


Performance Life Using Mechanistic–Empirical Analysis of Asphalt Mixtures in Arid Climatic Conditions—Case of Kuwait [†]

Taha Ahmed ^{1,*} , Aditya Singh ^{2,*}, Elie Hajj ² and Ahmad Saad ¹

¹ Civil Engineering Department, College of Engineering, Australian University, Kuwait City 13015, Kuwait; a.said@au.edu.kw

² Civil and Environmental Engineering Department, College of Engineering, University of Nevada, Reno, NV 89557, USA; elieh@unr.edu

* Correspondence: t.ahmed@au.edu.kw (T.A.); adityasingh@nevada.unr.edu (A.S.)

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Abstract: The extreme arid climatic conditions and poor asphalt mix design characteristics have further accelerated the rate of deterioration of in-service asphalt pavements in Kuwait. Pavement distresses, such as raveling, rutting, and fatigue cracks, worsen in severe climatic and loading conditions, such as high temperatures, elevated humidity levels, and high traffic loads on the pavement surfaces. In this study, a life performance evaluation using mechanistic–empirical analysis of a new modified Superpave mix design was undertaken. The performance life of the modified Superpave asphalt mixture was evaluated, and the results showed that the new modifications to the mix improved the rutting and fatigue cracking resistances of the asphalt mixture for the unconditioned state. However, fatigue cracking resistance under the moisture-conditioned state still needs further improvement for the newly modified Superpave asphalt mixture.

Keywords: arid climate; asphalt mixture; pavement distresses; Superpave; mechanistic empirical



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1. Introduction

The proper design and maintenance of asphalt pavement will extend its service life and help it to maintain a satisfactory level of service. However, due to in-service conditions, asphalt pavements can be damaged by certain types of distresses. Pavement distresses, such as raveling, rutting, and fatigue cracking, worsen in severe climatic and loading conditions, such as high temperatures, elevated humidity levels, and high traffic loads on the pavement. The extreme arid climatic conditions of Kuwait and poor asphalt mix design characteristics have further accelerated the rate of deterioration of in-service asphalt pavements [1]. To combat this issue, Kuwait's Ministry of Public Works (MPW) adopted the Superpave asphalt mix design from the Qatari Construction Specifications, which considers both climate and traffic, unlike the Marshall mix design approach. However, the long-term performance of this newly adopted Superpave asphalt mix design must be evaluated to determine its long-term resistance to common pavement distresses [2].

Mechanistic–empirical (ME) analysis is based on the theory of mechanics and predicts the responses of the pavement to the application of loads. The empirically derived models employ these pavement responses to forecast distress in terms of cracking and rutting. ME analysis can forecast asphalt pavement's long-term performance over its design period. As a result, the objective of this study was to use a ME analysis to assess the resistance of the Superpave asphalt mixture against prevalent pavement distresses, including rutting and fatigue cracking. This ME study assisted in comprehending how the modified material properties impact pavement performance over time and if further modifications are required to the newly approved mix design procedure.

2. Methods and Materials

In this research study, the local raw materials were acquired from Kuwait to develop Superpave asphalt mix design. The raw material types and the desired number of samples were selected according to the General Specifications for Kuwaiti Roads and Highways (MPW) [3] and the Qatar Construction Specifications [4]. Only one aggregate source and one asphalt binder grade were used for this research study. The selected aggregate was Gabroo aggregate, and the evaluated properties met the ASTM standard requirements. Figure 1 depicts the final aggregate gradation obtained for the Superpave mix design. Similarly, the asphalt binder properties were examined, and the final performance grade obtained following AASHTO M320 was PG 76-22 [2].

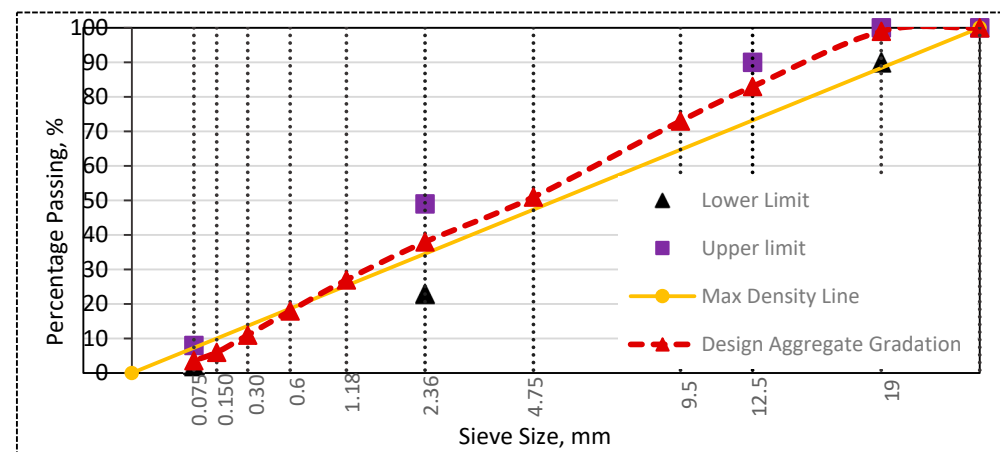


Figure 1. Verified Aggregate Gradation.

After evaluating the raw materials, the Superpave mix was performed as per AASHTO M 323, where the optimum binder content selected was 4.1% (TWM) at 4% air voids meeting the required volumetrics shown in Table 1.

Table 1. Superpave Mix Design Volumetric Requirements.

Property	Average Result	QCS Specifications
Design air void, %	4.0	4.0
Pb, %	4.1	-
VMA, %	13.21	13
VFA, %	70	50–75
DP	1.12	0.75–1.20
G_{mm} @ N_{ini}	87	Max. 88
G_{mm}	2.648	-
Air voids at N_{max} , %	2.7	Min. 2.0

After finalizing the mix design, performance testing such as dynamic modulus, cyclic fatigue, and stress sweep rutting tests were conducted for the Superpave asphalt mixture at the unconditioned state (UC) and moisture-conditioned at three freeze–thaw cycles (3-C). The engineering properties measured from these tests were used as the input parameters in the mechanistic–empirical analysis to predict the long-term pavement performance over 20 years.

Mechanistic–Empirical Analysis

The FlexPaveTM software was used to perform mechanistic–empirical analysis of the Superpave asphalt mixture at the UC state and after the 3-C state. FlexPaveTM is a modified linear viscoelastic pavement design for critical distresses (LVECD) based on the three-dimensional (3D) viscoelastic finite element technique (FEM) [5].

3. Results and Discussion

The required input parameters for the ME analysis are climate data, traffic data, material properties, pavement structure, and performance criteria. Local climate information for Kuwait was taken from the MEERA-2 global climatic database. Currently, the MPW is updating its traffic data collection system, and the most recent traffic data is not available. Therefore, the traffic parameters used in the analysis were the default values, as shown in Table 2. In Kuwait, there are currently no performance standards for rutting and fatigue cracking. Hence, the performance criteria used by researchers in neighboring countries with similar arid climate regions were considered.

Table 2. Input Parameters for Mechanistic–Empirical Analysis.

Single Axle Load	80 kN
Tire pressure	120 psi
Traffic levels	30 MESALS
Speed	97 km/h
Design Life	20 years
Cracking Limit	20%
Rutting Limit	0.75 inch (1.9 cm)

In this study, the thickness of the pavement was determined using the three methods listed in Table 3. Method A employs a similar pavement structure built in Kuwait before 2012, but Method B employs the AASHTO Guide to the Design of Pavement Structures, 1993 (referred to as AASHTO 93). Method C employs a pavement structure similar to Method B, but the asphalt (AC) layer thickness is increased until the rutting and cracking performance criteria are met. The AC layer was assumed to be a single layer, and the analysis was conducted for the Superpave asphalt mixture at the UC state and after the 3-C, respectively. Figure 2 shows the pavement structure used in the ME analysis for each method.

Table 3. Pavement Design Thickness for All Three Methods.

Design Method	AC Layer Thickness
Typical sections (A)	6.3 in. (16 cm)
AASHTO 93 (B)	7.9 in. (20 cm)
FlexPave™ (C)	8.7 in. (22 cm)

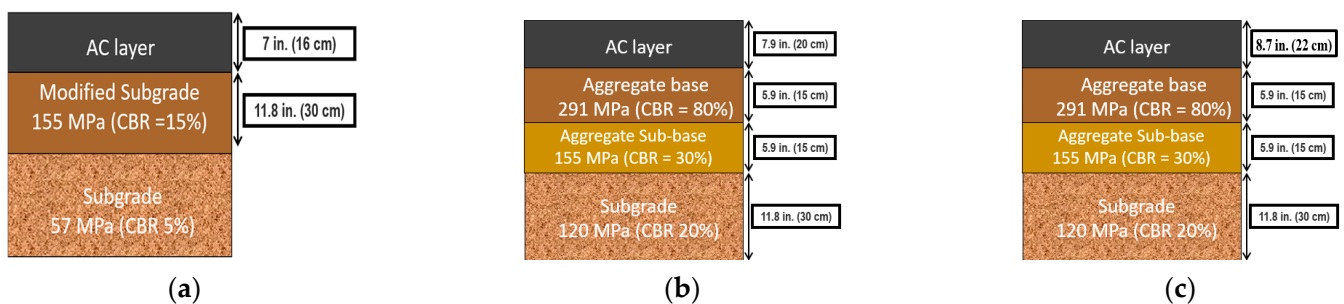


Figure 2. Pavement structure used in ME analysis. (a) Typical sections constructed before 2012 in Kuwait, (b) AASHTO 93 pavement structure, and (c) FlexPave™ pavement structure.

After inputting the above-mentioned parameters, the analysis was run using the FlexPave™ software. An example of the results obtained for the cracking and rutting for design method A is shown in Figure 3. Similarly, the analysis was performed for the other two design methods, and the final obtained results are discussed in Table 4.

As illustrated in Figure 3 and Table 4, pavement sections constructed before 2012 in Kuwait were inadequately designed for 30 MESALS of traffic. The pavement constructed

using Method B had a longer fatigue and rutting life, but it still required improvement to withstand the 20-year design traffic of 30 MESALS. Method C increased the asphalt pavement thickness until the pavement met the performance parameters for the Superpave asphalt mixture at the UC state. However, the pavement could only endure 5.5 years after the 3-C state indicating a durability issue in the mix design.

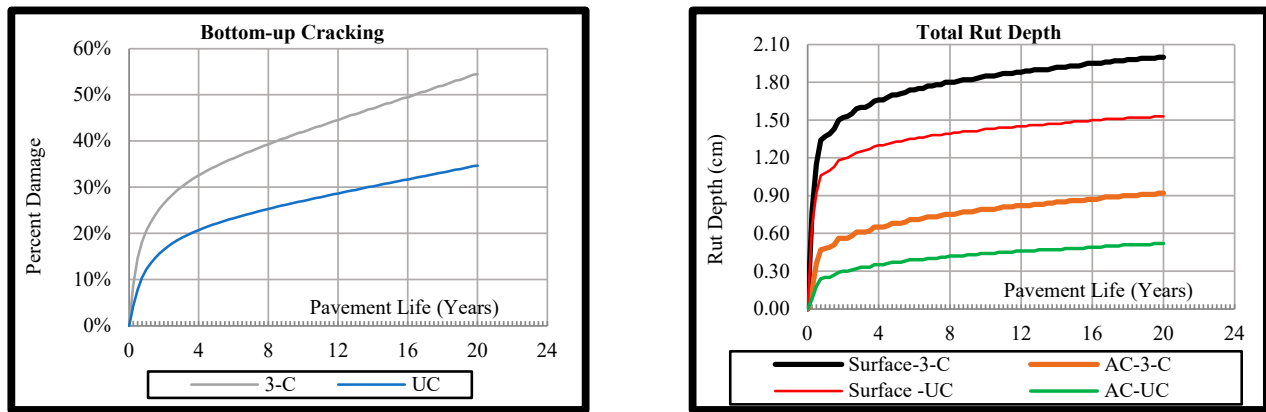


Figure 3. Example of FlexPave™ results for design method A.

Table 4. Pavement Design Life of the Superpave Asphalt Mixture for 30 MESALS Traffic.

Design Method	Fatigue Life (UC)	Rutting Life (UC)	Fatigue Life (3-C)	Rutting Life (3-C)
Typical sections (A)	3.75 years	20 years	1 year	12.75 years
AASHTO 93 (B)	18.25 years	20 years	4.25 years	20 years
FlexPave™ (C)	20 years	20 years	5.5 years	20 years

4. Conclusions and Recommendations

This study focused on the process and importance of conducting mechanistic–empirical analysis for the newly adopted Superpave asphalt mixture. Results showed that the newly adopted Superpave asphalt mixture enhanced the rutting and fatigue cracking resistances at the unconditioned state. However, fatigue cracking resistance under the moisture-conditioned state still needs further improvement for the newly modified Superpave asphalt mixture.

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