Modification of Hot Asphalt Mixtures in Jordan and Syria by Using Steel Slag

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ABSTRACT

Roads in the Arab world face so many problems, especially at the surface of the pavement due to the variations in the weather conditions (high and low temperatures) and the design methods of the hot asphalt mixes. Therefore, we need to avoid any defect in the asphalt pavement surface such as fatigue and thermal cracking.

The main objective of this study is to solve the problem of temperature variations in Syrian and Jordanian roads, by choosing the right type of asphalt binder that would be suitable to temperatures in a variety of areas, improving the design of hot asphalt mixtures in different areas according to temperature variations and selecting the right design method.

To do this, the asphalt binder was classified according to temperature variations. A temperature map was prepared by dividing Syria and Jordan into temperature zones. Steel slag was used in the hot asphalt mixtures with different percentages (15, 30 and 45%) according to the total weight of coarse aggregates in the mix. Marshal, Superpave and a combination of the two design methods were used.

Fatigue, indirect tensile strength, loss of indirect tensile strength and the resilient modulus laboratory tests were performed on all hot mixes. Tests results were studied and analyzed. It was found that using (30%) of the steel slag in the mixture was the most suitable manner. Using the Superpave mix design was best as it showed 20% more stability than the Marshall design method.

KEYWORDS: Superpave, Steel slag, Performance grade, Fatigue, Resilient modulus, Stability.

INTRODUCTION

Due to the variation of temperature and heavy traffic loading, different countries all over the world suffer from pavement surface problems that reflect on the safety, economy and the comfort of road users (Asi, 2004). Another very important factor to be considered in pavement is the design of hot asphalt mixes. In Jordan and Syria, the Marshall mix design method is used. This method does not give the accuracy required in determining the effects of climate, traffic load, material properties and the variations between laboratory design and field work (Roberts et al., 2002). Stability, durability, skid resistance and flexibility are the most important properties in bituminous paving mixtures which must be considered when designing an asphalt mixture (Asi, 2004). Many defects in the road surface are common in both countries (Jordan and Syria), like: raveling, bleeding, rutting, fatigue cracking and low temperature cracking. These defects occur at different stages of the life of the pavement and under relatively common temperature conditions (Asphalt Institute, 2001). Due to drawbacks of

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Marshall mix design procedure in many countries, the Strategic Highway Research Program (SHRP) has developed a superior performance asphalt pavement mix design procedure called "Superpave". The main objective of this program was to develop a mix method procedure that incorporates a performance based on the asphalt binder specification and accelerated performance based tests. For the asphalt binder, most tests are empirical and do not give information about the range of typical pavement temperature. For example, viscosity only gives information at high temperatures, while low and mid temperature data cannot be obtained (SHRP, 1993, 1994).

In this study, a zoning temperature map was prepared by using the temperature variations from different weather stations. The maximum seven-day temperature and the minimum one-day temperature were taken from 20 year records for different zones in Jordan and Syria. According to the requirements of the Superpave method, the Performance Grade (PG) was shown on the temperature zoning map (Brown et al., 2001).

According to Superpave requirements, different types of asphalt have been used in this study. In Jordan and Syria, asphalt types used were (60/70 and 80/100).

Steel slag was also used in this study in the hot asphalt mixtures by different percentages (15%, 30% and 45%) as part of the limestone coarse aggregates. Another hot mix was prepared without using the steel slag for comparison responses. Three methods of design were used; Marshall, Superpave and a combination of both methods called Marshall – Superpave. These methods were used to study the effect on the mix properties. Different tests like fatigue, indirect tensile strength, loss of indirect tensile strength and resilient modulus tests were also performed on the mixtures (Qasrawi et al., 2003).

EXPERIMENTAL WORK

The experimental work in this study was divided into different stages as follows:

Aggregate Tests: A group of tests for mechanical properties consensus properties, source properties and gradation was conducted. These tests of coarse and fine aggregates include: angularity, flat and elongated particles, sand equivalent, specific gravity of coarse and fine aggregates and Los Angeles abrasion (Anderson and Bahia, 1997) . Table 1 shows the test results.

Table 1. Properties of aggregates

Property	Test results	Specification
Coarse aggregate angularity	100/100%	100/100% min.
Fine aggregate angularity	46 %	45% min.
Flat particles	0	10 % max.
Sand equivalent	60 %	40 % min.
Specific gravity	2.575	
Abrasion loss	26 %	35 % max.

Performance Grade (PG) was determined by maximum seven-day and minimum-one day temperatures for a record of 20 years from different weather stations, using a computer program called (LTPP V 2.1) to convert the air temperature to pavement temperature. Figures 1, 2, 3 and 4 show the performance grade for Jordan and Syria at ESAL 10 and 30 million (FHWA, 1999).

The Superpave system included an asphalt specification that uses new binder physical property tests such as Rotational Viscometer (RV), Dynamic Shear Rheometer (DSR), Bending Beam Rheometer (BBR), Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV) (FHWA, 1995). This system realistically represents temperature and aging conditions encountered in service pavements. This way of design is used to prevent three defects; permanent deformation (rutting), fatigue cracking and low temperature cracking. Therefore, three types of asphalt were used for this study; two types from Syria (60/70) and (80/100) and from Jordan (60/70). These types are the most used in both countries. The performance grades (PG) for all of them are shown in Table 2.

Table 2. PG of asphalt

Type of asphalt	PG
60 / 70 Syria	PG (64 – 16)
80 / 100 Syria	PG (64 - 22)
60 / 70 Jordan	PG (64 – 16)

According to this classification for asphalt types, maps on Figures (5, 6, 7 and 8) show suitable places for using each kind of asphalt, this can be a guide for road engineers to use the right type of asphalt (Asphalt Institute, 2001).

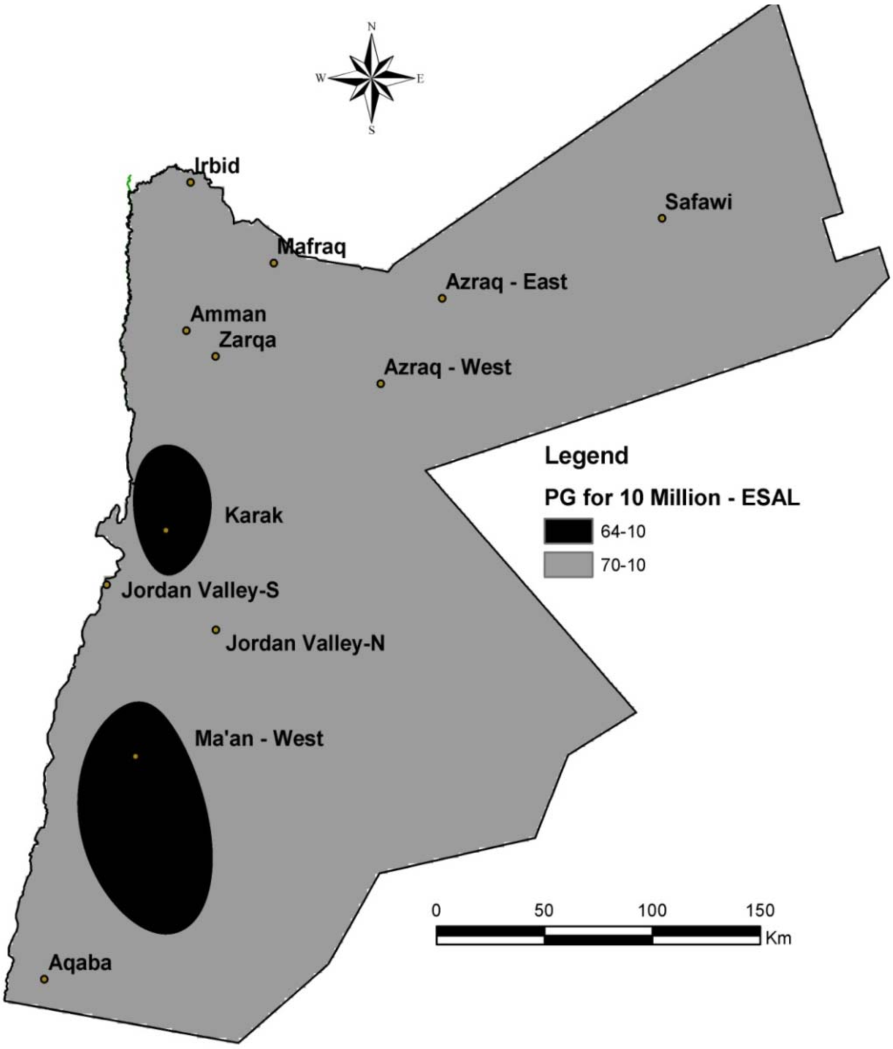

Figure 1: Performance Grade (PG) for Jordan for 10 Million ESAL

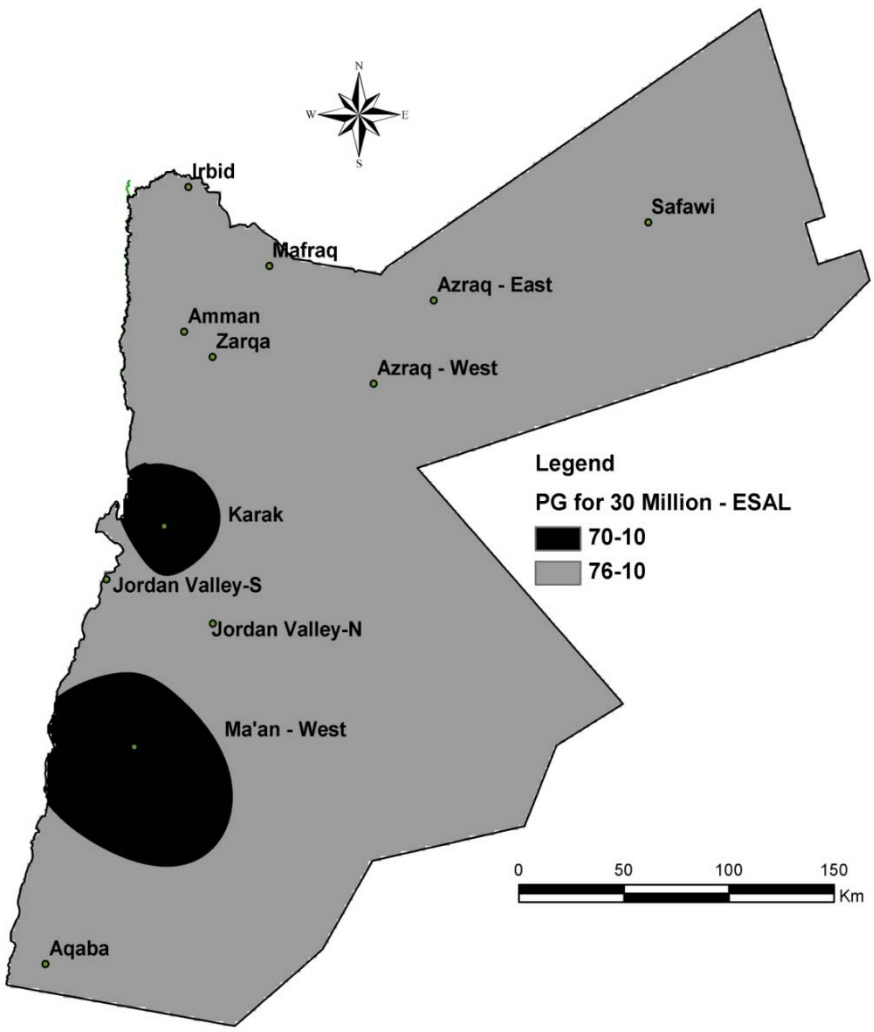

Figure 2: Performance Grade (PG) for Jordan for 30 Million ESAL

Laboratory compaction is accomplished by means of Superpave Gyratory Compactor (SGC) which is linked to a computer system giving the suitable mix to use in the field with air voids of 4%, the main criterion of the Superpave design. The (SGC) specifications are: 1.25º of gyration, rotation of 30 gyrations/min, 0.6 MPa ram pressure and 150 mm diameter of the mold. SGC was used for compacting the laboratory specimens whose volumetric and engineering properties adequately simulate those of the field specimens for a wide variety of pavements (Asphalt Institute, 2001).

Steel Slag was used in this study at different percentages of (15, 30 and 45%) from the total weight of the coarse aggregates in asphalt mixtures, in addition to another mixture without steel slag (MPWH, 1991). For the selection of the optimum asphalt content of the three design methods with different percentages of steel slag, a number of asphalt mixtures were prepared and tested. The optimum asphalt content (OAC) was determined. Table 3 shows (OAC) for all mixtures.

Table 3. Optimum asphalt content

Way of Design	Steel Slag %	OAC%
Superpave	0 %	4.3
	15 %	4.8
	30 %	5.4
	45 %	5.5
Marshall/ Superpave	0 %	5.0
	15 %	5.5
	30 %	6.0
	45 %	5.5
Marshall	0 %	5.5
	15 %	5.5
	30 %	6.0
	45 %	6.0

Tests on Hot Asphalt Mixtures

According to the Optimum Asphalt Content (OAC%) determined, 36 specimens of the hot asphalt mixtures were prepared. Three samples of each design method and each steel slag percentage were prepared, along with three specimens of each design method without using the steel slag.

The 36 specimens were tested for Marshall Stability, Indirect Tensile Strength, Loss of Indirect Tensile Strength, Resilient Modulus and Fatigue Life (Asi, 2007).

Marshall Stability Test (ASTM D 1559)

(ASTM D 1559) requires that the specimens must be 4 inches in diameter, and because Superpave specimens were 6 inches in diameter, coring was made and the sides were cut for the Superpave specimens so they can be tested according to ASTM D 1559 .

The results of the Marshall Stability Test are shown in Figure 9 for all specimens. Comparisons can easily be shown between the three design methods as well as the use of different percentages of steel slag or not using steel slag at all.

Based on the result analysis, it was noted that the Superpave sample stability values were greater than those of other methods. The stability of Marshall design was about 80% of the Superpave stability. This is attributed to the improved aggregate structure, the lower asphalt content and the way of compaction in the Superpave design procedure, which is very similar to the site compaction.

Indirect Tensile Strength and Water Sensitivity Test (AASHTO T – 283 -89)

This test is conducted using the Marshall Stability machine, using indirect tensile mode at 25ºC temperature at 2 hrs. The load reading at failure is recorded. By using this load in the following equation, the determination of the indirect tensile strength (ITS) is as follows:

$$ITS = 2P / td\pi \qquad ...(1)$$

where

ITS: indirect tensile strength, kPa;

P: failure load, kN;

T: sample thickness, m;

D: sample diameter, m.

In addition, the same numbers of samples were immersed in water for 24 hours at 60ºC and then tested the same way. Figure 11 shows the ITS, Figure 12 shows the loss of indirect tensile strength as a percentage. It is noted that the design of the Superpave gives higher values than Marshall and Marshall/Superpave. This behavior is related to the aggregate and percentage of asphalt. Due to the porousity of steel slag being more than that of limestone, 30% of the steel slag gave the best result in all tests.

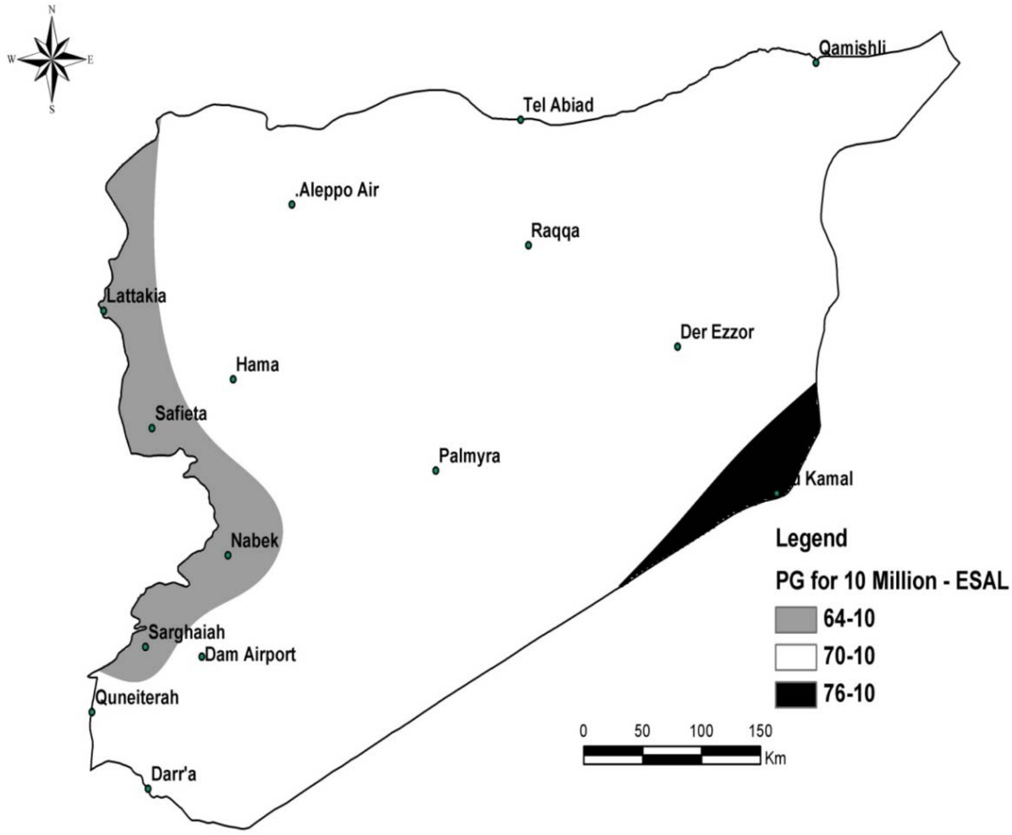

Figure 3: Performance Grade (PG) for Syria for 10 Million ESAL

Resilient Modulus Test (Mr) (ASTM D 4123)

Resilint modulus is the most important variable in the mechanistic design of pavement. The value of this factor was determined from the Fatigue Life Test. Figure 10 shows the values of the resilient modulus, the value of this modulus for Superpave is higher than for the other two methods. Therefore, the result is attributed to the lower asphalt content and coarser aggregate gradation.

Fatigue Performance

Different samples were prepared in the same way for the three methods of design, and three percentages of steel slag were added to the limestone. This test is done through a Dynamic Creep test by applying a repeated uniaxial stress on the samples and measuring the resulting deformations vertical to the direction of the applied load by using Linear Variable Differential Transducers (LVDT). The number of cycles at which the sample failure occurred was recorded; these samples were tested at different initial tensile strain levels. Figures 13, 14, 15 and 16 show the results of this test. It was concluded that there was a linear relationship between the logarithm of the initial strain and the number of applied load repetitions until sample failure. For every method of design and for each percentage of steel slag, a model is shown, which determines the number of repetitions at an initial strain at any stage. Superpave gave the best results and 30% of steel slag was the best percentage.

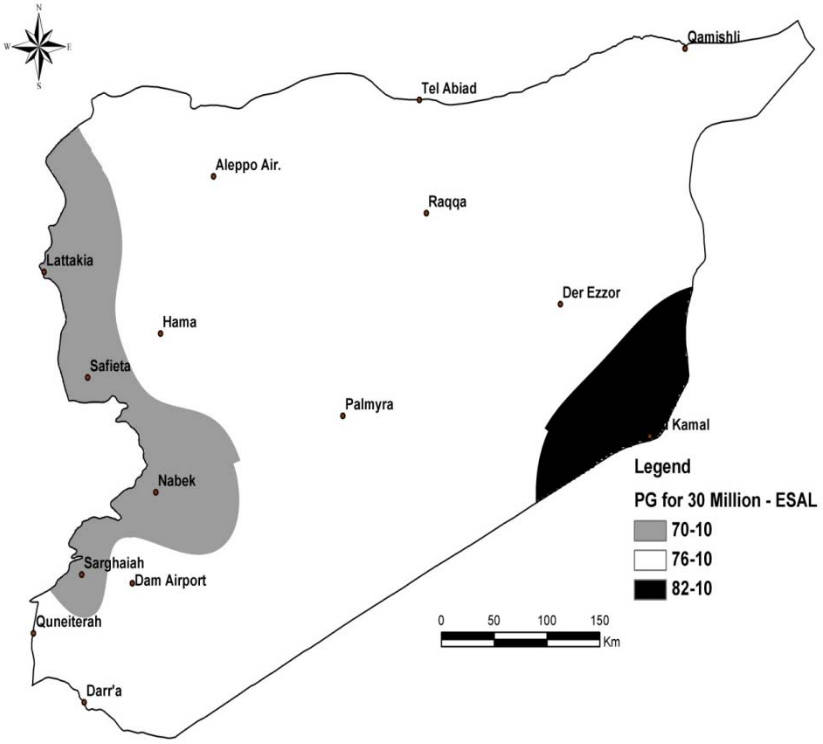

Figure 4: Performance Grade (PG) for Syria for 30 Million (ESAL)

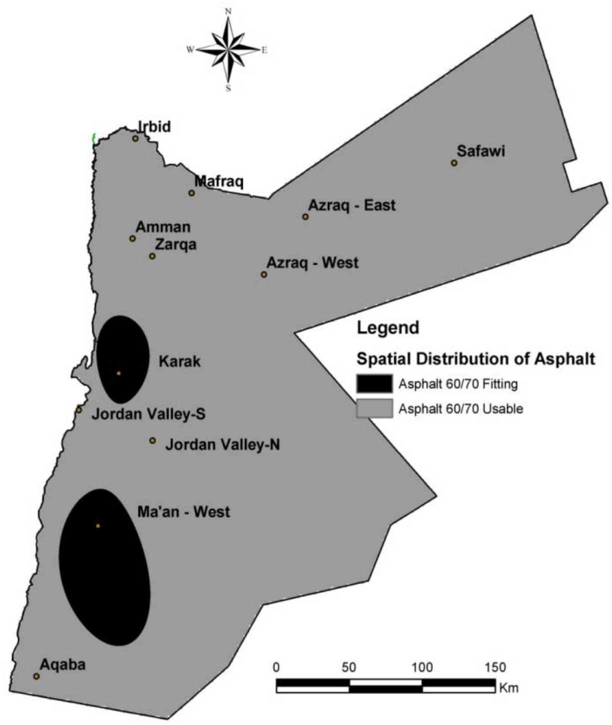

Figure 5: Location Map of Asphalt Distribution in Jordan for 10 Million ESAL

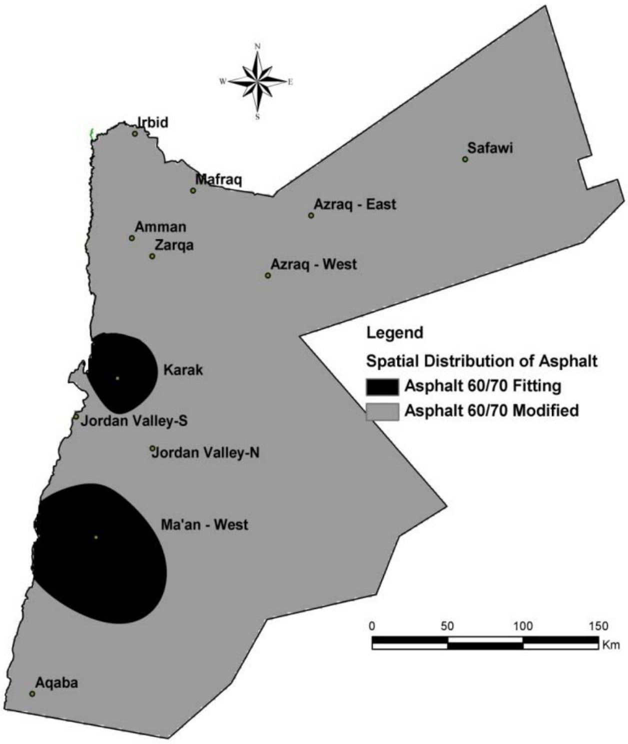

Figure 6: Location Map of Asphalt Distribution in Jordan for 30 Million ESAL

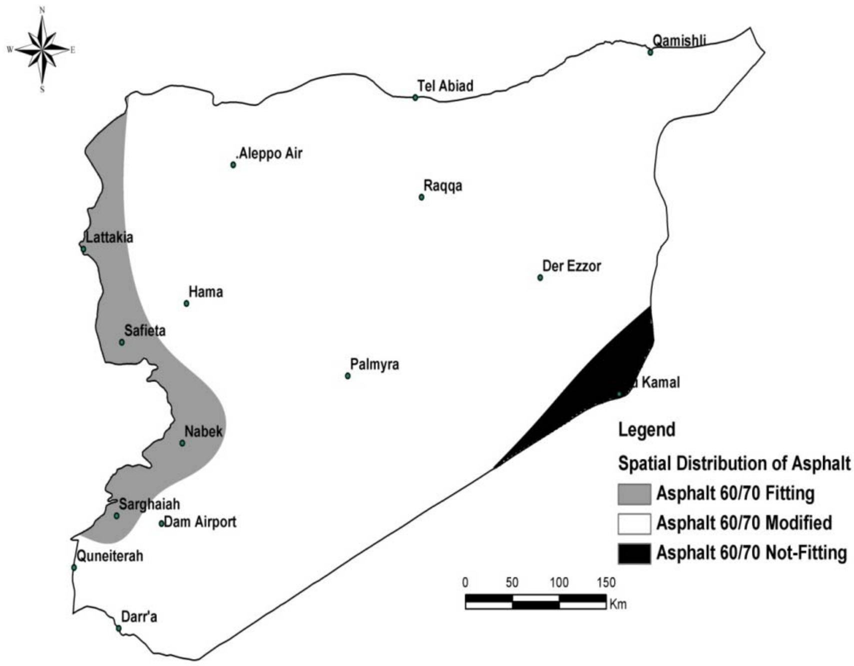

Figure 7: Location Map of Asphalt Distribution in Syria for 10 Million ESAL

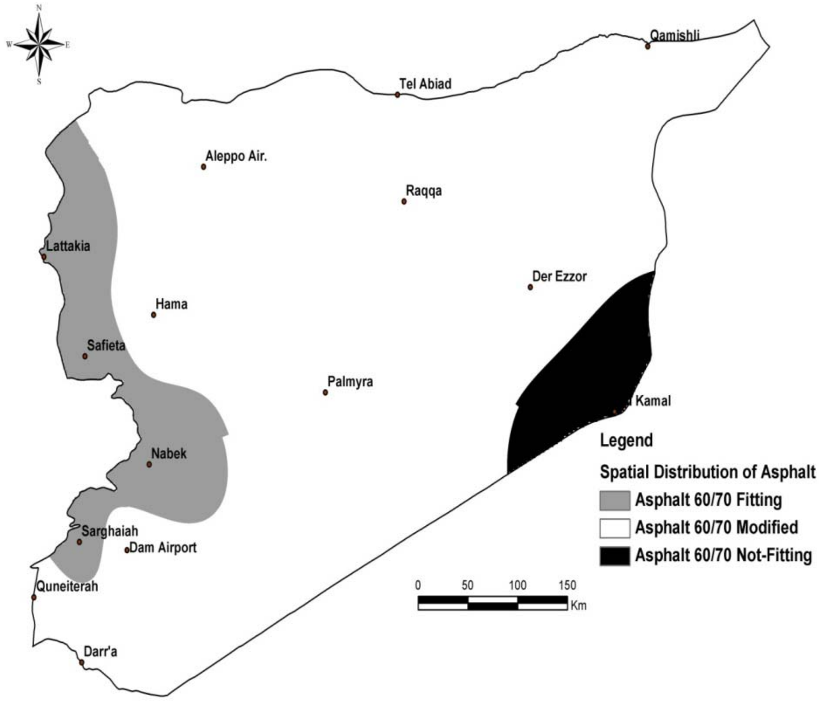

Figure 8: Location Map of Asphalt Distribution in Syria for 30 Million ESAL

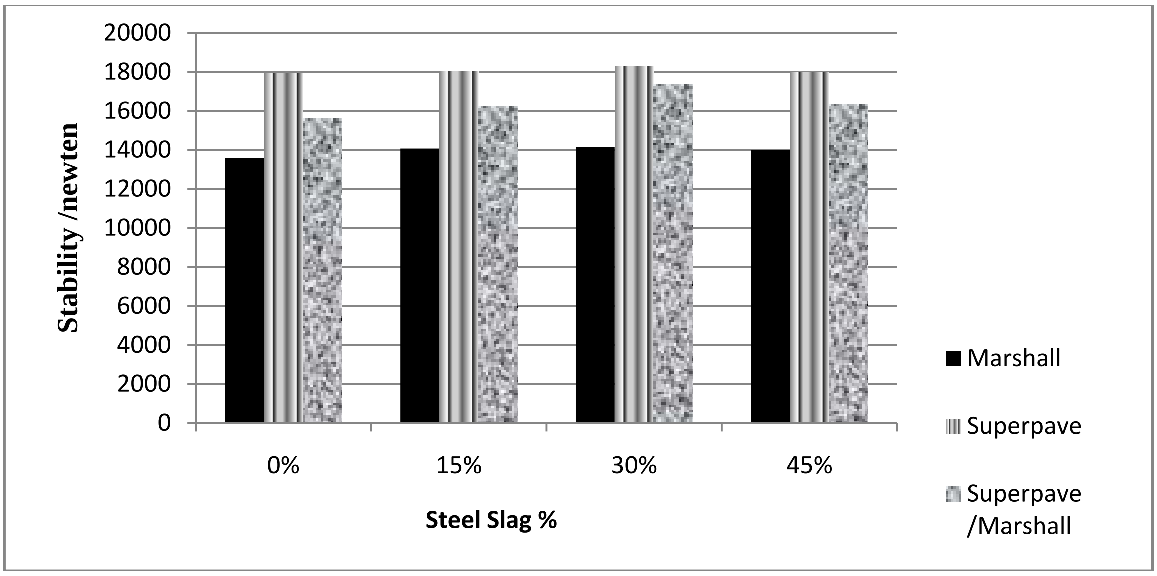

Figure 9: Effect of Steel Slag on Stability

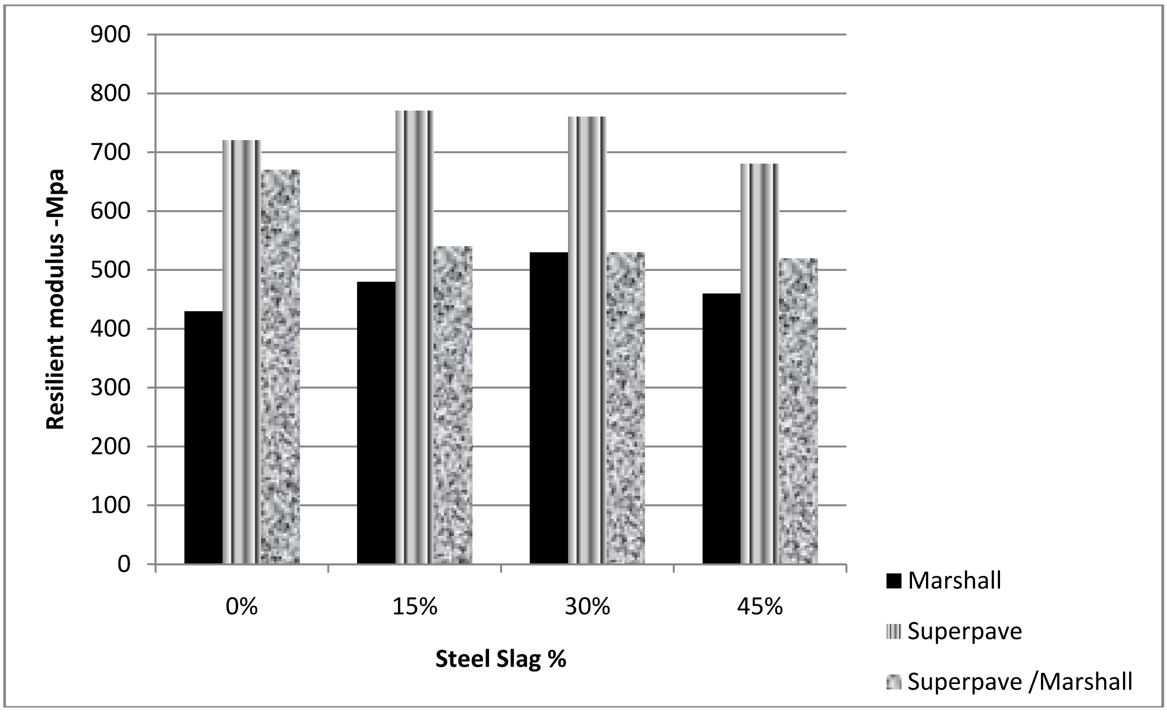

Figure 10: Effect of Steel Slag on Resilient Modulus

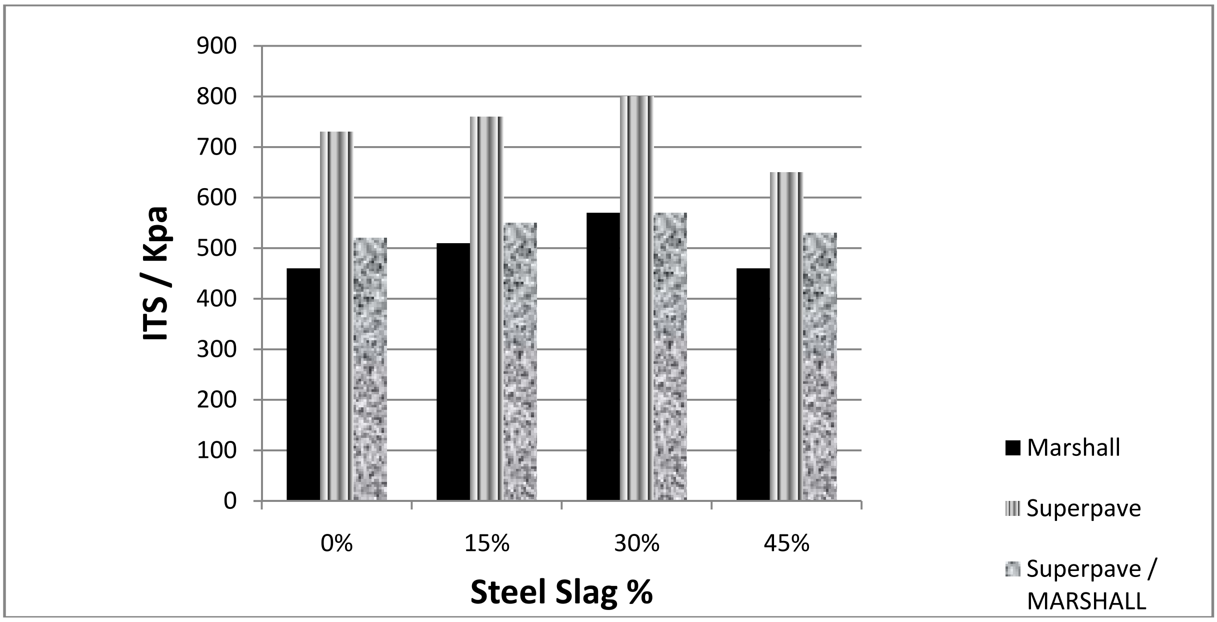

Figure 11: Effect of Steel Slag on Indirect Tensile Strength

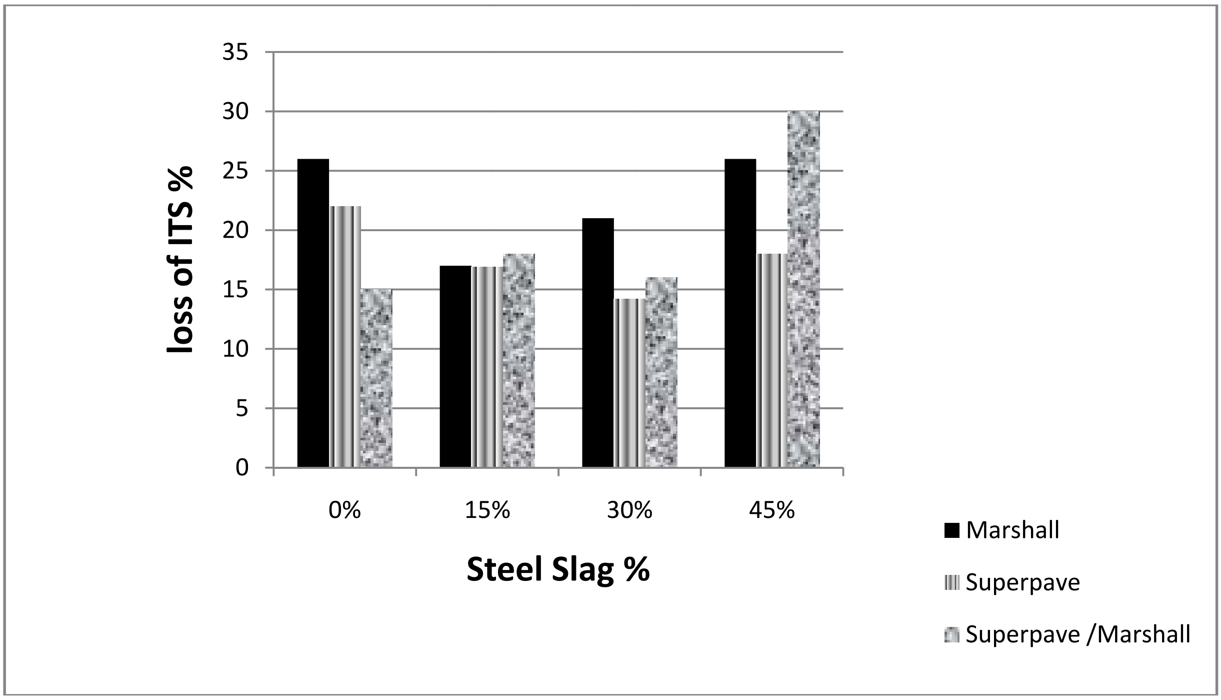

Figure 12: Effect of Steel Slag on Loss in Indirect Tensile Strength

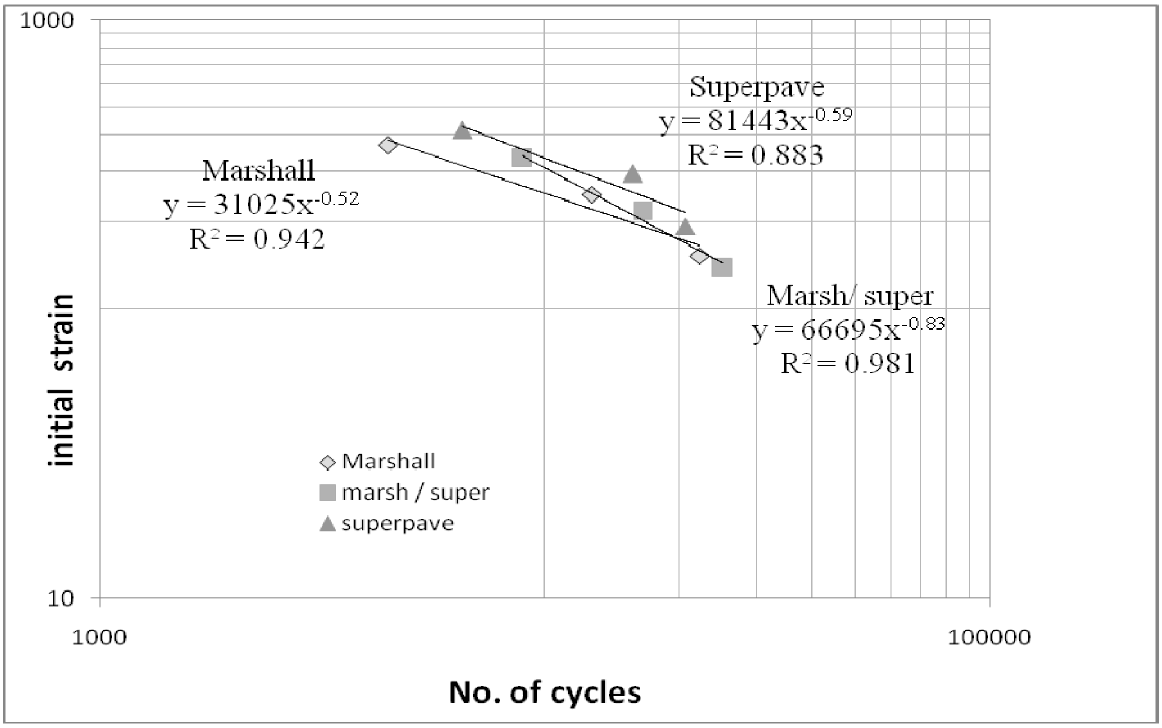

Figure 13: Fatigue Life for Limestone

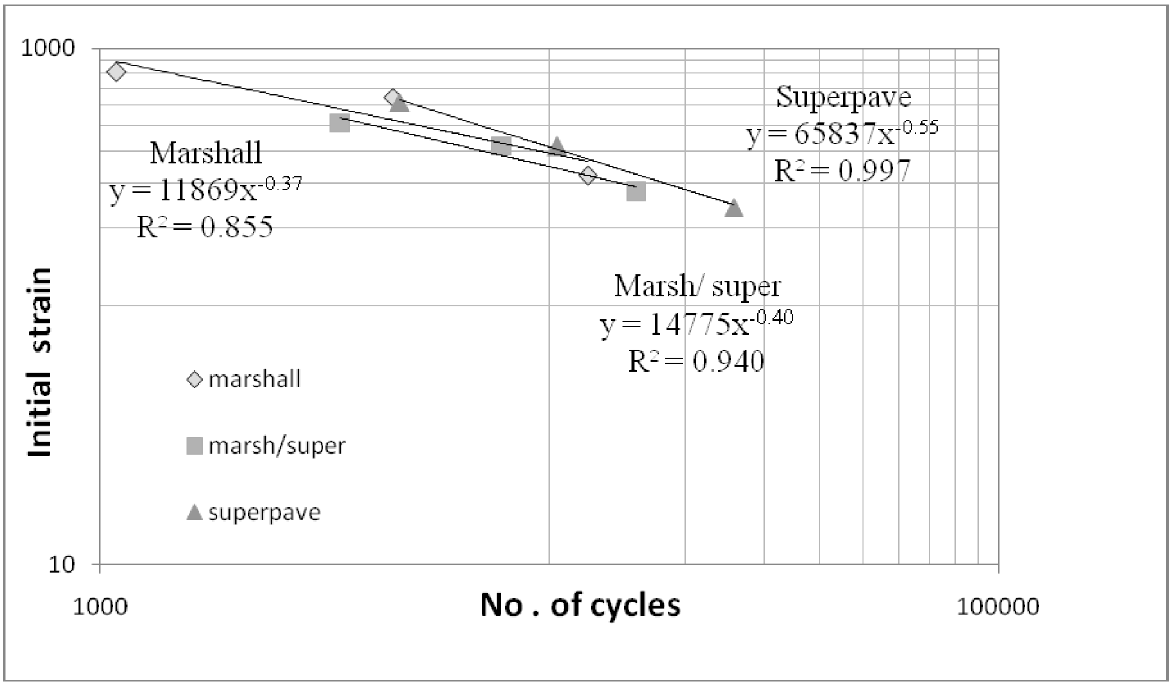

Figure 14: Fatigue Life for 15% Steel Slag

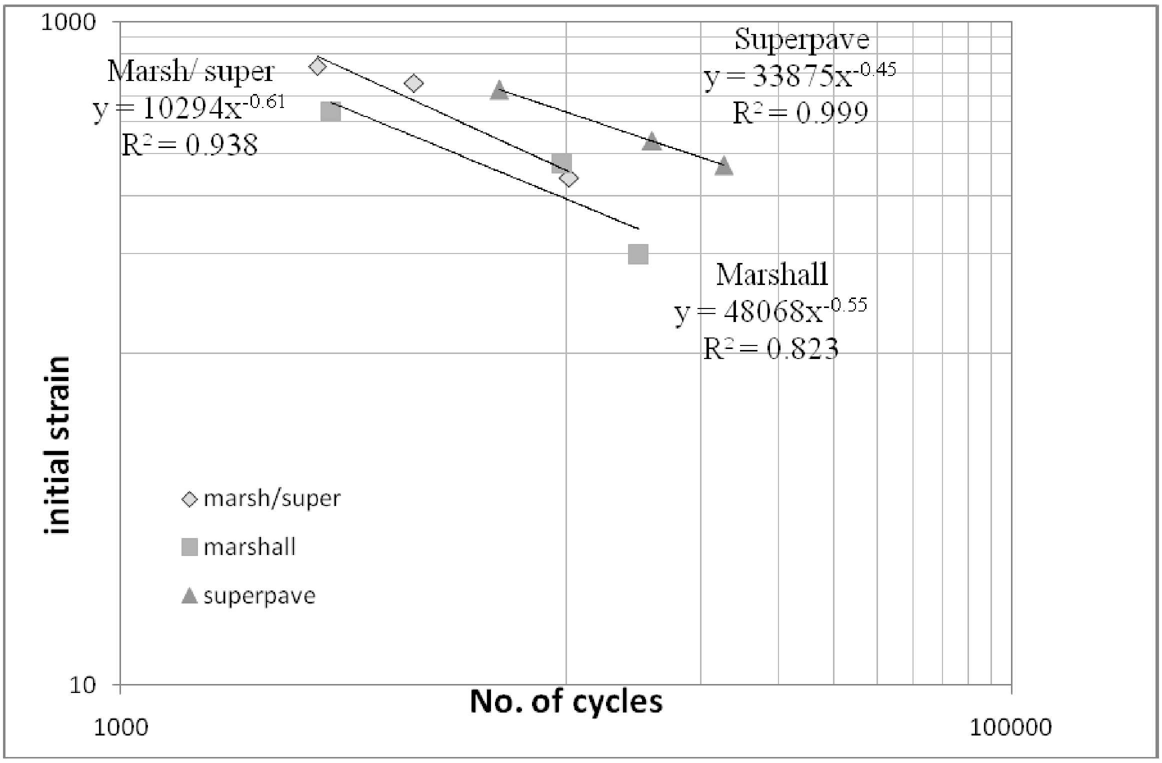

Figure 15: Fatigue Life for 30% Steel Slag

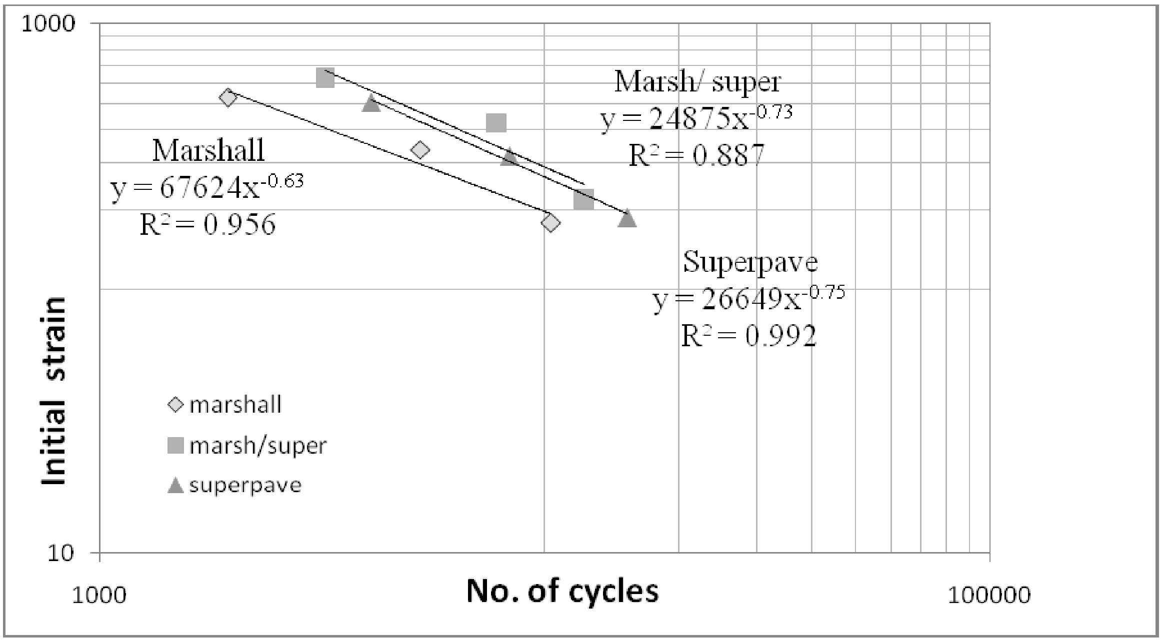

Figure 16: Fatigue Life for 45% Steel Slag

RESULTS

This study explored the performance grade for roads in Jordan and Syria depending on the air temperature variations, and the determination of the classification of (PG) was carried out using three types of asphalt bitumen (60/70 and 80/100) from Syria and (60/70) from Jordan.

Three methods of design were used for asphalt mixtures; Superpave, Marshall and Marshall/Superpave, with different percentages of steel slag and limestone. This research can be summarized as follows:

1. The performance grades in most Jordanian roads are PG (64 – 10) and PG (70 – 10) at ESAL of 10 million and 30 million PG (70 – 10) and PG (76 – 10).
2. The performance grades in most Syrian roads are PG (64 – 10), PG (70 – 10) and PG (76 -10) at 10 million ESAL, and 30 million ESAL PG (70–10), PG (76–10) and PG (82 -10).
3. Based on the tests carried out on the three types of asphalts following the requirements of Superpave, the classification of PG asphalt 60/70 from Jordan and Syria was PG (64 – 16) and that of asphalt 80 /100 from Syria was PG (64 – 22).
4. This grade of asphalt can be used in many places in both countries. The western areas in Syria and Jordan, like Bokamall and Alsafawy, need to shift the grade of asphalt at 10 and 30 million ESAL.
5. Locally used aggregate gradations had a problem with the fine aggregate angularity, which is required by the Superpave specification.
6. The Superpave mix design is suitable for harsh environmental and heavy load conditions, at lower asphalt content, higher stability and indirect tensile strength, lower percent in loss of indirect tensile strength and long life of fatigue for mixtures.
7. Using steel slag in the asphalt hot mixtures was found to be suitable for the mixture, and the best results were achieved at 30 % steel slag.

SUMMARY AND CONCLUSION

This study investigated the performance grade for roads in Jordan and Syria depending on air temperature variations.

The main objective of this study is to solve the problem of temperature variations in Syrian and Jordanian roads, by choosing the right type of the asphalt binder that would be suitable to temperatures in a variety of areas, improving the design of hot asphalt mixtures in different areas according to temperature variations and selecting the right design method. In addition, the determination of the classification of (PG) was carried out using three types of asphalt bitumen (60/70 and 80/100) from Syria and (60/70) from Jordan.

Three methods of design were used in this study for asphalt mixtures; Superpave, Marshall and Marshall/Superpave, with different percentages of steel slag and limestone.

Test results were studied and analyzed. It was found that using (30%) of steel slag in the mixture was the most suitable manner. Using the Superpave mix design was best, as it showed 20% more stability than Marshall design method.

According to the study results, it is concluded that steel slag can be used in our roads to improve the properties of asphalt mixtures for fatigue life and stability. Superpave is the best method of design related to the study results.

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