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Laboratory Evaluation of Rubberized Asphalt Using the Dry Process

Sari W. Abusharar
College of Applied Engineering and Urban Planning
University of Palestine
Gaza, Palestine
s.abusharar@hotmail.com

***Abstract*— In the present study, the effect of rubber and bitumen contents on various mechanical properties of rubberized asphalt mixture, containing 0%, 5%, 10% and 15% waste ground rubber tire powder (WGRTP) and 4.5%, 5% and 5.5% asphalt by weight of total mix, were investigated with laboratory tests. The volumetric and mechanical properties of asphalt mixes were Marshall Stability, flow, Marshall Quotient (MQ), bulk specific gravity, air voids and percent voids in compacted mineral aggregates (VMA). The Marshall tests of the rubberized asphalt showed that the properties of rubberized asphalt are highly affected by both the amount of rubber and bitumen contents added to the mix. The rubberized asphalt mix containing 5% bitumen and 5% rubber contents showed considerable improvement in various mechanical properties of the mix compared to the other contents.**

Keywords*— *Rubberized asphalt; Waste ground rubber tire powder; Dry process; Marshall test method

I. INTRODUCTION

The use of waste ground tire rubber (WGTR) from scrap tires in road application may be dated back to the 1960s when Charles MacDonald, during some maintenance work in urban areas, experienced the advantages of using tire rubber as an additive in asphalt cement for repairing potholes. MacDonals, in fact, found that accurately mixing the rubber into the bitumen and allowing the blend a sufficient reaction time, it was possible to obtain a product with new and improved properties with respect to those of the original bitumen, and started the experimental phase that led to the definition of a process that is known in the literature as Wet Process [1].

In parallel, two Swedish companies produced a surface asphalt mixture with the addition of a small quantity of ground rubber form discarded tires as a substitute for a part of the mineral aggregate in the mixture, in order to obtain asphalt mixture with improved resistance to studded tires as well as to snow chains, via a process known as Dry Process [2].

The main differences between these processes include size of rubber; in the dry process rubber is much coarser than wet process rubber, amount of rubber; the dry process uses rubber 2 to 4 times as much as the wet process, function of rubber; in the dry process the rubber acts more like an aggregate but in the wet process it acts more like the binder, and finally the ease of incorporation into the mix; in the dry process no special equipment is required while in the wet process special mixing chambers, reaction and blending tanks, and oversized pumps are required [3].

The primary reason for using waste rubber in asphalt pavements is that it provides significantly improved engineering properties over conventional asphalt pavements. As demonstrated by various researchers, waste rubber have reduced fatigue and reflection cracking, greater resistance to rutting, improved aging and oxidation resistance and better chip retention due to thicker binder films [4-10]. Also asphalt rubber pavements have been demonstrated to have lower maintenance costs [11-12], lower noise generation [13-15], higher skid resistance and better night-time visibility due to contrast in the pavement and stripping [13].

Several researches have focused on the reuse of waste tire rubber in asphalt pavements produced by dry process to improve its engineering properties. Fernandes et al. [16] have concluded that rubberized asphalt mixtures produced by dry process, have increased the elasticity of the mixture; it could enhance the bonding between binder and aggregates resulting in an increase in fatigue life, and resistance to rutting, and could lead to a reduction of the thermal and reflecting cracking of these mixtures. Khalid and Artamendi [17] have revealed that the control of rubber particles and asphalt interaction could not be done in an easy way since there was immediate mixing between aggregates and asphalt. When these mixtures were established correctly, such pavements were better for icy road conditions. Kettab and Bali [18] indicated that when rubber with particle size higher than 2 mm was added to asphalt mixtures, the compaction and strength characteristics were improved as the rubber fills the existing voids within the granular skeleton. Khalid and Artamendi [17] showed that the addition of rubber at (10–15)% (by weight of the asphalt) by dry process caused a reduction in penetration into bitumen and softening point, while viscosity increased with crumb rubber content and decreased as temperature was elevated. According to Fernandes et al. [16], rubberized dense asphalt mixtures has resulted in lower Marshall stability values than the virgin asphalt, while flowability increased with the increase of rubber content. Mashaan et al. [19] presented and discussed the findings from some of the studies on the use of crumb rubber in asphalt pavement. They showed that, it aspires to consider crumb rubber modifier in hot mix asphalt to improve resistance to rutting and produce pavements with better durability by minimizing the distresses caused in hot mix asphalt pavement. Abusharar and Al-Tayeb [20] have evaluated the effect of adding waste ground rubber tire powder (WGRTP) in hot mix asphalt prepared by dry process. They showed that, the waste polymer modified asphalt mix containing 5% WGRTP (by weight of mix) improved the various mechanical properties of the mix compared to the conventional asphalt mixture.

Although the dry process has the advantages concerning the lower costs involved and the higher amount of rubber to be used, the process is still need more investigation due to the irregular performance of some experiment sections built with it [21]. This paper presents the results of an experimental investigation studying the behavior of HMA containing waste ground rubber tire powder produced by dry process with various percentages of bitumen contents. The physical properties of waste ground rubber tire powder, bitumen, and crushed aggregate were first investigated. The effect of rubber and bitumen contents on various engineering properties of rubberized asphalt mixture were calculated and assessed with laboratory tests.

II. MATERIALS AND EXPERIMENTAL PROGRAM

A. *Materials*

The materials that have been used in the current study are WGRTP, bitumen, and crushed granite aggregate. Four types of available crushed stones classifies as 0/19, 0/12.5, 0/9.5 and 0/4.75 are locally known by Foliya, Adasia, Simsymia and Trabia respectively were used to obtain the specified gradation. Table 1 displays the selected gradation of the used aggregates and Table 2 shows their properties. The bitumen used for this study was 60/70 penetration grade. The physical properties of the used bitumen are available in Table 3. The applied WGRTP were used as partial replacement for aggregates. The gradation of WGRTP is displayed in Table 4.

TABLE I. THE GRADATION OF AGGREGATES.

Sieve size (mm)	0/19	0/12.5	0/9.5	0/4.75
19	100.00	100.00	100.00	100.00
12.5	27.56	49.09	99.76	100.00
9.5	13.31	13.70	97.17	100.00
4.75	2.27	2.50	24.34	99.30
2.36	0.73	0.33	6.93	84.76
1.20	0.20	0.33	1.59	66.48
0.60	0.15	0.32	1.47	52.51
0.30	0.15	0.32	1.47	24.71
0.18	0.15	0.32	1.17	9.19
0.075	0.15	0.32	1.08	8.20

TABLE II. PHYSICAL PROPERTIES OF THE CRUSHED AGGREGATES.

Properties	Test method	0/19	0/12.5	0/9.5	0/4.75
Abrasion (%)	ASTM C-131	28.4		-	-
Bulk dry S.G.	ASTM C-127	2.52	2.61	2.52	2.52
Bulk SSD S.G.	ASTM C-127	2.57	2.65	2.56	2.57
Apparent S.G.	ASTM C-127	2.64	2.73	2.64	2.64
Absorption	ASTM C-128	1.72	1.76	1.82	1.72

*Test was conducted on Sample Type B which is 2500 g passing sieve size 19 mm and 2500 g passing sieve size 12.5 mm.

TABLE III. PHYSICAL PROPERTIES OF 60/70 PENETRATION GRADE PAVING BITUMEN.

Test	Test Method	Unit	Value	ASTM limits
Penetration	ASTM D- 5-97	1/10 mm	60.67	60-70
Flash point	ASTM D-92	°C	265	Min 250°C
Fire point	ASTM D-92	°C	282	-
Ductility	ASTM D-113	cm	139	Min 100
Softening point	ASTM D-36	°C	47.9	45-52
Specific gravity	ASTM D-70	-	1.02	1.00-1.05

TABLE IV. THE GRADATION OF WGRTP.

Sieve size (mm)	Percent passing
0.063	100
Pan	0

B. *Experimental program*

- *Aggregate Blending*

Available crushed stones were combined together using a trial and error method for gradation design to obtain the specified gradation. The proportions of aggregate 0/19, 0/12.5, 0/9.5 and 0/4.75 used were found to be 18:32:21:29 respectively. Fig. 1 shows the results of a sieve analysis of samples from the used materials versus the limits, according to ASTM standards.

- *Preparation of specimens*

Rubberized asphalt mixes were prepared by mixing varying amounts of WGRTP (0%, 5%, 10% and 15% by weight of mix) into the pre-heated aggregate at 150‐160°C, followed by addition of the bitumen (4.5%, 5.0% and 5.5% by weight of mix). The bituminous mix was then placed in a Marshall mold and compacted by applying 75 blows on each side in the above temperature range. The samples were cooled at room temperature for a day and then placed in water at 60°C for 30 min. Three identical specimens for each percentage were fabricated and the average value is reported. The amount required for each specimen is about 1200 g. The Marshall stability was determined using Marshall test apparatus. The various engineering properties of rubberized asphalt mixes were evaluated to assess the effect of bitumen contents on bituminous mixes. The mix proportions were calculated for one sample and presented in Table 5.

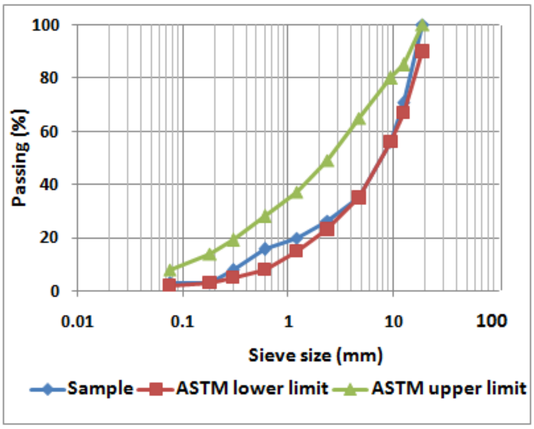

Fig. 1. *Gradation curve of bituminous concrete mix*

TABLE V. MIX PROPORTION FOR ONE SAMPLE (1200 GRAMS).

Job mix	WGRTP		Bitumen		Aggregate		Total (g)
	Proportion (%)	Weight (g)	Proportion (%)	Weight (g)	Proportion (%)	Weight (g)	
Mix A1	0	0	4.5	54	95.5	1146	1200
Mix A2	5	60	4.5	54	90.5	1086	1200
Mix A3	10	120	4.5	54	85.5	1026	1200
Mix A4	15	180	4.5	54	80.5	966	1200
Mix B1	0	0	5.0	60	95.0	1140	1200
Mix B2	5	60	5.0	60	90.0	1080	1200
Mix B3	10	120	5.0	60	85.0	1020	1200
Mix B4	15	180	5.0	60	80.0	960	1200
Mix C1	0	0	5.5	66	94.5	1134	1200
Mix C2	5	60	5.5	66	89.5	1074	1200
Mix C3	10	120	5.5	66	84.5	1014	1200
Mix C4	15	180	5.5	66	79.5	954	1200

III. RESULTS AND DISCUSSION

A. *Marshall Stability*

Fig. 2 illustrates the Marshall Stability value versus WGRTP content for each binder content. The results show that the stability values of the different binder content depend also on their relation with the WGRTP and bitumen content. The Marshall Stability slightly decreases with addition of WGRTP up to 5%, and then obviously decreases as the percentage of WGRTP is further enhanced from 10% to 15%. The only mixture that gave a higher stability value was the mixture with 5% WGRTP at 5% bitumen content. This phenomenon could be explained by the addition of WGRTP to the hot mix asphalt is attributed to better adhesion developing between the materials in the mix. However, further increase in the WGRTP content results in a decrease in the stability of the mixes, which may be ascribed to a reduction of the adhesiveness of the mix.

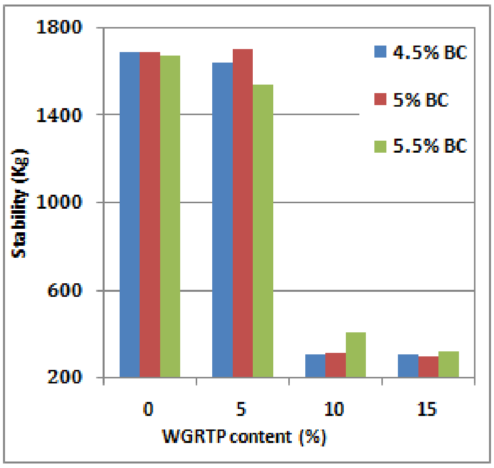

Fig. 2. *Stability value versus WGRTP content.*

B. Marshall Flow

As displayed in Fig. 3, an increase in the WGRTP causes the flow value to increase slightly until 5% of WGRTP and then it changes to a downward movement as the percentage of the WGRTP is further enhanced from 10% to 15%. As elaborated in the last section, this result can contribute to the formation of a lower stiff mixture.

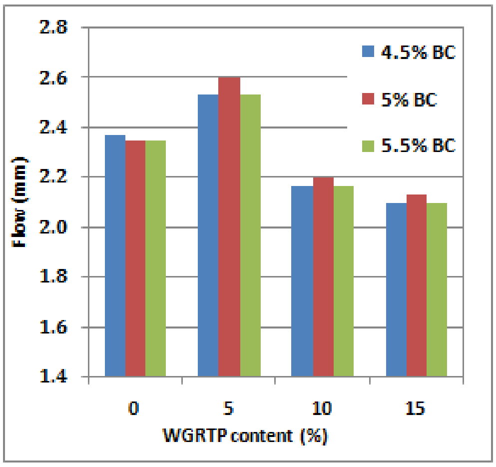

Fig. 3. *Marshall Flow value versus WGRTP content.*

C. Marshall Quotient

As Fig. 4 shows, the Marshall Quotient slightly decreases with addition of WGRTP up to 5%, and then obviously decreases as the percentage of WGRTP is further enhanced from 10% to 15%. Therefore, it can be concluded that the bituminous mixture with high WGRTP content has lower stiffness and worse resistance against serious deformation as a result of heavy loading.

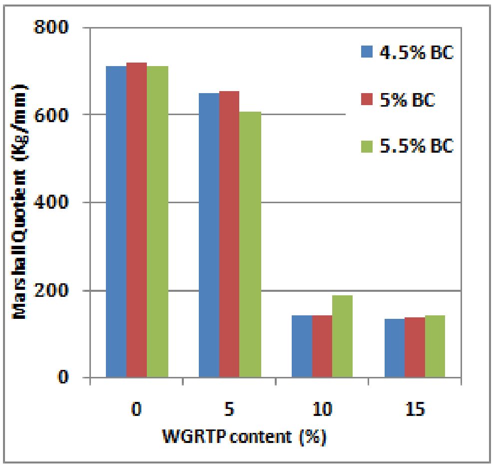

Fig. 4. *Marshall Quotient value versus WGRTP content.*

D. Bulk Specific Gravity

Regardless of the WGRTP content, the bulk specific gravity of the WGRTP mixture was lower than that of the control mixture. As Fig. 5 illustrates, any increase in WGRTP and bitumen content reduces the bulk specific gravity of the mix. The resulting decrease in the bulk specific gravity value is due to the lower specific gravity of the WGRTP and bitumen in comparison with the mineral aggregates.

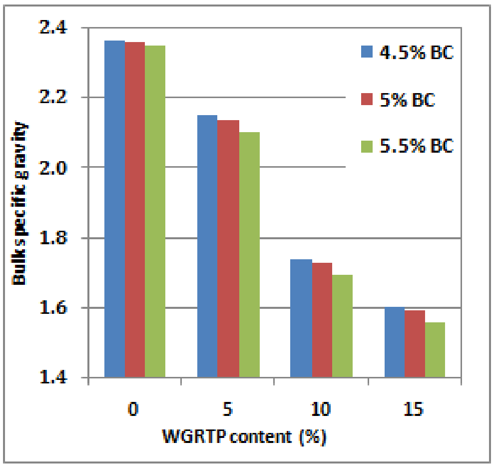

Fig. 5. *Bulk specific gravity value versus WGRTP content.*

E. Air Void

As Fig. 6 shows, increasing the WGRTP and bitumen content in the mixture results in less air voids in the mixture. The decrease in air voids upon increasing WGRTP and bitumen content depends partially on the total filler content. The air voids decrease slightly due to partial replacement of mineral aggregates by WGRTP which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix.

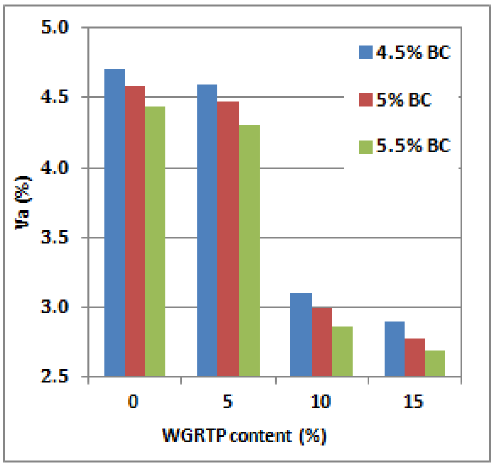

Fig. 6. *Air void value versus WGRTP content.*

F. Voids in Mineral Aggregate

As the figure displays, all VMA values decrease by increasing the WGRTP content. The resulting decrease in the VMA value is due to partial replacement of mineral aggregates by WGRTP which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix. Lower values of VMA result in less spaces to accommodate the required asphalt to produce good coating and durable mix.

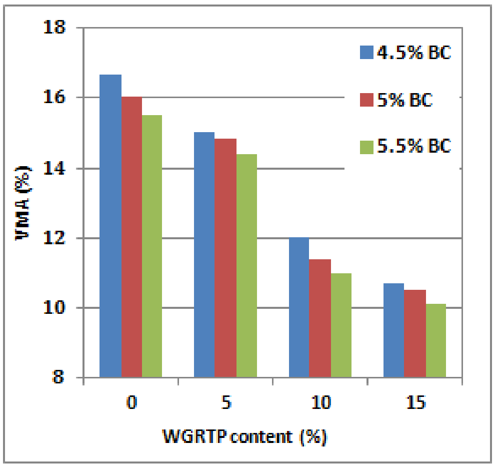

Fig. 7. *Void in mineral aggregate value versus WGRTP content.*

IV. CONCLUSIONS

The effect of waste ground rubber tire powder and bitumen on various mechanical properties of the bituminous concrete mixtures was evaluated. Summarizing the overall conclusions achieved through this research, the significant findings of the current study are as follows:

- The values of Marshall Stability were generally lower in comparison to the control mix. The only mixture that gave a higher stability value was the mixture with 5% WGRTP at 5% bitumen content.

- The flow initially increases with addition of the WGRTP up to 5%, but decreases as the percentage of the WGRTP is further enhanced from 5% to 15%

- Due to their low MQ, the WGRTP decreased the stiffness level of the mixture declining its resistance level against permanent deformation.

- Adding WGRTP to the mixture decreases the bulk specific gravity of the mixture due to the lower specific gravity of the WGRTP in comparison with the mineral aggregates.

- Adding WGRTP to the mixture decreases the air voids of the mixture and VMA due to partial replacement of mineral aggregates by WGRTP which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix.

- The appropriate amount of the added WGRTP was found to be 5% by weight of total mix at 5% bitumen content. This percentage results in the maximum level of stability.

- It can be concluded from the outcomes of the study that the effects of WGRTP and bitumen on air voids, bulk specific gravity and Marshall Stability of the mixture are significant.

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