



US Department of Transportation
Federal Highway Administration

Office of Pavement Technology
Asphalt Binder Testing Laboratory

April 9, 2004

John D'Angelo
Asphalt Materials Engineer
Federal Highway Administration
400 7th Street SW, Rm3118
Washington, D. C. 20590

RE: Characterization of PG 64-22(B6225), Vestenamer Polymer and Ground Tire Rubber Blends

Dear Mr. D'Angelo:

Per your request we have finished characterizing the PG 64-22, Vestenamer Polymer and Ground Tire Rubber blends according to AASHTO M320 & MP1-A specifications. The ground tire rubber supplied by Mr. Bernie Burns was labeled 14-30 mesh, which is said to be from passenger car tires. The Vestenamer polymer 8012 was supplied by Degussa.

Asphalt Binder PG 64-22 from CITGO Refineries was used as a base asphalt to prepare the following blends:

1. PG-64-22 – Base Asphalt (B6225 - TFHRC Lab ID)
2. PG 64-22 + 3% Vestenamer (by wt. of asphalt)
3. PG 64-22 + 5% GTR (By wt. of asphalt)
4. PG 64-22 + 5% GTR (by wt. of asphalt) + 4.5% Vestenamer (by wt. of GTR).

The above blends were prepared as per manufacturer suggested modification process at TFHRC Chemistry Laboratory by Mr. Terry Arnold. The polymer was readily dispersed in blend 2. It appeared that the ground tire rubber was not dissolved both in blends 3 & 4. Office of Technology –Asphalt Binder Testing Laboratory, conducted asphalt Binder testing.

The performance grade of base asphalt was found to be PG 64-22. The high temperature grade was improved by one grade for blends 2, 3, & 4. The low temperature remained same for all asphalt binders. Technicians were able to see the rubber particles in blends 3 & 4 during the testing process. These blends were found to be non-homogeneous. The

Experimental

1. The asphalt used is nominally PG 67, the crude source is 60% Bachequero-13 and 40% Menemota-21.
2. The polymer, Vestenamer 8012, is a polyoctenamer formed by ring opening of cyclooctene using a Ziegler-Natta catalyst. Both cis and trans isomers are possible, useful rubbery materials are made with a high trans content. The molecule may be represented as $(R-CH=CH-)_n$ where R is $-(CH_2)_6$. Many of the polymer chains probably exist as large rings (macrocylic) which gives rise to few chain ends. This is thought to account for the high tensile strength of even low molecular weight material.

Main use appears to be as an additive (<30phr) for rubbers to improve green strength and flow properties. Degussa describe Vestenamer 8012 as a reactive modifier for rubber/asphalt road surfacing.

3. The rubber used was provided by Satish. It was labeled as being 14-30 mesh and the package was mailed in Stamford TX on 2/26/04. The rubber was said to be from passenger car tires and to contain SBR.
4. Preparation was carried out in accordance with the work order given on page one.
 - a) **5% GTR** - Asphalt was heated to 160°C (320°F) and stirred under high shear with a Silverson stirrer. The rubber was added slowly and the mixture stirred for a further 30 minutes under high shear. The rubber did not appear to dissolve to any appreciable extent so the mixture was not put through a screen. The sample is labeled as TSA171
 - b) **5% GTR + 4.5% Vestenamer 8012** (based on the weight of the GTR) – Asphalt was heated to 160°C under high shear. 5% GTR was added as before and the mixture stirred for a further 30 minutes under high shear. The polymer was then added and mixing continued for a further 60 minutes. The sample was not screened. It is labeled as TSA172
 - c) **3% Vestenamer 8012** – the asphalt was heated to 160°C under high shear and the polymer added slowly. Mixing was continued for 60 minutes. There was some increase in viscosity. The polymer dispersed readily and there was no residue left either on the screen or in the bottom of the can after pouring. The samples were placed in an oven at 174°C overnight to ensure the polymer had time to react with the asphalt. Sample labeled as TSA173

The samples have been returned to Satish.

Since the asphalt contains so much solid rubber it may be difficult to obtain a meaningful result from physical testing with the DSR

Terry Arnold March 17 2004



U S Department of Transportation
Federal Highway Administration

Office of Pavement Technology
Asphalt Binder Testing Laboratory

April 9, 2004

ASPHALT BINDER TEST REPORT

Date Sampled:	03/14/2004
Date Test Completed:	3/30/2004
Project ID:	Polymer/Rubber Study
Sample ID:	B6225 - Base
Blend ID:	PG 64-22 - Base Asphalt
Lab ID:	031404-01
Tested By:	David Heidler/Darnell Jackson

M320 Performance Grade:

PG 64-22

M320 Continuous Grade:

PG 67.0-25.3

MP1-a Performance Grade:

PG 64-22

Critical Cracking Temperature:

-23.5 °C

Reported by:

David Heidler
Senior Engineering Technician

B. L. Salib

low temperature grade seems to have improved for the blend 4 based on the continuous grade. Table 1 shows the summary of the performance grade for the above blends.

Table1: Performance Grade Summary of PG 64-22, GTR & Vestenamer Blends

Asphalt Binder	M320 Grade	M320-Continuous Grade	MP1-a Grade	T _{cr}
PG 64-22 - Base	PG 64-22	PG 67.0-25.3	PG 64-22	-23.5
PG 64-22 + Polymer	PG 70-22	PG 73.3-23.8	PG 70-22	-25.3
PG 64-22 + GTR	PG 70-22	PG 70.3-26.1	PG 70-22	-24.7
PG 64-22 + Polymer + GTR	PG 70-22	PG 74.4-27.1	PG 70-22	-23.5

Attached please find the test reports for each of the above blends. The test report provides the summary of test results, M320 Performance Grade, M320 Continuous Grade MP1-a performance grade and the Critical Cracking Temperature (T_{cr}).

Should you have any questions please feel free to give me a call at (202) 493-3103.

Sincerely,



Satish Ramaiah
Project Engineer

CC: Tom Harman, TFHRC
Terry Arnold, TFHRC

Preparation of Asphalt Modified with GTR and Vestenamer Polymer 8012 from Degussa

Background from Satish Ramaiah March 4 2004:

Degussa has sent us Vestenamer 8012 polymer to look at. John D'Angelo would like to look at what it will do with Ground Tire Rubber (GTR) and a PG64-22 asphalt binder. He also, thinks that it is a good idea to use it without the GTR to see its affect. This is just a quick look to see the effect of the material on MP1-a performance grading.

We need to blend the polymer and GTR with PG 64-22 asphalt binder. The Vestenamer polymer is in the form of pellets. I would like to request your help in processing these materials. If you could please ask Mr. Terry Arnold to blend these materials for us, we would greatly appreciate it. If Mr. Terry Arnold could provide us with the blended material we would be able to conduct tests to determine MP1-a performance grade on the blended materials.

Work Plan

Purpose:

To determine the effect of Vestenamer Polymer (TOR) + Ground Tire Rubber (GTR) modification (using conventional asphalt binders) on MP1-a performance grade.

Materials:

Base Asphalt: PG 64-22
Vestenamer Polymer
Ground Tire Rubber (14-30 Mesh)

Manufacturer suggested Modification Process:

Vestenamer Polymer Modification:

Three percent of Vestenamer polymer mixed with asphalt based on the weight of the asphalt. The mixture is blended for 60 minutes at 320°F.

Vestenamer Polymer + GTR rubber Modification

Five percent of GTR rubber is mixed with asphalt based on the weight of the asphalt. Then 4.5% of Vestenamer Polymer is added to the asphalt based on the weight of the GTR. The mixture is blended for 60 minutes at 320°F.

Testing Plan:

Tests required to determine the performance grade according to AASHTO MP1-a will be performed on the following base asphalt & modified binders:

1. Base Asphalt: PG 64-22
2. PG 64-22 + Vestenamer Polymer (3%)
3. PG 64-22 + GTR (5% by wt. of asphalt) + Vestenamer (4.5% by wt. of GTR)

Analysis:

Comparison of MP1-a Grading.

Performance Graded (PG) Asphalt Binder

Project: RUBBER SDY	Binder ID: B6225 BASE
Specifying Agency: FHWA	Refiner:
Laboratory: TE-39	Crude Source:
State/County: VA	Sample Date: / /
Contractor:	Sample Location:

Performance Grade, PG	High	Low	Continuous PG Grade	High	Low	Linearity	
	64	-22		67.0	-25.3	PASS	

Binder Grading Test Results

<u>Test</u>	<u>Original Binder</u> <u>Test Temp, °C</u>	<u>Test Results</u>	<u>Criteria</u>	<u>Pass/Fail</u>
(1) Specific Gravity, (T 228)		No Data		
(2) Flash Point (T 48)		No Data °C	≥ 230 °C	<input type="checkbox"/>
(3) Viscosity (ASTM D 4402)	135.0	0.45 Pa-s	≤ 3.00 Pa-s	PASS
(4) Dynamic Shear, G*/Sinδ, (TP5)	64.0	1.57 kPa	≥ 1.00 kPa	

Rolling Thin Film Oven (RTFO) Residue (T 240)

<u>Test</u>	<u>Test Temp, °C</u>	<u>Test Results</u>	<u>Criteria</u>	<u>Pass/Fail</u>
(5) Rolling Thin Film Oven Mass Loss		0.119 %	≤ 1.00 %	PASS
(6) Dynamic Shear, G*/Sinδ, (TP5)	64.0	3.21 kPa	≥ 2.20 kPa	

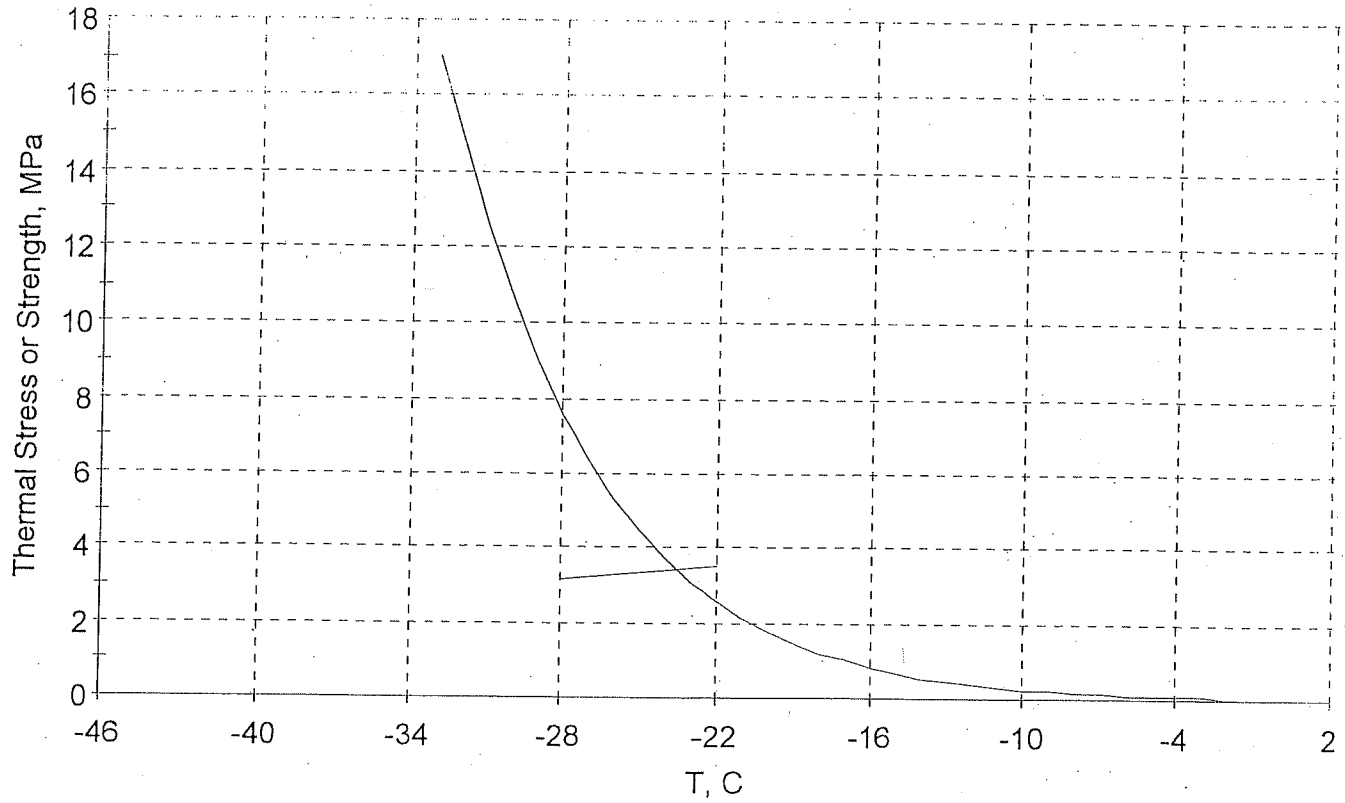
Pressure Aging Vessel (PAV) Residue (PP1)

<u>Test</u>	<u>Test Temp, °C</u>	<u>Test Results</u>	<u>Criteria</u>	<u>Pass/Fail</u>
(7) Dynamic Shear, G*/Sinδ, (TP5)	25	2,722 kPa	≤ 5,000 kPa	NOTE
(8) Creep Stiffness, S, (TP1)	-12.0	182,500 kPa	≤ 300,000 kPa	
m-Value		0.376	≥ 0.300	
(9) T critical, T _{cr}		-23.5 °C		

NOTE: The dynamic shear results (PAV residue) fail to satisfy the criteria at the intermediate temperature based on the maximum High and minimum Low temperatures satisfied. The Low temperature grade has been increased so the dynamic shear results pass.

Reviewed by: _____ Date: _____

PAV Fracture Strength & Thermal Stress, MPa
Critical Temperature -23.5 C



Sample ID: B6225 BASE

Technician BUTCH

Date Tested 03/14/2004

Binder Viscosity by Rotational Viscometer

Temp, °C	Speed, rpm	Torque, %	Viscosity, cP	Shear Stress, D/cm ^a	Shear Rate, 1/sec	Time, sec	Viscosity, Pa·s	Viscosity, Poise
135.0	20.0	3.6	450	30.6	6.8	60	0.45	4.5
			450					
						Average	0.45	4.5
					Standard Deviation		0.00	0.0

ORIGINAL BINDER - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/18/2004

Criteria

$G^*/\sin \delta \geq 1.00 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G*/Sin δ kPa	Log of G*/Sin δ
1	58	64	3.333	85.03	0.996	3.35	0.52
2	64	64	1.570	86.62	0.998	1.57	0.19
3	70	64	0.750	87.41	0.999	0.75	-0.12
4	76						

PG Rating based upon maximum temperature to satisfy criteria 64

Continuous (True) PG Rating 67.7

Original Binder - Strain Sweep, Linearity Test

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/18/2004

Strain Rate	Test Temp, °C	Complex Modulus G*, kPa	Phase Angle, degrees	Loss Ratio, G*/G* @ 2%	Linearity Check
2.0%	64.0	1.527	88.27	100.0%	LINEAR
4.0%	64.0	1.535	86.73	100.5%	LINEAR
6.0%	64.0	1.532	86.18	100.3%	LINEAR
8.0%	64.0	1.533	86.62	100.4%	LINEAR
10.0%	64.0	1.541	86.51	100.9%	LINEAR
12.0%	64.0	1.539	86.54	100.8%	LINEAR
14.0%	64.0	1.537	86.47	100.7%	LINEAR
16.0%	64.0	1.536	86.52	100.6%	LINEAR
18.0%	64.0	1.535	86.47	100.5%	LINEAR
20.0%	64.0	1.532	86.50	100.3%	LINEAR
22.0%	64.0	1.534	86.49	100.5%	LINEAR
24.0%	64.0	1.530	86.55	100.2%	LINEAR
26.0%	64.0	1.529	86.59	100.1%	LINEAR
28.0%	64.0	1.529	86.59	100.1%	LINEAR
30.0%	64.0	1.527	86.53	100.0%	LINEAR

RTFO RESIDUE - MASS LOSS

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/18/2004

RTFO Masses

Specimen	"A"	"B"
(A) Bottle Tare Mass	166.440	163.475
(B) Mass of Bottle & Binder	201.657	198.789
(C) Final Mass of Bottle & Binder	201.620	198.742
Percent Mass Loss, $100(B-C)/(B-A)$	0.105	0.133
	Average	0.119

RTFO RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/23/2004

Criteria

$G^*/\sin \delta \geq 2.20 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G^* kPa	Delta, δ degrees	$\sin \delta$	$G^*/\sin \delta$ kPa	Log of $G^*/\sin \delta$
1	58	64	6.998	81.20	0.988	7.08	0.85
2	64	64	3.193	83.43	0.993	3.21	0.50
3	70	64	1.497	85.36	0.997	1.50	0.17
4	76						

PG Rating based upon maximum temperature to satisfy criteria 64

Continuous (True) PG Rating 67.0

PAV RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/24/2004

Criteria

$G^* \sin \delta \leq 5,000 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G* Sin δ kPa
1	25	25	3,460.0	51.88	0.787	2,722.0

2	28	25	2,145.0	55.07	0.820	1,758.5
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3	31					
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4	34					
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Lowest temperature to satisfy criteria 25

PAV Residue - Creep Stiffness, BBR

Project RUBBER SDY Technician BUTCH Criteria, S 300000 kPa
 Binder ID B6225 BASE Date Tested 03/24/2004 Criteria, M 0.300

Test Temp #1 -12 Avg Creep Stiffness, MPa 182,500 Avg Slope, m-value 0.376
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9890	0.9860	360,000	359,000	0.293	0.295
15	0.9880	0.9840	297,000	296,000	0.320	0.319
30	0.9880	0.9830	235,000	235,000	0.349	0.346
60	0.9870	0.9810	182,000	183,000	0.378	0.373
120	0.9850	0.9800	139,000	140,000	0.408	0.400
240	0.9830	0.9800	103,000	105,000	0.437	0.426

Test Temp #2 -18 Avg Creep Stiffness, MPa 450,500 Avg Slope, m-value 0.323
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9950	0.9870	762,000	830,000	0.234	0.247
15	0.9950	0.9810	652,000	705,000	0.260	0.273
30	0.9940	0.9810	539,000	578,000	0.288	0.301
60	0.9930	0.9780	437,000	464,000	0.316	0.329
120	0.9910	0.9780	347,000	366,000	0.345	0.358
240	0.9900	0.9780	271,000	282,000	0.373	0.386

Test Temp #3 -24 Avg Creep Stiffness, MPa Avg Slope, m-value
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8						
15						
30						
60						
120						
240						

PG Rating based upon minimum temperature to satisfy criteria -22

Continuous PG Grade (True Grade) -25.3

PAV Residue - Direct Tension, DTT

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BASE

Date Tested 03/30/2004

Test Number	Test Temp, °C	Failure Strain	Average	Failure Stress, Pa	Average
1	-12	1.12		3.000	
		0.85		2.430	
		1.53		3.580	
		1.76		3.940	
		1.42		3.470	
		1.08	1.46	2.910	3.498
2	-18	0.33		2.290	
		0.36		2.360	
		0.69		4.130	
		0.43		2.760	
		0.44		2.930	
		0.45	0.50	2.930	3.178
3	-24				
4	-30				

Critical Cracking Temperature -23.5

PG Rating based upon minimum temperature to satisfy criteria -22



U S Department of Transportation
Federal Highway Administration

Office of Pavement Technology
Asphalt Binder Testing Laboratory

April 9, 2004

ASPHALT BINDER TEST REPORT

Date Sampled:	03/14/2004
Date Test Completed:	3/30/2004
Project ID:	Polymer/Rubber Study
Sample ID:	B6225 - Poly
Blend ID:	PG 64-22 - 3% Vestenamer
Lab ID:	031404-02
Tested By:	David Heidler/Darnell Jackson

M320 Performance Grade:

PG 70-22

M320 Continuous Grade:

PG 73.3-23.8

MP1-a Performance Grade:

PG 70-22

Critical Cracking Temperature:

-25.3 °C

Reported by:

David Heidler
Senior Engineering Technician

Reviewed by Satish Ramaiah
Project Engineer

Performance Graded (PG) Asphalt Binder

Project:	RUBBER SDY	Binder ID:	B6225 POLY
Specifying Agency:	FHWA	Refiner:	
Laboratory:	TE-39	Crude Source:	
State/County:	VA	Sample Date:	/ /
Contractor:		Sample Location:	

Performance Grade, PG	High	Low	Continuous PG Grade	High	Low	Linearity	
	70	-22		73.3	-23.8		PASS

Binder Grading Test Results

		Original Binder			Criteria	Pass/Fail
Test	Test Temp, °C	Test Results				
(1) Specific Gravity, (T 228)		No Data				
(2) Flash Point (T 48)		No Data °C	≥	230 °C		
(3) Viscosity (ASTM D 4402)	135.0	0.88 Pa-s	≤	3.00 Pa-s		PASS
(4) Dynamic Shear, G*/Sinδ, (TP5)	70.0	1.70 kPa	≥	1.00 kPa		

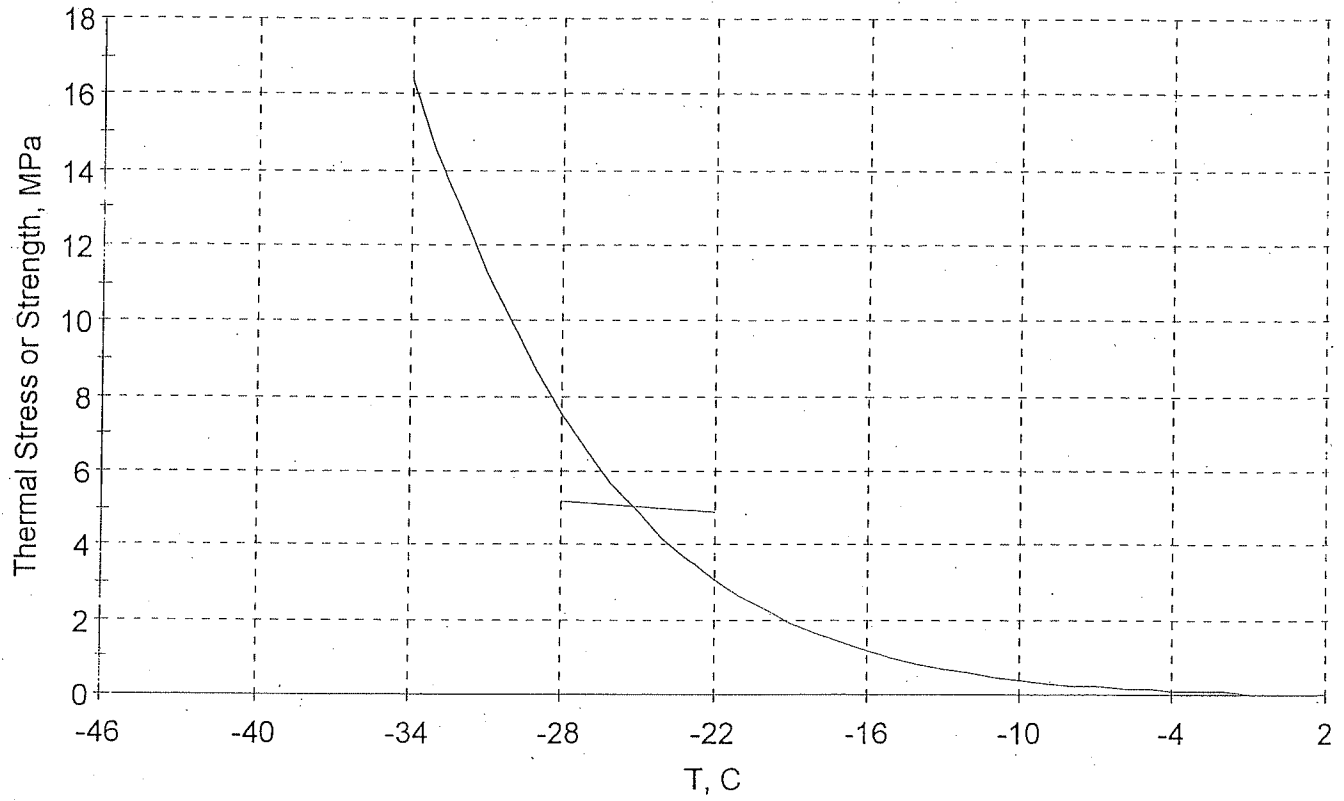
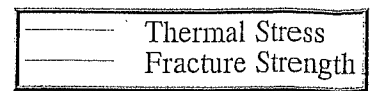
		Rolling Thin Film Oven (RTFO) Residue (T 240)			Criteria	Pass/Fail
Test	Test Temp, °C	Test Results				
(5) Rolling Thin Film Oven Mass Loss		0.102 %	≤	1.00 %		PASS
(6) Dynamic Shear, G*/Sinδ, (TP5)	70.0	3.28 kPa	≥	2.20 kPa		

		Pressure Aging Vessel (PAV) Residue (PP1)			Criteria	Pass/Fail
Test	Test Temp, °C	Test Results				
(7) Dynamic Shear, G*/Sinδ, (TP5)	28	2,511 kPa	≤	5,000 kPa		NOTE
(8) Creep Stiffness, S, (TP1)	-12.0	232,000 kPa	≤	300,000 kPa		
m-Value		0.316	≥	0.300		
(9) T critical, T _{cr}		-25.3 °C				

NOTE: The dynamic shear results (PAV residue) fail to satisfy the criteria at the intermediate temperature based on the maximum High and minimum Low temperatures satisfied. The Low temperature grade has been increased so the dynamic shear results pass.

Reviewed by: _____ Date: _____

PAV Fracture Strength & Thermal Stress, MPa
Critical Temperature -25.3 C



Sample ID: B6225 + POLY

Original Binder - VISCOSITY

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/14/2004

Binder Viscosity by Rotational Viscometer

Temp, °C	Speed, rpm	Torque, %	Viscosity, cP	Shear Stress, D/cm ²	Shear Rate, 1/sec	Time, sec	Viscosity, Pa·s	Viscosity, Poise	
135.0	20.0	7.0	875	59.5	6.8	60	0.88	8.8	
			875						
							Average	0.88	8.8
							Standard Deviation	0.00	0.0

ORIGINAL BINDER - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/14/2004

Criteria

$G^*/\sin \delta \geq 1.00 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G*/Sin δ kPa	Log of G*/Sin δ
1	58	64	7.421	80.29	0.986	7.53	0.87
2	64	64	3.534	82.45	0.991	3.56	0.55
3	70	64	1.689	84.38	0.995	1.70	0.23
4	76	64	0.832	86.08	0.998	0.83	-0.08

PG Rating based upon maximum temperature to satisfy criteria 70

Continuous (True) PG Rating 74.4

Original Binder - Strain Sweep, Linearity Test

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/14/2004

Strain Rate	Test Temp, °C	Complex Modulus G*, kPa	Phase Angle, degrees	Loss Ratio, G*/G* @ 2%	Linearity Check
2.0%	70.0	1.677	83.65	100.0%	LINEAR
4.0%	70.0	1.657	84.76	98.8%	LINEAR
6.0%	70.0	1.651	84.27	98.5%	LINEAR
8.0%	70.0	1.655	84.33	98.7%	LINEAR
10.0%	70.0	1.650	84.40	98.4%	LINEAR
12.0%	70.0	1.649	84.39	98.3%	LINEAR
14.0%	70.0	1.652	84.14	98.5%	LINEAR
16.0%	70.0	1.652	84.42	98.5%	LINEAR
18.0%	70.0	1.654	84.34	98.6%	LINEAR
20.0%	70.0	1.655	84.42	98.7%	LINEAR
22.0%	70.0	1.655	84.42	98.7%	LINEAR
24.0%	70.0	1.655	84.34	98.7%	LINEAR
26.0%	70.0	1.657	84.38	98.8%	LINEAR
28.0%	70.0	1.655	84.37	98.7%	LINEAR
30.0%	70.0	1.659	84.44	98.9%	LINEAR

RTFO RESIDUE - MASS LOSS

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/14/2004

RTFO Masses

Specimen	"A"	"B"
(A) Bottle Tare Mass	171.978	163.158
(B) Mass of Bottle & Binder	207.862	198.831
(C) Final Mass of Bottle & Binder	207.825	198.795
Percent Mass Loss, $100(B-C)/(B-A)$	0.103	0.101
	Average	0.102

RTFO RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/23/2004

Criteria

$G^*/\sin \delta \geq 2.20 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G^* kPa	Delta, δ degrees	$\sin \delta$	$G^*/\sin \delta$ kPa	Log of $G^*/\sin \delta$
1	64	64	6.877	78.04	0.978	7.03	0.84
2	70	64	3.237	80.82	0.987	3.27	0.51
3	76	64	1.563	83.12	0.993	1.57	0.19
4	82						

PG Rating based upon maximum temperature to satisfy criteria 70

Continuous (True) PG Rating 73.3

PAV RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/24/2004

Criteria

$G^* \sin \delta \leq 5,000 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G^* kPa	Delta, δ degrees	$\sin \delta$	$G^* \sin \delta$ kPa
1	28	25	3,409.0	47.44	0.737	2,510.9
2	31					
3	34					
4	37					

Lowest temperature to satisfy criteria 28

PAV Residue - Creep Stiffness, BBR

Project RUBBER SDY Technician BUTCH Criteria, S 300000 kPa
 Binder ID B6225 POLY Date Tested 03/24/2004 Criteria, M 0.300

Test Temp #1 -12 Avg Creep Stiffness, MPa 232,000 Avg Slope, m-value 0.316
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9910	0.9850	412,000	408,000	0.249	0.247
15	0.9900	0.9830	350,000	347,000	0.269	0.269
30	0.9880	0.9830	288,000	285,000	0.292	0.294
60	0.9880	0.9830	233,000	231,000	0.314	0.318
120	0.9850	0.9850	186,000	183,000	0.336	0.342
240	0.9850	0.9850	146,000	143,000	0.358	0.366

Test Temp #2 -18 Avg Creep Stiffness, MPa 442,500 Avg Slope, m-value 0.263
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9810	0.9790	684,000	716,000	0.188	0.195
15	0.9790	0.9770	603,000	629,000	0.211	0.217
30	0.9790	0.9750	517,000	536,000	0.263	0.241
60	0.9790	0.9740	435,000	450,000	0.261	0.265
120	0.9760	0.9750	360,000	371,000	0.286	0.289
240	0.9740	0.9730	292,000	301,000	0.311	0.313

Test Temp #3 -24 Avg Creep Stiffness, MPa Avg Slope, m-value
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8						
15						
30						
60						
120						
240						

PG Rating based upon minimum temperature to satisfy criteria -22

Continuous PG Grade (True Grade) -23.8

PAV Residue - Direct Tension, DTT

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 POLY

Date Tested 03/30/2004

Test Number	Test Temp, °C	Failure Strain	Average	Failure Stress, Pa	Average
1	-12	2.25		5.210	
		1.80		4.610	
		1.83		4.760	
		2.11		5.120	
		1.46		4.120	
		0.78	2.00	2.600	4.925
2	-18	0.93		5.000	
		0.52		3.090	
		0.70		4.050	
		0.91		5.020	
		1.00		5.470	
		1.02	0.97	5.470	5.205
3	-24				
4	-30				

Critical Cracking Temperature -25.3

PG Rating based upon minimum temperature to satisfy criteria -22



U S Department of Transportation
Federal Highway Administration

Office of Pavement Technology
Asphalt Binder Testing Laboratory

April 9, 2004

ASPHALT BINDER TEST REPORT

Date Sample prepared:	03/14/2004
Date Test Completed:	3/31/2004
Project ID:	Polymer/Rubber Study
Sample ID:	B6225 - GTR
Blend ID:	PG 64-22 -- 5% GTR
Lab ID:	031404-03
Tested By:	David Heidler/Darnell Jackson

M320 Performance Grade:

PG 70-22

M320 Continuous Grade:

PG 70.3-26.1

MP1-a Performance Grade:

PG 70-22

Critical Cracking Temperature:

-23.5 °C

Reported by:

David Heidler
Senior Engineering Technician

Reviewed by Satish Ramaiah
Project Engineer

Performance Graded (PG) Asphalt Binder

Project: RUBBER SDY	Binder ID: B6225 GTR
Specifying Agency: FHWA	Refiner:
Laboratory: TE-39	Crude Source:
State/County: VA	Sample Date: / /
Contractor:	Sample Location:

Performance Grade, PG	High	Low	Continuous PG Grade	High	Low	Linearity
	70	-22		70.3	-26.1	NO DATA

Binder Grading Test Results

Original Binder					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(1) Specific Gravity, (T 228)		No Data			
(2) Flash Point (T 48)		No Data °C	≥ 230 °C		
(3) Viscosity (ASTM D 4402)	135.0	0.63 Pa-s	≤ 3.00 Pa-s		PASS
(4) Dynamic Shear, G*/Sinδ, (TP5)	70.0	1.03 kPa	≥ 1.00 kPa		

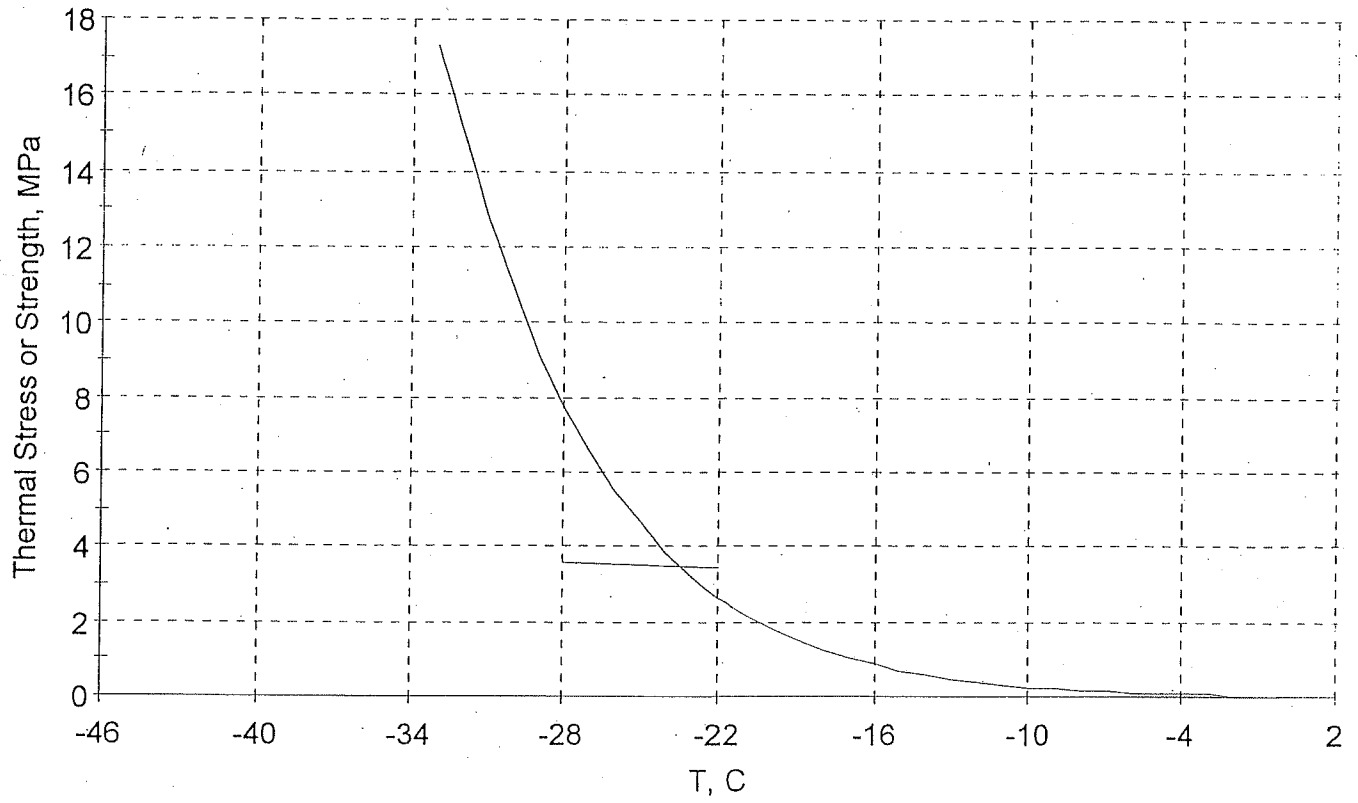
Rolling Thin Film Oven (RTFO) Residue (T 240)					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(5) Rolling Thin Film Oven Mass Loss		0.162 %	≤ 1.00 %		PASS
(6) Dynamic Shear, G*/Sinδ, (TP5)	76.0	3.36 kPa	≥ 2.20 kPa		

Pressure Aging Vessel (PAV) Residue (PP1)					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(7) Dynamic Shear, G*/Sinδ, (TP5)	28	2,425 kPa	≤ 5,000 kPa		NOTE
(8) Creep Stiffness, S, (TP1)	-12.0	157,000 kPa	≤ 300,000 kPa		
m-Value		0.358	≥ 0.300		
(9) T critical, T _{cr}		-23.5 °C			

NOTE: The dynamic shear results (PAV residue) fail to satisfy the criteria at the intermediate temperature based on the maximum High and minimum Low temperatures satisfied. The Low temperature grade has been increased so the dynamic shear results pass.

Reviewed by: _____ Date: _____

PAV Fracture Strength & Thermal Stress, MPa
Critical Temperature -23.5 C



Sample ID: B6225 GTR

Original Binder - VISCOSITY

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/14/2004

Binder Viscosity by Rotational Viscometer

Temp, °C	Speed, rpm	Torque, %	Viscosity, cP	Shear Stress, D/cm ²	Shear Rate, 1/sec	Time, sec	Viscosity, Pa·s	Viscosity, Poise	
135.0	20.0	5.0	625	42.5	6.8	60	0.63	6.3	
			625						
							Average	0.63	6.3
							Standard Deviation	0.00	0.0

ORIGINAL BINDER - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/14/2004

Criteria

$G^*/\sin \delta \geq 1.00 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G*/Sin δ kPa	Log of G*/Sin δ
1	58	70	4.512	83.21	0.993	4.54	0.65
2	64	64	2.135	84.96	0.996	2.14	0.33
3	70	64	1.030	86.59	0.998	1.03	0.01
4	76	64	0.508	87.72	0.999	0.51	-0.29

PG Rating based upon maximum temperature to satisfy criteria 70

Continuous (True) PG Rating 70.3

Original Binder - Strain Sweep, Linearity Test

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/24/2004

Strain Rate	Test Temp, °C	Complex Modulus G*, kPa	Phase Angle, degrees	Loss Ratio, G*/G* @ 2%	Linearity Check
2.0%	70.0	0.987	87.06	100.0%	LINEAR
4.0%		0.994	87.16	100.7%	LINEAR
6.0%		0.990	86.59	100.3%	LINEAR
8.0%		0.990	86.49	100.3%	LINEAR
10.0%		0.989	86.64	100.2%	LINEAR
12.0%		0.994	86.62	100.7%	LINEAR
14.0%		0.991	86.70	100.4%	LINEAR
16.0%		0.986	86.53	99.9%	LINEAR
18.0%		0.991	86.67	100.4%	LINEAR
20.0%		0.988	86.62	100.1%	LINEAR
22.0%		0.993	86.73	100.6%	LINEAR
24.0%		0.991	86.66	100.4%	LINEAR
26.0%		0.990	86.66	100.3%	LINEAR
28.0%		0.992	86.75	100.5%	LINEAR
30.0%		0.989	86.83	100.2%	LINEAR

RTFO RESIDUE - MASS LOSS

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/18/2004

RTFO Masses

Specimen	"A"	"B"
(A) Bottle Tare Mass	165.349	167.764
(B) Mass of Bottle & Binder	200.312	202.601
(C) Final Mass of Bottle & Binder	200.255	202.545
Percent Mass Loss, $100(B-C)/(B-A)$	0.163	0.161
	Average	0.162

RTFO RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/23/2004

Criteria

$G^*/\sin \delta \geq 2.20 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G*/Sin δ kPa	Log of G*/Sin δ
1	64	70	8.761	61.43	0.878	9.97	0.99
2	70	70	5.044	62.29	0.885	5.69	0.75
3	76	70	2.957	61.69	0.880	3.35	0.52
4	82	70	1.874	59.37	0.860	2.17	0.33

PG Rating based upon maximum temperature to satisfy criteria

76

Continuous (True) PG Rating

81.4

PAV RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/24/2004

Criteria

$G^* \sin \delta \leq 5,000 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G^* kPa	Delta, δ degrees	$\sin \delta$	$G^* \sin \delta$ kPa
1	28	28	3,082.0	51.90	0.787	2,425.3
2	31					
3	34					
4	37					

Lowest temperature to satisfy criteria 28

PAV Residue - Creep Stiffness, BBR

Project RUBBER SDY Technician BUTCH Criteria, S 300000 kPa
 Binder ID B6225 GTR Date Tested 03/24/2004 Criteria, M 0.300

Test Temp #1 -12 Avg Creep Stiffness, MPa 157,000 Avg Slope, m-value 0.358
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9920	0.9950	311,000	291,000	0.280	0.292
15	0.9860	0.9920	259,000	240,000	0.305	0.312
30	0.9870	0.9890	207,000	192,000	0.330	0.334
60	0.9860	0.9880	163,000	151,000	0.359	0.357
120	0.9850	0.9880	126,000	117,000	0.386	0.379
240	0.9850	0.9860	95,000	89,000	0.413	0.402

Test Temp #2 -18 Avg Creep Stiffness, MPa 406,000 Avg Slope, m-value 0.310
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9890	0.9930	683,000	718,000	0.225	0.235
15	0.9880	0.9920	588,000	615,000	0.252	0.258
30	0.9870	0.9920	489,000	509,000	0.280	0.284
60	0.9860	0.9900	398,000	414,000	0.309	0.310
120	0.9870	0.9900	318,000	331,000	0.338	0.336
240	0.9860	0.9900	249,000	260,000	0.367	0.361

Test Temp #3 -24 Avg Creep Stiffness, MPa Avg Slope, m-value
 (°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8						
15						
30						
60						
120						
240						

PG Rating based upon minimum temperature to satisfy criteria -22

Continuous PG Grade (True Grade) -26.1

PAV Residue - Direct Tension, DTT

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 GTR

Date Tested 03/31/2004

Test Number	Test Temp, °C	Failure Strain	Average	Failure Stress, Pa	Average
1	-12	1.36		3.170	
		2.48		4.480	
		1.31		3.150	
		1.18		2.750	
		1.23		3.000	
		0.96	1.60	2.440	3.450
2	-18	0.23		1.330	
		0.50		2.840	
		0.53		2.850	
		0.92		4.610	
		0.62		3.490	
		0.57	0.66	3.490	3.550
3	-24				
4	-30				

Critical Cracking Temperature -23.5

PG Rating based upon minimum temperature to satisfy criteria -22



U S Department of Transportation
Federal Highway Administration

Office of Pavement Technology
Asphalt Binder Testing Laboratory

April 9, 2004

ASPHALT BINDER TEST REPORT

Date Sample prepared:	03/14/2004
Date Test Completed:	3/31/2004
Project ID:	Polymer/Rubber Study
Sample ID:	B6225 - Both
Blend ID:	PG 64-22 - 5% GTR + 4.5% Vestenamer
Lab ID:	031404-04
Tested By:	David Heidler/Darnell Jackson

M320 Performance Grade:

PG 70-22

M320 Continuous Grade:

PG 74.4-27.1

MP1-a Performance Grade:

PG 70-22

Critical Cracking Temperature:

-24.7 °C

Reported by:

David Heidler
Senior Engineering Technician

Reviewed by Satish Ramaiah
Project Engineer

Performance Graded (PG) Asphalt Binder

Project:	RUBBER SDY	Binder ID:	B6225 BOTH
Specifying Agency:	FHWA	Refiner:	
Laboratory:	TE-39	Crude Source:	
State/County:	VA	Sample Date:	/ /
Contractor:		Sample Location:	

Performance	High	Low	Continuous	High	Low	
Grade, PG	<div style="border: 1px solid black; padding: 2px;">70</div>	<div style="border: 1px solid black; padding: 2px;">-22</div>	PG Grade	<div style="border: 1px solid black; padding: 2px;">74.4</div>	<div style="border: 1px solid black; padding: 2px;">-27.1</div>	Linearity <div style="border: 1px solid black; padding: 2px;">PASS</div>

Binder Grading Test Results

Original Binder					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(1) Specific Gravity, (T 228)		No Data			
(2) Flash Point (T 48)		No Data °C	≥ 230 °C		<div style="border: 1px solid black; width: 40px; height: 20px;"></div>
(3) Viscosity (ASTM D 4402)	135.0	0.73 Pa-s	≤ 3.00 Pa-s		<div style="border: 1px solid black; padding: 2px;">PASS</div>
(4) Dynamic Shear, G*/Sinδ, (TP5)	70.0	1.58 kPa	≥ 1.00 kPa		

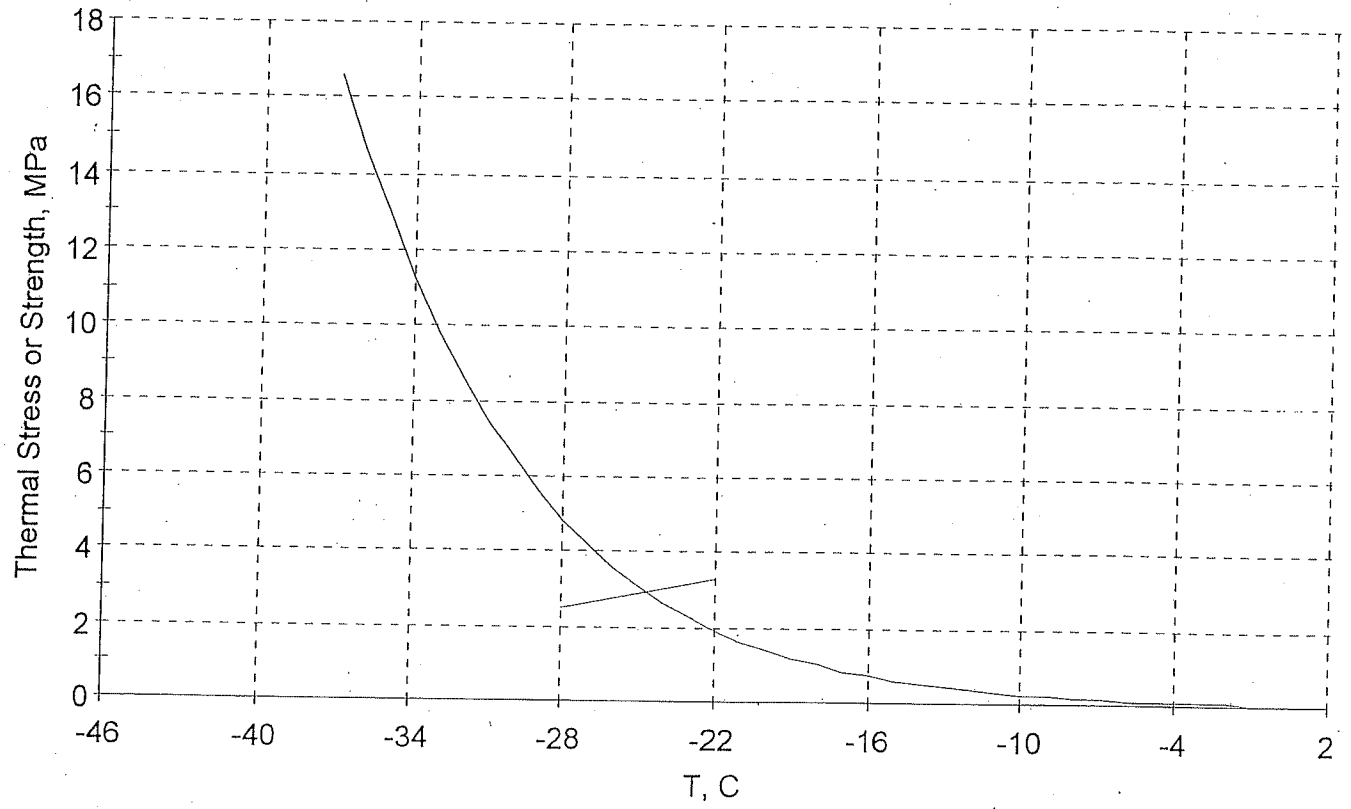
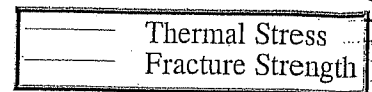
Rolling Thin Film Oven (RTFO) Residue (T 240)					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(5) Rolling Thin Film Oven Mass Loss		0.129 %	≤ 1.00 %		<div style="border: 1px solid black; padding: 2px;">PASS</div>
(6) Dynamic Shear, G*/Sinδ, (TP5)	76.0	2.39 kPa	≥ 2.20 kPa		

Pressure Aging Vessel (PAV) Residue (PP1)					
Test	Test Temp, °C	Test Results	Criteria	Pass/Fail	
(7) Dynamic Shear, G*Sinδ, (TP5)	28	1,826 kPa	≤ 5,000 kPa		<div style="border: 1px solid black; padding: 2px;">NOTE</div>
(8) Creep Stiffness, S, (TP1)	-12.0	165,500 kPa	≤ 300,000 kPa		
m-Value		0.357	≥ 0.300		
(9) T critical, T _{cr}		-24.7 °C			

NOTE: The dynamic shear results (PAV residue) fail to satisfy the criteria at the intermediate temperature based on the maximum High and minimum Low temperatures satisfied. The Low temperature grade has been increased so the dynamic shear results pass.

Reviewed by: _____ Date: _____

PAV Fracture Strength & Thermal Stress, MPa
Critical Temperature -24.7 C



Sample ID: B6225 + BOTH

Original Binder - VISCOSITY

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/14/2004

Binder Viscosity by Rotational Viscometer

Temp, °C	Speed, rpm	Torque, %	Viscosity, cP	Shear Stress, D/cm ²	Shear Rate, 1/sec	Time, sec	Viscosity, Pa·s	Viscosity, Poise	
135.0	20.0	5.8	725	49.3	6.8	60	0.73	7.3	
			725						
							Average	0.73	7.3
							Standard Deviation	0.00	0.0

ORIGINAL BINDER - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/14/2004

Criteria

$G^*/\sin \delta \geq 1.00 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G*/Sin δ kPa	Log of G*/Sin δ
1	58	70	6.146	76.84	0.974	6.31	0.80
2	64	70	3.041	78.21	0.979	3.11	0.49
3	70	70	1.544	77.85	0.978	1.58	0.19
4	76	70	0.834	75.23	0.967	0.86	-0.06

PG Rating based upon maximum temperature to satisfy criteria 70

Continuous (True) PG Rating 74.4

Original Binder - Strain Sweep, Linearity Test

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/24/2004

Strain Rate	Test Temp, °C	Complex Modulus G*, kPa	Phase Angle, degrees	Loss Ratio, G*/G* @ 2%	Linearity Check
2.0%	70.0	1.506	76.78	100.0%	LINEAR
4.0%	70.0	1.497	77.14	99.4%	LINEAR
6.0%	70.0	1.492	77.25	99.1%	LINEAR
8.0%	70.0	1.497	77.99	99.4%	LINEAR
10.0%	70.0	1.497	78.04	99.4%	LINEAR
12.0%	70.0	1.500	78.43	99.6%	LINEAR
14.0%	70.0	1.499	78.77	99.5%	LINEAR
16.0%	70.0	1.494	79.27	99.2%	LINEAR
18.0%	70.0	1.495	79.58	99.3%	LINEAR
20.0%	70.0	1.492	79.81	99.1%	LINEAR
22.0%	70.0	1.495	80.11	99.3%	LINEAR
24.0%	70.0	1.492	80.37	99.1%	LINEAR
26.0%	70.0	1.490	80.60	98.9%	LINEAR
28.0%	70.0	1.490	80.60	98.9%	LINEAR
30.0%	70.0	1.488	80.63	98.8%	LINEAR

RTFO RESIDUE - MASS LOSS

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/19/2004

RTFO Masses

Specimen	"A"	"B"
(A) Bottle Tare Mass	171.067	169.711
(B) Mass of Bottle & Binder	206.951	204.926
(C) Final Mass of Bottle & Binder	206.905	204.880
Percent Mass Loss, $100(B-C)/(B-A)$	0.128	0.131
	Average	0.129

RTFO RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/23/2004

Criteria

$G^*/\sin \delta \geq 2.20 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G^* kPa	Delta, δ degrees	$\sin \delta$	$G^*/\sin \delta$ kPa	Log of $G^*/\sin \delta$
1	64	70	7.846	68.15	0.928	8.45	0.92
2	70	70	4.190	70.16	0.941	4.45	0.64
3	76	70	2.264	71.52	0.948	2.38	0.37
4	82						

PG Rating based upon maximum temperature to satisfy criteria 76

Continuous (True) PG Rating 76.7

PAV RESIDUE - DYNAMIC SHEAR

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/24/2004

Criteria

$G^* \sin \delta \leq 5,000 \text{ kPa}$

Test Number	Test Temp °C	Zero Gap Temp °C	G* kPa	Delta, δ degrees	Sin δ	G* Sin δ kPa
1	28	28	2,376.0	50.23	0.769	1,826.2
2	31					
3	34					
4	37					

Lowest temperature to satisfy criteria 28

PAV Residue - Creep Stiffness, BBR

Project RUBBER SDY Technician BUTCH Criteria, S 300000 kPa
Binder ID B6225 BOTH Date Tested 03/24/2004 Criteria, M 0.300

Test Temp #1 -12 Avg Creep Stiffness, MPa 165,500 Avg Slope, m-value 0.357
(°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9850	0.9850	334,000	295,000	0.281	0.279
15	0.9830	0.9850	278,000	246,000	0.305	0.301
30	0.9800	0.9840	223,000	197,000	0.331	0.328
60	0.9810	0.9850	175,000	156,000	0.357	0.356
120	0.9810	0.9800	135,000	120,000	0.383	0.384
240	0.9810	0.9800	103,000	91,000	0.409	0.411

Test Temp #2 -18 Avg Creep Stiffness, MPa 331,500 Avg Slope, m-value 0.306
(°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8	0.9860	0.9870	592,000	547,000	0.235	0.225
15	0.9850	0.9770	508,000	471,000	0.256	0.250
30	0.9820	0.9750	421,000	392,000	0.281	0.278
60	0.9840	0.9740	343,000	320,000	0.307	0.305
120	0.9840	0.9720	275,000	256,000	0.332	0.333
240	0.9830	0.9770	216,000	201,000	0.358	0.361

Test Temp #3 -24 Avg Creep Stiffness, MPa Avg Slope, m-value
(°C) (at 60 sec) (at 60 sec)

Time sec	Load, Newtons		Estimated Creep Stiffness (kPa)		Slope, m-value	
	Test1	Test2	Test1	Test2	Test1	Test2
8						
15						
30						
60						
120						
240						

PG Rating based upon minimum temperature to satisfy criteria -22

Continuous PG Grade (True Grade) -27.1

PAV Residue - Direct Tension, DTT

Project RUBBER SDY

Technician BUTCH

Binder ID B6225 BOTH

Date Tested 03/31/2004

Test Number	Test Temp, °C	Failure Strain	Average	Failure Stress, Pa	Average
1	-12	1.06		2.600	
		1.32		2.970	
		1.65		3.450	
		1.95		3.710	
		0.84		2.120	
		1.22	1.54	2.920	3.263
2	-18	0.24		1.330	
		0.53		2.520	
		0.72		3.330	
		0.45		2.460	
		0.31		1.580	
		0.31	0.50	1.580	2.473
3	-24				
4	-30				

Critical Cracking Temperature -24.7

PG Rating based upon minimum temperature to satisfy criteria -22

