LOUISIANA TRANSPORTATION RESEARCH CENTER

Technical Summary

LTRC Report 710

SIO No. DOTLT1000390
LTRC Project No. 21-1B

Development of a Cyclic Semi-Circular Bend Test to Evaluate Asphalt Mixture Crack Propagation Properties at Intermediate Temperature

Introduction

Ensuring adequate crack resistance in asphalt mixtures is critical for asphalt pavement performance. The Louisiana Department of Transportation and Development (DOTD) currently requires the use of the Semi-Circular Bend (SCB) test as part of its balanced mix design framework for paving asphalt mixtures. The SCB test is conducted at 25°C following ASTM D8044 to obtain the critical strain energy release rate (J_c), an indicator of the crack resistance of asphalt mixtures. The DOTD specification stipulates a minimum J_c value of 0.6 kJ/m^2 for Level 2 mixtures and 0.5 kJ/m^2 for Level 1 mixtures.

While the SCB test effectively differentiates asphalt mixtures based on fracture resistance, its suitability for characterizing fatigue cracking resistance, as characterized by the J_c parameter, has been questioned. Fatigue tests under cyclic loading can better simulate the damage accumulation in asphalt pavement compared to fracture tests under monotonic loading. It is noted that the crack propagation generated in cyclic SCB tests is often modeled using Paris' Law to characterize the fatigue properties of asphalt materials.

The process of determining the Paris' Law coefficients in a crack propagation test, such as a cyclic SCB test, requires the measurement of the crack length. However, the crack length cannot be measured directly using conventional sensors, such as strain gauges, extensometers, or linear variable displacement transducers. Therefore, Digital Image Correlation (DIC) has been introduced to overcome this limitation. DIC is a non-contact optical-based technique used to measure the full-field 2D or 3D displacement and strain on the surface of a test specimen throughout a mechanical test. Researchers have employed the DIC technique in asphalt mixture testing to investigate crack propagation in asphalt mixtures by digitizing light intensity and measuring changes between deformed and undeformed images. DIC provides an innovative approach to investigating cracking phenomena and fracture characteristics in asphalt mixtures. Thus, there is a need to employ DIC for crack propagation characterization and to investigate the optimal testing parameters of the cyclic SCB test.

Objective

The objective of this study was to develop a standard cyclic SCB test coupled with a DIC technique for characterizing the crack resistance of asphalt mixtures at intermediate temperatures. The specific objectives of the study included:

- Set up the DIC configurations for the optimization of deformation and crack propagation measurements of samples during cyclic SCB testing;
- Develop a standard cyclic SCB test method for characterizing the fatigue cracking resistance of asphalt mixtures; and
- Investigate the fatigue model based on the Paris' Law coefficients for predicting the fatigue life of asphalt pavements.

Scope & Methodolology

The DIC system was acquired and set up for the optimization of deformation and crack propagation measurements of mixture specimens during cyclic SCB testing; see Figure 1. A plant-mixed asphalt mixture was selected for optimizing the parameters of the cyclic SCB test. Various specimen notch depths (i.e., 15, 20, and 25 mm) and loading frequencies (i.e., 1, 5, and 10 Hz) were investigated to find an optimal combination that yields reasonable results with the lowest test variability. Parameters,

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Funding
SPR: TT-Fed/TT-Reg - 5

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namely the number of cycles to failure (N_f) and Paris' Law model coefficients (n and $Log(A)$) were used for crack characterization. A sensitivity analysis was designed and conducted to further investigate whether the developed test protocol was effective in differentiating asphalt mixtures with different fatigue cracking resistances. Number of cycles to failure (N_f) and Paris' Law coefficients were used to evaluate asphalt mixture cracking resistance. Three 12.5 mm limestone asphalt mixtures with expected distinct cracking resistance performances were prepared and evaluated using the proposed cyclic SCB test. An innovative method was developed to directly measure the crack length during the cyclic SCB test, and the measured crack length curve was used to determine the coefficients of the Paris' Law model. The Paris' Law coefficients obtained from the cyclic SCB test were further used in the preliminary application of the pavement fatigue model for the subsequent prediction of the fatigue life of asphalt pavements.

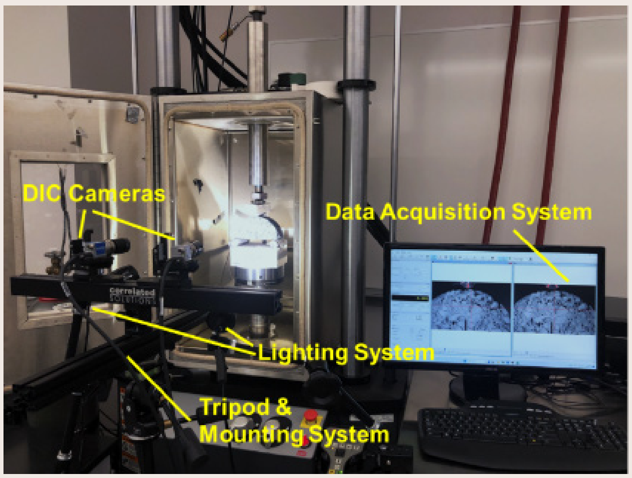

Figure 1. DIC equipment

Conclusions

The following conclusions are drawn based on the results of this research:

- Results from the cyclic SCB test demonstrated good repeatability, as indicated by the low variance observed. Considering both test variability and practical considerations, a notch depth of 25 mm and a loading frequency of 10 Hz are recommended as the optimal parameters for conducting cyclic SCB tests at intermediate temperatures.
- The Paris' Law coefficients obtained from the cyclic SCB tests showed relatively lower variance values than N_f. Based on statistical analysis, N_f was found to be dependent on the notch depth and loading frequency parameters of the cyclic SCB test. N_f increased with decreasing notch depth and increasing loading frequency, whereas the Paris' Law coefficients are independent of notch depth or loading frequency, suggesting that the Paris' Law coefficients represent fundamental material properties. The Paris law coefficient *n* exhibited a strong correlation with the anticipated ranking of fatigue cracking resistance of the mixtures considered,
- The range of stress intensity factor values plays a crucial role in evaluating the cracking resistance of asphalt mixtures through fracture testing. While materials with high fracture strength, such as RAP-blended HMA, demonstrate lower crack propagation rates at low stress intensity factor values, they can become significantly more susceptible to cracking at higher stress intensity factor values. These higher values are particularly relevant to the long-term performance of asphalt pavements,
- This study introduced an innovative method that leveraged digital image correlation (DIC) confidence margins, denoted as *sigma*, to directly and efficiently measure crack propagation during cyclic SCB testing. This approach overcame key limitations of traditional methods, which relied on indirect crack estimation and manual labeling during analysis, streamlining the process while improving accuracy.
- Fracture mechanics-based Paris' Law model demonstrated superior sensitivity to variations in mixture cracking performance compared to the mechanistic-empirical Pavement ME fatigue model. To address this, a modified Pavement ME fatigue model was developed by incorporating the Paris' Law coefficients derived from cyclic SCB tests. This adaptation demonstrated enhanced predictive accuracy for pavement fatigue life compared to the original Pavement ME framework.

Recommendations

To advance the developed cyclic SCB test protocol integrated with Digital Image Correlation (DIC), the following steps are recommended:

- **Field Validation Using Pavement Cores:** Collect asphalt pavement cores from in-service roads with documented fatigue cracking performance and characterize them using the cyclic SCB test. This will validate the protocol's ability to differentiate field-validated fatigue resistance levels using mixtures of known performance rankings. Further, leverage DIC technology to quantify crack propagation parameters during cyclic SCB testing of cores. This will allow linking of DIC-derived parameters to fatigue life.
- **Fatigue Model Development and Calibration:** Expand the modified Pavement ME fatigue model by integrating cyclic SCB-derived Paris' Law coefficients and field-calibrated adjustment factors, building on frameworks that connect laboratory fatigue parameters to mechanistic-empirical predictions. This will allow the validation of the model using independent datasets from diverse pavement sections, ensuring robustness across mixture types and environmental conditions.