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Effect of binder grade on performance parameters of asphaltic concrete paving mixtures

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Abstract

This study explores effect of binder grade variation on the performance parameters of stiffness, fatigue, and permanent deformation using different asphaltic concrete paving mixtures. Two penetration grade binders (40/50 and 80/100), four gradations (two wearing and two base courses) and single limestone aggregate source were used. Superpave Gyratory Compactor (SGC) was employed to fabricate specimens for Dynamic Modulus $|E^*|$ test, Repeated Load Deformation Test (Flow Number Test, FN) and Static Creep Test (Flow Time test, FT) using Asphalt Mixture Performance Tester (AMPT). The $|E^*|$ test was carried out for a range of temperatures (4.4–54.4 °C) and a frequency sweep (25–0.1 Hz), while FN and FT tests were performed at a single effective temperature of 54.4 °C and 300 kPa stress level. The $|E^*|$ test results were subjected to the non-linear optimization technique to develop the stress-dependent master curves which reveal that the grade of bitumen significantly influences the stiffness of mixtures. The combination of the $|E^*|$ and the phase angle pronounced into fatigue parameter which describes the fatigue behavior of a mix, and results indicate that the softer grade translates into higher fatigue resistance and vice versa. We observe that the 40/50 binder, on average, is 1.8 times more rut-resistant than the 80/100 binder. Further, this study also develops a non-linear regression model to express $|E^*|$ as a function of testing temperature, loading frequency, and mixture volumetric parameter.

Keywords: Binder; Dynamic Modulus; Flow Number; Flow Time; Non-linear regression

1. Introduction

Asphalt Concrete (AC) primarily entails aggregate and binder as their major constituents. The service life of a flexible pavement and its response mainly depends on the combined interaction of these two ingredients coupled with environmental factors like temperature, moisture, and loading conditions such as frequency of loading and its magnitude. Severe loading, environmental conditions, and inadequate structural design manifest various kinds of distresses that result in premature failure of flexible pavements. This premature failure can largely be attributed to empirical design procedures used for pavement design and analysis. In order to improve AC technologies and mix design procedures (empirical to Mechanistic-Empirical, M-E), improved material characterization models, and advanced laboratory testing methods, FHWA and NCHRP

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conducted various research studies and projects. The 2002 AASHTO Mechanistic-Empirical Pavement Design Guide (M-EPDG) is one of the major outcomes which is adopted in most parts of the world and is being part of researchers' attention nowadays [1]. The M-EPDG recommends three candidate tests for complete characterization of AC mixtures: Dynamic Modulus ($|E^*|$) test, Flow Number, FN (Repeated Load Deformation Test) and Flow Time, FT (Static Creep Test); these test are collectively known as simple performance tests (SPTs).

The advent of M-EPDG have attracted the attention of researchers, and consequently various studies were underway to characterize mixtures as per M-EPDG testing protocols. Bonaquist [2] performed $|E^*|$ testing using AMPT at three different testing temperatures i.e. 4, 20, and 35 °C and loading frequencies i.e. 10, 1, and 0.1 Hz. Results suggest that difference in $|E^*|$ values was not large for the gradations from the same source. Similarly, Flintsch et al. [3] carried out $|E^*|$ test on eleven diverse kinds of surfaces, intermediate and base course mixtures collected from various asphalt plants in Virginia. This study reveals that mixtures of the similar type of surfaces resulted in discrete measured $|E^*|$ values because of various elements e.g., kind of aggregate, bitumen percentage, reclaimed asphalt pavement (RAP) percentage. Cross et al. [4] reported that $|E^*|$ results are affected by temperature and frequency after conducting a test on 21 AC mixtures composed from various aggregate sources and binders. This study does not explicitly describe the effect of binder. Lee et al. [5] used granite as an additive in AC mixtures and performed $|E^*|$ test and results were compared to predictive equations developed in NCHRP 1-37A.

Nega et al. [6] investigated the effect of polymer modified binder on pavement performance using $|E^*|$ testing. The influence of temperature, loading frequency, and confining pressure on the dynamic characteristic of asphalt mixture was analyzed and master curves were developed. Another study determined the dynamic strength of the fiber added asphalt mixtures and developed master curves. This study concludes that all fiber modified mixtures have a higher modulus than conventional mixtures [7]. Joshua [8] conducted a research to stabilize the soil using RAP and sugarcane bagasse ash used for pavement construction in order to sustain the loads, and determined that addition of RAP (6–8%) produced maximum stiffness. Rahman & Tarefder [9] tested three common Superpave mixtures used in New Mexico using $|E^*|$ test and developed master curves to examine the effect of difference performance grade of asphalt binder on master curves, and reported that AC mixtures with stiffer binder produced higher $|E^*|$ values. A study developed $|E^*|$ prediction model using artificial neural network methodology and suggested that proposed model have significantly higher prediction ability than already developed regression models and capable of being included in M-EPDG [10].

Mohammad et al. [11] performed four tests including $|E^*|$ and FN on six plant-produced asphalt mixtures. From the results, the authors arrived at the conclusion that FN test results were almost consistent with the field performance of the mixtures under consideration. Additionally, the value of parameters calculated from permanent strain cycles curve ("*a*" and "*b*") and FN results showed a strong correlation. Uzan [12] predicted permanent deformation using M-E procedure and found out that material properties can vary with change in testing conditions. Moreover, $|E^*|$ master curves were developed using Fillers–Moonan–Tschoegl (FMT) equation and concluded that developed master curves for accumulated permanent to resilient strain ratio were partially successful. Yu & Shen [13] carried out $|E^*|$ performance testing using seven plant-produced mixtures of Washington State. After analyzing the results, they suggested the use of Hirsch Model and modified FN prediction model for conventional dense-graded asphalt mixtures for Washington State. Furthermore, it was also reported that air voids significantly affect both the $|E^*|$ and FN. Ameri et al. [14] evaluated and compared several methods used for calculating the tertiary flow of AC mixtures (conventional versus modified) and results reveal that Francken model have shown less variability compared to other methods, and recommended its use for determination of FN. Li [15] determined optimal percentage of RAP and performed testing for rutting resistance, anti-cracking, moisture susceptibility, and fatigue resistance. The performance of asphalt materials is increased with addition of RAP in the conventional mixture.

The review of past studies suggests that various state department and researchers have characterized local mixtures by developing master curves [16–20] and determining FN [21–24], but very limited studies have used full protocol of SPT for complete characterization of mixtures which is precursor (i.e., three candidate tests) for M-EPDG. Hence, this study characterizes AC mixtures by performing NCHRP's three nominated tests i.e., $|E^*|$, FN, and FT.

2. Objectives and scope

The purpose of this study was to determine the effect of binder on performance of AC mixtures by analyzing stiffness using $|E^*|$ test, permanent deformation (rutting) using repeated load (FN) and static creep (FT) tests and fatigue life using fatigue parameter derived from stiffness and viscoelastic response of a mix. This study used two binders, four mixtures (a pair of wearing course and a pair of base course) with single limestone aggregate source. The experimental design and study variables are presented in Fig. 1.

3. Methodology

The selection of materials, determination of optimum bitumen content (OBC) and performance testing are described in ensuing paragraphs.

3.1. Selection of materials and specimen preparation

Limestone aggregate used in this research study was from a single source whereas binder was of two penetration