TECHSUMMARY April 2021
State Project No. DOTLT1000002 | LTRC Project No. 14-5PF

Design and Analysis Procedures for Asphalt Mixtures Containing High RAP Contents and/or RAS

INTRODUCTION

Asphalt recycling has become an important instrument used to minimize production costs of new pavements as well as to mitigate its impacts on the environment. Some of the benefits of utilizing recycled materials include the conservation of nonrenewable natural resources such as virgin aggregates and asphalt binder, reduction in the amount of construction debris disposed of in landfills, decrease of the variability in material expenditures, and potential reduction of the overall life-cycle cost. Recycling also helps minimize greenhouse gas emissions by reducing the energy spent on extraction and processing of petroleum products and aggregates. Moreover, the increasing price of asphalt binder along with more restrictive environmental legislation has forced highway agencies and contractors to search for alternative materials and construction techniques. Such efforts are aimed at fulfilling current sustainability needs without compromising pavement quality and performance. There is, at this time, considerable emphasis on the use of reclaimed asphalt pavement (RAP) as preferred recycled material for roadway construction due to its abundance and successful prior experiences. Recycled asphalt shingles (RAS) has also become another promising recycling candidate due to their potential use in asphalt mixtures. However, to ensure successful use of RAP and/or RAS, their impact on the engineering performance of asphalt mixtures should be addressed. It is generally found that use of RAP and/or RAS in asphalt mixtures would increase stiffness and rutting resistance while attaining a satisfactory or reduced moisture susceptibility. However, the introduced oxidized asphalt binders tend to embrittle the mixture, reduce stress relaxation capability, and increase asphalt mixtures' propensity to cracking. To address this inadequacy, strategies such as the use of WMA technologies, soft base asphalt binder, and recycling agents have demonstrated the potential in accommodating the recycled asphalt binders to produce asphalt mixtures with similar performance as compared to conventional asphalt mixtures.

Conventional asphalt mixture design methodologies such as Superpave, Marshall, and Hveem are used to determine the optimum asphalt binder content by means of empirical laboratory measurements. Marshall and Hveem asphalt mixture design procedures utilize both volumetric computation and stability measurements, while Superpave requires a volumetric and densification criteria evaluation of the asphalt mixture. Superpave was implemented to address the inadequacies of the Marshall and Hveem procedures. Despite recent advancements in the design and performance evaluation of asphalt mixtures containing RAP and/or RAS, many states are cautious in their specifications to avoid premature fatigue cracking related to the use of these recycled materials. In many states, RAP is currently not allowed in highest-class asphalt mixtures. In addition, high percentages of RAP exceeding 25% are not commonly used in practice. Meanwhile, other state agencies are taking a more aggressive approach by considering increasing the allowable percentages of RAP in asphalt mixture to take full advantage of this promising technology. For instance, up to 50% RAP has been used in some asphalt mixtures, which produced an acceptable level of performance. In order to establish confidence and promote the use of RAP and/or RAS in asphalt pavement, it is necessary to assess existing, well-established performance evaluation test methods and to develop proper criteria to ensure adequate field performance of asphalt mixtures against fatigue cracking. It is also relevant for materials selection and design to understand the effect of aged asphalt binder on the chemical and rheological properties of asphalt binders.

OBJECTIVES

The objectives of this research project were to:

- Assess the impact of RAP and/or RAS asphalt binders on the chemical and rheological properties of their blends with virgin asphalt binders in relation to cracking resistance;
- Establish mechanistic test criteria that ensures acceptable pavement fatigue performance for hot- and warm-mix asphalt mixtures containing high percentages of RAP and/or RAS; and
- Conduct a comparative study of the various asphalt mixture fatigue/fracture performance test methods and develop a score card ranking system for a comprehensive comparison that provides a guideline for selection of the optimum test methods.

SCOPE

A total of 16 plant-produced loose asphalt mixtures from four participating agencies (sources): FHWA accelerated loading facility (ALF), Colorado DOT, Florida DOT, and Louisiana DOTD (hereafter referred to as ALF, CO, FL, and LA mixtures, respectively) were collected.

The ALF materials (Source 1) consisted of 10 asphalt mixtures that were sampled during construction of full-scale test lanes at McLean, Virginia in 2013. The ALF source included three composition factors, namely, recycled materials (RAP and RAS), warm-mix technologies (water foaming and Evotherm), and base asphalt binder performance grades (PG 58-28 and PG 64-22). The incorporation of RAP and/or RAS was expressed in terms of recycled binder ratio (RBR), defined as the percentage of the recycled asphalt binder

LTRC Report 639

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FUNDING:
SPR: Pooled Fund: TT-Fed

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in the total asphalt binder of the mixture. The maximum RBR used in the ALF mixtures was 40% for RAP in both hot- and warm-mix asphalt (HMA and WMA) mixtures, and 20% RAS in the HMA mixture. In addition to the loose asphalt mixtures collected, ALF full-scale fatigue experiment provided fatigue performance measurements of the test lanes. ALF fatigue loading was performed using a single wide-base tire with 63.2 kN wheel load and 689 kPa contact pressure moving at a speed of 4.9 m/s. During loading, the asphalt layer was maintained at a temperature of 20°C. Surface cracking was regularly monitored.

Two asphalt mixtures were provided by Colorado DOT, which contained 0% and 18% RAP. A softer base asphalt binder was included in the 18% RAP mixture (PG 58-28). A PG 64-22 base asphalt binder was included in the asphalt mixture with 0% RAP. Florida DOT provided two asphalt mixtures containing 17% and 36% RAP. A softer base asphalt binder was utilized in the 36% RAP mixture (PG 52-28), while the asphalt mixture with 17% RAP contained a PG 58-22 base asphalt binder. Louisiana DOTD provided two asphalt mixtures containing 18% and 26% RAP. The same base asphalt binder performance grade (PG 70-22) was used in both asphalt mixtures.

A suite of asphalt mixture and asphalt binder testing methods were employed to achieve the objectives of the study. The asphalt mixture tests consisted of simplified viscoelastic continuum damage (S-VECD), Texas overlay (OT), four-point bending beam fatigue (BF), semi-circular bend (SCB), indirect tension (IDT), and Illinois flexibility index (I-FIT) tests. The asphalt binder testing consisted of Superpave performance grading, frequency sweep, and linear amplitude sweep (LAS) for rheological characterization. Chemical evaluation consisted of saturates, aromatics, resins, and asphaltenes (SARA) fractionation, gel permeation chromatography (GPC), and Fourier transform infrared (FTIR) spectroscopy.

METHODOLOGY

Laboratory experiments were performed on asphalt mixtures and asphalt binders with various compositions according to the latest test methods. For each test method, a thorough literature review was conducted on the underlying principle and theory to identify and/or develop test parameters that best suited the objectives of the study. With the obtained parameters, effects of mixture composition factors on cracking performance were assessed. Mixture composition factors consisted of recycled materials, warm-mix technologies, and base asphalt binder performance grade (PG) to which the sensitivity of the evaluation parameters was investigated and compared. Field performance measurements from material source 1 (ALF) was employed to further evaluate the competence of each test parameter in predicting/correlating with the field performance. Asphalt mixture performance parameters were correlated with the measured field fatigue data, and based on the resulting relationships, a design criterion was established for each parameter. Finally, all the asphalt mixture performance tests were compared in a total of 14 aspects as included in a score card ranking system.

CONCLUSIONS

This study assessed the cracking resistance of 16 plant-produced asphalt mixtures with different composition factors using six laboratory fatigue/fracture performance tests. These asphalt mixtures were evaluated with respect to asphalt mixture discriminating potential of each test method parameter according to the material composition. Based on the findings, the following conclusions were drawn:

(1) With respect to the asphalt mixture cracking resistance:

- In general, asphalt mixtures containing increased RAP content or RAS exhibited reduced cracking resistance. All test methods evaluation parameters considered, except Texas overlay CCPR parameter, were able to capture the reduced crack resistance due to increased RAP contents.
- Asphalt mixture with 20% RAS was less crack resistant than those with 20% RAP as RAS asphalt binder was more oxidatively aged than that from the RAP asphalt binder.
- In general, the two WMA technologies (water foaming and Evotherm) produced asphalt mixtures that were similar in cracking performance compared to their HMA mixtures counterpart. Different asphalt mixture evaluation parameters yielded different ranking results for the two WMA processes as compared to each other and to the HMA process. Thus, results were not conclusive.
- Use of soft base asphalt binder was found to be more effective in asphalt mixtures containing high RAP than those with RAS in improving asphalt mixtures' cracking resistance. All asphalt mixture evaluation test method parameters consistently ranked this observation, except Nf,BF (BF), FI (I-FIT), and CPR (TO).

(2) With respect to the rheological and chemical properties of extracted asphalt binders in relation to cracking resistance:

- As expected, asphalt binders extracted from asphalt mixtures containing higher RAP contents or RAS yielded higher values of high temperature performance grade (PG), frequency sweep rheological index R, asphaltenes fraction, high molecular weight (HMW) component, FTIR carbonyl index, lower linear amplitude sweep ALAS, and more negative ΔTc. These observations indicate lower cracking resistance of asphalt binders evaluated within the scope of this study. Rheological and chemical parameters provided reasonable trends with an increase in asphalt mixture RAP content. Proposed immediate indicator of fatigue resistance, ALAS parameter, was able to properly rank asphalt binders extracted from asphalt mixtures containing 20% RAP and 20% RAS.
- The two WMA technologies did not yield conclusive results in terms of rheological and chemical properties in the extracted asphalt binders as compared to each other and to asphalt binders extracted from their HMA mixtures counterpart. Various test parameters evaluated provided different ranking results.
- The use of soft base asphalt binder was more effective in asphalt mixtures containing high RAP than those with RAS in improving asphalt binders' cracking resistance. All rheological and chemical parameters obtained for extracted asphalt binders consistently led to this conclusion.

(3) With respect to the relationship between asphalt mixture parameters, ALF fatigue performance, and preliminary test criteria:

- BF, TO, S-VECD, and SCB tests exhibited similar ranking to ALF fatigue performance. Further, TO, S-VECD, and SCB tests were recommended as routine tests to be used for performance evaluation of the intermediate-temperature cracking resistance.

(4) With respect to the score ranking among the asphalt mixture test methods:

- A total of 14 factors covering aspects of testing, analysis, and correlation with field performance were evaluated for each of the six asphalt mixture test methods. The ranking results from best to the least desired were SCB, I-FIT, OT, IDT, BF, and S-VECD.

RECOMMENDATIONS

Findings in this study are expected to assist state agencies and practitioners in selecting the laboratory performance test methods to address cracking resistance of asphalt mixtures. Future work may include evaluating the predicting/correlating capability of laboratory methodologies using filed performance data from pavements subjected to actual traffic and environmental conditions.