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Utilization of Syrian Natural Asphalt in Hot – Mix Concrete Mixtures

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ABSTRACT

This research covers evaluating the design and performance of hot-mix asphalt concrete mixtures for highways by utilizing Al-Beshery natural asphalt-sand material either alone or modified by compatible, low-cost and practical additives.

Results of laboratory tests showed that Al-Beshery natural asphalt contains about 18% asphalt cement mixed with open-graded natural sand. Al-Beshery asphalt cement was found to be aged, stiff and hard as reflected by its high viscosity and low penetration values. Chemical analysis of this asphalt also indicated its hardness nature as explained by high asphaltenes content and heavy molecular weight of oils.

Two types of rejuvenating agents were investigated to soften the aged Al- Beshery asphalt. The first is a compatible waste hydrocarbon material (lubricating used oil). The second is soft refinery asphalt (200-250 pen-grade). Different combinations between Al-Beshery natural asphalt and the two additive types were investigated to choose optimum contents of additives. Optimum contents for the waste hydrocarbon material and refinery 200-250 pen-grade asphalt cement were concluded as 6% and 30%, respectively, by weight of Al-Beshery extracted asphalt cement.

Performance of designed asphalt concrete mixtures was measured under static and dynamic loading. Stability, indirect tensile strength, resilient modulus, fatigue cracking and rutting tests were all utilized to measure the different mechanical properties of the designed hot-mix asphalt concrete mixtures.

Results of this research yielded promising improvements in the chemical and physical characteristics of Al-Beshery asphalt. Furthermore, performance of Al- Beshery treated asphalt concrete mixtures was significantly improved compared to the base case (i.e., no treatment).

KEYWORDS: Concrete, Cracking, Fiber Optic Sensors, Strain.

INTRODUCTION

Natural asphalt can be found worldwide in different countries such as Venezuela. Trinidad Lake Asphalt (TLA) is a natural product from the famous Asphalt or "Pitch" Lake located in Trinidad, West Indies (TLA of America, 2002). TLA consists of a mixture of bitumen (54%), sand (36%) and other minor constituents (10%). The bitumen component is made of maltenes (65%) and asphaltenes (35%). Current applications of TLA include paving highways and runways. Previous research effort (TLA of America, 2002) was made to rejuvenate some properties of the bitumen extracted from TLA by adding soft refinery asphalt. Standard specification for graded

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Trinidad Lake modified asphalt binder is included in ASTM D6626-01 (ASTM, 2006; TLA, 2006).

Al-Beshery material contains a natural mix of sand and asphalt and is more promising than Kefria because of its higher asphalt and lower clay contents, respectively (Guha and Al-Betar, 1963). Al-Beshery sand-asphalt material consists of natural layers of silty sand that carries natural asphalt. Al-Beshery asphalt layers may be found at ground surface or covered by a thin sand layer, which can be easily removed by simple field equipments. The average thickness of layers that carry natural asphalt is between 3 and 4.5 m and may reach in some places 13 m. The estimated available Al-Beshery asphalt quantity is about 100 million tons (Geology Study, 2002; SENR, 2006); a quantity huge enough to supply the different needs for asphalt pavement construction in Syria for several decades. The percentage of asphalt cement in Al-Beshery mix is between 15% and 22% of total weight of the sand asphalt mix (GSCRB, 2002).

The use of this resource is currently still limited to low-volume roads in which the raw asphalt mix is crushed and laid down in layers, to act as a low-quality surface dressing. The Ministry of Transportation (GSCRB, 2002) in Syria describes in detail the way of constructing low-cost road surfaces as single or double surface treatments utilizing Al-Beshery natural asphalt.

A previous study by one of the authors (Alfa, 2004) involved evaluation of bituminous mixtures that consisted of one-third Al-Beshery natural asphalt and two-thirds of local crushed gravels. Performance of the studied mixes was evaluated using Marshall stability and flow tests. This previous study also discussed the economic benefits of utilizing Al-Beshery natural asphalt in highways.

RESEARCH METHODOLOGY

The research methodology started with determining the main constituents of Al-Beshery natural asphalt (percentages of volatile matters and bitumen, percentage of sand and its gradation) by extraction methods. Extraction tests were carried out on several samples and the average was calculated. The extracted asphalt was separated into oil, resin, asphaltenes and wax. Physical properties of the extracted asphalt were also determined.

Measured physical properties and determined chemical constituents of asphalt cement extracted from Al-Beshery sand-asphalt- mix were compared to those of the local 60-70 pen-grade asphalt cement manufactured by Houmse Petroleum Company. This local Syrian asphalt cement was selected because of its wide usage in pavement construction in Syria. Furthermore, this grade of asphalt cement is also commonly used in pavement construction in Syria.

Then, the research study evaluated the performance of asphalt concrete mixtures made only of Al-Beshery natural asphalt without rejuvenating agents (adding only aggregate to Al-Beshery natural material, mix A). Selected gradation of added coarse aggregate was based on the dense-graded hot asphalt concrete mixtures (Egyptian Code, 1998). This gradation is commonly used in the surface and binder asphalt layers. The research was extended to include the improvement of mix properties by adding rejuvenating agents to the design mixes (Mixes B and C). Evaluation of the mixes (Mixes A, B and C) was based on Marshall stability, resilient modulus, fatigue cracking and rutting tests.

Gradation of the natural sand of Al-Beshery asphalt was taken into consideration in order to prepare test specimens achieving a certain gradation of mineral aggregate. In addition, the weights of natural asphalt needed to produce specimens with certain asphalt contents were also carefully calculated based on the percentage of bitumen in Al-Beshery natural asphalt. The weight of Al-Beshery natural sand was omitted from standard gradation of the aggregate (dense or open) under sieve size No.4 (fine aggregate) because Al-Beshery natural sand is of open gradation located between sieve sizes No.50 and No.200.

RESULTS

Components of Al-Beshery Natural Asphalt-Sand Mix

As explained in the research methodology, the first stage of the laboratory work was to determine the bitumen content in Al-Beshery sand-asphalt mix. Results of the extraction tests showed that the asphalt cement content is around 19.6%, while the volatile content is 1% and sand represents 79.4%. Sieve analysis is then carried out on the extracted sand of Al-Beshery raw material. Results are summarized in Table 1. The gradation of sand contained in Al-Beshery raw material is mainly open located between sieve numbers 50 and 200. The measured bulk and apparent specific gravities of the extracted sand were 2.545 and 2.594 ton per cubic meter, respectively.

Table 1. Gradation of Sand Contained in Al-Beshery Raw Material

Sieve Size	No. 8	No.30	No.50	No.100	No.200
% Passing	100	96.6	66.5	10.4	0.3

Table 2. Physical Properties of Al-Beshery Extracted Asphalt Cement

Test	**Extracted Asphalt**	**Refinery Asphalt 60-70 Pen-grade**
Penetration (@25º C, 100g, 5 S), (0.1mm)	37	62
Kinematic Viscosity (@ 135 ºC), C. St.	1,439	390
Absolute Viscosity (@ 60 ºC), (Poise)	17,323	2,342
Softening Point (Ring-and-Ball), (ºC.)	60	51
Ductility (@25ºC, 5 cm/min), (cm)	60	+100
(TFOT): Penetration of Residue (@ 25º C, 100g, 5 S), (0.1mm) after:		
-Heating for 5 Hours.	23	41
-Heating for 10 Hours.	18	32
-Heating for 15 Hours.	-	23
Weight Loss after 5 Hours, (%)	0.4	0.2

Table 3. Chemical Constituents of Al-Beshery Extracted Asphalt Cement

Test	**Extracted Asphalt Cement**	**Refinery Asphalt 60-70 Pen-grade**
Chemical Constituents and Wax Content		
• Asphaltenes, (%)	27.2	22.3
• Oils, (%)	29.3	32.4
• Resins, (%)	43.4	45.3
• Wax, (%)	0.1	5.4
• Sulfur, (%)	2.15	0.1 - 0.8
Molecular Weight of Oils	1287	339
Molecular Weight of Resins	-	1368

Table 4. Physical Properties of Used Oil

Test	Result
Kinematic Viscosity (@ 135 º C), (C. St.)	9
Water Content, (%)	0
Distillation at 125°, 225º and 360ºC, (%)	7

Physical Properties and Chemical Constituents of Al-Beshery Extracted Asphalt Cement

A pure Trichloroethylene solvent is used to separate Al-Beshery asphalt cement from sand. The Abson recovery method (ASTM D 1856) was followed at a temperature between (160º-166ºC) to evaporate completely the solvent so as to get the pure asphalt cement material alone.

Table 5. Physical Properties of the Refinery Asphalt Cement 200-250 Pen-Grade

Test	Result
Penetration (@25º C, 100g, 5 S), (0.1mm)	248
Kinematic Viscosity (@ 135 º C), (C. St.)	119
Absolute Viscosity (@ 60º C), (Poise)	218
Softening Point (Ring-and-Ball), (ºC.)	46.5
Ductility (@25ºC, 5 cm/min), (cm)	+100
Flashing Point, (ºC.)	+250

Physical Properties of Extracted Al-Beshery Asphalt Cement

Table 2 shows results of tests performed on the extracted asphalt cement. The table also shows a comparison between these results and those of the commonly used Houmse refinery 60-70 pen-grade asphalt cement. These results indicate the hardness and stiffness nature of Al-Beshery natural asphalt cement compared to the 60-70 pen-grade refined asphalt. This fact is clearly reflected by its lower penetration, higher viscosity, higher softening point and lower ductility values.

A previous study (Shaker, 1983) indicated that cracking of asphalt pavements might be expected if penetration of asphalt falls down with time to approximately 20. This reduction is usually expected to occur due to the effects of environmental factors, such as temperature and oxidation. To investigate susceptibility of Al-Beshery extracted asphalt to hardening with heat, Thin Film Oven Test (TFOT) was carried out. Results of this test (Table 2) indicated that this asphalt may reach the critical limit of 20-pen much faster than the commonly used 60-70 pen-grade refinery asphalt cement.

Chemical Constituents of Al-Beshery Extracted Asphalt Cement

Results of tests performed to determine the chemical constituents of extracted asphalt cement are summarized in Table 3. Results show a higher value of asphaltenes and a lower wax content compared to those of the refinery asphalt cement. Results also clearly indicate the rather much higher molecular weight of the oils component of Al-Beshery extracted asphalt in comparison with the refinery asphalt cement (1287 compared to 339 for the refinery asphalt). This high molecular weight of oil (1287) makes it approximately near to that of resins (1368) for the refinery asphalt, indicating again the stiff nature of the natural Al-Beshery asphalt.

Table 6. Chemical Constituents of the Refinery Asphalt Cement 200-250 Pen-Grade

Constituent	Result
Oils, (%)	40.6
Resins, (%)	53.3
Asphaltenes, (%)	6.1

Table 7. Physical Properties of Al-Beshery Extracted Asphalt Modified with Waste Lubricating Oil

Test	**% of Used Oil (by Totals Weight of Asphalt)**				**Refinery 60-70 Pen-grade Asphalt Cement**
	0	5	6	7	
Penetration (@ 25º C, 100g, 5 S), (0.1mm)	37	54	62	70	62
Softening Point (Ring-and-Ball), (ºC)	60	58	57	56	51
Kinematic Viscosity (@ 135 ºC), (C. St.)	1,439	850	736	652	390
Absolute Viscosity (@ 60 º C), Poise.	1,7323	7300	5,014	4,140	2,342
(TFOT): Penetration of Residue(@ 25º C, 100g,5 S), (0.1mm), Heating for 5 hours	23	26	28	33	41
Softening Point: Heating for 5 hours	-	68	67	66	-
Weight Loss, (%)	0.4	1.5	2.6	2.7	0.2

This finding can be explained by the fact that oils changed to resins and resins changed to asphaltenes in the aged Al-Beshery material. The higher molecular weight of oils indicates the stiff nature of Al-Beshery extracted asphalt cement due to aging and oxidation for several centuries. This aging and oxidization of Al-Beshery natural material resulted in higher specific gravity and molecular weight of oils compared to the refinery 60-70 pen-grade asphalt cement.

This stiff nature of Al-Beshery asphalt cement results in difficulty of mixing with mineral aggregates, shorter life time and higher tendency for cracking, especially at low-temperature climates. Therefore, usage of this material in Syria was very limited in the past to only local, low-volume roads.

Physical Properties of Used Oil and Refinery Asphalt 200-250 Pen-grade

In this study, two kinds of combatable hydrocarbon material were used to make Al-Beshery natural material workable. The first was lubricating used oil (waste material produced from cars), and the physical properties of it are shown in Table 4. The second was soft refinery asphalt 200-250 pen-grade imported from Houmse, and the physical properties of it are shown in Table 5.

The first modifier (waste lubricating oil) has obvious advantages of being a waste material that has almost no value, except its transportation cost, a hydrocarbon material compatible with Al-Beshery raw material, and it also represents a continuous supply source that will never end.

The second modifier (refinery 200-250 pen-grade asphalt cement), secured from Houmse, is used in this phase of the study. The physical properties and chemical constituents of this asphalt grade are as shown in Tables 5 and 6.

Table 8. Chemical Constituents of the Optimum Blend (Compared to the Raw Al-Beshery Material and the 60-70 Pen-Grade Refined Asphalt)

Constituent	Al-Beshery Extracted Asphalt Cement	Al-Beshery Extracted Asphalt + 6% Used Oil	Refinery 60-70 Pen-grade Asphalt
Asphaltenes, (%)	27.2	25.5	22.3
Maltenes (Oils + Resins), (%)	72.7	74.5	77.7

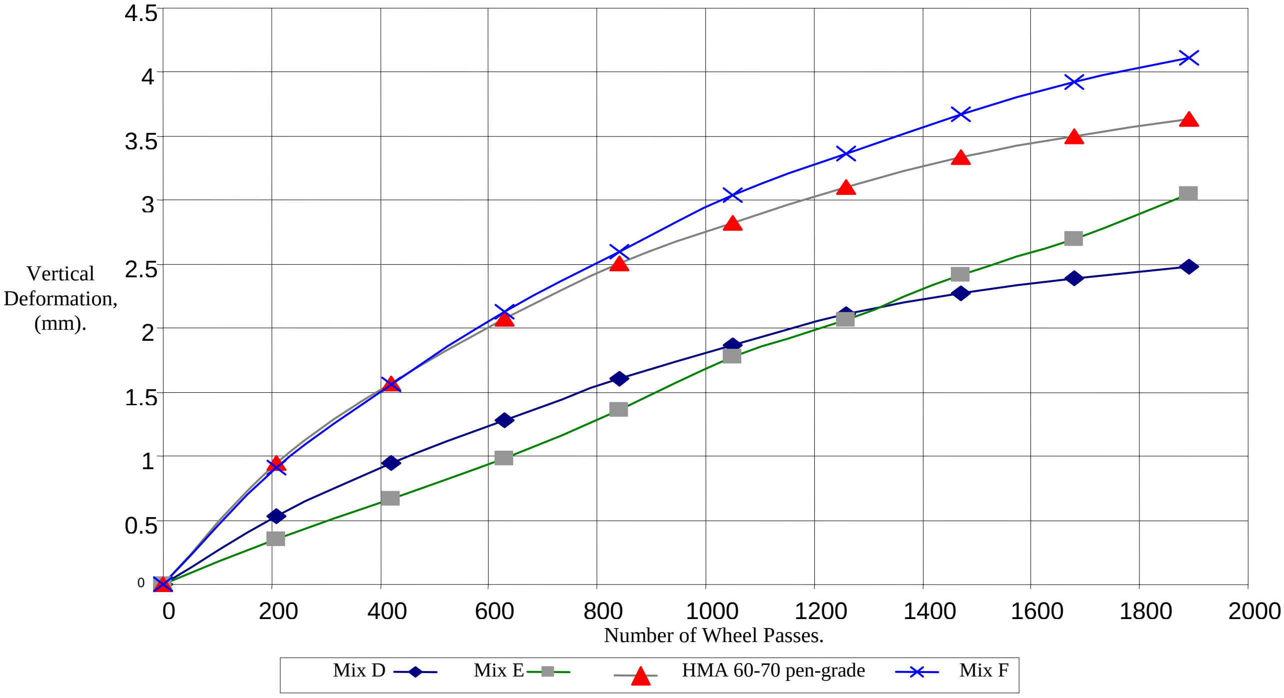

Figure 1: Wheel Tracking Test Results (Rut Depth, (mm)) for Mixes D, E and F Compared to Those of the Traditional 60-70 HMA

Physical Properties and Chemical Constituents of Mix between Extracted Al-Beshery Asphalt Cement and Lubricating Used Oil at Various Percentages

Results shown in Table 7 clearly indicate that if 6% of the waste lubricating oil is used as a modifier to Al-Beshery natural asphalt, the final blend achieves all the desired properties, compared to the commonly-used 60-70 pen-grade refinery asphalt cement. The 94-6% blend of Al-Beshery asphalt and used oil, respectively, has shown remarkably higher viscosity values (both absolute and kinematic) than those of the traditional refinery asphalt. This finding may be attributed to the almost non-waxy nature of this blend which obviously results in much higher viscosity.

As used oil usually contains approximately 4% volatile matter, the weight loss of the extracted Al-Beshery asphalt modified by this oil is expected to be higher than that of the traditional asphalt (2.6 compared to 0.2%, respectively).

Table 9. Physical Properties of Al-Beshery Extracted Asphalt Modified with Soft Refinery 200-250 Pen-Grade Asphalt

Test	**% of Refinery Asphalt 200-250 pen. grade (by Total Weight of Asphalt)**					**Refinery Asphalt 60-70 Pen-grade**
	0	**25**	**30**	**40**	**45**	
Penetration (@ 25º C, 100g, 5 S), (0.1mm)	37	49	57	65	-	62
Softening Point (Ring-and-Ball), (ºC)	60	58	57	55	-	51
Kinematic Viscosity (@ 135 ºC), (C. St.)	1,439	750	627	605	517	390
Absolute Viscosity (@ 60 º C), (Poise.)	17,323	6500	4,764	3,642	2,594	2,342
(TFOT): Penetration of Residue(@ 25º C, 100g,5 S), (0.1mm), After Heating for 5 Hours	23	30	38	40	-	41
Softening Point: Heating for 5 Hours, (ºC)	-	66	65	64	-	-
Weight Loss, (%)	0.4	1.2	1.4	1.8	-	0.2

Table 10. Chemical Constituents of 30%-70% (Refinery 200-250 Pen-grade Asphalt + Al-Beshery Asphalt Cement) Blend Compared to the Raw Al-Beshery Material and the 60-70 Pen-grade asphalt

Constituent	Al-Beshery Extracted Asphalt Cement	Al-Beshery Extracted Asphalt + 30% Used Oil	Refinery Asphalt 60-70 pen-grade
Asphaltenes, (%)	27.2	24	22.3
Maltenes (Oils + Resins), (%)	72.7	76	77.7

In general, results shown confirm that 6% used oil may be considered optimum in modifying the properties of the extracted Al-Beshery asphalt cement.

Table 8 shows chemical constituents of the optimum blend between Al-Beshery asphalt extracted cement and 6% used oil.

These results indicate that adding 6% of used oil reduces the asphaltenes and increases the maltenes contents, respectively. This implies that the so–treated asphalt will be less stiff and, consequently, its concrete mixtures will be less subject to cracking in the future.

Table 11. Mineral Aggregate and Filler Properties

Test	Dolo mite	Natural Sand	Al-Beshery Sand	Limestone Dust	Specification Limits
Los Angeles Abrasion Test Percent Wear, (%) -After 100 Revolutions. - After 500 Revolutions.	 3.8 17.9	 - -	 - -	 - -	 - < 50
Water Absorption, (%)	1.3	0.827	0.7	3.252	< 5
Disintegration, (%)	0.1	-	-	-	-
Bulk Specific Gravity	2.678	2.695	2.545	2.675	-
Saturated Surface - Dry Specific Gravity	2.713	-	-	-	-
Apparent Specific Gravity	2.775	2.757	2.594	2.930	-

Table 12. Comparison between Treated and Untreated Al-Beshery Asphalt Concrete Mixtures and Traditional 60-70 Pen-Grade HMA

Property		Types of Mix				Specification Limits for the Wearing Surface Layers
		(Mix A) Al-Beshery Untreated	Mix B (Al-Beshery Asphalt Cement+ Waste Oil)	Mix C (Al-Beshery Asphalt Cement+ Refinery Asphalt)	Traditional 60-70 HMA	
Optimum Asphalt Content, (%)		4.9	4.63	5.0	5.35	3.5 – 7
Marshall Stability, (lbs.)		2,780	2,300	1.800	2,050	Min.1800
Flow, (0.01-in.)		9.5	8.80	11.6	9.6	8 - 16
Air Voids, (%)		4.50	3.40	3.03	4.0	3 - 5
Unit Weight, (t/m^3)		2.390	2.405	2.403	2.35	-
VMA, (%)		14.450	13.790	14.340	16.3	Min.14
IDT, (PSI) at 25°C		189	117	104	99	-
MR, (MPa), at:	5ºC	25,055	13,194	17,600	7,908	-
	25ºC	5,524	1,870	2,639	2,642	-
	40ºC	1,236	642	635	503	-
N_F , at:	5ºC- MR	22,773	95,933	110,825	119,793	-
	25ºC- MR	158,014	1,171,924	1,259,732	487,932	-
	40ºC- MR	1,075,342	4,609,734	7,820,368	4,084,577	-

Physical Properties and Chemical Constituents of Mix between Extracted Al-Beshery Asphalt Cement and Refinery Asphalt 200-250 Pen-grade at Various Percentages (30%, 40% and 45%)

Results shown in Table 9 indicate that 30% to 40% content of 200-250 pen-grade asphalt cement used as modifier results in blends that achieve the desired limits of pen-grade and softening point of the conventional refinery 60-70 pen-grade asphalt cement. The 30% refinery 200-250 pen-grade asphalt blend achieves physical properties such as penetration and softening point. However, kinematic viscosity at 135ºC is much higher than that of the traditional asphalt 60-70 pen-grade. Again, this is attributed to Al-Beshery stiff material (wax content is 0.1). Weight loss of Al-Beshery asphalt modified by the refinery 200-250 pen-grade asphalt is higher than that of the traditional 60-70 pen-grade asphalt. This is due to the higher volatile content of the refinery 200-250 pen-grade asphalt. Thin film oven test results after 5 hours of Al-Beshery modified asphalt (38-40) are so close to those of the traditional 60-70 pen-grade asphalt (41).

Table 13. Results of WTT for Mixes D, E, and F Compared to Those of the Traditional 60-70 HMA

Time, (min)	No of Wheel Passes	Rut Depth, (mm)			
		Al-Beshery Untreated Asphalt Cement	Mix B (Al-Beshery Asphalt Cement+ Waste Oil)	Mix C (Al-Beshery Asphalt Cement+ Refinery 200-250 Pen grade Asphalt)	Traditional 60-70 HMA
0	0	0	0	0	0
5	210	0.531	0.349	0.911	0.949
10	420	0.949	0.667	1.556	1.569
15	630	1.278	0.984	2.125	2.075
20	840	1.607	1.365	2.593	2.511
25	1050	1.866	1.778	3.036	2.827
30	1260	2.113	2.064	3.365	3.099
35	1470	2.277	2.413	3.669	3.340
40	1680	2.391	2.699	3.922	3.498
45	1890	2.479	3.048	4.111	3.631
Rutting Depth (RD), (mm)	2.479		3.048	4.111	3.631
Track Rate (TR), (mm/hour $\times 10^{-2}$)	147.32		393.7	299.72	213.36
Comprehensive Track Rate, (mm/hour $\times 10^{-2}$)	326.6		409.16	531.57	458.3
Dynamic Stability (DS), (Number of Wheel Passes/mm)	771.59		615.89	474	550

Table 14. Number of Repetitions to Failure for Mixes D, E, F and Traditional 60-70 HMA

Mix Type	Description	Number of Repetitions to Failure (at 60°C)
Mix A	Untreated Al-Beshery HMA	771.59
Mix B	Modified Al-Beshery HMA by 60%-Used Oil	615.89
Mix C	Modified Al-Beshery HMA by 30%-Used Oil	474
Traditional 60-70 HMA	Datum for Comparisons	550

Table 10 shows chemical constituents of the blend between Al-Beshery asphalt cement and 30% refinery 200-250 pen-grade asphalt.

These results indicate that adding 30% of the refinery 200-250 pen-grade asphalt reduces the asphaltenes and increases the maltenes contents, respectively. This implies that the so–treated asphalt will be less stiff and, consequently, its concrete mixtures will be less susceptible to cracking in the future.

Results of Mechanical Properties Tests

Marshall specimens of Al-Beshery asphalt for three mixes (Mixes A, B and C) were prepared in order to measure Marshall stability, indirect tensile strength, resilient modulus, fatigue cracking and wheel tracking testes. One level of compaction was applied (75 blows per side for heavy traffic). The research then continued to try to improve mix properties by adding at first only the aggregate to Al-Beshery natural asphalt in order to adjust mix skeleton to satisfy specification limits and in the second stage of the research rejuvenating agents with the aggregate were added to Al-Beshery natural material to improve the long-term performance of this natural material because of its stiff nature. The selected coarse aggregate, fine aggregate and mineral filler were dolomite, natural sand and lime stone, respectively. Properties of these aggregates are summarized in Table 11. Two different Marshall designs (Mixes B and C) with adding rejuvenating agents (used oil or soft refinery asphalt pen-grade 200-250) were measured compared to the base case (Al-Beshery with adding only the aggregate, Mix A). Properties of the three mixes design are summarized in Table 12.

It is clear from Table 12 that Al-Beshery untreated mix (Mix A) has the lowest number of repetitions to fatigue cracking compared to traditional 60-70 HMA and Al-Beshery mixtures treated with used oil or refinery 200-250 pen-grade asphalt (Mixes B and C) under different environmental and loading conditions. Also, Al-Beshery modified asphalt concrete mixes (Mixes B and C) are expected to have long-term performance better than the traditional 60-70 HMA used in the construction of roads for several decades at moderate and high temperatures of 25° and 40°C. Modulus of resilience values at various pulse widths for Mix A at 5°, 25° and 40°C are greater than those of Mixes B and C due to the stiff nature of natural asphalt mixture. Modulus of resilience values at various pulse widths for Mix C-30% at 5° and 25°C are greater than those of Mix B-6%. However, the condition is reversed at higher temperature of 40°C. This is due to the presence of wax in Mix C.

Wheel Tracking Test for Mixes A, B and C Compared to Traditional 60-70 HMA

Rut depth was determined using the wheel-track test (WTT) that measures the resistance of bituminous mixtures to rutting procedure. Pavement rutting usually implies a measure of pavement strength (Elmitiny, 1980). It can be used to compare the stability of different mixes. The wheel-track test is a simulative rutting, developed by the British Transportation Road Research Laboratory (TRRL). The WTT consists of a loaded wheel and a table on which the specimen is rigidly restrained at its four sides. The table moves at a rate of 42 passes per minute. The solid rubber-tired wheel indents a straight track in the specimen. The track depth at the mid point of its length is recorded at regular 5-minute intervals up to 60 minutes. The WTT is usually carried out at a temperature of 60ºC. Figure 1 shows the typical traces for the vertical deformation of the investigated specimens (rutting depth, mm) *versus* number of wheel passes. As can be seen from this figure, the deformation of all specimens follows the same trend. All plots start out as straight lines having small rates of increase in deflection (rutting depth, mm) with the increase in the number of wheel passes (changing the time to number of wheel passes). The plots then show an upward deviation from the straight lines. This is considered the failure point of the slab.

Rutting depth for the three Mixes A (2.5mm), B (3.1mm) and C (4.1mm) increase gradually as the stiffness decreases gradually (see Table 13).

CONCLUSIONS

Based upon the results of this research, the following can be concluded:

1) Results of the extraction tests performed on Al-Beshery natural asphalt-sand mix show that the bitumen content is around 19.63%. The gradation of sand contained in Al-Beshery natural material

is open located between sieve numbers 50 and 200. The measured bulk and apparent specific gravities of the extracted sand are 2.545 and 2.594 ton per cubic meters, respectively.

2) Al-Beshery natural asphalt cement is a hard and stiff binder compared to the commonly-used 60-70 pen-grade refined asphalt reflected by its lower penetration, higher viscosity, higher softening point and lower ductility values.

3) Drop in penetration value after 5 hours by TFOT (23) showed that cracking of Al-Beshery unmodified asphalt pavement may be expected to occur faster than the traditional asphalt or the modified Al-Beshery HMA concrete mixtures (Shaker, 1983).

4) Bitumen extracted from Al-Beshery natural material contains maltenes (72.6%) and asphaltenes (27.4%). The maltenes component is made up of oils (29.2%), resins (43.3%) and wax (0.1%).

5) Mechanical properties of Al-Beshery natural asphalt concrete mixtures indicated high stability, low rutting depth and high resilient modulus compared to traditional mixtures. However, cracking of these mixtures may be expected soon after construction as indicated by the fatigue results.

6) Al-Beshery HMA concrete mixtures are expected to be less susceptible to rutting than those produced utilizing the common 60-70 HMA concrete mixtures. Therefore, Al-Beshery natural material is advised to be applied in hot-climate areas.

7) An improvement scheme utilizing approximately 30% soft refinery asphalt cement (200-250 pen-grade) as an additive produces promising lab results for both the asphalt binder and its concrete mixtures.

8) Similarly, adding 6% of compatible, very low-cost, hydro-carbon waste product (used oil) to Al-Beshery natural material yields highly significant improvements to the binder and its asphalt concrete mixtures.

9) Both improvement schemes produce asphalt binders and concrete mixtures comparable to a great extent with traditional 60-70 pen-grade refinery asphalt and concrete mixtures.

10) Field applications of modified Al-Beshery asphalt concrete mixtures would follow technologies similar to those adopted for pavement recycling with minor modifications.

11) Lubricating used oil is more economic than the refinery 200-250 pen-grade asphalt due to the following:

- Used oil is added to the HMA without heating, in contrary to the refinery asphalt.
- Molecular weight of used oil is less, compared to that of refinery asphalt cement.
- Used oil is much less viscous than refinery 200-250 pen-grade asphalt (9 C. St.-kinematic viscosity at 135 ºC) and ,therefore, can be easily mixed with other mix components.

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