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Adaptation of Superpave Asphalt Concrete Mix Design Procedure to Jordan Climatic and Traffic Conditions

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Abstract: Highways in Jordan are typically designed and constructed to last at least 20 years. However, it is not uncommon to see flushing, rutting, and cracking in asphalt pavements well before that period, especially in areas exposed to harsh environmental conditions and heavy traffic loadings. The Superpave (Superior Performance Pavements) system was developed to give highway engineers the tools they need to design asphalt pavements that will perform better under temperature extremes and heavy traffic loads. This research was established to study the possibility of adopting the Superpave mix design procedure in Jordan using prevailing traffic and environmental conditions. In this study, a map showing the different temperature zones available in Jordan was developed. A comparison study was carried out utilizing local materials to design asphalt mixes using both Marshall and Superpave mix design procedures. It was found that the Superpave mix design procedure recommended, for the local environmental and loading conditions, lower asphalt content than that predicted by Marshall mix design procedure. In addition, it was found that using the presently recommended local aggregate gradation for heavy traffic in the Superpave design method gave dust proportion higher than the maximum specified limit by the Superpave procedure. High dust proportion will usually lead to brittleness of the mixes. Therefore, shifting to the Superpave design procedure might help in solving the bleeding problem and some of the distresses common in the local asphalt structures.

Key words: *Marshall; Performance grading; Superpave; Temperature zoning.*

Introduction

During the last decades, the Hashemite Kingdom of Jordan (HKJ) experienced a rapid rate of development in many areas. Construction of thousands of kilometers of freeways, urban arterials, and agricultural roads has played an important role in such development. In the last 50 years, Jordan has invested about JD 1 billion in constructing about 8000 km of roads with an approximate construction cost of JD 150,000 (US$180,000) per kilometer. These roads were designed for the anticipated number of traffic load repetitions for a design life of 20 years. Growths in socio-economic and industrial sectors were encouraged and this resulted in the generation of a great deal of city and intercity heavy vehicle transportation. Due to this, and due to the local environmental conditions in the country, a number of segments of these highways experienced high degrees of rutting and/or fatigue cracking in a period less than the anticipated design life of the roadway.

Recent research and development efforts in the Strategic Highway Research Program (SHRP) focused on the establishment of performance-based asphalt binder and asphalt mix specifications [1]. The main objectives of SHRP Asphalt Research Program were to investigate why some pavements perform well, while others do not, develop tests and specifications for materials that will outperform and outlast the pavements constructed today, and to work with highway agencies and industry to have the new specifications put to use [2-3]. The product that was designed by the new mixture design system was known as Superpave.

Adjacent countries to Jordan started evaluating the adaptation of the newly developed programs as early as 1992. Saud Arabia listed Superpave in its specification in 2008. In Saudi Arabia, it was found that plain asphalt cement, which is used in road construction, is only suitable for about 40% of the constructed roads [4].

The SHRP program had proven to be beneficial in most, if not all, cases. The development in the program itself is still ongoing. No serious steps were taken toward the adoption of the SHRP program in Jordan. This study was undertaken to evaluate the use of local materials, both asphalt and aggregate, in both Marshall and Superpave mix design procedures and compare between both procedures for the local environmental and loading conditions.

Available Mix Design Procedures

The major properties to be incorporated in bituminous paving mixtures are stability, durability, flexibility, and skid resistance (in the case of wearing surface). Traditional mix design methods are established to determine the optimum asphalt content that would perform satisfactorily, particularly with respect to stability and durability. There are many mix design methods that are used throughout the world, e.g., Marshall mix design method, Hubbard-field mix design method, Hveem mix design method, Asphalt Institute Triaxial method of mix design, etc. Out of these only two are widely used, namely the Marshall mix design method and Hveem mix design method [5].

Improved Mix Design and Performance Testing

In the Hveem mix design method, the Hveem Stabilometer test is an

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empirical test and is not widely known [6]. In the Marshall mix design procedure, the impact method of compaction does not simulate densification that occurs under traffic in a real pavement, the strength parameter does not adequately measure the shear strength of the HMA, and loading is perpendicular to compaction axis [6]. Finn et al. [7] reported on an airport pavement in the Middle East that the asphalt concrete mix design according to the Marshall method gave higher optimum asphalt content for the mix than that evaluated by research carried out using supplementary tests such as the Hveem stability and creep test. Those tests showed that, at the design optimum asphalt content, the mix was susceptible to rutting and bleeding; therefore asphalt content for wearing course was reduced.

Due to the drawbacks in both binder and mix specification, the US congress, in 1987, supported a $150 million five year research program to improve the performance and durability of the US roads and to make those roads safer to both motorists and highway workers. A total of $50 million of the SHRP research funds were used for the development of performance based asphalt specifications to directly relate laboratory analysis with field performance [8].

A bimodal grading system, which is based on rational performance indices, was established for both low temperature and high temperature pavement service. Thus, precise grade may be selected to accommodate the need to control low-temperature cracking, rutting, or both in a particular construction project. In addition, it will address certain aspects of fatigue cracking [9].

In the Superpave mix design and analysis system, the mix designer selects and proportions materials to create an asphalt mix that will withstand the traffic and environmental conditions at a project site. Superpave mixes are designated as being level 1, 2, or 3. All Superpave mixes are designed using the level 1 mix design system (Fig. 1) [10, 11]. It involves screening proposed materials, including the binder, and compacting and analyzing the volumetric properties and strength of the mix using the Superpave E gyratory compactor. The magnitude of compaction depends on the traffic and environmental conditions at the project site.

A SHRP gyratory compactor (1.25°, 30 gyration/min and 0.6 MPa ram pressure for 150 mm mold) is used for the evaluation of volumetric properties and strength of compacted mixes [12, 13].

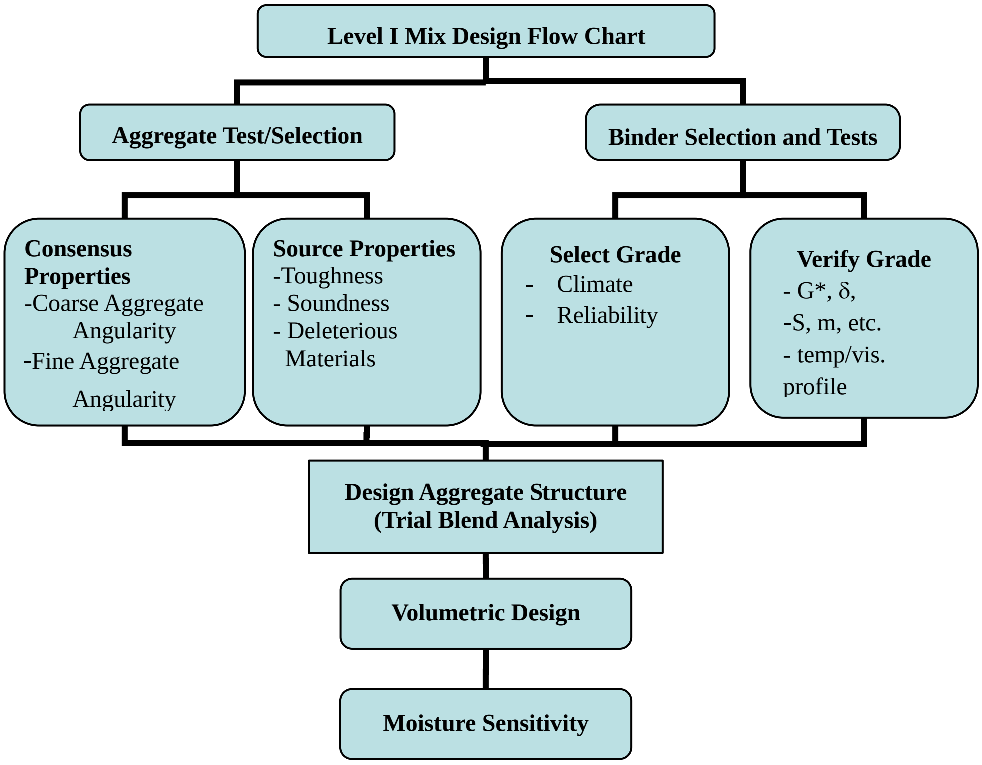

Fig. 1. Superpave Level I Mix Design Flow Chart [11].

The results of studies [14-17] established that the Texas gyratory (shear) compactor is capable of producing laboratory specimens whose volumetric and engineering properties adequately simulate those of field specimens from a wide variety of pavements.

Experimental Program

The experimental program followed in this investigation was divided into three phases. Phase I included collection and characterization of the aggregate and asphalt cement according to both traditional and Superpave test procedures. Asphalt samples were collected from the asphalt cement-producing refinery in Jordan. Physical characterization of the collected asphalt samples was conducted and results are shown in Table 1. Characterization using traditional methods was conducted in the Highway Materials Laboratory at the Hashemite University in Jordan. While performance grading of the asphalt samples was performed in the Ministry of Transport in Saudi Arabia.

Table 1. Physical Properties of the Used Asphalt Cement.

Test	Test Result	Criteria
Flash Point	320	230 C minimum
Rotational Viscosity at 135°C	0.488 Pa.s	3 Pa.s maximum
Rotational Viscosity at 165°C	0.150 Pa.s	n/a
Penetration	66	60-70
Specific Gravity at 25°C	1.019	1.01-1.06
Ductility at 25°C	134	100 minimum
Softening Point, °C	53	48-56
Penetration of Residue, % of Original	66	54 minimum
Weight Loss on Heating, %	0.22	0.8 maximum
$G^*/\sin\delta$ @ 64°C (Fresh) kPa	1.765	1.0 minimum
$G^*/\sin\delta$ @ 64°C (RTFO) kPa	4.010	2.2 minimum
$G^* \sin\delta$ @ 28°C (PAV) MPa	1.344	5.0 maximum
Stiffness S @ -6°C (PAV) MPa	66.67	300 maximum
Slope m @ -6°C (PAV)	0.304	0.3 minimum

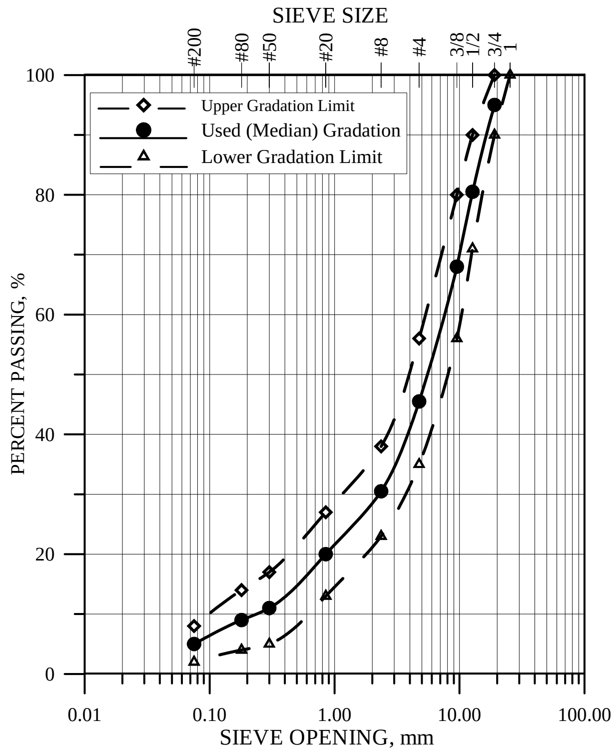

Fig. 2. MPWH Specified Gradation Limits and Used Gradation.

The selected aggregate for the laboratory work was crushed limestone, which was obtained from Amman vicinity, Jordan. The selected aggregate gradation was in accordance with the Jordanian Ministry of Public Works & Housing (MPWH) recommended gradation for heavy traffic wearing course (Fig. 2).

Phase II was devoted for collecting the data from the different weather stations located in the different parts of the HKJ. Collected data were analyzed and used to generate the temperature-zoning map for HKJ.

In Phase III, Marshall mix design (ASTM D1559) and Superpave mix design (AASHTO TP4) procedures were used to design asphalt concrete mixes using the local materials. In these mixes MPWH recommended gradation for heavy traffic wearing course were followed. In addition, two extra gradations were suggested and evaluated in this phase.

Results and Discussion

Characterization of the Asphalt and Aggregate

Classification tests were performed on the asphalt cement that was used in the study. Results of the performed tests, as indicated in Table 1, show that the used asphalt can be graded as 60/70-penetration asphalt according to AASHTO M 20 specifications. The used asphalt was classified according to SHRP binder performance specification (AASHTO MP1). It was found that the performance grade of the asphalt is PG 64-16 (Table 1). Therefore, this asphalt has met both the high temperature property requirements at least up to a temperature of 64°C and low temperature physical property requirements at least down to -16°C [6].

Superpave requirements for aggregate properties are based on both consensus properties and source properties. Consensus properties include coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. Consensus properties levels of acceptance depend on traffic level and depth of the layer below the surface. Source properties include toughness, soundness, and deleterious materials.

Testing of aggregate was conducted in the Highway Materials Laboratory at the Hashemite University in Jordan. Table 2 shows the used aggregate properties. Table 2 also indicates that used aggregate meets both the consensus properties and source (Jordan MPWH) properties requirements for high traffic volumes regardless of depth.

Temperature Zoning for Hashemite Kingdom of Jordan

The suitability of a given asphalt binder to a certain area is determined by the extreme temperatures (average 7-day maximum pavement design temperature and the minimum pavement design temperature), required reliability, traffic level, and speed anticipated to use the facility under consideration. The asphalt binder rheological properties related to both high temperature distresses

Table 2. Physical Properties of the Used Aggregate.

Property	Criteria	Blend 1	Blend 2	Blend 3
Coarse Agg. Angularity	100/100% min	100/100%	100/100%	100/100%
Fine Aggregate Angularity	45% min	52%	53%	55%
Flat/Elongated	10% max	0%	0%	0%
Sand Equivalent	45 min	56	59	57
Coarse Agg. Specific Gravity	n/a	2.539	2.539	2.539
Coarse Agg. Absorption	n/a	2.7%	2.7%	2.7%
Fine Agg. Specific Gravity	n/a	2.502	2.502	2.502
Fine Agg. Absorption	n/a	5.0%	5.0%	5.0%
Combined Agg. Specific Gravity	n/a	2.524	2.522	2.520
Combined Agg. Apparent Specific Gravity	n/a	2.777	2.784	2.791
Abrasion Loss (500 Rev), %	35% max	25.6	25.6	25.6
Abrasion Ratio (100/500), %	25% max	13.8	13.8	13.8

Table 3. Minimum and 7-day Maximum Air and Pavement Temperatures at the Different Weather Stations.

Station	Longitude	Latitude	Elevation (m)	7-day Maximum Temperature (°C)				Minimum Temperature (°C)			
				Mean Air✪	std☜	50% Rel.●	98% Rel.⬥	Mean Air✪	std☜	50% Rel.●	98% Rel.⬥
Amman	35.98	31.98	780	36.1	1.7	57.9	61.4	-0.9	1.6	-0.9	-4.1
Baqura	35.62	32.63	-170	41.0	1.3	62.5	65.3	2.0	1.6	2.0	-1.3
Irbed	35.85	32.55	616	34.5	1.2	56.3	58.7	-1.0	1.5	-1.0	-4.1
Deir Ala	35.62	32.22	-224	41.4	1.1	62.9	65.3	5.9	1.7	5.9	2.3
Ghorsafi	35.47	31.03	-350	42.6	1.2	64.3	66.8	5.8	1.3	5.8	3.1
Dhulail	36.28	32.15	580	39.0	1.6	60.7	64.0	-3.4	1.6	-3.4	-6.6
Mafraq	36.25	32.37	686	37.0	1.5	58.7	61.8	-3.8	1.5	-3.8	-7.0
Ruwaishied (H4)	38.20	32.50	683	40.6	1.7	62.1	65.6	-4.1	1.9	-4.1	-8.0
Ma'an	35.78	30.17	1069	37.4	1.4	59.4	62.3	-4.3	1.7	-4.3	-7.8
Shoubak	35.53	30.52	1365	32.4	2.7	54.6	60.1	-8.5	2.5	-8.5	-13.7
Aqaba	35.00	29.55	51	42.1	0.9	64.0	65.9	4.7	1.2	4.7	2.3

Mean Air✪: mean air temperature
std☜: standard deviation of temperature
50% Rel.●: calculated pavement temperature at 50% reliability.
98% Rel.⬥: calculated pavement temperature at 98% reliability.

such as rutting or shoving, and low temperature thermal cracking distress were specified and are required to satisfy a certain threshold value at the temperature regime in which the binder is expected to serve.

The issues of concern at this point are (1) the 7-day consecutive maximum pavement design temperature and (2) the minimum pavement design temperature prevailing in the country so that an appropriate asphalt binder can be selected or modified by air blowing or by polymer modification to meet the required performance related rheological parameters.

In this study, weather data from 11 weather stations distributed across HKJ were collected. Collected data covered a minimum of 20 years of continuous temperature recording extending in the period from 1980 to 2007. The data were analyzed to obtain the yearly minimum recorded air temperature, the yearly average consecutive 7-day maximum air temperature, in addition to standard deviations of both temperatures. Calculated average temperatures at all stations in addition to stations locations are shown in Table 3.

Since it is required for selecting asphalt binder grades to use pavement temperature rather than air temperature, obtained air temperatures should be converted into pavement temperatures. For surface layers, Superpave defines the location for high pavement design temperature at a depth 20 mm below the pavement surface, and the low pavement design temperature at the pavement surface. LTPP Bind software [18] was used to convert the air temperatures into pavement temperatures. Two reliability levels (50% and 98%) were used in this conversion (Table 3). Reliability is the percentage probability in a single year that the actual temperature (one-day low or 7-day high) will not exceed the design temperature. A higher reliability means lower risk. Selection of degree of reliability depends on road class, traffic level, and binder cost and availability.

Figs. 3 and 4 show the low pavement temperature and the 7-day high pavement temperature contour maps for HKJ at 98% reliability, respectively. Depending on these two figures, Fig. 5 was drawn to divide the HKJ into the different temperature zones. For the HKJ, four asphalt grades are required. PG 64-10 is suitable for most areas of Jordan; Shoubak requires the asphalt to be of PG 64-16 grade. In Aqaba, Ruwaishied, and Ghorsafi, PG 70-10 grade of asphalt is required.

Selected high temperature asphalt grades have to be shifted one or two grades up for slow or standing loads. In addition, high temperature grades have to be shifted up in case of extraordinarily high numbers (higher than 30 million) of heavy traffic loads. Since a high reliability value was used in calculating the high and low pavement temperatures and since limited number of highways in Jordan has equivalent single axle loads higher than 30 million, no

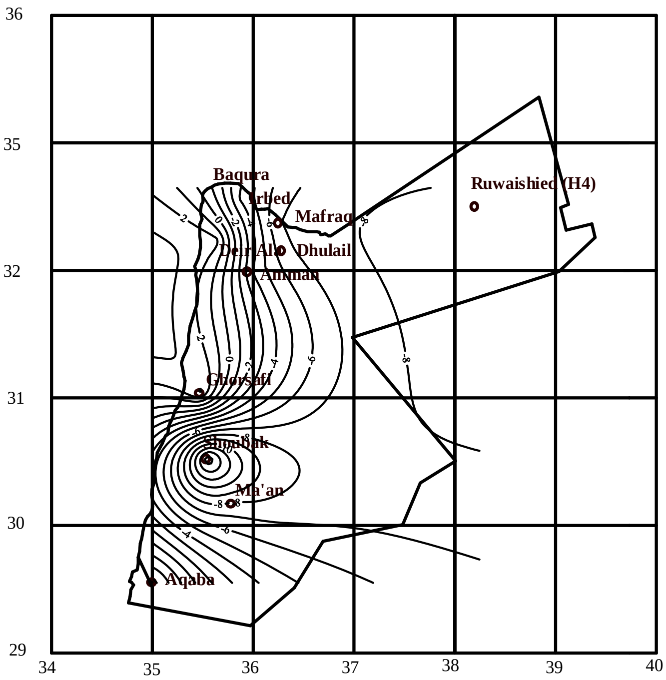

Fig. 3. Minimum Pavement Temperature Contour for Jordan.

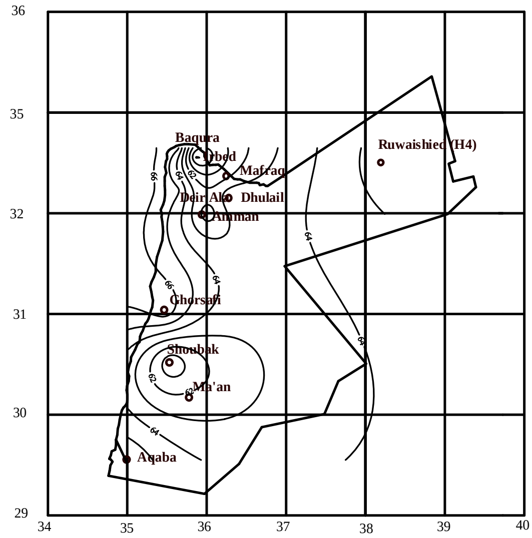

Fig. 4. Maximum Pavement Temperature Contour for Jordan.

shift in the high temperature grade will be applied.

Since local asphalt grade is PG 64-16, it can be used in all parts of Jordan except Aqaba, Ruwaishied, and Ghorsafi. In these areas, local asphalt should be modified to shift its grade to PG 70-10. This modification might just require air blowing of the local asphalt. In steep climbing lanes in these areas, where there will be a reduction in the speed of the heavy trucks, it is required to shift the required asphalt grade by one extra grade. Therefore, the required grade is PG 76-10. To reach to this grade, local asphalt has to be modified using polymers.

Marshall Stability Test Results (ASTM D1559)

For the selected aggregate gradation, MPWH recommended gradation for heavy traffic wearing course (Fig. 2), Marshall mix

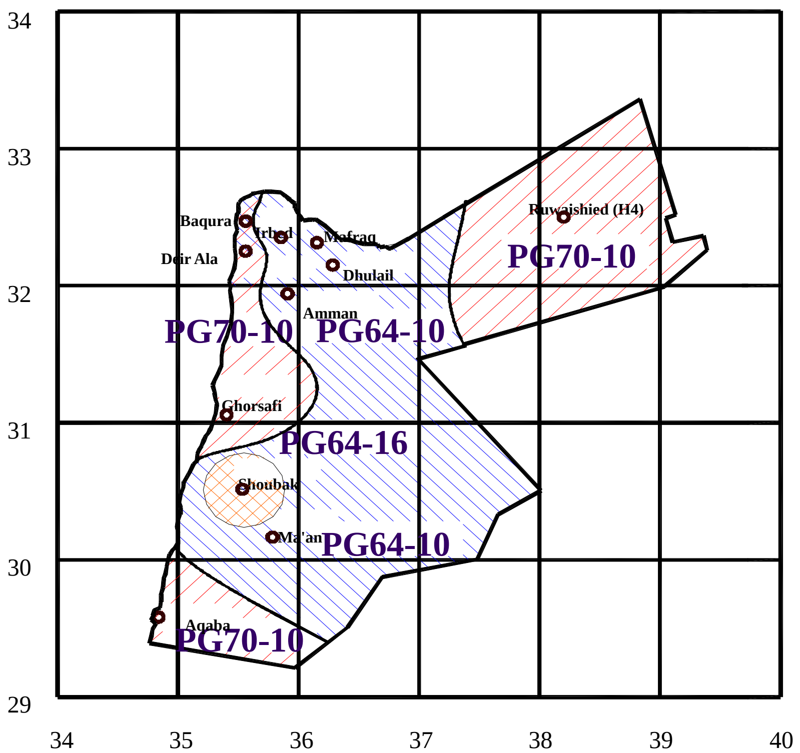

Fig. 5. Temperature Zoning for Asphalt Binder Specifications for Jordan.

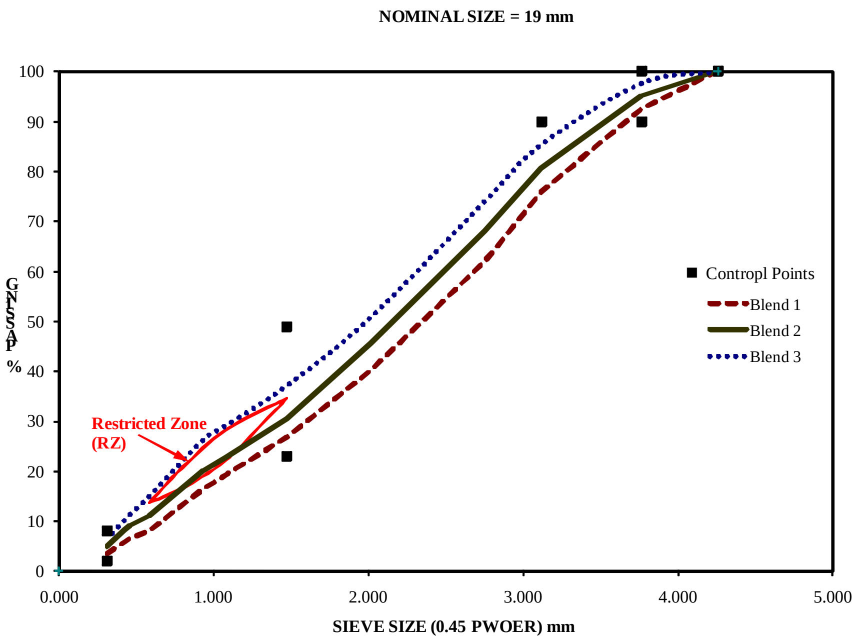

Fig. 6. Gradation of the Different Used Blinds According to Superpave Recommended Gradation.

Table 4. Estimated Properties of the Trial Blends to Achieve 4% Air Voids at N_d.

Blend	Trial	Estimated Properties to Achieve 4% Air Voids at N_d								
	AC%	AC%	VMA%	Criteria	VFA %	Criteria	$\%G_{mm}$ @ N_i	Criteria	Dust Proportion	Criteria
1	5.2	5.0	13.4	13 min	70.18	65-75	84.4	89 max	0.8	0.6-1.2
2	5.2	4.6	12.5	13 min	67.97	65-75	84.7	89 max	1.4	0.6-1.2
3	5.2	5.1	13.3	13 min	69.95	65-75	86.0	89 max	1.6	0.6-1.2

design procedure (ASTM D1559), currently followed procedure in Jordan for asphalt concrete mix design using 102-mm samples, was used to determine the optimum asphalt content. Optimum asphalt content (OAC) was selected to produce 4% air voids. Obtained OAC was 5.20% AC of total mix weight. At obtained OAC, Marshall stability, flow, voids filled with asphalt, and voids in mineral aggregate values were checked. They are within the specification limits of MPWH for heavy traffic loads wearing course.

Superpave Mix Design (AASHTO TP4)

Superpave uses volumetric analysis for the mix design and follows three major steps in the testing and analysis process. They are: selecting a design aggregate structure, optimizing the asphalt content for the selected structure, then evaluating moisture sensitivity of the design mixture.

For the sake of comparison, two extra aggregate structures were selected in addition to the MPWH recommended gradation for heavy traffic loads for wearing course. Fig. 6 shows the selected gradations. Blend 1 was selected to be below the restricted zone. Blend 2 was MPWH recommended gradation for heavy traffic loads for wearing course. To cover the other extreme of the gradation limits, blend 3 was selected to be above the restricted zone. It can be seen that blend 2 passes through the restricted zone. Superpave doesn't restrict this but recommends that special precautions should be taken when compacting these mixes in the field.

Since the gyratory compactor is used in Superpave mix design, the number of gyratory compactor gyrations should be specified. The number of gyrations depends on both average design high air temperature and design equivalent single axle load (ESAL). A traffic level higher than 30 million ESALs and lower than 100 million ESALs was selected. This traffic level was selected for comparison reasons and because it is usually the highest traffic level that can be observed on Jordan highways. At this traffic level, and at the average design high air temperature of Jordan (39°C), the recommended numbers of gyrations are N-initial = 9 gyrations, N-design = 125 gyrations, and N-maximum = 205 gyrations. These levels of gyrations were kept constant for the rest of the study.

The initial trial asphalt binder content for the three blends was estimated to be 5.2%. Two specimens from each trial blend were compacted using Rainhart Superpave Gyratory Compactor (SGC) available in the Highway Materials Laboratory at the Hashemite University in Jordan. Table 4 shows the results of the tested samples in addition to the estimated properties (VMA, VFA, $\%G_{mm}$ at N_i, and dust proportion) at the estimated asphalt content to achieve 4% air voids at N-design.

Table 4 indicates that blend 2 fails to meet the VMA and dust proportion criteria. Blend 3 fails to meet the dust proportion criteria. Just blend 1 satisfied all the specification limits; therefore, it will be carried to the second design stage, i.e., optimization of the asphalt content.

It is worth mentioning that the locally used MPWH gradation for heavy traffic loads wearing courses failed Superpave mix design criteria in more than one property. In addition, Superpave recommended asphalt content is 4.6%, which is much lower than Marshall Design recommended optimum asphalt content. This might explain the reason that most of HKJ roads are having bleeding problems. In addition, obtained dust proportion is higher than the maximum specified limit. High dust proportion will usually lead to brittleness of the mixes [6].

The design optimization curves for the selected blend (blend 1) revealed a design asphalt binder content of 4.8%. Evaluation of the moisture sensitivity of the design mixture was performed according to the AASHTO T283 test procedure. Obtained ratio of the indirect tensile strength for the obtained mix structure at the optimum asphalt content was 83.2%, which exceeded the minimum criteria limit.

In this research, local asphalt concrete materials were used to design asphalt concrete mixes according to Superpave mix design recommended procedure under prevailing environmental and loading conditions. This study is the first step in adopting a Superpave design procedure in the Hashemite Kingdom of Jordan. Further mechanical evaluation of the obtained mix should be implemented in addition to construction of test sections to ensure the suitability of Superpave design procedure to Jordan.

Conclusions

The research was conducted to find the adoptability of Superpave (superior performance asphalt pavements) mixture specifications to the Hashemite Kingdom of Jordan specific materials, traffic, and environmental conditions. A comparison study was carried out to use local materials to design the asphalt mixes using both Marshall and Superpave mix design procedures. Based on the findings of the experimental results, the following main conclusions can be drawn:

1. The performance grade of the locally produced asphalt is PG 64-16.
2. A temperature-zoning map was developed for the Hashemite Kingdom of Jordan. It consisted of three grade zones, PG 64-10, PG 64-16, and PG 70-10.
3. Locally produced asphalt can be used without the need of modification in all parts of Jordan except Aqaba, Ruwaishied, and Ghorsafi. In these areas, it should be modified to shift its grade to PG 70-10. This modification might just require air blowing of the local asphalt.
4. Local aggregate meet both Superpaveconsensus properties and source properties.
5. Locally used aggregate gradations are not suitable according to Superpave mix design procedure.
6. Superpave mix design procedure recommended, for the local environmental and loading conditions, using lower asphalt content than that predicted by Marshall Mix design procedure. Therefore, using Superpave mix design procedure might solve the bleeding problem of the asphalt concrete surfaces in Jordan.
7. Using MPWH recommended gradation for heavy traffic loads for wearing courses in Superpave mix design produced mixes having a dust proportion higher than the maximum specified limit by the Superpave procedure. High dust proportion will usually lead to brittleness of the mixes.
8. In Jordan, shifting to the Superpave design procedure might help solve the bleeding problem and some of the distresses common in local asphalt structures.

Recommendations

This research depended on laboratory fabricated samples and on comparison between volumetric properties. The following actions should be taken to verify obtained results:

1. A comprehensive performance evaluation using mechanical comparison testing between both Superpave and Marshall mix designs using local materials and traffic conditions should be performed.
2. To evaluate long term performance of Superpave mixes in Jordan, field test sections according to the Superpave design procedure should be constructed.
3. Serious plans should be set up to shift from the presently used Marshall mix design procedure to Superpave mixture specifications.

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