Characterization and Design of a Crumb Rubber Modified Asphalt Mix Formulation

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***Abstract*—**Laboratory trial results of mixing crumb rubber produced from discarded tires with 60/70 pen grade Kuwaiti bitumen are presented on this paper. PG grading and multiple stress creep recovery tests were conducted on Kuwaiti bitumen blended with 15% and 18% crumb rubber at temperatures ranging from 40 to 70 °C. The results from elastic recovery and non-recoverable creep presented optimum performance at 18% rubber content. The optimum rubberized-bitumen mix was next transformed into a pelletized form (PelletPave®), and was used as a partial replacement to the conventional bitumen in the manufacture of continuously graded hot mix asphalts at a number of binder contents. The trialed PelletPave® contents were at 2.5%, 3.0%, and 3.5% by mass of asphalt mix. In this investigation, it was not possible to utilize the results of standard Marshall method of mix design (i.e. volumetric, stability and flow tests) and subsequently additional assessment of mix compactability was carried out using gyratory compactor in order to determine the optimum PelletPave® and total binder contents.

***Keywords*—**Crumb rubber, Marshall mix design, PG grading, rubberized-bitumen.

I. Introduction

A SIGNIFICANT proportion of Kuwait asphalt pavement network is suffering from various forms of extensive distress including: rutting, fatigue cracking, potholes, bleeding and raveling resulting from a series of human factors and environmental conditions. Factors contributing towards the widespread pavement distresses include incorrect bitumen grade, high traffic loadings, excessive binder oxidation, incorrect mix design and binder contents, settlement failure in the lower layers etc. The deteriorated paved roads come at a high cost to Kuwait in terms of damages to passenger vehicles, distress to road users and repeated road surfacing maintenance operations.

In order to address the latter challenges, it was decided to explore the viability of rubberized hot mix asphalt (HMA) using crumb rubber, recycled from the world's largest waste tire landfill located in Kuwait, and the standard Kuwait 60/70 pen grade bitumen in addition to a locally sourced aggregates as a high performance mix. This paper presents experimental results evaluating the rheological properties of rubber-bitumen blend with various rubber contents. Furthermore, the paper contains results of Marshall mix design of rubberized HMA containing PelletPave® additive technology.

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II. Materials Used and Sample Preparation

Materials used in the investigation were locally produced crumb rubber from discarded tires, Kuwaiti 60/70 pen grade bitumen, PG 67-22 bitumen from Inman refinery USA, 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.

Helium pycnometer (Micromeritics AccuPyc II TEC) specific gravity determinations were conducted on samples of PelletPave® and crumb rubber (30-mesh crumb sourced from same batch used in the PelletPave® formulation). Summary of test results are shown in Table I.

TABLE I
Specific Gravity Determinations on the Used Materials

Sample Type	*Specific Gravity*
PelletPave®	1.155
Crumb rubber (30 mesh)	1.216
60/70 pen Q8	1.046
PG 67-22 Inman	1.038
Gabbro aggregate	2.856

PG grading of all binders was carried out in accordance with AASHTO T315 [1] and Multiple Stress Creep Recovery (MSCR) tests were carried out in accordance with AASHTO T350 both elastic recovery and non-recoverable creep compliance (J_{nr}) were assessed [2]. The recently introduced PG grade requirement for bitumen as stipulated in the State of Kuwait Ministry of Public Works (MPW) specifications is PG 76H-10. The symbol H is the designation for heavy traffic i.e. 10 to 30 million equivalent single axle load (ESALs) [3].

The Marshall method of mix design in accordance with the new Kuwait MPW specifications was used to compact and test rubberized-HMA mixes to assess and evaluate the mixes volumetric, stability and flow results [4].

III. Results and Analysis

Dynamic shear rheometer (DSR) test conditions and rheological characteristics of all five binders are shown in Tables IIA and IIB. The result of $G^*/\sin\delta$ shown in Table IIB indicate that the Inman rubber modified binder surpasses the 76°C requirement at 15% of crumb rubber content, the minimum specified amount of rubber by the US Rubber Pavement Association (RPA) [5], [1]. The Q8+15% rubber was not tested as a result of unexpected equipment failure. At 18% rubber content, the Q8 bitumen satisfied the G*/sinδ 1 kPa target at 89 °C, whereas the Inman bitumen passes target at 100 °C for the 18% rubber content. A higher G*/sinδ values in bitumen indicates a better resistance to rutting as a consequence of reduced amount of dissipated energy, assuming that rutting is a stress controlled, cyclic phenomenon [6].

TABLE IIA
EFFECT OF DSR TEST TEMPERATURE ON PHASE ANGLE RESULTS

	Test Temp. (°C)	Shear Stress (kPa)	Phase angle (deg)
Inman	70	0.081	88
Q8	76	0.065	87.7
Inman +15%	100	0.082	48.6
Inman +18%	100	0.125	54.1
Q8+18%	94	0.076	51.2

TABLE IIB
PG GRADING RESULTS AT 10 RAD/S AND 12% STRAIN

	Ave. G* (kPa)	G*/sinδ (kPa)	Pass/Fail temp. (°C)
Inman	0.7	0.68	Pass 67
Q8	0.5	0.54	Pass 70.7
Inman +15%	0.7	0.91	Pass 97.9
Inman +18%	1.0	1.28	Pass 100
Q8+18%	0.6	0.81	Pass 89.1

The percent recovery determination in the MSCR test measures modified binders elastic response [2]. At 15% and 18% crumb rubber content, the MSCR elastic recovery test results at 3.2 kPa shear stress were very high, as shown in Table IIIA. The recommended level of binder non-recoverable compliance (J_{nr}) at 3.2 kPa applied stress is set at ≤ 2 kPa^{-1} [6]. The Inman and Q8 binders non-recoverable creep compliance (J_{nr}) were below 2 kPa^{-1} at 70 °C for the 15% rubber content, whereas the J_{nr} for Q8 binder was below 0.5 kPa^{-1} at 18% rubber content, as shown in Table IIIb. Based on the binder analysis, it was decided to proceed with 18% crumb rubber modified bitumen for the formulation of PelletPave®.

TABLE IIIA
MSCR, % ELASTIC RECOVERY TEST RESULTS

	Ave. Recovery at 3.2 kPa (%)			
	40 °C	50 °C	60 °C	70 °C
Inman	0	2.08	0	0
Q8	25.27	6.11	0	0
Inman +15%	82.21	70.59	34.77	9.84
Q8+15%	76.47	57.95	22.48	5.18
Inman +18%	87.53	80.4	49.05	16.72
Q8+18%	88.9	92.81	79.18	29.94

The state of Kuwait pavement specifications for HMA wearing courses is shown in Table IV, and the dense aggregate gradation used for all mixes in this investigation is shown in Fig. 1. In relation to the rubberized asphalt mixes, the gradation was specifically designed to be slightly on the finer side of maximum to attain a higher optimum binder contents than the current standard Kuwait HMA specifications which recommends the optimum bitumen content in the range of 3.4 to 4.4%. The higher binder content deliberately acts as a preventive measure against bitumen stripping and fatigue cracking in wet conditions. A higher binder stiffness and elastic recovery properties should additionally contribute towards eliminating the risk of rutting.

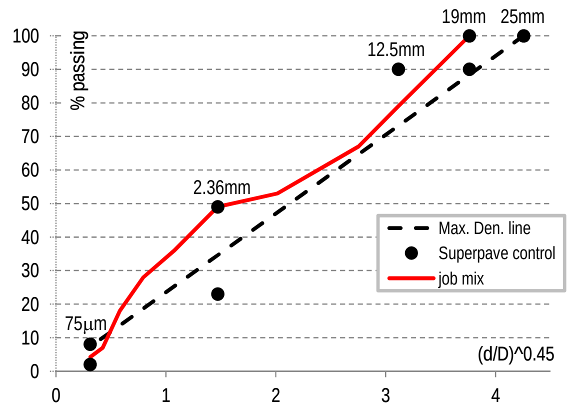

Fig. 1 Aggregate gradation used for production of rubberized-HMA mixes in this investigation

TABLE IIIB
MSCR, NON-RECOVERABLE CREEP COMPLIANCE (J_{NR}) RESULTS

	Ave. J_{nr} at 3.2 kPa (1/kPa)			
	40 °C	50 °C	60 °C	70 °C
Inman	0	0.945	4.3377	15.7782
Q8	0.0899	0.5926	2.765	10.1493
Inman +15%	0.0082	0.0456	0.3521	1.6916
Q8+15%	0.0072	0.0477	0.3401	1.5496
Inman +18%	0.0036	0.017	0.1429	0.8841
Q8+18%	0.0024	0.0049	0.0399	0.443

TABLE IV
KUWAIT MPW MARSHALL DESIGN CRITERIA FOR TYPE III WEARING COURSE ASPHALT CONCRETE MIX

	Min.	Max.
No. of compaction blows each end of specimen		75
Stability (N)	11500	-
Flow (0.25mm)	8	16
VMA (%)	14	-
Air Voids (%)	4	6
Aggregate Voids Filled with Bitumen (%)	63	75

Rubberized HMA mixes were produced at three PelletPave® contents i.e. 2.5%, 3.0%, and 3.5% by the mass of total HMA mix. At each PelletPave® content, mixes were also produced at a range of total binder content by mass of mix. The total binder content is defined as PelletPave® content plus additional unmodified bitumen content.

Air voids, voids filled with bitumen and voids in mineral aggregate values of the 2.5%, 3.0%, and 3.5% PelletPave® mixes are shown in Figs. 2-4. The optimum total binder contents for the 2.5%, 3.0% and 3.5% PelletPave® mixes were determined at 5.5%, 5.7% and 5.8% respectively. All Marshall specifications requirement were satisfied at the optimum binder content for all the PelletPave® proportions.

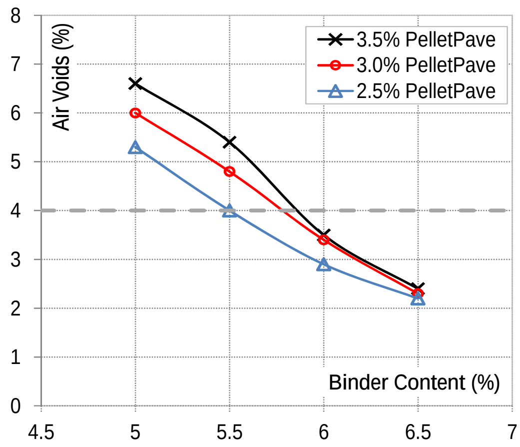

Fig. 2 Air voids versus binder content for 2.5%, 3.0% and 3.5% PellePave® HMA mixes

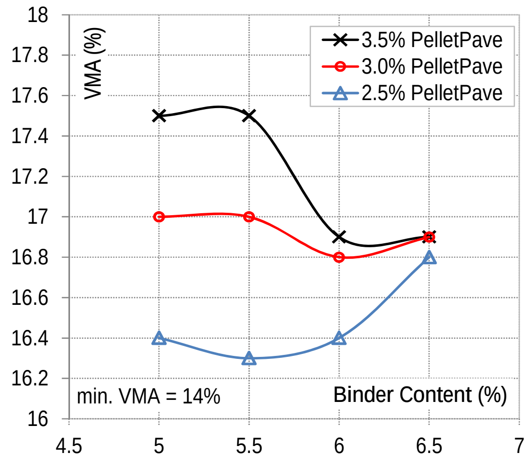

Fig. 3 VMA versus binder content for 2.5%, 3.0% and 3.5% PellePave® HMA mixes

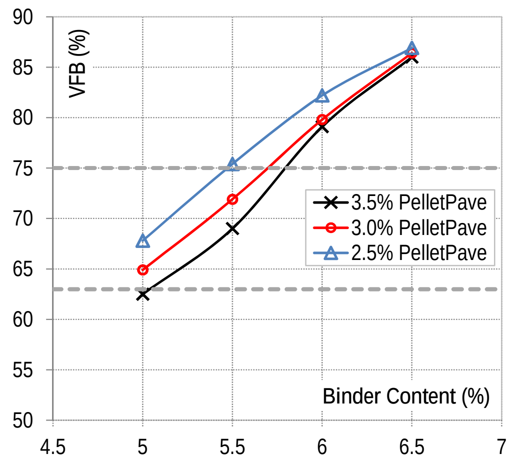

Fig. 4 VFB versus binder content for 2.5%, 3.0% and 3.5% PellePave® HMA mixes

In general, the results were not conclusive to enable the selection of best performing PelletPave® formulation while taking into consideration the satisfactory results from the Marshall method of mix design.

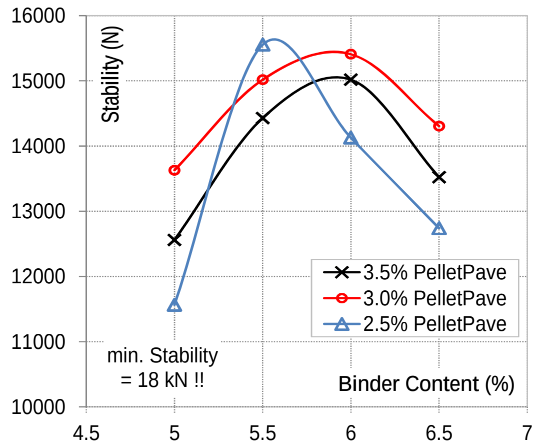

Fig. 5 Marshall Stability versus binder content for 2.5%, 3.0% and 3.5% PellePave® HMA mixes

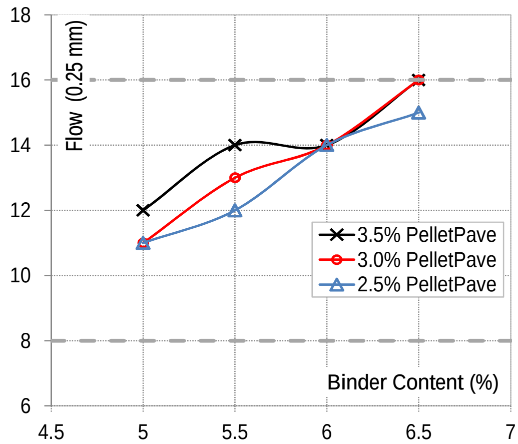

Fig. 6 Flow versus binder content for 2.5%, 3.0% and 3.5% PellePave® HMA mixes

A. Further Mix Analysis

In the following step, one specimen from each of the three rubberized asphalt mixes at 2.5%, 3.0%, and 3.5% PelletPave® contents was compacted using a gyratory compactor to refusal. The volume of the gyratory compacted specimen at refusal density can be measured as the difference between saturated surface dry mass and the mass of sample immersed in water. The diameter of all samples were constant at 150 mm, using the average measured sample height at refusal, eased to back-calculate the actual height of the specimen at any number of compaction revolutions. Knowing the mix proportions and specific gravity of each mix component, it is possible to produce a plot of air voids versus no. of gyrations to refusal. The relationship between voids and number of gyratory revolutions is shown in Fig. 7. Based on the compaction curve, the 3.5% PelletPave® content was eliminated and labeled as a "less workable mix".

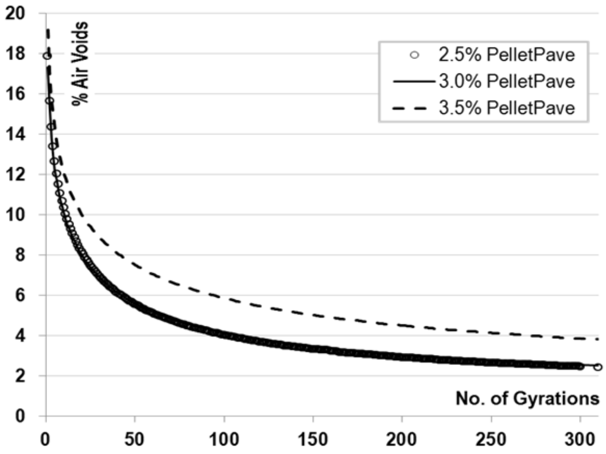

Fig. 7 Porosity versus number of gyrations for 3 compacted specimens

The focus in next part of the investigation shifted to assessing the effect of "excess bitumen" on mix compatibility and rate of densification on the 2.5% and 3.0% PelletPave® mixes. The allowable bitumen content tolerance specified by Kuwait's (MPW) is 0.3%.

Mix formulations A & E represent the original 2.5% and 3.0% PelletPave® rubberized asphalt mix designs as described in the previous sections of this paper. Mixes B & C represent an additional 0.2% and 0.4% bitumen content relative to Mix A, whereas Mix F represents an additional 0.2% bitumen content relative to Mix E as shown in Table V. Mix B and Mix C were designed to have the same bitumen content of samples E and F respectively. Mix D design aimed to achieve almost zero voids at 350 gyrations. The bulk density results from Mix D were used to verify the accuracy of G_{mm} values as determined in the lab.

TABLE V
ADDITIONAL FORMULATIONS TO ASSESS THE EFFECT OF ADDITIONAL BITUMEN CONTENT ON MIX COMPACTABILITY

Gyratory Sample	PelletPave® Content by Mass of Total Mix (%)	Bitumen Content by Mass of Total Mix (%)	Total Binder Content by Mass of Total Mix (%)	% PelletPave® in Total Binder
A	2.5	3.0	5.5	45.45
B	2.5	3.2	5.7	43.86
C	2.5	3.4	5.9	42.37
D	2.5	5.0	7.5	33.33
E	3.0	2.7	5.7	52.63
F	3.0	2.9	5.9	50.85

Two samples from groups A and F were additionally gyratory compacted to refusal, therefore, leading to the possibility of assessing the repeatability of the compaction or densification process.

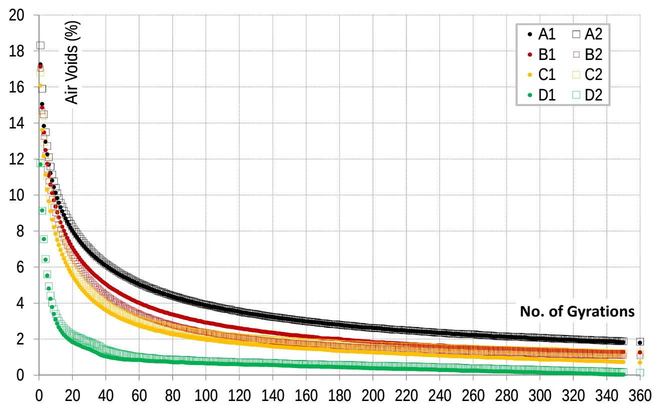

Fig. 8 Gyratory densification curves for 2.5% PelletPave® mixes at various bitumen contents

It is interesting to note from Fig. 8 and 9 the high repeatability of the densification curves for each mix type. Moving from mix A to D, a reduction in air voids at any particular level of compaction is expected as a result of the higher total binder content, which is exactly what is shown in Fig. 8. Comparing the effect of increasing the total binder content from 5.7 to 5.9% for mix pairs (B and C) versus (E and F) reveals that the higher PelletPave® content in mixes (E and F) causes a significant increase in resistance of mix to densification. With respect to the 3.0% PelletPave® content mixes, the curves for mixes E and F were almost identical, indicating that there was little influence on rate of densification as a result of increasing the bitumen content by 0.2%.

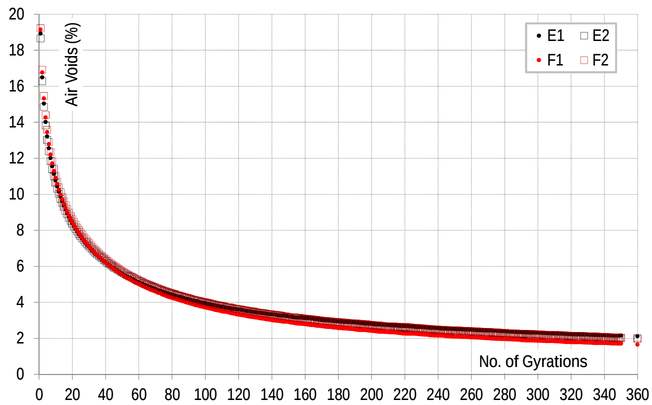

Fig. 9 Gyratory densification curves for 3.0% PelletPave® mixes at two bitumen contents

Considering the compaction curves presented in both Figs. 8 and 9, the preferred mix would be the one with the lower rate of densification and the lower sensitivity to increased bitumen content. Thus far in this investigation, out of the three original PelletPave® contents, the best performing mix was identified as 3.0% PelletPave® content.

IV. Conclusion and Recommendations

In this investigation, the best performing rubberized asphalt HMA mix was identified as the mix containing 3.0% PelletPave® content. Further laboratory work will need to be carried out to characterize the 3.0% PelletPave® mix including stiffness, creep, and fatigue testing prior to embarking on any full scale trials.

Acknowledgment

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