PANYNJ-RU9247

Laboratory Evaluation of Vestoplast Modified Hot Mix Asphalt (HMA)

Final Report
December 2007

Submitted by
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In cooperation with

The Port Authority of NY/NJ,
Materials Engineering Division
And
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

The scope of the work encompassed evaluating the affect of Vestoplast on the performance of hot mix asphalt. The Vestoplast was added to a PANYNJ FAA #3 asphalt mixture with a PG64-22 asphalt binder. Two baseline mixes were also evaluated for comparisons; 1) FAA #3 with a PG64-22 and 2) FAA #3 with a PG76-22. The FAA #3 with a PG64-22 was the base mix used prior to the addition of the Vestoplast. This allows for a comparison of the increase or decrease in performance simply due to the addition of the Vestoplast additive. The FAA #3 with PG76-22 would be the performance striving to achieve due to the Vestoplast modification.

17. Key Words Flexural Beam Fatigue Testing, Permanent Deformation, Dynamic Modulus	18. Distribution Statement

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Introduction

The scope of the work encompassed evaluating the affect of Vestoplast on the performance of hot mix asphalt. The Vestoplast was added to a PANYNJ FAA #3 asphalt mixture with a PG64-22 asphalt binder. Two baseline mixes were also evaluated for comparisons; 1) FAA #3 with a PG64-22 and 2) FAA #3 with a PG76-22. The FAA #3 with a PG64-22 was the base mix used prior to the addition of the Vestoplast. This allows for a comparison of the increase or decrease in performance simply due to the addition of the Vestoplast additive. The FAA #3 with PG76-22 would be the performance striving to achieve due to the Vestoplast modification. Mixture design information, conducted by the PANYNJ, can be found in the Appendix.

Three different characterization tests were used to evaluate the mixtures performance;

1. Dynamic Modulus (AASHTO TP62-07) – used to evaluate the stiffness properties over a wide range of temperatures and loading frequencies. The different mixes were tested in triplicate and averaged for comparison purposes.
2. Flexural Beam Fatigue (AASHTO T321) – used to evaluate the flexural fatigue properties of hot mix asphalt due to traffic loading. Five test specimens for each mix was tested at a different tensile strain to develop a relationship between tensile strain and fatigue life
3. Repeated Load (NCHRP Report 465) – used to evaluate the resistance to permanent deformation due to cyclic loading at elevated temperatures. The different mixes were tested in triplicate and average for comparison purposes.

Repeated Load Test Results

All test samples were conditioned to 140^{o}F. A dummy sample, instrumented with internal and skin thermocouples, was used to ensure the test sample reaches the required test temperature. Once temperature was achieved, the samples were cyclically loaded using a haversine waveform. A deviatoric cyclic stress of 25 psi was applied for a duration of 0.1 seconds and then followed by a 0.9 second rest period.

The Flow Number and Accumulated Permanent Deformation were used to compare the relative performance of the different mixtures. These parameters are explained below.

1. Flow Number (F_N) – The Flow Number is the number of applied loads required to cause the sample to achieve tertiary flow, or mixture failure (the point where the permanent deformation curve starts to curve

upward). The larger the flow number, the more resistant the HMA mix is to permanent deformation; and

2. Accumulated Permanent Deformation at 1,000 and 10,000 Loading Cycles (ε_P (%) @ N = 1,000) – The accumulated permanent deformation is simply the magnitude of deformation accumulated during testing. The larger the ε_P (%) @ 1,000 and 10,000 cycles, the greater the potential for rutting in the field.

These parameters were shown to provide the best correlation to measured field rutting (NCHRP 465) when conducting the repeated load permanent deformation test. The correlation results determined in NCHRP 465 are shown in Table 1. The table clearly shows that at the test temperature of 130°F, the R^2 values for these parameters when compared to measured field rutting were all greater than 0.86. This should also correspond to the requested test temperature of 140°F used in this study.

The final repeated load results of the mixtures are shown in Table 2. The test results clearly show a difference in mixture performance among the three different mixtures. The PG64-22 samples performed the worst while the PG76-22 mixture performed the best. The addition of the Vestoplast additive clearly increased the PG64-22 mixtures resistance to permanent deformation, however, not to the extent of the PG76-22 mixture performance. Figures 1 through 3 show the test results for the individual mixes.

Table 1 – Results of Test Parameter Correlation to Field Rutting (NCHRP 465)

Unconfined Repeated Load	Model	100°F				130°F			
		R^2	Se/Sy	Rational	Rating	R^2	Se/Sy	Rational	Rating
Flow Number (F_N)	Power	0.96	0.229	Yes	Excellent	0.90	0.359	Yes	Good
Slope (b)	Linear	0.59	0.743	Yes	Fair	0.87	0.393	Yes	Good
Permanent Strain	Linear	0.95	0.256	Yes	Excellent	0.86	0.410	Yes	Good
Resilient Strain	Linear	0.90	0.362	Yes	Excellent	0.66	0.652	Yes	Fair
Resilient Modulus at Flow	Linear					0.72	0.548	Yes	Good
$\varepsilon_p/\varepsilon_r$ Ratio	Linear	0.83	0.472	Yes	Good	0.59	0.676	Yes	Fair
Mu (μ)	Linear	0.79	0.530	-	Good	0.25	0.881	-	Poor
Intercept (a)	Linear	0.30	0.964	Yes	Poor	0.13	1.055	Yes	Very Poor

Table 2 – Summary of Test Results from the Repeated Load Permanent Deformation Test

Sample Type	Sample ID	Air Voids (%)	Flow Number (F_N)	Permanent Strain (%)	
				1,000 Cycles	10,000 Cycles
PG64-22	# 4	5.4	411	2.06	> 5%
	# 6	5.5	471	1.95	> 5%
	# 8	5.5	431	1.89	> 5%
	Average	***5.5***	***438***	***1.97***	***> 5%***
PG64-22 + Vestoplast	# 1	5.7	2,011	0.82	> 5%
	# 2	5.5	1,831	0.79	> 5%
	# 3	5.3	3,191	0.72	2.47
	Average	***5.5***	***2,344***	***0.78***	***> 5%***
PG76-22	# 1	5.9	8,991	0.43	0.72
	# 4	5	5,571	0.6	1.1
	# 5	5.3	6,091	0.81	1.67
	Average	***5.4***	***6,884***	***0.61***	***1.16***

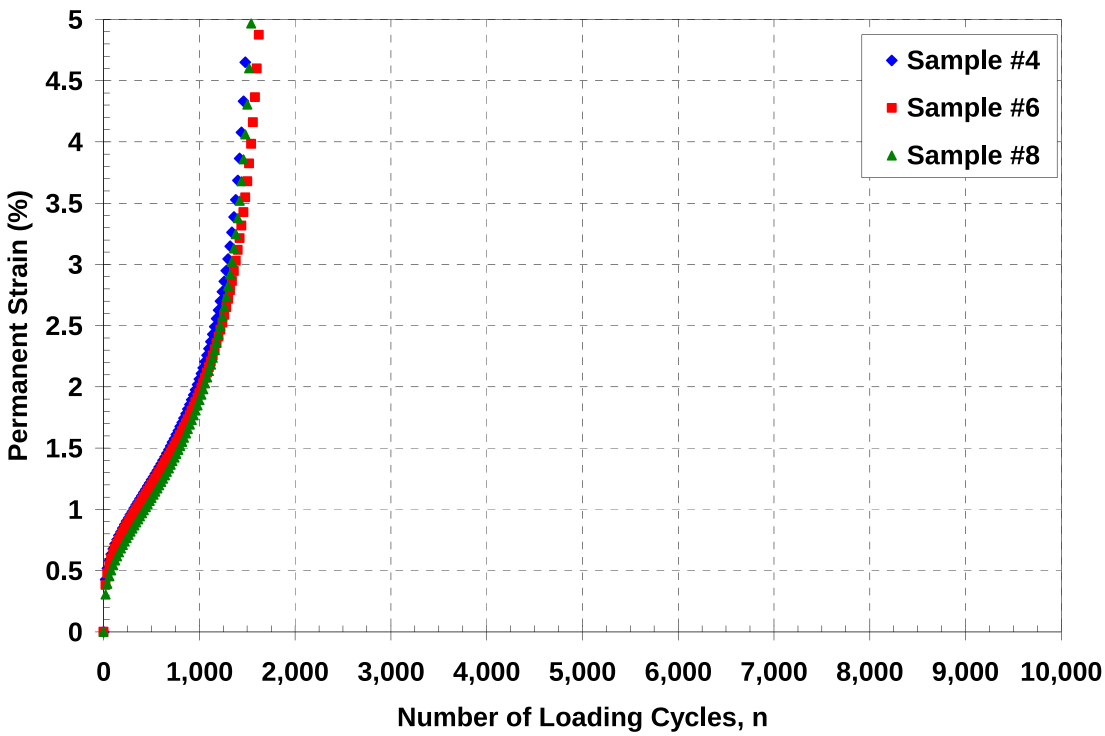

Figure 1 – Repeated Load Test Results for the PG64-22 Mixture

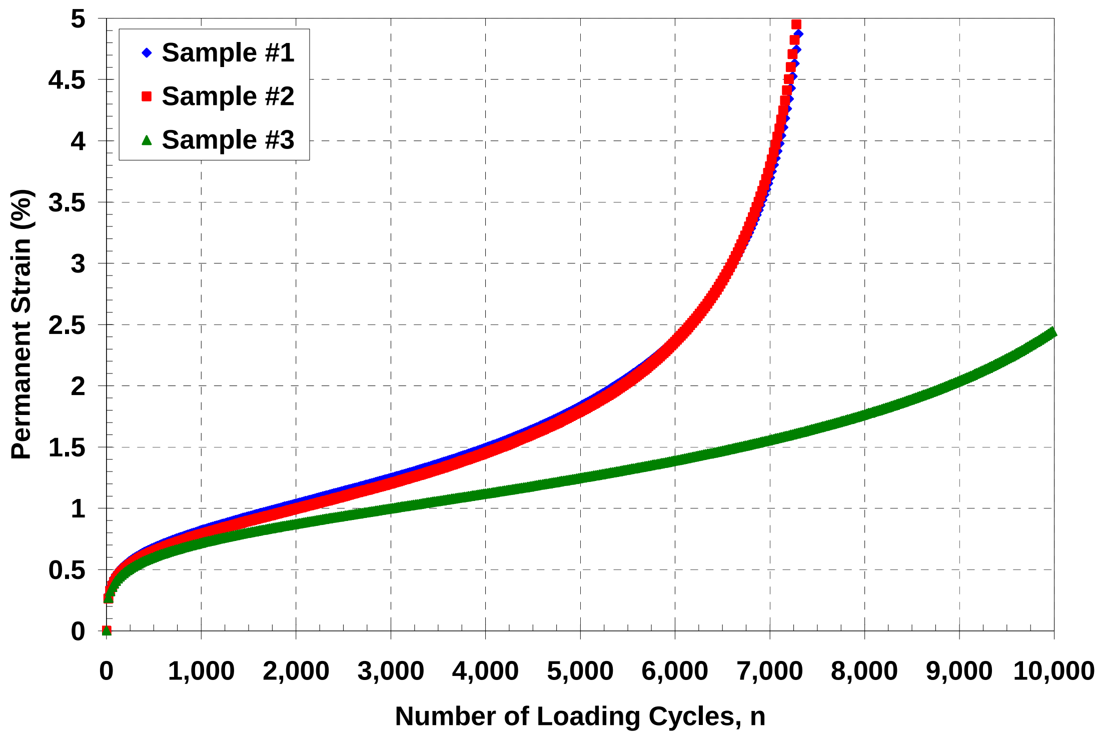

Figure 2 – Repeated Load Test Results for the Vestoplast Modified Mixture

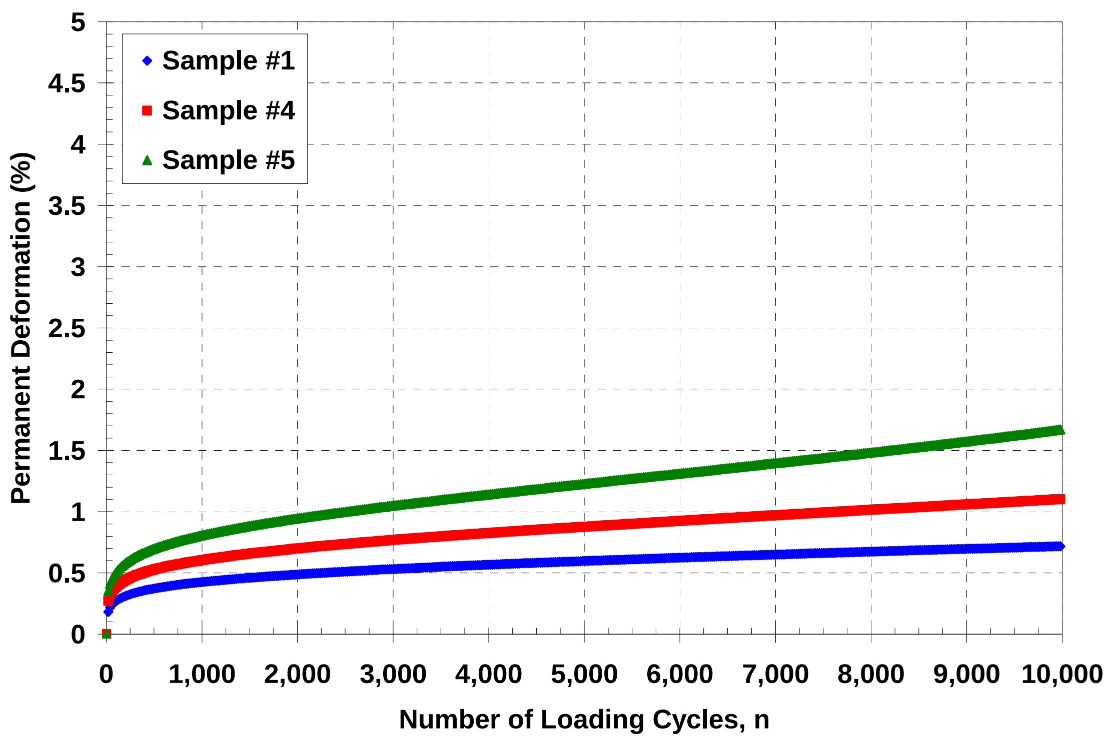

Figure 3 – Repeated Load Test Results for the PG76-22 Mixture

Flexural Beam Fatigue Test Results

All samples were tested at a test temperature of $15^{o}C$. The test specimens were tested until the specimen's flexural strength reached approximately 50% of its initial flexural stiffness. The methodology outlined in AASHTO T321 was used to determine the number of loading cycles to fatigue failure (N_f). A loading frequency of 10 Hz was used at five (5) different tensile strain levels; 400, 550, 700, 900, and 1000 μ-strains.

Throughout the test, the flexural stiffness of the samples was calculated and recorded. The stiffness of the beams was plotted against the load cycles and the resulting data was fitted to an exponential function as follows (AASHTO T321):

$$S = S_O e^{bN} \qquad (1)$$

where,

S = flexural stiffness after the n load cycles;
S_O= initial flexural stiffness;
e = natural algorithm to the base e
b = constant from regression analysis
N = number of load cycles

Equation (1) was then modified to determine the number of loading cycles to achieve 50% of the initial flexural stiffness. This was conducted for the five different applied strain levels to provide a regression equation in the form of Equation (2).

$$N_f = k_1 \varepsilon_t^{\,k_2} \qquad (2)$$

where,

N_f = number of loading repetitions until fatigue failure (50% of the initial stiffness)
k_1, k_2 = regression coefficients depending on material type and test conditions
ε_t = tensile strain

The test results of the Flexural Beam Fatigue testing are shown in Figure 4. The test results show that, overall, the PG64-22 mixture achieved the highest resistance to fatigue cracking, while the Vestoplast mixture achieved the lowest. This was somewhat surprising since past experience has shown that PG76-22 asphalt binders provide better fatigue resistance than PG64-22 asphalt binders. Comparing the Vestoplast mixture to the PG64-22 mixtures shows that the addition of the Vestoplast additive may lower the fatigue cracking resistance of the mixture. Table 3 provides the individual test results for further review.

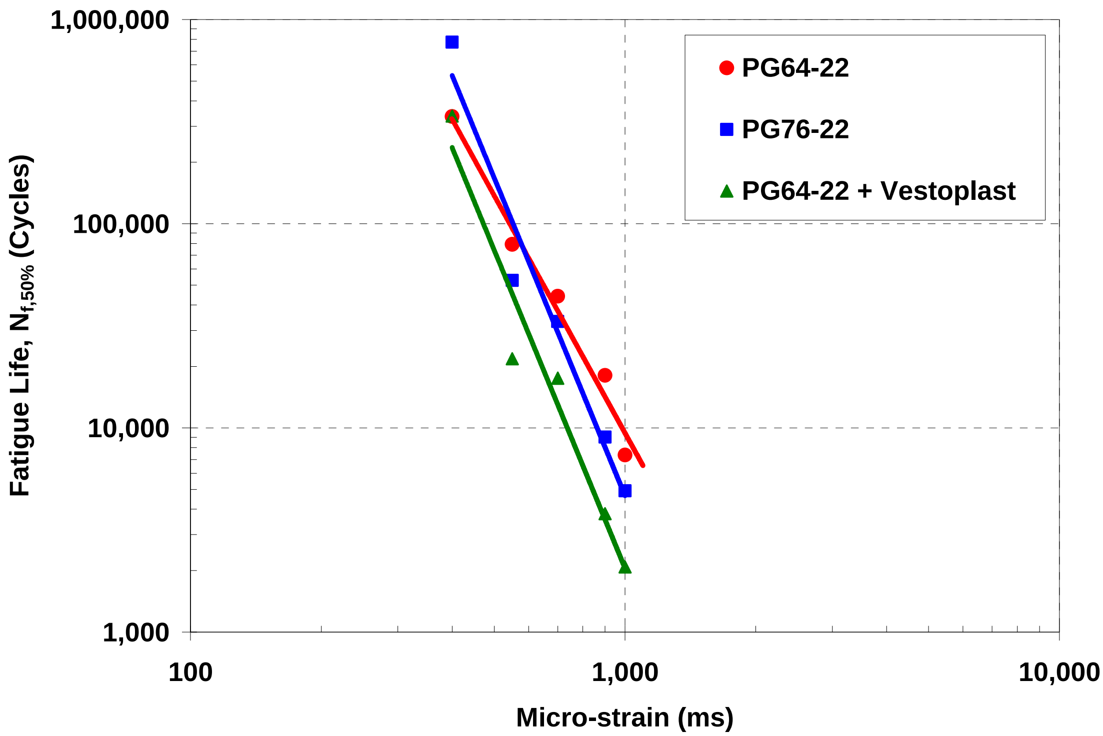

Figure 4 – Fatigue Life vs Applied Tensile Strain Relationship for Mixtures Tested

Table 3 – Summary of Flexural Beam Fatigue Results

Sample Type	Micro-Strain, μ-strain	Air Voids (%)	Fatigue Life, N_f (Cycles)	Initial Stiffness, S_O (MPa)	Regression Constant, b	Initial Modulus, E_O (psi)
PG64-22	400	5.3	334,393	5,228.9	-2.07E-06	895,230
	550	5.5	79,212	4,761.4	-8.75E-06	883,033
	700	5.1	44,119	3,809.0	-1.57E-05	738,428
	900	5.9	18,066	3,506.3	-3.84E+00	675,872
	1000	5.6	7,352	3,874.9	-9.43E-05	764,999
PG64-22 + Vestoplast	400	5.3	336,970	6,621.8	-2.06E-06	1,124,669
	550	5.6	21,786	5,742.2	-3.18E-05	1,008,362
	700	4.9	17,514	4,654.6	-3.96E-05	918,669
	900	5.7	3,803	4,701.4	-1.82E-04	919,844
	1000	5.4	2,086	5,791.1	-3.32E-04	1,000,616
PG76-22	400	5.2	775,088	6,234.9	-8.94E-07	1,022,924
	550	5.4	52,691	5,705.6	-1.32E-05	973,929
	700	5.9	33,213	5,097.6	-2.09E-05	937,655
	900	5.3	9,023	4,854.3	-7.68E-05	972,624
	1000	5.5	4,923	5,853.3	-1.41E-04	1,053,556

Dynamic Modulus (Stiffness) Test Results

The Dynamic Modulus (E*) test procedure is used to characterize the stiffness of HMA mixtures under a wide range of temperatures and loading frequencies (AASHTO TP62-07). The samples are tested using the same test equipment as the repeated load test (Figure 5). However, the stresses were applied in a manner to test the stiffness of the HMA within its respective linear elastic range, while minimizing permanent deformation of the sample.

Figure 5 – Test Machine for Repeated Load and Dynamic Modulus Test

Dynamic modulus and phase angle data were measured and collected in uniaxial compression following the method outlined in AASHTO TP62-07, *Standard Test Method for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures*. The data was collected at three temperatures; 4, 20, and 35^{o}C (for the PG64-22 binder) and 45^{o}C (for the PG76-22 binder), using loading frequencies of 25, 10, 5, 1, 0.5, 0.1, and 0.01 Hz. Samples were tested in triplicate after short-term aging following the procedures outlined in AASHTO R30, *Mixture Conditioning of Hot-Mix Asphalt (HMA)*.

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 3 and 4. The reference temperature used for the generation of the master curves and the shift factors was 20^{o}C.

$$\log|E^*| = \delta + \frac{(Max - \delta)}{1 + e^{\beta + \gamma\left\{\log \omega + \frac{\Delta E_a}{19.14714}\left[\left(\frac{1}{T}\right) - \left(\frac{1}{T_r}\right)\right]\right\}}} \tag{3}$$

where:

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

$$\log[a(T)] = \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \tag{4}$$

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)

The master stiffness curves, generated using the dynamic modulus test results, are shown in Figure 6. The results indicate that a clear increase in material stiffness is achieved at each temperature and loading frequency when the PG64-22 mix is modified with the Vestoplast additive. The mixture stiffness of the Vestoplast mixture was the highest at intermediate and lower temperatures, while the PG76-22 achieved the highest stiffness values at higher temperatures. In general, mixtures that achieve higher mixture stiffness at lower temperatures will generally have poorer fatigue resistance. Mixtures that achieve higher mixture stiffness at higher temperatures will generally have better resistance to permanent deformation. The results of the dynamic modulus testing, and the corresponding master stiffness curves, compare well to the Repeated Load Permanent Deformation and Flexural Beam Fatigue test results.

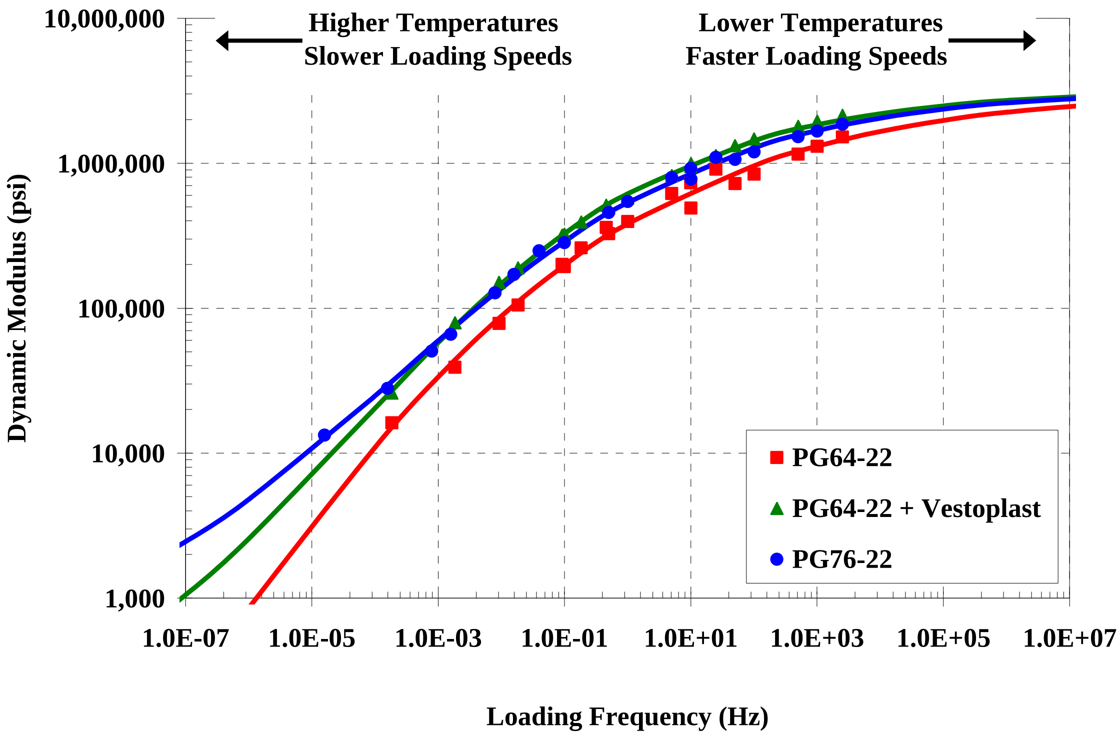

Figure 6 – Master Stiffness Curve of Mixtures Tested in Study

Conclusions

A laboratory test program was conducted to assess the change in mixture performance due to the addition of a Vestoplast additive. Permanent Deformation, Flexural Fatigue, and Dynamic Modulus (Mixture Stiffness) testing was conducted on laboratory produced mixtures for performance evaluation. The results of the testing program indicate that:

1. The addition of Vestoplast to the PG64-22 mixture increased its resistance to permanent deformation, as determined from laboratory Repeated Load Permanent Deformation testing. However, the permanent deformation resistance of the Vestoplast modified mixture was not as great as the PG76-22 mixture. The PG76-22 mixture achieved the highest Flow Number and lowest accumulated permanent deformation.
2. The addition of Vestoplast to the PG64-22 mixture decreased its resistance to fatigue cracking, as determined from laboratory Flexural Beam Fatigue testing. In fact, the PG64-22 mixture achieved the highest level of flexural fatigue resistance, as determined using the Fatigue Life vs Applied Tensile Strain relationship determined at 5 different tensile strains. This was surprising since past laboratory experience with PG76-22

asphalt binders were shown to have greater fatigue resistance than neat binders (i.e. - PG64-22).

3. The addition of Vestoplast to the PG64-22 mixture increased the material stiffness at each temperature and loading frequency evaluated. The Vestoplast modified mixture achieved the highest material stiffness at the intermediate and lower temperatures, which generally attributes to lower fatigue resistance. This was validated with the Flexural Fatigue results. The PG76-22 asphalt mixture achieved that highest material stiffness at the higher test temperatures, which generally attributes to better resistance to permanent deformation. This was validated with the Repeated Load Permanent Deformation test results.

Overall, the PG64-22 mixture modified with Vestoplast will have an increased resistance to rutting when compared to the unmodified PG64-22 mixture. However, it will not be as rut resistant as the PG76-22 asphalt mixture. The PG64-22 mixture modified with Vestoplast may have an issue with fatigue cracking. It achieved the lowest fatigue resistance of all three mixtures tested. The fatigue resistance of the PG76-22 asphalt binder did not perform as expected. Further review of this binder source is recommended.

Appendix

THE PORT AUTHORITY OF NY & NJ

ENGINEERING DEPARTMENT

MATERIALS ENGINEERING DIVISION

PYCNOMETER TEST RESULTS

MIX TYPE:	FAA # 3 with Vestoplast	LOT #:	Trail # 6
JOB DESCRIPTION:		CONTRACT #:	EWR-914.605
PLANT:	Tilcon NY Inc., Mt. Hope, NJ - C Plant	LOCATION:	
CONTRACTOR:		SUBCONTRACTOR:	

Line #	Test # / Date	6B 1/28/08	1/28/08	6C 1/29/08	1/29/08				
1	Tare + Mix								
2	Tare								
3	Sample Weight (1 - 2)	2088.0	2099.7	2082.5	2084.2				
4	Pycnometer + Water	7435.3	7616.7	7434.3	7615.8				
5	Total (3 + 4)	9523.3	9716.4	9516.8	9700.0				
6	Pycnometer + Water + Mix	8680.9	8869.9	8678.4	8860.9				
7	Displaced Water (5 - 6)	842.4	846.5	838.4	839.1				
8	Water Temperature	25.0	25.0	25.0	25.0				
9	Max. Sp. Gr. (3 / 7)	2.479	2.480	2.484	2.484				
10	Average	2.480		2.484					

Q.C. Technician __________ P.A. Technician : J. Varrone, D.Rana

Remarks : Trial # 6 B & C - Material Conditioned for 1 1/2 Hours @ 320°F

THE PORT AUTHORITY OF NY & NJ
MATERIALS ENGINEERING DIVISION
LABORATORY BATCH PROPORTIONS

CONTRACT # :	EWR-914.605
PLANT :	Tilcon NY Inc., Mt. Hope, NJ - 'C' Plant
MIX :	FAA # 3
TECHNICIAN :	J. Varrone, D. Rana
DATE :	1/24/08
REMARKS :	Trial # 6

MATERIAL	LOT NUMBER	MATERIAL SOURCE	TYPE / SIZE	PROPORTIONS
BIN # 5 - 1 " STONE			1" STONE	0.0 %
BIN # 4 - 3/4 " STONE	A 07 - 4	Tilcon NY Inc., Mt. Hope, NJ	3/4" STONE	11.9 %
BIN # 3 - 3/8 " STONE	A 07 - 3	Tilcon NY Inc., Mt. Hope, NJ	3/8" STONE	19.0 %
BIN # 2 - 1/4 " STONE	A 07 - 2	Tilcon NY Inc., Mt. Hope, NJ	1/4" STONE	29.5 %
BIN # 1 - SCREENINGS	A 07 - 1	Tilcon NY Inc., Mt. Hope, NJ	0 % Screenings	33.3 %
STONE SAND	A 07 - 1	Tilcon NY Inc., Mt. Hope, NJ	100 % Stone Sand	
FILLER	A 07 - 5	Tilcon NY Inc., Mt. Hope, NJ	Reclaimed Fines	1.4 %
ASPHALT CEMENT	A 07 - 7	Chevron, Perth Amboy, NJ (+ 0.5% ARR- MAZ AD-Here LOF65-00 Anti St	PG64-22	4.930 %
ADDITIVE		Evonik Degussa Corp., Parsippany, NJ	Vestoplast S	0.370 %

INDIVIDUAL COMPONENTS	PERCENTAGES BY WEIGHT	BATCH WEIGHTS IN GRAMS				
		1x4" MARSHALL	PCYNOMETER	3x4" MARSHALLS	1x6 " MARSHALL	GYRATORY
AGGREGATE TOTAL	100.0%		2000.0	3800.0		
BIN # 5 - 1 " STONE	0.0%		0.0	0.0		
BIN # 4 - 3/4 " STONE	12.5%		250.0	475.0		
BIN # 3 - 3/8 " STONE	20.0%		400.0	760.0		
BIN # 2 - 1/4 " STONE	31.0%		620.0	1178.0		
BIN # 1 - SCREENINGS	35.0%		700.0	1330.0		
STONE SAND						
FILLER	1.5%		30.0	57.0		
ASPHALT CEMENT	4.930%		104.1	197.8		
ADDITIVE	0.370%		7.8	14.8		

THE PORT AUTHORITY OF NY & NJ
MATERIALS ENGINEERING DIVISION
LABORATORY BATCH PROPORTIONS

CONTRACT # :	EWR-914.605
PLANT :	Tilcon NY Inc., Mt. Hope, NJ - 'C' Plant
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TECHNICIAN :	J. Varrone, D. Rana
DATE :	1/24/08
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MATERIAL	LOT NUMBER	MATERIAL SOURCE	TYPE / SIZE	PROPORTIONS
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BIN # 3 - 3/8 " STONE	A 07 - 3	Tilcon NY Inc., Mt. Hope, NJ	3/8" STONE	19.0 %
BIN # 2 - 1/4 " STONE	A 07 - 2	Tilcon NY Inc., Mt. Hope, NJ	1/4" STONE	29.5 %
BIN # 1 - SCREENINGS	A 07 - 1	Tilcon NY Inc., Mt. Hope, NJ	0 % Screenings	33.3 %
STONE SAND	A 07 - 1	Tilcon NY Inc., Mt. Hope, NJ	100 % Stone Sand	
FILLER	A 07 - 5	Tilcon NY Inc., Mt. Hope, NJ	Reclaimed Fines	1.4 %
ASPHALT CEMENT	A 07 - 7	Chevron, Perth Amboy, NJ (+ 0.5% ARR- MAZ AD-Here LOF65-00 Anti St	PG64-22	4.930 %
ADDITIVE		Evonik Degussa Corp., Parsippany, NJ	Vestoplast S	0.370 %

INDIVIDUAL COMPONENTS	PERCENTAGES BY WEIGHT	BATCH WEIGHTS IN GRAMS				
		1x4" MARSHALL	PCYNOMETER	3x4" MARSHALLS	1x6 " MARSHALL	GYRATORY
AGGREGATE TOTAL	100.0%		2000.0	3800.0		
BIN # 5 - 1 " STONE	0.0%		0.0	0.0		
BIN # 4 - 3/4 " STONE	12.5%		250.0	475.0		
BIN # 3 - 3/8 " STONE	20.0%		400.0	760.0		
BIN # 2 - 1/4 " STONE	31.0%		620.0	1178.0		
BIN # 1 - SCREENINGS	35.0%		700.0	1330.0		
STONE SAND						
FILLER	1.5%		30.0	57.0		
ASPHALT CEMENT	4.930%		104.1	197.8		
ADDITIVE	0.370%		7.8	14.8		

The Port Authority Of NY & NJ
Engineering Department
Materials Engineering Division
Calculation Of Effective Asphalt Content & Asphalt Film Thickness

Contract #:	EWR-914.605	**Date:**	1/31/08
Plant:	Tilcon NY Inc. - 'C' Plant	**Location:**	Mt. Hope, NJ
Mix:	**FAA # 3 PG64-22 & Vestoplast S**	**Technician:**	J. Varrone, D. Rana
Test #:	Trial # 6	**Remarks:**	HMA Conditioned for 1 1/2 Hours @ 320°F

Constituents	Source	Specific Gravity		Mix Composition
		Apparent	Bulk	
Coarse Aggregate	5/8" Stone - Tilcon NY Inc., Mt. Hope, NJ	2.695	2.657	**11.9**
Coarse Aggregate	3/8" Stone - Tilcon NY Inc., Mt. Hope, NJ	2.697	2.658	**19.0**
Coarse Aggregate	1/4" Stone - Tilcon NY Inc., Mt. Hope, NJ	2.702	2.652	**29.5**
Fine Aggregate	Stone Sand - Tilcon NY Inc., Mt. Hope, NJ	2.697	2.673	**33.3**
Fine Aggregate		2.697	2.673	**0.0**
Mineral Filler	Reclaimed Fines - Tilcon NY Inc., Mt. Hope, NJ	2.697	2.673	**1.4**
Asphalt Cement	PG 64-22 Chevron, Perth Amboy, NJ (+ 0.5% ARR-MAZ AD-Here LOF65-00 Anti Strip	1.030		**4.930**
Additive	Vestoplast S - Evonik Degussa Corp., Parsippany, NJ	0.870		**0.370**

Compacted Mix Bulk Specific Gravity - ASTM D-2726 (Gmb)	2.395
Mix Maximum Specific Gravity - ASTM D-2041 (Gmm)	2.482

Bulk Specific Gravity Of Aggregate (Gsb)	2.661	
Effective Specific Gravity Of Aggregate (Gse)	2.700	
Apparent Specific Gravity Of Aggregate (Gsa)	2.698	
Asphalt Absorption (Pba)	0.55	
Effective Asphalt Content (Pbe)	4.78	**Specification**
% Air Voids In Compacted Mixture (Va)	**3.5**	2.0 - 5.0
% Voids Filled With Asphalt (VFA)	**76.3**	67.0 - 77.0
% Voids In Mineral Aggregate (VMA)	**14.8**	14.0 Min

Gradation		
Sieve Size	**% Passing**	**Specification**
1 1/2"	100.0	100
1 "	100.0	100
3/4"	100.0	100
1/2"	94.4	88 - 100
3/8"	82.1	73 - 85
# 4	45.6	42 - 54
# 8	33.0	32 - 42
# 16	28.1	19 - 29
# 30	21.9	14 - 20
# 50	14.0	9 - 15
# 100	6.7	4 - 8
# 200	3.0	1 - 5
Effective AC	**4.78**	
Filler / AC Ratio	**0.63**	

Surface Area (Sq. Ft. / Lbs. Of Aggregate)	22.57
Bitumen Index	0.002118
Asphalt Film Thickness (Microns)	**10.31**

2/13/08