTM D6927-15
Average	2.20			
Marshall stiffness ($kgmm^{-1}$)	891			ASTM D1559-89
Gsb of aggregate (gcm^{-3})	2.772			ASTM C127-15
Gse of aggregate (gcm^{-3})	2.808			ASTM C127-15
Bitumen specific gravity (gcm^{-3})	1.019			ASTM D70-18
Rubber specific gravity (gcm^{-3})	0.911			ASTM D792-13

Table 14: Marshall results for HMA with 20% rubber

Test certificate for uncompacted bituminous paving mixtures				
Asphalt work				
Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 22/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	20.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17^{e1}
Bulk specific gravity				
Wt in air dry (g)	1205.6	1202.4	1207.1	ASTM D2726-17
WT in water (g)	1215.2	1211.3	1217.0	
Wt in Surface dry, SSD (g)	728.5	724.7	728.7	
Volume (cm^{-3})	486.7	486.6	488.3	
Bulk specific gravity, Gmb (gcm^{-3})	2.477	2.470	2.472	
Average		2.473		
Maximum theoretical density, Gmm (cm^{-3})	2.595			ASTM D2041-11
Air voids, AV (%)		4.7		ASTM D3203-17
Voids in mineral aggregate, VMA (%)	14.7			ASTM D6995-13
Void filled, VFB (%)	68.0			ASTM D6927-15
Marshall stability after 30 min/Reading	73.0	72.0	72.0	ASTM D6927-15
Dial factor	24.01	24.01	24.01	
Measured stability (kg)	1752.7	1728.7	1728.7	
Correction factor	1.09	1.09	1.09	
Corrected stability (kg)	1910	1884	1884	
Average corrected stability after 30 min	1892			
Average corrected stability after 24 h	1657			
Loss of stability (%)	12.4			
Marshall flow (mm)	2.10	2.20	2.15	ASTM D6927-15
Average	2.15			
Marshall stiffness ($kgmm^{-1}$)	880			ASTM D1559-89
Gsb of aggregate (gcm^{-3})	2.772			ASTM C127-15
Gse of aggregate (gcm^{-3})	2.802			ASTM C127-15
Bitumen specific gravity (gcm^{-3})	1.019			ASTM D70-18
Rubber specific gravity (gcm^{-3})	0.911			ASTM D792-13

and the experimental mixture contained 5 values of asphalt rubber percents; 5, 10, 15, 20 and 25% by asphalt cement weight. In order to find an initial value of optimum rubber content. The results of modifying asphalt binders with CRM using a wet process are called either rubberized asphalt or Asphalt Rubber (AR). Rubberized asphalt is a term applied to rubber modified asphalt with up to 15% rubber by total weight of the asphalt while AR has at least 15% rubber as defined by American Society for Testing and Materials (ASTM) Specification D 6114-97. Table 9-17 and Fig. 2 show Marshall mix test results.

Table 15: Marshall results for HMA with 25% rubber

Test certificate for uncompacted bituminous paving mixtures

Asphalt work

Layer type: wearing mix	Location: mix design (Trial No. 2)			Date: 22/7/2018
Number of blows	75			Test standards
Rubber content by WT of asphalt (%)	25.00			
Asphalt content by WT of mix (%)	4.40			ASTM D2172-17^{e1}
Bulk specific gravity				
Wt in air dry (g)	1206.1	1200.9	1209.3	ASTM D2726-17
WT in water (g)	1215.9	1209.7	1219.4	
Wt in surface dry, SSD (g)	725.2	717.9	725.2	
Volume (cm$^{3)}$	490.7	491.8	494.2	
Bulk specific gravity, Gmb (g cm^{-3})	2.458	2.442	2.447	
Average		2.449		
Maximum theoretical density, Gmm (g cm^{-3})	2.592			ASTM D2041-11
Air voids, AV (%)		5.5		ASTM D3203-17
Voids in Mineral Aggregate, VMA (%)	15.5			ASTM D6995-13
Void filled, VFB (%)	64.5			ASTM D6927-15
Marshall stability after 30 min/Reading	72.6	70.0	72.0	ASTM D6927-15
Dial factor	24.01	24.01	24.01	
Measured stability (kg)	1743.1	1680.7	1728.7	
Correction factor	1.09	1.09	1.09	
Corrected stability (kg)	1900	1832	1884	
Average corrected stability after 30 min	1872			
Average corrected stability after 24 h	1587			
Loss of stability (%)	15.2			
Marshall flow (mm)	1.90	2.25	2.25	
Average	2.20			ASTM D6927-15
Marshall stiffness (kg mm^{-1})	851			ASTM D1559-89
Gsb of aggregate (g cm^{-3})	2.772			ASTM C127-15
Gse of aggregate (g cm^{-3})	2.606			ASTM C127-15
Bitumen specific gravity (g cm^{-3})	1.019			ASTM D70-18
Rubber specific gravity (g cm^{-3})	0.911			ASTM D792-13

Table 16: The Marshall criteria

	Heavy traffic		Medium-light traffic	
Mix property	Binder	Wearing	Binder	Wearing
Stability (kg)	900	1000	800	900
Flow (mm)	2-3.5	2-3.5	2-4	2-4
VMA	13(-1)	14(-1)	13(-1)	14(-1)
Air voids (%)	4-7	4-6	3-5	3-5
Loss of stability	25 (max)	25 (max)	25 (max)	25 (max)

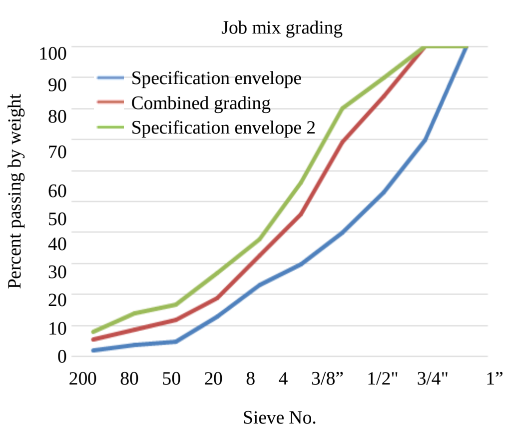

Fig. 1: The gradation curve

RESULTS AND DISCUSSION

The penetration test shows that the asphalt rubber has more consistency than the asphalt cement. It is found that the optimum rubber content is 17% by the weight of the asphalt cement. This meets the ASTM Standards 2001 and Jordanian MPWH requirements. Mixing the CRM with asphalt cement will increase the VMA because of that the rubber particles swell (react) causing the viscosity to increase and if heat is maintained for a prolonged time, the rubber may melt and break down, resulting in an undesirable decrease in viscosity. It is desirable to use the asphalt rubber binder after it has reached its maximum viscosity but before the rubber breaks down, however, rubber breakdown is not the only concern. If a short time is required to achieve maximum viscosity, the fine rubber

Rubber content (%)	Bulk SG.
0.0	2.523
5.0	2.510
10.0	2.491
15.0	2.480
20.0	2.473
25.0	2.449

Rubber content (%)	Air voids (%)
0.0	5.0
5.0	4.8
10.0	4.6
15.0	4.7
20.0	4.7
25.0	5.5

Rubber content (%)	VMA (%)
0.0	13.0
5.0	3.4
10.0	14.1
15.0	14.5
20.0	14.7
25.0	15.5

Rubber content (%)	Flow mm
0.0	2.35
5.0	2.33
10.0	2.27
15.0	2.20
20.0	2.15
25.0	2.20

Rubber content (%)	Stability (kg)
0.0	1907
5.0	1961
10.0	1998
15.0	1961
20.0	1892
25.0	1872

Rubber content (%)	Stiffness (kgmm^{-1})
0.0	811
5.0	842
10.0	880
15.0	891
20.0	880
25.0	851

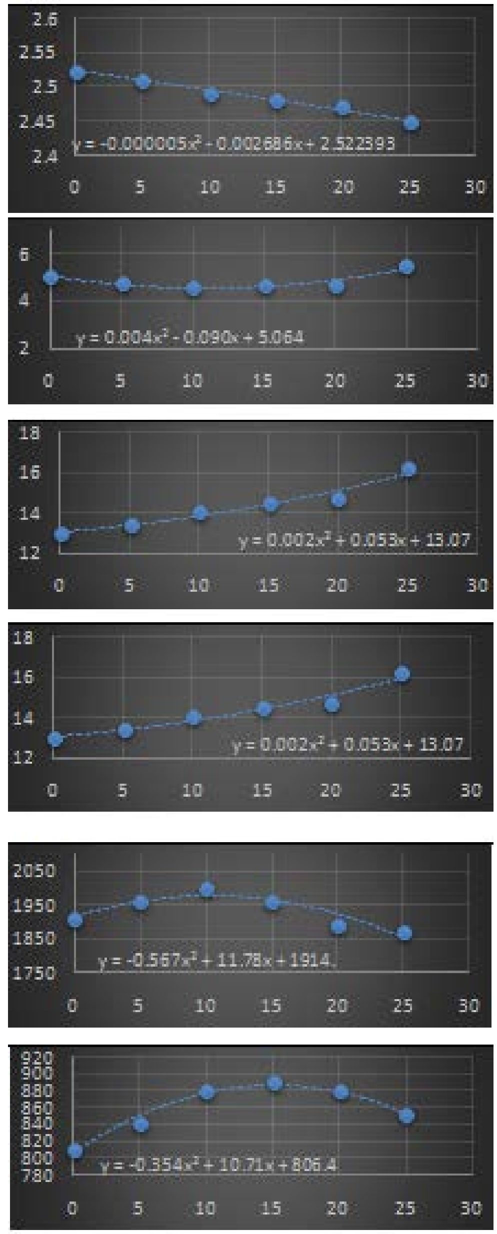

Fig. 2: Marshall results

Table 17: The results of all trials

Trial asphalt mixes result									
Rubber cont. (%)	Spes. No.	Bulk specific gravity	Maximum theoretical Sp. Gr.	Air voids (%)	VMA (%)	VFB (%)	Marshall stability (kg)	Marshall flow (mm)	Marshall stiffness (kg mm^{-1})
0.0	1	2.521					1916	2.30	
	2	2.525					1889	2.40	
	3	2.524					1916	2.35	
	Avg.	2.523	2.656	5.0	13.0	61.5	1907	2.35	811
5.0	1	2.515					1984	2.30	
	2	2.508					1916	2.35	
	3	2.507					1982	2.35	
	Avg.	2.510	2.637	4.8	13.4	64.2	1961	2.33	842

Table 17: Continue

Rubber cont. (%)	Spes. No.	Bulk specific gravity	Maximum theoretical Sp. Gr.	Air voids (%)	VMA (%)	VFB (%)	Marshall stability (kg)	Marshall flow (mm)	Marshall stiffness (kg mm^{-1})
Trial asphalt mixes result									
10.0	1	2.489					2025	2.25	
	2	2.488					1998	2.30	
	3	2.496					1971	2.25	
	Avg.	2.491	2.611	4.6	14.1	67.4	1998	2.27	880
15.0	1	2.483					1971	2.20	
	2	2.480					1971	2.15	
	3	2.477					1943	2.25	
	Avg.	2.480	2.602	4.7	14.5	67.6	1961	2.20	891
20.0	1	2.477					1910	2.10	
	2	2.470					1884	2.20	
	3	2.472					1884	2.15	
	Avg.	2.473	2.595	4.7	14.7	68.0	1892	2.15	880
25.0	1	2.458					1900	1.90	
	2	2.442					1832	2.25	
	3	2.447					1884	2.25	
	Avg.	2.449	2.592	5.5	15.5	64.5	1872	2.20	851

Bulk specific gravity of combined aggregate (Gsb), 2.772; Effective specific gravity of combined aggregate (Gse), 2.808; Specific gravity of bitumen (Gb), 1.009; Absorbed asphalt by weight of aggregate (Pba), 0.5

will require less elaborate blending equipment than the coarse rubber. HMA with AR is more stiffness than the conventional mixes. The mixtures with coarser crumb rubber required approximately more binder than similar mixtures with fine crumb rubber. Because the rubber particles do not melt completely, they tend to push the aggregate particles apart and will increase VMA in all mixtures that have higher rubber content.

Mixing the CRM by the wet process to introduce the modifier binder will result different effects than mixing it by dry process to introduce rubber aggregate. Where the role of rubber will change between the two applications. Once the rubber will behave as a binder and then it becomes an aggregate.

CONCLUSION

The laboratory tests show that optimum rubber content is 17% by the weight of the asphalt cement. This meets the ASTM Standards 2001 and Jordanian MPWH requirements. Adding the CRM to HMA will increase the consistency and viscosity of the mixes which leads to higher rutting resistance, reduce fatigue and reflecting cracking and improve durability.

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