Advanced Characterization Testing of RAP Mixtures Designed and Produced Using a "RAP Binder Contribution Percentage"

Submitted to:

New York State Department of Transportation (NYSDOT)
Bureau of Materials
50 Wolf Road
Albany, NY 12232

Conducted by:

Thomas Bennert, Ph.D.
The Rutgers Asphalt/Pavement Laboratory (RAPL)
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University
Department of Civil and Environmental Engineering
623 Bowser Road
Piscataway, NJ 08854

AASHTO R18

Rutgers Asphalt/Pavement Laboratory (RAPL) is an accredited laboratory of the AASHTO AMRL Program

INTRODUCTION

The scope of the study was to evaluate the mechanical properties of an asphalt mixture designed and produced using a "RAP Binder Contribution Percentage". The concept of this methodology is that it is hypothesized that during production, the highly oxidized RAP binder does not completely "melt" off of the RAP aggregate, thereby limiting the amount of blending that occurs between the virgin and RAP binders. Conceptually, if there remains RAP binder on the RAP aggregate, the virgin binder will coat both the virgin aggregate, as well as the RAP particles. If this does occur, the resultant mixture will be under-asphalted and may be subject to premature cracking/durability issues.

In order to evaluate the potential of implementing the "RAP Binder Contribution Percentage", the NYSDOT Materials Bureau conducted an experiment using a single asphalt mixture, designed and plant produced using three different RAP binder contributions; 100%, 75%, and 50%. In order to compensate for the reduced RAP binder contribution, the asphalt plant was required to use additional virgin asphalt binder. This resulted in the following total asphalt (virgin + RAP binder) contents in the mix:

- 100% RAP Binder Contribution = 5.3% total asphalt binder
- 75% RAP Binder Contribution = 5.55% total asphalt binder
- 50% RAP Binder Contribution = 5.8% total asphalt binder

Laboratory testing consisted of asphalt mixture performance tests to evaluate the stiffness, rutting potential and fatigue cracking potential mixtures. The laboratory testing included;

- Dynamic Modulus (AASHTO TP79);
- Rutting Evaluation
    - Asphalt Mixture Performance Tester (AMPT) Repeated Load Flow Number (AASHTO TP79)
- Fatigue Cracking Potential
    - Flexural Beam Fatigue (AASHTO T321)
    - Overlay Tester (TxDOT TEX-248F)

All laboratory testing was conducted on specimens prepared from collected loose mix that was reheated to a representative field compaction temperature of 290 to 300^{o}F and then compacted into test specimens.

Dynamic Modulus (AASHTO TP79)

Dynamic modulus and phase angle data were measured and collected in uniaxial compression using the Simple Performance Tester (SPT) following the method outlined in AASHTO TP79, *Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)* (Figure 1). The data was collected at three temperatures; 4, 20, and 35^{o}C using loading frequencies of 25, 10, 5, 1, 0.5, 0.1, and 0.01 Hz.

Figure 1 – Photo of the Asphalt Mixture Performance Tester (AMPT)

The dynamic modulus of asphalt mixtures provides an assessment of the overall stiffness properties of the asphalt mixture. Asphalt mixtures with higher stiffness' at elevated temperatures will be more rut resistant at higher temperatures. Meanwhile, asphalt mixtures with lower stiffness properties at intermediate and lower temperatures will generally be less likely to result in intermediate and low temperature cracking.

The collected modulus values of the varying temperatures and loading frequencies were used to develop Dynamic Modulus master stiffness curves and temperature shift factors using numerical optimization of Equations 1 and 2. The reference temperature used for the generation of the master curves and the shift factors was 20°C.

$$\log\left|E^*\right| = \delta + \frac{(Max - \delta)}{1 + e^{\beta + \gamma\left\{\log\omega + \frac{\Delta E_a}{19.14714}\left[\left(\frac{1}{T}\right) - \left(\frac{1}{T_r}\right)\right]\right\}}} \tag{1}$$

where:

$|E^*|$ = dynamic modulus, psi
ω_r = reduced frequency, Hz
Max = limiting maximum modulus, psi
δ, β, and γ = fitting parameters

$$\log[a(T)] = \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \tag{2}$$

where:

a(T) = shift factor at temperature T
T_r = reference temperature, °K
T = test temperature, °K
ΔE_a = activation energy (treated as a fitting parameter)

Figure 2 shows the master stiffness curves of the three different RAP binder contribution mixtures. The master stiffness curves for the three mixtures show that even though the total asphalt binder contents varied, the resultant mixture stiffness properties of the asphalt mixtures were essentially the same.

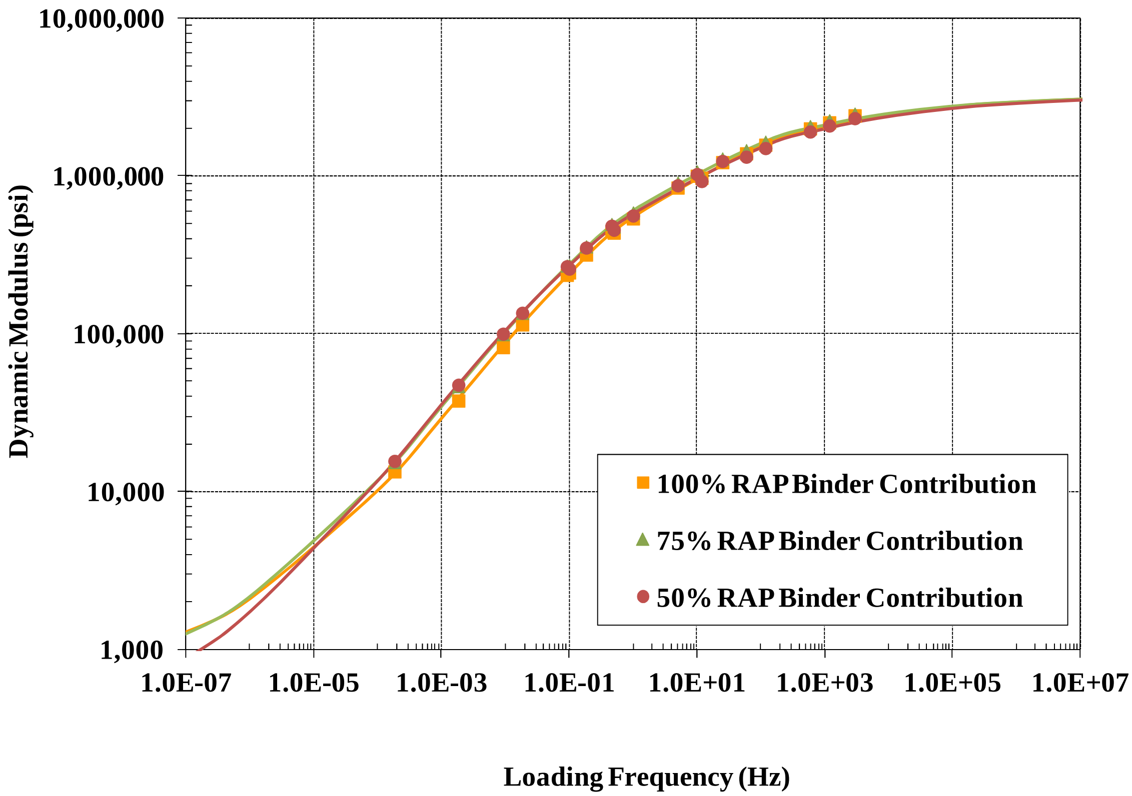

Figure 2 – Master Stiffness Curves of RAP Binder Contribution Mixes

Rutting Potential - Repeated Load Flow Number (AASHTO TP79)

Repeated Load permanent deformation testing was measured and collected in uniaxial compression using the Simple Performance Tester (SPT) following the method outlined in AASHTO TP79, *Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT).* The unconfined repeated load tests were conducted with a deviatoric stress of 600 kPa and a test temperature of 50^{o}C, which corresponds to approximately New York's average 50% reliability high pavement temperature at a depth of 25 mm according the LTPPBind 3.1 software. These testing parameters (temperature and applied stress) conform to the recommendations currently proposed in NCHRP Project 9-33, *A Mix Design Manual for Hot Mix Asphalt*. Testing was conducted until a permanent vertical strain of 5% or 10,000 cycles was obtained.

The resultant test results are shown in Figure 3 and Table 1. The resultant indicate that all three mixtures performed in a very similar manner, as noted by the average values and error bars (shown in Figure 3), which represents the standard deviation above and below the average.

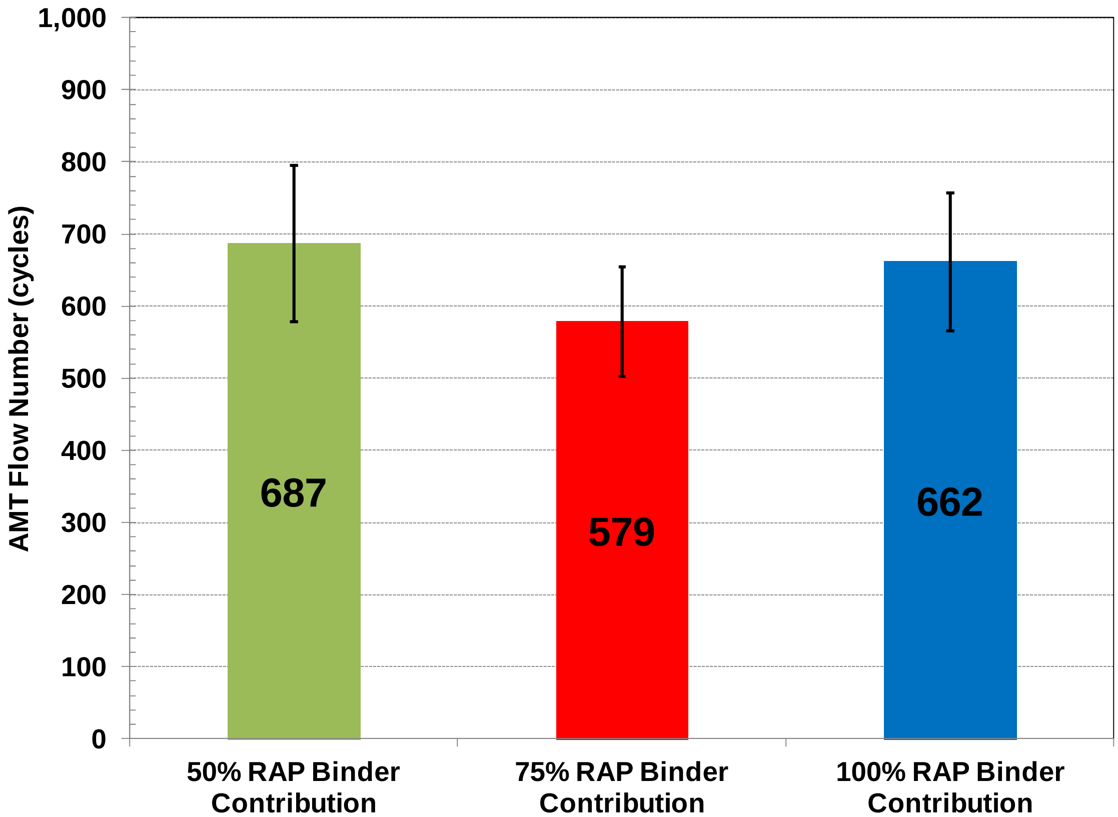

Figure 3 – AMPT Flow Number Test Results

Table 1 – AMPT Flow Number Results

Mix Type	Sample ID	Flow Number (cycles)	Cycles to Achieve 5% Strain
50% RAP Binder Credit (Total AC = 5.8%)	1	809	1,825
	2	604	1,431
	3	649	1,431
	Average	***687***	***1,562***
75% RAP Binder Credit (Total AC = 5.6%)	1	664	1,690
	2	519	1,301
	3	554	1,454
	Average	***579***	***1,482***
100% RAP Binder Credit (Total AC = 5.3%)	1	734	1,798
	2	699	1,636
	3	554	1,297
	Average	***662***	***1,577***

A statistical analysis was conducted using a Student's t-test analysis (two sample assuming equal or unequal variances) using the Data Analysis tool in Excel. The analysis was utilized to determine if the samples were statistically equal or statistically not equal among the common test results and parameters. A 95 percent confidence interval was chosen for the analysis. The statistical analysis showed that all three mixtures were statistically equal to one another at a 95% confidence level.

Table 2 provides recommendations for minimum Flow Number values based on the anticipated traffic level of the pavement the mixture is intended to be placed on. According to the Flow Number values measured during this study, it would appear that the mixtures would be highly rut resistant, with all three mixtures essentially meeting the >30 million ESAL traffic level (i.e. – should be noted that the minimum for >30 million ESAL's is 580 cycles, while the 75% RAP Binder Contribution mixture achieved an average of 579 cycles).

Table 2 – Minimum Flow Number Requirements for Various Traffic (ESAL) Levels (after Advanced Asphalt Technologies, 2011)

Traffic Level *Million ESALs*	**Minimum Flow Value** *Cycles*
<3	---
3 to < 10	200
10 to < 30	320
> 30	580

Resistance to Fatigue Cracking

The fatigue cracking properties of the mixtures were evaluated using two test procedures; 1) Flexural Beam Fatigue (AASHTO T321) and 2) the Overlay Tester (TxDOT TEX-248F). The Flexural Beam Fatigue test evaluates the crack initiation properties of the asphalt mixture in flexural mode. Mixtures that have better flexural fatigue properties will last longer "flexing" due to applied traffic before cracking will initiate. Meanwhile, the Overlay Tester measures the mixture's resistance to crack propagation. Mixtures that perform better in the Overlay Tester should be able to better resist the crack propagating through the asphalt mixture, similar to a crack initiating at the bottom of an asphalt pavement and propagating to the surface of the pavement.

Flexural Beam Fatigue (AASHTO T321)

Fatigue testing was conducted using the Flexural Beam Fatigue test procedure outline in AASHTO T321, *Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending* (Figure 4). The applied tensile strain levels used for the fatigue evaluation were; 300, 500, 600, and 700 micro-strains.

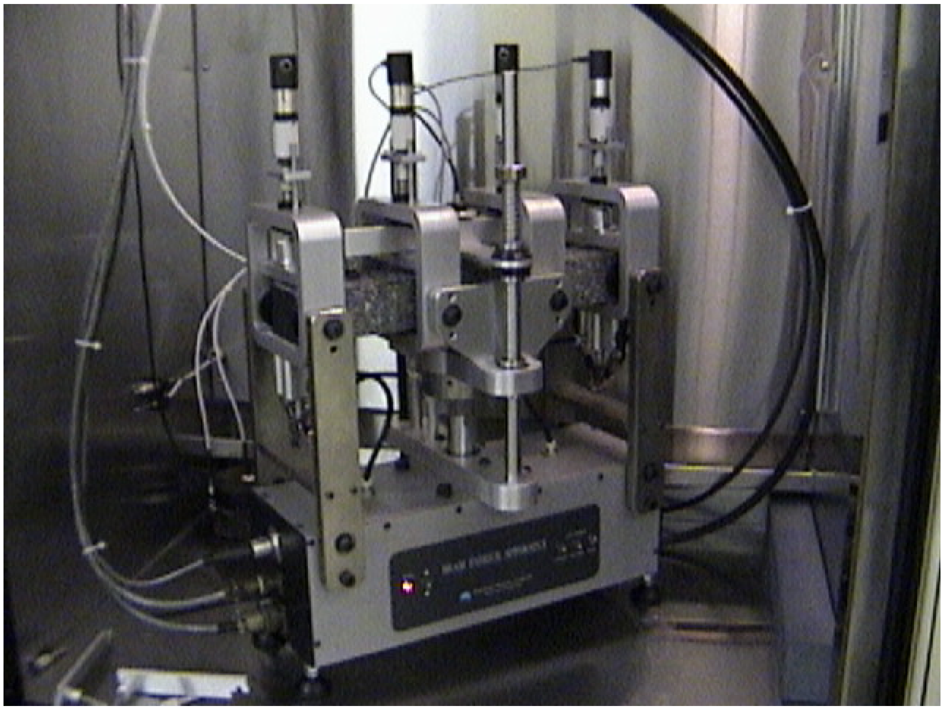

Figure 4 – Flexural Beam Fatigue Apparatus

Samples used for the Flexural Beam Fatigue test were compacted using a vibratory compactor designed to compact brick samples of 400 mm in length, 150 mm in width, and 100 mm in height. After the compaction and aging was complete, the samples were trimmed to within the recommended dimensions and tolerances specified under AASHTO T321. The test conditions utilized were those recommended by AASHTO T321 and were as follows:

- Test temperature = 15^{o}C;
- Haversine waveform;
- Strain-controlled mode of loading; and
- Loading frequency = 10 Hz;

The test results from the Flexural Fatigue testing are shown in Figure 5. The test results show that mixture performing the worst in the flexural fatigue mode was the 100% RAP Binder Contribution. This mixture resulted in the lowest number of cycles to initiate fatigue cracking at all applied tensile strains evaluated. Meanwhile, the 75% and 50% RAP contribution mixes performed in a similar manner at the lower strain levels (less than 500 micro-strains). However, at the higher strain levels, the 50% RAP contribution mixture performed better than the 75% RAP contribution mix (i.e. – more applied loading cycles until fatigue crack initiation).

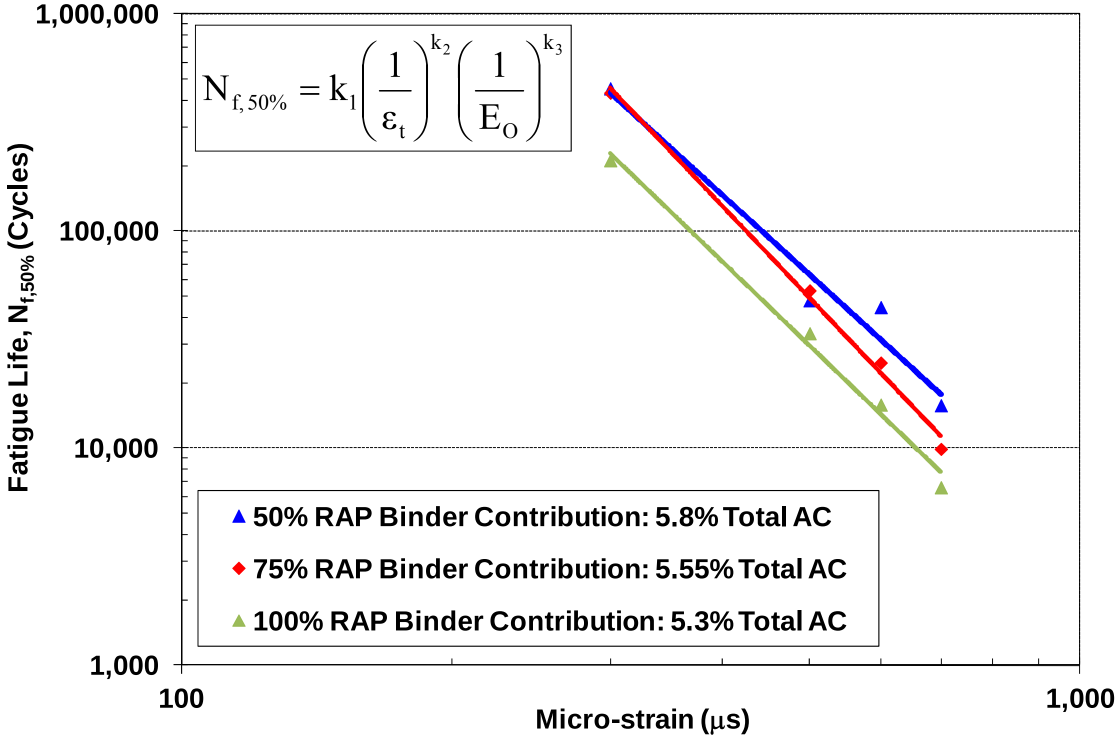

Figure 5 – Flexural Fatigue Results of the RAP Binder Contribution Mixes

Overlay Tester (TxDOT TEX-248F)

The Overlay Tester, described by Zhou and Scullion (2007), has shown to provide an excellent correlation to field cracking for both composite pavements (Zhou and Scullion, 2007; Bennert et al., 2009) as well as flexible pavements (Zhou et al., 2007). Figure 6 shows a picture of the Overlay Tester used in this study. Sample preparation and test parameters used in this study followed that of TxDOt TEX-248F, *Overlay Test for Determining Crack Resistance of HMA*. These included:

- 25°C (77°F) test temperature;
- Opening width of 0.025 inches;
- Cycle time of 10 seconds (5 seconds loading, 5 seconds unloading); and
- Specimen failure defined as 93% reduction in Initial Load.

The test results for the Overlay Tester are shown in Figure 7 and Table 3. The trend of the Overlay Tester results are similar to that of the flexural beam fatigue test, where the worst performing mixture, with respect to fatigue cracking in the Overlay Tester, was the 100% RAP contribution mixture. On average, the best performing mixture in the Overlay Tester was the 50% RAP contribution mixture.

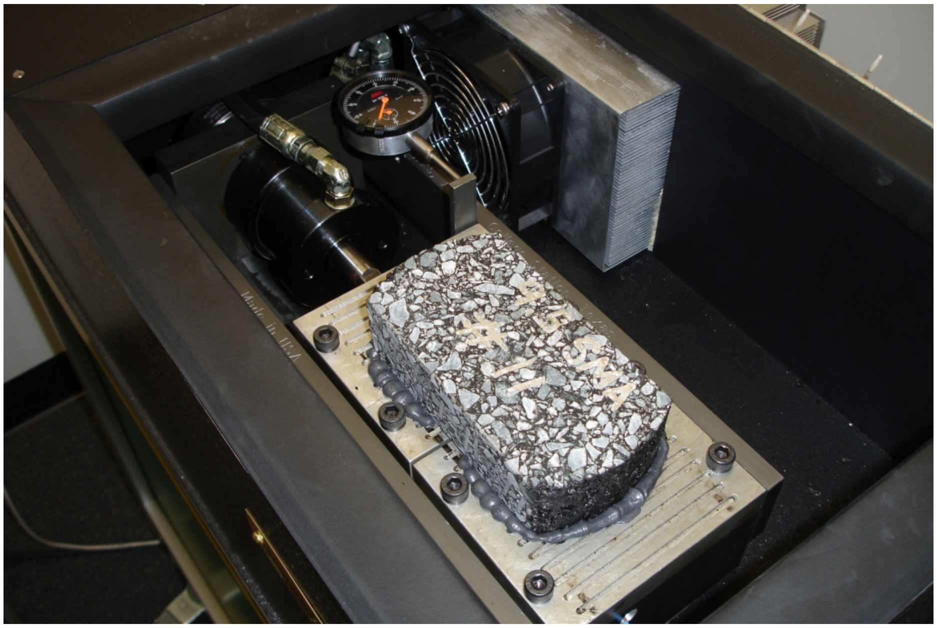

Figure 6 – Picture of the Overlay Tester (Chamber Door Open)

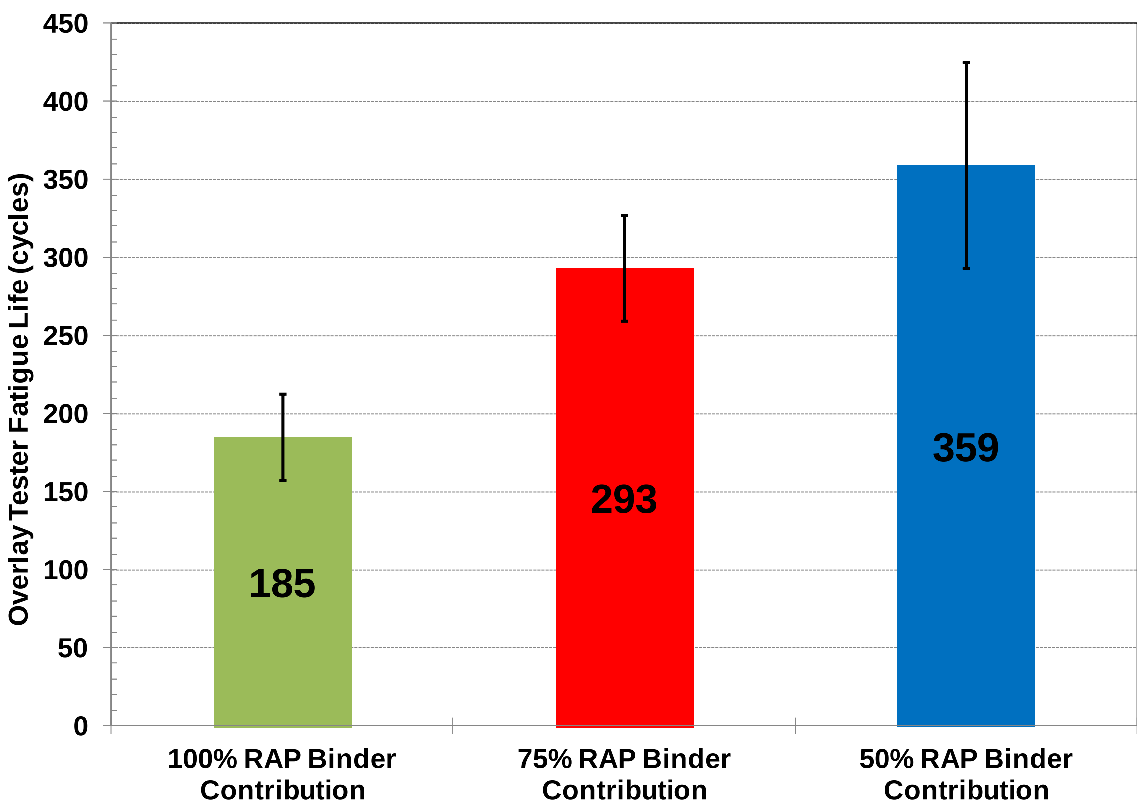

Figure 7 – Overlay Tester Results for RAP Contribution Mixtures

Table 3 – Overlay Tester Results for RAP Contribution Mixtures

100% RAP Binder Contribution				
Sample ID	Air Voids (%)	Temp (F)	Displacement (inches)	Fatigue Life (cycles)
#1	7	77	0.025	163
#2	5.6			176
#3	5.8			216
Average	**6.1**			**185**
75% RAP Binder Contribution				
Sample ID	Air Voids (%)	Temp (F)	Displacement (inches)	Fatigue Life (cycles)
#1	5.6	77	0.025	273
#2	6.2			332
#3	5.8			274
Average	**5.9**			**293**
50% RAP Binder Contribution				
Sample ID	Air Voids (%)	Temp (F)	Displacement (inches)	Fatigue Life (cycles)
#1	6.5	77	0.025	284
#2	5.9			385
#3	6.2			408
Average	**6.2**			**359**

The Overlay Tester results were also evaluated using the student t-Test described earlier to determine if the test results were statistically equal at a 95% confidence interval. The results of the statistical analysis indicated that the 100% RAP contribution mixture was **NOT** statistically equal to either the 75% or 50% RAP contribution mixture. However, the student t-Test did indicate that the Overlay Tester results between the 75% and the 50% RAP contribution were statistically equal to one another, even though on average the 50% RAP contribution mixture resulted in a higher number of cycles to failure.

SUMMARY OF TEST RESULTS

The performance testing conducted on the three RAP binder contribution mixtures indicated:

- All three mixtures resulted in similar stiffness properties over the temperature and loading frequencies evaluated in this study;

- AMPT Flow Number results showed that all three of the mixtures were highly rut resistant. The Flow Number values of all three mixtures were also found to be statistically equal to one another at a 95% confidence interval.
- The fatigue cracking testing of the mixtures indicated;
  - In the flexural fatigue mode (crack initiation), the 100% RAP contribution mixture performed the worst, resulting in the lowest number of cycles to initiate fatigue cracking at all strain levels evaluated. Meanwhile, the 75% and 50% RAP binder contribution mixtures had similar flexural fatigue properties at the lower tensile strain levels (< 500 micro-strains). However, at the higher strain levels (> 500 micro-strains), the 50% RAP binder contribution mixture resulted in the best flexural fatigue performance of the three mixtures tested.
  - In the Overlay Tester (crack propagation), the 100% RAP binder contribution mixture once again performed the worst, resulting in the lowest number of cycles to failure. The 100% RAP contribution mixture was also found to be **NOT** statistically equal at a 95% confidence interval to the 75% and 50% RAP binder contribution mixtures. On average, the 50% RAP binder contribution mixture resulted in the highest number of cycles to failure in the Overlay Tester. However, the results of the 50% and 75% RAP binder contribution mixtures were found to be statistically equal at a 95% confidence interval.