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Optimizing PelletPAVE™ Rubberized Asphalt Mix Design Using Gyratory Compaction and Volumetrics

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Abstract**—**In this investigation, rubberized HMA technology was examined to address the most critical forms of pavement distresses in the State of Kuwait, namely, high temperature rutting, and moisture induced raveling. PelletPAVE™ additive was selected as the preferred technology, since it offered a convenient method of directly modifying the exiting local HMA recipe without having to polymer modify the bitumen. Experimental work, using various Pelletpave contents was carried out at Kuwait Institute for Scientific Research (KISR) to design an optimum rubberized HMA formulation prior to conducting a pilot-scale road trial. With the aid of a gyratory compactor, the compaction and volumetric properties of HMAs containing 2.5% and 3.0% Pelletpave additive were investigated at a range of bitumen contents, all by mass of total mix.

Keywords**—**Modified bitumen, rubberized hot mix asphalt, gyratory compaction, volumetric properties.

I. Introduction

THE blending process of rubber produced from waste tires into hot bitumen produces what is called the rubberized HMA, a high resilient-performance modified binder that is used and practiced widely across the world in road paving operations [1]. The rubber-bitumen blending originates in the United States of America back in 1960s and showed tangible resiliency and improved the resistance of asphalt mixtures to rutting, thermal cracking, load induced fatigue cracking's and reflective cracking's [2]. The rubber-modified bitumen showed other ideal benefits that satisfy road users and increasing road safety that include a smooth ride, good skid resistance, noise reduction and less frequent maintenance operations [3]. Sacramento County investigated the benefit of rubberized asphalt surfaces against the conventional asphalt overlay since 1993 and it was reported that the rubberized asphalt achieved a reduction in traffic noise levels of an average of 4 decibels (dB) as compared to the conventional HMA [4]. This degree of noise reduction is significant as it represents 60% reduction in traffic noise energy.

The use of recycled tire rubberized-bitumens is proven to be suitable as a substitute to Polymer Modified Bitumens (PMBs) by a study conducted by the advisory board of the Rubber Asphalt Foundation [3]. The rubberized bitumen showed stellar performance and achieves the same performance grading specifications as the PMBs [3], [5].

The use of rubberized HMA mixtures is legislated in 25 states in the United States of America to improve the road performance and reduces the maintenance operations and costs. The Rubber Pavement Association (RPA) published a standard practice guide that provides all essential information in relevance to the design and use of rubberized HMA [6].

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The experimental data presented in this paper are the results of a preliminary laboratory trials conducted at KISR laboratories to evaluate and assess the performance of the volumetric properties of rubberized HMA containing 2.5% and 3.0% PelletPave additive at a range of various bitumen contents and the moisture sensitivity of the optimized rubberized asphalt mix.

II. Materials Used and Sample Preparation

Materials used in the investigation were Kuwaiti 60/70 pen grade bitumen, locally sourced Gabbro coarse and fine aggregates and PelletPave® (a pelletized rubber modified binder patented by Phoenix Industries USA).

PelletPave® is comprised of approximately 10 mm size pellets formulated from a mix of tire derived crumb rubber and pen grade bitumen, blended using high shear mixers at 175 °C.

For the formulation of rubberized asphalt mixes, PelletPave® is pre-weighed and added in dry pelletized form to the aggregate during the hot mixing stage followed by the required amount of pen grade bitumen.

TABLE I
Specific Gravity Determinations on the Used Materials

Sample Type	Specific Gravity
Gabbro aggregate	2.82
60/70 pen Q8	1.046

TABLE II
Particle Size Distribution of 5 Gabbro Aggregate Blends

Sieve Size		*Particle size distribution*				
mm	*in.*	*Blend 1*	*Blend 2*	*Blend 3*	*Blend 4*	*Blend 5*
25	1	100	100	100	100.0	100.0
19	3/4	97.8	98.0	97.9	98.1	99.7
12.5	1/2	83.2	84.5	83.8	84.9	86.0
9.5	3/8	72.9	74.4	74.0	75.9	77.5
4.75	No.4	52.4	52.2	54.8	50.1	53.1
2.36	No.8	37.4	36.9	39.5	33.5	35.0
1.18	No.16	23.3	22.9	24.7	23.5	23.7
0.6	No.30	16.3	16.0	17.3	15.1	15.4
0.3	No.50	13.7	13.4	14.6	11.2	11.3
0.15	No.100	9.7	9.4	10.3	6.8	8.0
0.075	No.200	6.8	6.7	7.2	5.1	6.5

The design gradations of five asphalt mix blends were all in compliance with type III wearing course asphalt mixes in accordance with the new Kuwait Ministry of Public Works (MPW) specifications with a nominal maximum aggregate size of 19 mm [7]. The Aggregate Effective (G_{se}), Bulk (G_{sb}) Specific Gravities, Volume of Absorbed binder (V_{ba}), and voids in mineral aggregate (VMA) were established to select the optimal blend that satisfy all of the asphalt mix volumetric requirements and blend No. 5 was selected. Specific gravity values for the Gabbro aggregate and 60/70pen Q8 are shown in Table I and the particle size distribution of all five mixes are shown in Table II and Fig. 1 (traditional log-normal scale) and Fig. 2 (0.45 power scale in accordance with SuperPave).

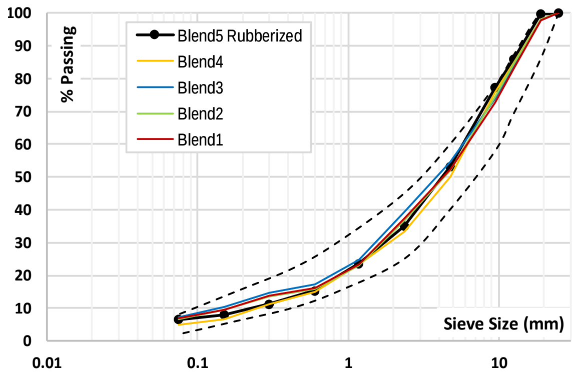

Fig. 1 Gradation of 5 rubberized asphalt mixes (log-normal axis)

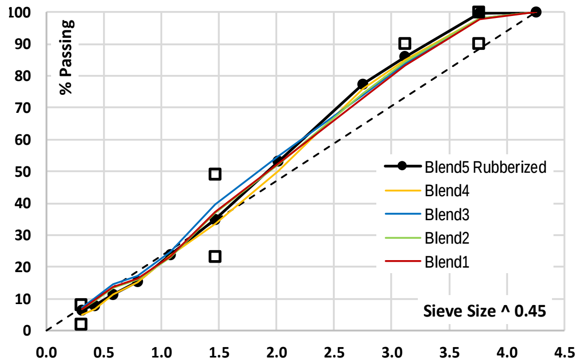

Fig. 2 Gradation of 5 rubberized asphalt mixes (0.45 power axis)

Pellet plus 60/70pen grade bitumen was introduced to aggregate blend No. 5 to produce rubberized asphalt mixes. Gyratory compactor was used on two PelletPave contents groups (3.0% and 2.0%) with each group having samples divided in a subgroup of different 60/70pen bitumen content. The asphalt blends were compacted to refusal to ensure volumetric properties were within target specifications and determine the optimum combination of PelletPave and 60/70 pen bitumen. The laboratory compaction selected was suitable for asphalt mixes designed for medium to heavy traffic (i.e., 3 to < 30 million standard axles (ESALs)) [7]. The initial, design and maximum gyratory compaction effort was pre-set at N_{ini} = 8, N_{des} = 100 and N_{max} = 160 gyrations,d respectively. The mixing temperature was specified at 180 °C whilst the target compaction temperature range was 157-158 °C.

In compliance with the new Kuwait MPW SuperPave specifications, the required gyratory compacted asphalt mix density (%G_{mm}) values and their equivalent were as follows:

- N_{ini} ≤ 89% (i.e., 11% voids), Ndes = 96% (i.e., 4% voids), Nmax ≤ 98% (i.e., 2% voids at refusal density),
- at N_{des}; Voids in Mineral Aggregate (VMA) ≥ 13%, and Voids Filled with Bitumen (VFB) = 65-75%,
- Dust proportion = 0.6-1.2, Tensile Strength Ratio (TSR) ≥ 80%.

The optimized rubberized asphalt performance was evaluated and assessed for water resistance, rutting and the moisture sensitivity in compliance with the American Association of State Highway and Transportation Officials (AASHTO T324) (AASHTO T283) [8], [9].

III. Results and Analysis

A. Determining the Optimum Volumetric Properties

The compaction results in Fig. 3 show the compaction profiles of four rubberized asphalt samples all composed of 3% PelletPave plus 1.75% 60/70pen (giving a total binder content = 4.75% by mass of total asphalt mix). They failed to satisfy the Kuwait MPW's volumetric requirement at N_{des} or $N_{max,}$ where the standards specify that N_{des} = 96% (i.e., 4% voids), N_{max} ≤ 98% (i.e., 2% voids at refusal density). Therefore, the binder content was increased gradually whilst maintaining the PelletPave content at 3.0% by mass of the mix. Fig. 4 shows the effect of increasing the binder content on the volumetric properties.

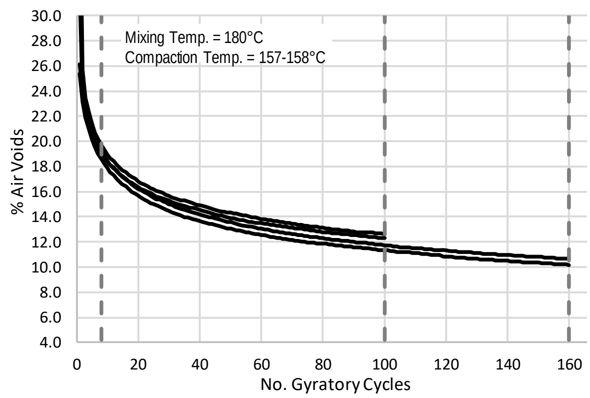

Fig. 3 Gyratory compaction curves for mixes composed of 3% PelletPave, 1.75% 60/70pen bitumen (total binder content = 4.75%)

The mix behavior during the mixing process in the laboratory showed that for all three mixes, the PelletPave did not disperse adequately and uniformly throughout the asphalt the asphalt mix, even after continuous high temperature mixing. The 3% PelletPave group did not satisfy the compaction requirement of the MPW specifications.

The results of gyratory compaction of 2.5% PelletPave content ranging from 3.25% to 4.85% by mass of total mix are shown in Fig. 5. The rubberized asphalt mix with 2.5% PelletPave plus 4.55% 60/70pen bitumen was found to satisfy voids requirements of Kuwait MPW at N_{des} and N_{max}.

Fig. 6 presents a comparison of the average density values at N_{ini}, N_{des} and N_{max} for all rubberized asphalt mix trials as a percentage of the maximum theoretical density values (%G_{mm}) for each formulation. Kuwait MPW requirements are as follows: $N_{ini} \leq 89\%$, $N_{des} = 96\%$, $N_{max} \leq 98\%$. The 2.5% PelletPave containing 4.55% 60/70pen bitumen content was found to possess optimum volumetric properties.

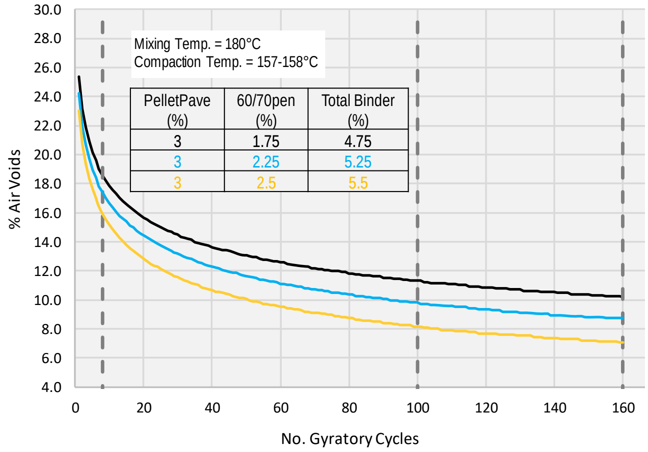

Fig. 4 Gyratory compaction curves for 3% PelletPave mixes with 1.75%, 2.25% and 2.5% 60/70pen bitumen content

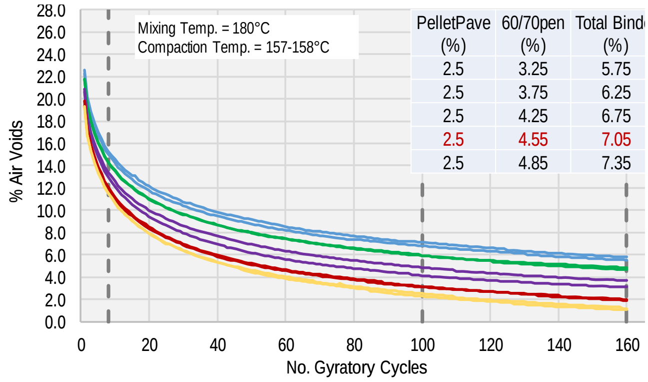

Fig. 5 Gyratory compaction profiles of 2.5% PelletPave content mixes at various 60/70pen content

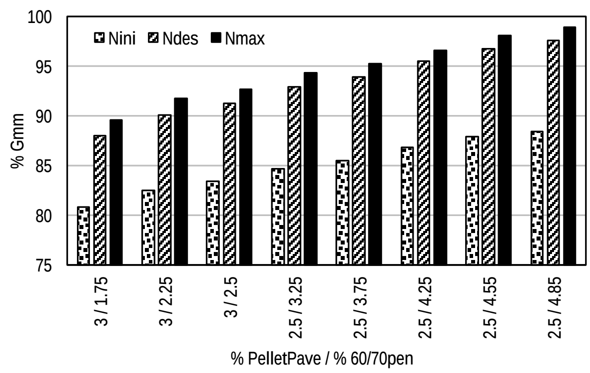

Fig. 6 %%G_{mm} versus rubberized asphalt mix composition

B. Assessing the Performance of the Optimized Rubberized Asphalt Mix

The total binder content of the optimized rubberized asphalt (i.e., 2.5% PelletPave + 4.55% 60/70pen bitumen) was equal to 7.05% which exceeds the optimum binder contents of a typical non-rubber modified continuously graded mixes of 5% to 6%. Thus, the rubberized asphalt mix designed can be classified as a binder rich mix. Binder rich mixes are more durable to the environmental exposure (i.e., better resistance to water stripping and oxidation) due to the thicker binder layer coating the mineral aggregates, on the other hand, a thicker binder layer has the potential to reduce the resistance of the mix to externally applied shear stresses (i.e., reduced rutting resistance) [3].

Immersion wheel tracking test was carried out to assess rutting and water resistance in compliance with (AASHTO T324) on the optimized rubberized asphalt mix of 2.5% PelletPave + 4.55% 60/70pen grade bitumen [8]. Fig. 7 shows the wheel tracking result on the (2.5% PelletPave + 4.55% 60/70pen) as shown by the black line. The pass/fail criterion stipulated within Kuwait's MPW is a maximum of 12 mm rut depth at 20,000 cycles and 60 °C water temperature and the results (see black line) indicate that unfortunately the mix is susceptible to high temperature rutting (though visual inspection of the tracked specimens did not reveal any binder stripping which was a very positive indicator).

C. Laboratory Design of Rubberized Asphalt Mix (2.5% PelletPave + 4.55% PMB) for Heavy Traffic

The wheel tracking results indicate that the optimized rubberized asphalt mix did not satisfy the requirements for medium to heavy traffic, therefore, it was decided to add a new variation on the optimized mix by replacing the 60/70pen bitumen component by the same mass of polymer (Elvaloy) modified bitumen (PMB). The mix designation thus became (2.5% PelletPave + 4.55% PMB). The PMB type satisfies the Kuwait MPW performance requirements for PG 76-10 [7]. Fig. 7 shows the wheel tracking results of the (2.5% PelletPave + 4.55% PMB) mix (coloured lines). When compared to the (2.5% PelletPave + 4.55% 60/70pen) (black line), a significant improvement in rutting performance can be observed. The PMB modified rubberized asphalt will thus readily satisfy Kuwait's MPW SuperPave rutting and stripping requirements.

As shown in Fig. 9, the (PelletPave/PMB) mix was first investigated for compaction properties using gyratory compactor in order to determine the number of gyrations necessary to produce around 4% voids (i.e., N_{des}). This was found to be approximately 70 gyrations (see the blue lines in Fig. 9). The figure also compares the effect on rate of densification caused by changing the 60/70pen to PMB binder and was found to be negligible.

The normal gyratory compaction specimens (used for assessing densification) were approximately 110 mm in height whilst gyratory specimens destined for wheel tracking were compacted to a height of 92 mm and the top and bottom ends of each cylinder trimmed to the final required wheel tracking specimen height (approximately 65 mm).

D.Assessing the Moisture Sensitivity of Optimized Rubberized Asphalt Mix (2.5% PelletPave + 4.55% 60/70pen)

The resistance of the optimized rubberized asphalt mixes was tested using Tensile Strength Ratio (TSR) test (AASHTO T283) in accordance with the new Kuwait MPW specification [9]. Six nearly identical gyratory specimens were produced, three specimens were tested in a dry state whilst the other three were conditioned in water at 60 °C for 24 hours, and all specimens were tested for tensile strength at 25 °C. For SuperPave and Kuwait MPW requirements, the minimum TSR (average ratio of strength of three conditioned to three dry specimens) must be 80% which was readily satisfied by the (2.5% PelletPave content + 4.55% 60/70pen bitumen) rubberized asphalt mix formulation (average retained ITS achieved = 95%).

The densification and voids profiles (yellow lines) of the TSR specimens and final compacted height details (yellow cells) are all summarized in Fig. 9 in comparison to earlier gyratory compaction trials. The voids of the TSR specimens were approximately 6% which was 2% higher than the expectation at 70 gyratory revolutions.

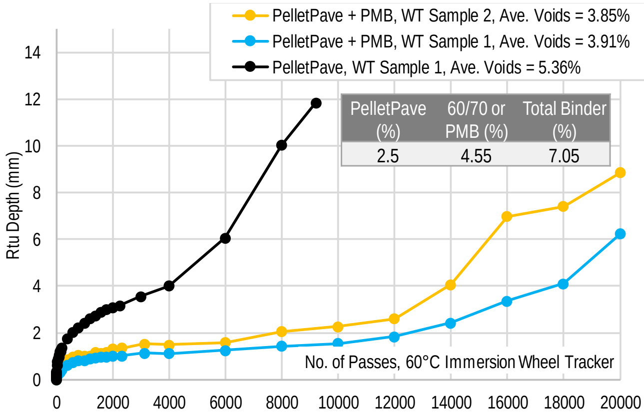

Fig. 7 Immersion wheel tracking test results on optimized 2.5% PelletPave mix plus 4.55% 60/70pen bitumen (black line) in comparison to 2 runs of 2.5% PelletPave plus 4.55% PMB mix (yellow & blue lines)

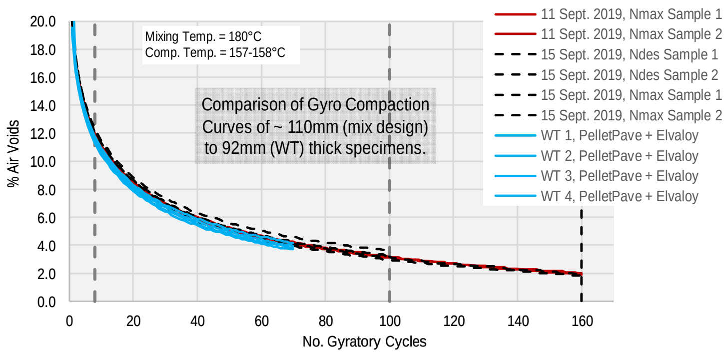

Fig. 8 Comparison of gyratory compaction profiles of rubberized asphalt mixes with (2.5% PelletPave content + 4.55% 60/70pen bitumen) versus ((2.5% PelletPave + 4.55% PMB) at the same mixing and compaction temperatures

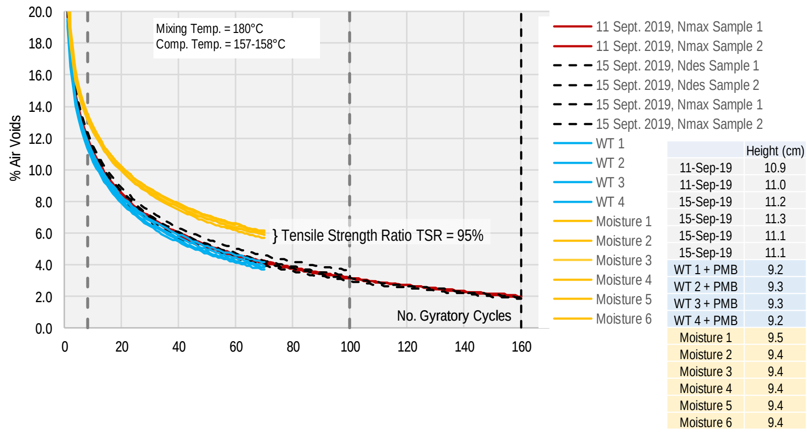

Fig. 9 Comparison of gyratory compaction profiles of rubberized asphalt mixes with (2.5% PelletPave content + 4.55% 60/70pen bitumen) composition

IV. Conclusion and Recommendations

Based on the gyratory compaction results, the optimized rubberized asphalt mix with 2.5% PelletPave + 4.55% 60/70pen grade bitumen content satisfied the optimum voids properties required at the MPW specification at N_{ini}, N_{des} and N_{max}. However, the optimized rubberized asphalt mix would not be ideal for medium to heavy volume trafficked roads (> 3 million standard axles) because the wheel tracking result indicates that the mix is susceptible to high temperature rutting. Thus, it was decided to replace the 60/70pen bitumen component by the same mass of polymer (Elvaloy) modified bitumen (PMB) for further investigation. The results of TSR specimens void achieved results were higher than the expectations at 70 gyratory revolutions. This only feasible explanation was that lack of achieving the exact required compaction mix temperature.

Despite the manifested rutting, the designed rubberized HMA mix would perform to a very high standard for low intensity loaded roads due to the high overall binder content with durable performance that may last not less than 20 years with no stripping or fretting or raveling.

Acknowledgment

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