Selection and verification of performance grading for asphalt binders produced in Jordan

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Selection of proper binder is one of the most important factors considered in mixture design. Three different asphalt grading systems are normally used; they are penetration grading system, viscosity grading system and performance grading (PG) system. PG system is a method of measuring asphalt binder performance; it was originally developed during strategic highway research program in the early 1990s in order to accurately and fully characterise asphalt binders for use in hot mix asphalt pavements. PG system is based on the idea that the properties of an asphalt binder should be related to the conditions under which it is being used. This involves expected climatic conditions, pavement temperature as well as ageing conditions. Performance-graded asphalt binders are selected to meet expected climatic conditions as well as traffic speed and load conditions. Therefore, the PG system uses a common set of tests to measure physical properties of the binder which can be directly related to field performance of the pavement at its service temperatures. In order to adopt the Superpave system in Jordan, it is essential to develop climatic zones for Jordan and to select the proper performance-graded binder to be used in different regions in Jordan. Selection of performance-graded binder is based mainly on the air temperature of the desired location. Several models were used to calculate the pavement temperature. Different reliability levels were used in developing the climatic zones in Jordan. Finally, Jordan was divided into different zones and specific binder type to be used there. On the basis of analysis, binder grade having designation PG 64-10 can be used in most parts of Jordan. The only source for asphalt binders used in the construction of flexible pavements for Jordan’s highways and streets is the Jordan Petroleum Refinery (JPR). Typically, the JPR produces two main types of original asphalt binders; these are 60/70 penetration grade asphalt binder and 85/100 penetration grade asphalt binder. On the basis of laboratory test and according to the Superpave asphalt binder classification system, the 60/70 penetration grade asphalt binder can be classified as PG 64-16 and the 85/100 penetration grade asphalt binder as PG 58-16.

Keywords: performance grading; climate condition; asphalt binder; pavement temperature; Jordan

Introduction

Traffic and environment are the two primary factors that cause distresses in pavement. Environmental factors affecting pavements are temperature and water. Difference in air temperature and rainfall can have a profound impact upon pavement distress mechanisms and pavement performance in different climate regions.

Asphalt binders are commonly graded using the penetration and viscosity grading systems. These grading systems were developed to suite lower traffic loading conditions. Penetration and viscosity grading systems suffer from many limitations such as (Roberts et al. 1996):

- Penetration is empirical test.
- Testing temperature is constant regardless of the real field service temperature.
- Testing temperature does not cover the entire pavement service temperatures especially the low temperature ranges.
- Do not consider long-term binder ageing to account for fatigue cracking and low temperature cracking.
- For the same binder grading, different material properties may exist.

- It is not appropriate to grade modified binders, because it was developed originally to grade regular binders.

Owing to all of these limitations, a new binder grading system was developed [i.e. the performance grading (PG) system] based on new tests and specifications. The PG system considers wide pavement service temperatures that address the three major structural distresses, namely fatigue cracking, low temperature cracking and rutting. Different countries all over the world have started developing their own climatic zones in order to select the PG grades suitable to their own conditions (Al-Abdul Wahhab et al. 1997; Mirza et al. 2011). Furthermore, climatic regions are essential in mechanistic–empirical pavement design (Harvey et al. 2000).

The PG system is based on the idea that the properties of the hot-mix asphalt (HMA) binder should be related to the conditions under which it is used; especially, ageing, climatic and traffic conditions expected to occur in the field. The PG grading system simulates better the real pavement service conditions, and has the following characteristics (Roberts et al. 1996):
Field performance is directly related to the physical properties of the measured material.

The material is tested at different temperatures for the same testing criteria.

The expected pavement service temperature is completely covered.

Different ageing conditions are considered, which includes the original asphalt binder condition, short-term binder ageing condition and the long-term binder ageing condition.

The overlap between grades is reduced significantly.

It can be used for both modified and unmodified binders.

In this study, climatic zones have been developed based on temperature data for the different regions in Jordan for the last 20 years.

Jordan is located in the Middle East region between longitude 31°N and latitude 36°E. It occupies an area of about 89,342 km². Jordan’s topography is mostly desert in the east, and mountainous in the west where the Jordan River formed a deep valley at the west side.

Desert climate covers most of Jordan’s land; however, the western part of Jordan is of more Mediterranean climate. There are two main seasons in Jordan: the summer season, which is hot and dry (between May and October), and the wet season which is cool to cold and rainy (between November and April). Snow is not frequent in Jordan; it is more occasional on the mountains at the western part of the country.

The coldest month in Jordan is January, and the hottest month is August. Rainfall occurs during winter and varies from about 660 mm (26 in.) in the western part to less than 127 mm (5 in.) in the eastern part.

Superpave background

The word `Superpave’ is an abbreviation of SUperior PERforming asphalt PAVEments. Superpave as a system is the outcome of the asphalt research part of a $150 million applied research programme that was conducted during 1987–1992. The entire programme was called the Strategic Highway Research Program (SHRP). The main goal behind this research programme was to improve the performance, durability, safety and efficiency of the US highway system.

The resulting Superpave system includes (1) asphalt binders PG system, (2) asphalt binder tests and specifications, (3) aggregate tests and criteria, (4) new requirements for the selection of asphalt binders and design aggregate structure and gradation, (5) new method and specifications for the compaction process of asphalt mixtures and (6) performance tests that simulate field performance of asphalt pavements.

The Superpave asphalt binders PG system classifies asphalt binders accurately based on prevailing climatic conditions. In the Superpave asphalt binder PG system, the following factors are considered: (1) minimising the overlap between the different performance grades, (2) the prevailing climatic and environmental conditions at a particular site, (3) the temperature range at a particular site and (4) simulating short- and long-term ageing that normally take place during mixing and laydown, and during the service life of asphalt pavements. Physical consensus properties measured for aggregates are directly related to field performance. Tests and specifications of asphalt binders have aimed at including both unmodified and modified asphalt binders, and the evaluation process is based on pavement performance. The Superpave system also accounts for traffic loading in the design lane over a 20-year design period. Traffic speed is also considered in the overall process during asphalt mixture design.

Objectives

The main objectives of this study are the following:

1. To develop climatic (temperature) zones for Jordan according to the Superpave asphalt binders PG system.
2. To evaluate the asphalt binders produced by the Jordan Petroleum Refinery (JPR).
3. To select the proper PG of asphalt binder for the different regions in Jordan.
4. To check the possibility of adopting the Superpave system in Jordan.

Materials and methodology

Asphalt binders

The only source for asphalt binders used in the construction of flexible pavements for Jordan’s highways and streets is the JPR located in the Zarqa City in the middle region of Jordan. Typically, the JPR produces two main types of fresh asphalt binders; these are 60/70 penetration grade asphalt binder and 85/100 penetration grade asphalt binder. The main crude source of Jordan’s asphalt is the Kingdom of Saudi Arabia. In addition, the production of asphalt grades is mostly consistent since the method of refining at the JPR is the same over time. In order to classify the asphalt binder produced from the refinery in accordance with the Superpave asphalt binder PG classification system, the following test procedures were carried out: Superpave PG (Superpave Procedures/AASHTO MP1/Practice PP6). These procedures involve conducting the following Superpave asphalt binder tests:

- Dynamic shear rheometer (DSR) test for the unaged (fresh) asphalt binder before the rolling thin-film oven (RTFO) test to determine the $G''/\sin \delta$ at 10 rad/s and test temperatures of 58, 64, 70 and 76°C.
- RTFO test for the asphalt binder at a test temperature of 163°C.
- DSR test for the RTFO-aged asphalt binder after the RTFO test to determine the $G^\prime\sin \delta$ at 10 rad/s and test temperatures of 58, 64, 70 and 76°C.
- Pressure ageing vessel (PAV) test for the RTFO-aged asphalt binder after the RTFO test at a temperature of 100°C and pressure of 300 psi.
- DSR test for the PAV-aged asphalt binder after the PAV test to determine the $G^\prime\sin \delta$ at 10 rad/s and temperatures of 25, 28, 31, 34 and 37°C.
- Bending beam rheometer (BBR) test for the PAV-aged asphalt binder after the PAV test to determine the creep stiffness and $m$-value (slope of creep stiffness vs. time curve) at 60 s and test temperatures of 0, −6 and −12°C.

The DSR, RTFO, PAV and BBR tests were conducted according to the test procedures described in the AASHTO standard test methods AASHTO T315, T240, R28 and T313, respectively.

The flash point (FP) test was also conducted for the asphalt binders according to the AASHTO T48 test method to ensure that their flash point values are higher than the minimum required limit in the Superpave system, which is 230°C.

The rotational viscosity (RV) test was conducted on the asphalt binders in accordance with the AASHTO T316 standard test method (2008). The Superpave specification for the RV value for fresh asphalt binders is 3 Pa s (3000 cP).

The next section presents a brief description of each test of the aforementioned Superpave tests that were used to classify and evaluate the asphalt binders in Jordan.

**RV test**

The RV test samples for 60/70 and 85/100 asphalt binders were prepared according to the procedures in the AASHTO T316 test method.

The RV test was conducted for the fresh asphalt binder at 135°C, representing the average mixing and laydown temperature for HMA. In the RV test, a cylindrical spindle having a specified diameter and effective length rotates inside a container filled with the asphalt material at a speed of 20 rpm. The torque required to maintain this constant rotational speed is measured.

The shear strain rate and the torque are converted into RV as described in the following equation:

$$\eta = \frac{\tau}{\dot{\gamma}},$$

where

$\eta$ is the dynamic (rotational) viscosity (Pa s), $\tau$ is the shear stress (N/cm²) and $\dot{\gamma}$ is the shear strain rate (/s).

The Superpave specification for the RV value at 135°C is a maximum of 3 Pa s (3000 cP).

**DSR test**

The DSR test was conducted on the prepared samples of 60/70 and 85/100 asphalt binders at four test temperatures (58, 64, 70 and 76°C) and at a frequency of 10 rad/s (1.59 Hz) according to the procedures described in the AASHTO T315 test method (2008).

The DSR test applies a shearing load to an asphalt disc placed between two plates: the lower plate and the upper plate. The lower plate is fixed, whereas the upper plate oscillates back and forth across the asphalt sample at a frequency of 10 rad/s (1.59 Hz) to create shearing.

In the DSR test, the value of the complex shear modulus ($G^*$) and that of the phase angle ($\delta$) of the tested asphalt sample are measured.

**BBR test**

The BBR test was conducted on the prepared samples of 60/70 and 85/100 asphalt binders according to the AASHTO T316 standard test method. The BBR test applies a constant small load (100 g) to the asphalt sample beam for 240 s. The test samples used in the BBR test have to be previously aged in RTFO and PAV tests.

The deflection and load are recorded with time during the test using the data acquisition system of the BBR test. The stiffness ($S(t)$) and the $m$-value (the rate of change of stiffness with time) are then calculated. $S(t)$ and the $m$-value are determined at a time of 60 s from the best fit curve of the recorded data [$S(t)$ vs. time]. Superpave specifies a maximum limit of 300 MPa for the $S(t)$ and a minimum limit of 0.300 for the $m$-value.

**RTFO test**

The RTFO test simulates the short-term ageing that occurs in asphalt binders during mixing and laydown of HMA. The RTFO test is conducted at a temperature of 163°C according to the AASHTO T240 test method.

The mass loss of the test samples is then calculated as the percentage difference between the original mass and the mass after the RTFO test divided by the original mass. The Superpave system specifies a maximum limit of 1.0% for the mass loss after the RTFO test.

**PAV test**

The PAV test simulates the long-term ageing that occurs in asphalt binders during the service life of HMA pavements. The PAV test was conducted at a test temperature of 90, 100 or 110°C and high pressure of 300 psi for 20 h according to the AASHTO R28 test method.

The Superpave test results for the asphalt binders produced in Jordan are summarised in Tables 1 and 2 below. On the basis of these results and according to the Superpave asphalt binder classification system, the 60/70 penetration
grade asphalt binder can be classified as PG 64-16 and the 85/100 penetration grade asphalt binder as PG 58-16.

Results and discussion

PG classification for asphalt binders

The RV test results were obtained at only one test temperature (135°C) according to the Superpave specifications to ensure fluidity of asphalt binder and workability for pumping, mixing and laydown. The RV test results are shown in Tables 1 and 2. As shown in these tables, the RV values for the 60/70 and 85/100 asphalt binders were 560 (0.56 Pa s) and 319 cP (0.32 Pa s), respectively. Both values passed the Superpave specifications for RV results (a maximum value of 3 Pa s = 3000 cP). The RV results along with the Superpave specification are illustrated in Figure 1.

Figure 1. RV values for fresh asphalt binders.

The DSR test results for the 60/70 and 85/100 asphalt binders were obtained. The complex shear modulus ($G^*$) value and the phase angle ($\delta$) were determined for the fresh
asphalt binders as well as for the RTFO-aged asphalt binders at four test temperatures: 58, 64, 70 and 76°C. Figure 2 shows the plot of $G^*/\sin \delta$ value versus test temperature for the fresh asphalt binders. In this figure, a polynomial of the second degree was the best function that fitted these data for both the 60/70 and 85/100 asphalt binders. The Superpave criterion for the $G^*/\sin \delta$ value for fresh asphalt binders (a minimum of 1.0 kPa) was also plotted in this figure to compare the results. It is obvious from this figure that the 60/70 asphalt binder passed the Superpave specifications at a maximum test temperature of 64°C, whereas the 85/100 asphalt binder passed the Superpave specifications at a maximum test temperature of 58°C.

Figure 3 illustrates the $G^*/\sin \delta$ value versus test temperature plot for the RTFO-aged asphalt binders. A polynomial of the second degree was also the best function that fitted these data for both the 60/70 and 85/100 RTFO-aged asphalt binders. The Superpave criterion for the $G^*/\sin \delta$ value for RTFO-aged asphalt binders (a minimum of 2.2 kPa) is shown in this figure for comparison of the results. The figure shows clearly that the 60/70 RTFO-aged asphalt binder passes the Superpave specifications at a maximum test temperature of 64°C, whereas the 85/100 asphalt binder passed the Superpave specifications at a maximum test temperature of 58°C.

On the other hand, the 85/100 RTFO-aged asphalt binder passes the Superpave specifications at a maximum test temperature of 58°C. Consequently, these two asphalt binders (60/70 and 85/100) were classified for the high PG grade according to the Superpave asphalt binders grading (classification) system as PG 64 and PG 58, respectively.

The BBR test results were also obtained for the PAV-aged asphalt binders at −6°C. The BBR creep stiffness ($S(t)$) and the slope of the creep stiffness versus time curve ($m$-value) at 60 s were determined from the test data for both asphalt binders. The test data were plotted in the histograms shown in Figure 4(a),(b) to compare the results of the two asphalt binders. The Superpave criteria are 300 MPa as a maximum value for the BBR creep stiffness and a minimum value of 0.300 for the $m$-value for PAV-aged asphalt binders. It is clear from this histogram that both asphalt binders (60/70 and 85/100) pass the Superpave criteria for BBR test results at the test temperature of −6°C. Consequently and according to the Superpave asphalt binders classification system, both asphalt binders can be graded for the low PG grade as PG-16. In conclusion and based on these results, the 60/70 and 85/100 asphalt binders have Superpave performance grades of PG 64-16 and PG 58-16, respectively.

**PG climatic zones**

The highest and lowest hourly temperatures for different weather stations were collected from the public records of the Meteorology Department in Jordan. The mean for the maximum and minimum air temperatures and the standard deviations for all weather stations are shown in Table 3. The average 7-day maximum annual temperature and the lowest annual temperature were also determined for all weather stations. The mean and the standard deviations for the average 7-day maximum annual temperature and for the lowest annual temperature were also determined as shown in Table 3.

The high and the low pavement temperatures were calculated using two models:

1. The SHRP (Asphalt Institute 1996) algorithm:

   $$T_{pav} = 0.9545 (T_{Air} - 0.00618 Lat^2 + 0.2289 Lat + 42.4) - 17.78,$$

   where $T_{pav}$ represents high pavement temperature at 20 mm below surface (°C), $T_{Air}$ represents 7-day average high air temperature (°C) and Lat represents the geographic latitude of the project location (°).

2. The formula:

   $$T_{min} = 0.859 T_{Air} + 1.7°C,$$

   where $T_{min}$ represents minimum pavement design temperature (°C) and $T_{Air}$ represents minimum air temperature in average year (°C).
(2) Federal highway administration (FHWA 1999) algorithm:

\[
T_{\text{High Pav}} = 54.32 + 0.78T_{\text{Air}} - 0.0025\text{Lat}^2 \\
-15.14\log(H + 25) - z(9 + 0.61\sigma_{\text{Air}})^{1/2},
\]

where \(T_{\text{High Pav}}\) represents high asphalt concrete pavement temperature below surface (°C), \(T_{\text{Air}}\) represents 7-day average high air temperature (°C), \(\text{Lat}\) represents the geographic latitude of the project location (°), \(z\) represents standard normal distribution table, \(z = 2.055\) for 98% reliability, \(H\) represents depth below surface (mm) and \(\sigma_{\text{Air}}\) represents standard deviation of the mean low air temperature (°C).

\[
T_{\text{Low Pav}} = -1.56 + 0.72T_{\text{Air}} - 0.0044\text{Lat}^2 \\
+6.26\log(H + 25) + z(4.4 + 0.52\sigma_{\text{Air}})^{1/2},
\]

where \(T_{\text{High Pav}}\) represents high asphalt concrete (AC) pavement temperature below surface (°C), \(T_{\text{Air}}\) represents minimum air temperature in average year (°C), \(\text{Lat}\) represents the geographic latitude of the project (°), \(z\) represents standard normal distribution table, \(z = 2.055\) for 98% reliability, \(H\) represents depth below surface (mm) and \(\sigma_{\text{Air}}\) represents standard deviation of the mean low air temperature (°C).

The high and the low pavement temperatures calculated using the SHRP-SP2 algorithm are shown in Table 4; on the other hand, the high and the low pavement temperatures calculated using the FHWA–LTPP (Long-Term Pavement Performance), bind program algorithm are shown in Table 5. From Tables 4 and 5 it is noted that both algorithms produce almost the same results. It should be noted that reliability should be considered when calculating the high and low temperatures. In the SHRP models, there is no reliability, whereas in the FHWA–LTPP models, the reliability has been considered. In addition, the differences in the maximum pavement temperature between the SHRP models and FHWA–LTPP models are due to modelling computations. In addition, in the FHWA–LTPP models, the depth below surface (\(H\)) is one of the inputs in the models.

Contour map of the 7-day maximum air temperature for different cities in Jordan was drawn as shown in Figure 5. It is clear from Figure 5 that the 7-day maximum air temperature at most areas of Jordan is about 40°C; the
The minimum pavement air temperatures for different cities in Jordan were drawn in Figure 6. The minimum air temperature ranges from about 2°C to about −5°C.

Table 4. Calculated pavement temperatures using SHRP algorithms.

<table>
<thead>
<tr>
<th>City/location</th>
<th>50% Reliability</th>
<th>98% Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. pavement temp. (°C)</td>
<td>Min. air temp. (°C)</td>
</tr>
<tr>
<td>Irbid</td>
<td>58.9</td>
<td>−1.7</td>
</tr>
<tr>
<td>Mafraq</td>
<td>61.6</td>
<td>−6.0</td>
</tr>
<tr>
<td>Amman airport</td>
<td>61.3</td>
<td>−2.6</td>
</tr>
<tr>
<td>Queen A. airport</td>
<td>62.5</td>
<td>−4.3</td>
</tr>
<tr>
<td>Ghor Safi</td>
<td>66.0</td>
<td>−0.4</td>
</tr>
<tr>
<td>Maan</td>
<td>61.8</td>
<td>−7.2</td>
</tr>
<tr>
<td>H-4 Irwaished</td>
<td>64.8</td>
<td>−5.2</td>
</tr>
<tr>
<td>H-5 Safawi</td>
<td>65.3</td>
<td>−4.5</td>
</tr>
<tr>
<td>Aqaba</td>
<td>66.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 5. Calculated pavement temperatures using FHWA–LTPP algorithms.

<table>
<thead>
<tr>
<th>City/location</th>
<th>50% Reliability</th>
<th>98% Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. pavement temp. (°C)</td>
<td>Min. air temp. (°C)</td>
</tr>
<tr>
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<td>−1.3</td>
</tr>
<tr>
<td>Mafraq</td>
<td>60.0</td>
<td>−4.9</td>
</tr>
<tr>
<td>Amman airport</td>
<td>59.7</td>
<td>−1.9</td>
</tr>
<tr>
<td>Queen A. airport</td>
<td>60.7</td>
<td>−3.3</td>
</tr>
<tr>
<td>Ghor Safi</td>
<td>63.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Maan</td>
<td>60.2</td>
<td>−5.4</td>
</tr>
<tr>
<td>H-4 Irwaished</td>
<td>62.6</td>
<td>−4.2</td>
</tr>
<tr>
<td>H-5 Safawi</td>
<td>63.0</td>
<td>−3.6</td>
</tr>
<tr>
<td>Aqaba</td>
<td>64.1</td>
<td>2.7</td>
</tr>
</tbody>
</table>

On the basis of the 7-day maximum pavement temperature and the minimum pavement temperature, a PG zone was developed for Jordan as shown in Figure 7. It is clear from Figure 7 that binder grade 64-10 can be used for most locations in Jordan. The hot areas in Jordan such as...
as Aqaba in the south, Ghor in the west and the desert in the east are better addressed by using binder PG 70-10.

Conclusions and recommendations

On the basis of the analysis and results of this study, the following conclusions and recommendations are drawn:

1. There are two main climatic zones in Jordan: the first zone includes the desert area in the east, the Ghor area in the west and the Aqaba area which needs binder PG 70-10, whereas the remaining areas of Jordan are suitable for binder PG 64-10.

2. On the basis of the DSR and BBR test results and according to the Superpave asphalt binder classification system, the two main types of original asphalt binders produced by the JPR are classified as PG 64-16 for the 60/70 penetration grade asphalt and PG 58-16 for the 85/100 penetration grade asphalt binder.

3. On the basis of the analysis and results of this study, modification to the asphalt binder produced in Jordan will be needed to satisfy the required binder grade for some climatic areas in Jordan such as epoline EE2 polymer and Styrene Butadiene Styrene (SBS) modifiers.

4. Due to the fact that Jordan’s climate is not as extreme as the US climate in the low temperature region, the direct tension test was not needed in this study, the BBR stiffness of the asphalt binders tested at low temperatures in these regions did not exceed 50 MPa.

5. Currently, JPR produces original binders classified as PG 64-16 and PG 58-16; however, based on the results of this study it is found that PG 64-10 and PG 70-10 are the required performance grades in Jordan. Therefore, it is recommended that the JPR should start producing asphalt binders that satisfy Jordan’s climatic conditions.

6. According to Superpave specifications, binder grade should be pumped one or two grades at slower speeds or very heavy traffic. Therefore, it is recommended that the JPR should provide different binder grades for such special conditions using some modifiers to the fresh asphalt binder such as epoline EE2 polymer and SBS modifiers to improve the high PG grade.

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Notes

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References


California Department of Transportation, University of California at Berkeley, Pavement Research Center.


The Asphalt Institute (AI), 1996. Superpave Series No. 2 (SP-2), Superpave Mix Design.