Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Fatigue Performance

Work Done This Quarter

Investigation of the applicability and validity of the linear amplitude sweep (LAS) as an accelerated binder fatigue test continued. Analysis of binder and mixture fatigue data was completed using the framework of viscoelastic continuum damage (VECD). LAS results and strain-controlled time sweeps were both performed for comparison and verification purposes. Time sweeps were analyzed using VECD in the same manner as the LAS.

Fatigue data (i.e., LAS and time sweep at 5% and 7% strain levels) of binders from two Transportation Pooled Fund studies (TPF-5(080) and TPF-5(146)) were analyzed this quarter. Binders from the TPF-5(080) study include: 64-28 unmodified, 64-28 styrene-butadiene-styrene (SBS) polymer-modified, 58-34 terpolymer, and 64-34 terpolymer. The binders from the TPF-5(146) study are described in the previous quarterly report. Note that all binders were rolling thin film oven (RTFO)-aged and that the TPF-5(080) binders were tested at an iso-stiffness condition. The iso-stiffness temperature was defined as the temperature where $|G^*|\sin\delta$ is equal to 5000 kPa as determined by master curve generation from frequency sweep test results. The TPF-5(146) binders were tested at 20 °C to allow for comparison with fatigue mixture testing conducted at the University of Massachusetts, Dartmouth.

As discussed in previous quarterly reports, the use of the VECD framework for both the time and amplitude sweep tests allows for the estimation of fatigue life ($N_f$). $N_f$ is calculated based on the parameters $A$ and $B$ and the strain level of the binder ($\gamma_{\text{max}}$) in the pavement structure, as shown in equations F2e.1 and F2e.2:

$$A = \frac{f(D_f)^k}{k\left[\frac{\pi^{\frac{1}{2}}}{|G^*|^{\frac{1}{2}}} C_1 C_2\right]^\alpha} |G^*|^{-\alpha}$$  \hspace{1cm} (F2e.1)

$$B = -2\alpha.$$  \hspace{1cm} (F2e.2)

The relationship between time sweep results and LAS test results was investigated by comparing the parameter $A$ and the number of cycles to failure ($N_f$) obtained from both procedures. Results from the ALF binders discussed in the previous quarterly report were also included in the comparison. A plot comparing the parameter $A$ determined from both the LAS and time sweep conducted at 5% strain is shown in figure F2e.1.
There is a statistically significant correlation between the LAS “A” and time sweep “A” obtained from the ALF and TPF-5(080) binders. There is also a strong correlation between the LAS and time sweep "A" for the TPF-5(146) binders, but the relationship differs from the ALF and TPF-5(080) binders. It is also noteworthy that the best correlation between time sweep and LAS results is obtained when the frequency sweep is used to determine the parameter $\alpha$ used in VECR analysis.

The relationship between the $N_f$ predicted using results from both the LAS and time sweeps conducted at 5% strain for the TPF-5(080) and ALF binders was investigated. A strain level (i.e., $\gamma_{\text{max}}$) of 3% was selected for $N_f$ prediction. The correlation between the $N_f$ predicted using the LAS and time sweep is shown in figure F2e.2. There was a strong correlation ($R^2=0.97$) found between the $N_f$ predicted using LAS and time sweep.
In addition to comparing fatigue performance of binders from LAS and time sweep test, a comparison between binder and mixture results was carried out for the TPF-5(146) binders. Fatigue mixture testing and analyses conducted by Professor Mogawer at the University of Massachusetts, Dartmouth, and Professor Kutay at Michigan State University were used in the comparison. The mixtures were tested using uniaxial push-pull and the experimental data was analyzed based on VECD approach described in Kutay et al. (2008). As shown in table F2e.1, the ranking of the binders based on the LAS parameter A and the ranking of the corresponding mixtures based on the number of cycles to a 50% reduction in stiffness at a strain level of 350 με is similar. This comparison with mixture performance shows the promising potential of the amplitude sweep procedure for fatigue characterization of binders.

Table F2e.1. Comparison between LAS and mixture uniaxial push-pull VECD results (1 = most fatigue resistant; 5 = least fatigue resistant).

<table>
<thead>
<tr>
<th>Binder</th>
<th>LAS - A</th>
<th>5%TS - A</th>
<th>7%TS - A</th>
<th>VECD - 75με</th>
<th>VECD - 175με</th>
<th>VECD - 350με</th>
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<tbody>
<tr>
<td>PG64-34</td>
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<td>5</td>
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<td>4</td>
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</tr>
</tbody>
</table>

PPA = polyphosphoric acid. TPF = Transportation Pooled Fund.

Significant Results

Based on the results obtained in this quarter, it appears that there is a good correlation between the LAS and time sweep model parameters using VECD. Similar rankings observed for the fatigue performance of binders using LAS and mixtures using uniaxial push-pull indicate the potential of the proposed accelerated procedure. A paper discussing details of the implementation of the LAS has been submitted to Road Materials Pavement and Design.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The research team will continue implementation and verification of the LAS test by testing the remaining LTPP binders (eight completed and 22 to be tested). The research team will also focus its efforts on completing the following tasks:
• Further investigate the relationship between LAS results and asphalt mixture testing (uniaxial push-pull) results by testing typical mixtures prepared with locally available aggregates.

• Compare the Binder Yield Energy Test (BYET) at intermediate temperatures and the percent recovery from the Multiple Stress Creep and Recovery (MSCR) test at high temperatures.

• Develop a method to determine damage model coefficients ($C_0$, $C_1$ and $C_2$) without using solver in Excel (e.g., using closed-form solutions for the least squares problem).

• Send a set of binders from which LAS data is available to Turner-Fairbank Highway Research Center (TFHRC) for Double-Edge Notched Tension (DENT) testing to calculate the equivalent work of fracture (EWF) and its relation to fatigue performance.

• Perform a sensitivity analysis of all the parameters involved in the VECD calculation of the damage curves in LAS procedure.

Cited References