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PERFORMANCE PREDICTION OF WARM MIX ASPHALT PAVEMENT
CONTAINING RECLAIMED ASPHALT PAVEMENT IN RHODE ISLAND

BY

NEHA SHRESTHA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
TRANSPORTATION ENGINEERING

UNIVERSITY OF RHODE ISLAND

2019

MASTER OF SCIENCE THESIS

OF

NEHA SHRESTHA

APPROVED:

Thesis Committee:

Major Professor

K. Wayne Lee

George Veyera

Mike Greenfield

Nasser H. Zawia

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
2019

ABSTRACT

The warm mixed asphalt (WMA) technology has gained a lot of interests in the recent years in academia, state agencies and industries. WMA technology allows reductions in production and compaction temperatures guaranteeing relevant environmental and cost saving benefits. The purpose of the present study was to study and evaluate the performance of a typical additive in WMA pavement with Reclaimed Asphalt Pavement (RAP) on rutting, fatigue cracking and thermal cracking resistance on RI Route 102.

In the present study, the asphalt binder was tested at different dosages of additive using Dynamic Shear Rheometer (DSR), Rolling Thin Film Oven (RTFO), Pressure Aging Vessel (PAV), Multiple Stress Creep Recovery (MSCR) and Bending Beam Rheometer (BBR). From the overall test, it was found that 0.7% additive would lessen pavement damage due to rutting, fatigue cracking and thermal cracking.

Based on the results of binder test, Hot Mix Asphalt (HMA) and WMA specimens containing 20 % RAP were prepared using PG 58-28 asphalt binder and Superpave Gyratory Compactor (SGC). From the volumetric analysis of both HMA and WMA specimens, it was determined that the optimum binder content (OBC) for HMA with 20% RAP was 5.3 percent and the OBC for WMA (0.7% additive with RAP) was 5.6%. It was found that the required amount of neat regular asphalt binder for WMA specimen was higher than the one required by HMA. HMA and WMA Specimens with each containing 20% RAP were prepared at OBC and indirect tensile (IDT) strength test were conducted on that specimen. The test indicated that the performance of HMA mixtures was better than WMA with same amount of RAP.

RI Route 102 was used as case study in this research study. Route 102 was rehabilitated

through Full Depth Reclamation (FDR) in 2015. First half road of RI Route 102 was built with HMA base and surface layer and the other half was built with WMA base and surface layer using a typical additive. It was found that both sections have similar value in Pavement Serviceability Index (PSI) and in International Roughness Index (IRI) at this time.

Four specimens were prepared to predict the performance of asphalt pavement using the dynamic modulus and the master curve. Two HMA specimens each were prepared with and without RAP. Similarly, other two WMA specimens were prepared with and without RAP. These four specimens were tested with the Asphalt Mixture Performance Tester (AMPT) machine and developed the master curves for each specimen. The results of the material testing were used to predict the performance of each test sections by using AASHTOWare Pavement ME Design (PavementME) software.

It was found that the WMA-RAP performed better in fatigue cracking resistance but was found to perform poor in rutting resistance than HMA and HMA-RAP. This indicated that fatigue cracking was not a problem with WMA-RAP mixtures whereas rutting resistance still requires further investigation and improvement.

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CHAPTER-1

INTRODUCTION

Increasing truck traffic loads and traffic volumes have led to high demand of more durable and sustainable pavements. It has been estimated that the truck traffic on our highways will be increasing and surpassing all other modes of freight shipments in the near future. Tractor trailers and heavy vehicles account for much of the damage done to highways (Lee and Peckham 1990). Thus, there is need of lots of rehabilitation of the pavement. In such cases, substantial volumes of removed asphalt concrete are created during rehabilitation and reconstruction. The disposal of this material consumes a great deal of land and creates the potential for pollution of the environment. These excess materials, in turn, can create an opportunity for great amounts of the old asphalt pavement to be re-used and reclaimed. Thus, it saves the expensive virgin materials use, production and hauling costs. Furthermore, increasing costs of asphalt binder, dwindling budgets, growing traffic have caused desire to find more sustainable pavement strategies and techniques. Moreover, maximizing the recycling of reclaimed asphalt pavement (RAP) can promote better performance, construction, and budgets costs.

1.1 Reclaimed Asphalt Pavement

RAP is granular pavement materials containing mixture of bitumen and aggregates produced after the removal of the asphalt pavement by milling partial or full depth. Asphalt pavement rehabilitation involves milling and resurfacing of the existing asphalt pavement to mitigate the rutting, cracking, potholes and other distresses. Use of RAP saves natural resources and money, and it is environment friendly. There are millions of tons of RAP stockpiled in the north-eastern United States.

There are several studies that RAP materials could be used to resist rutting, thermal

cracking and temperature susceptibility using different recycling techniques (Lee et al. 1998; Lee et al. 1999; Lee et al. 2014; Lee et al. 2016; Mallick et al. 2008; Saleh et al. 2016). One of the advantages from RAP utilization is that it doesn't have to be heated to a high temperature to prevent further aging (of its already aged binder) and rapid restoration. In fact, to prevent RAP from getting heated to a very high temperature (very high referring to conventional virgin mix production temperature, e.g., 150°C; recommended ranges of generally accepted RAP temperatures are 110°C to 135°C), the material will be introduced in a separate spot in recycling drum plant, so that it does not come in contact with the heater flame, but instead is heated by contact with the superheated (190 °C) virgin aggregates (Zhang et al 2015).

1.2 Warm Mix Asphalt

Warm Mix Asphalt (WMA) is a recent broad category of technology in the asphalt industry which is aimed at reduction in energy consumption for the production and construction of asphalt pavement (Mallick et al. 2008). WMA is produced at temperature about 15 to 40°C lower than those required to produce hot mixed asphalt (HMA). This technology provides a method of attaining low viscosity in asphalt at relatively low temperatures (Hernandez and Lee 2012). Energy savings come with two major benefits: lower construction costs and reduced emissions, which make the construction of asphalt pavements more affordable and more environmentally conscious. Sebaaly et. al (2015) concluded that WMA performed comparatively to HMA.

Incorporating RAP in WMA can increase the sustainability benefits and enhance the performance of asphalt pavement against rutting (Saleh et al. 2016). And, WMA allows high proportions of RAP in asphalt mixtures (Mallick et al. 2008; Saleh et al. 2016).

WMA uses additives (organics/chemicals) or a water-based foaming process to reduce the temperature needed to produce asphalt materials (Rubio et al. 2012).

1.2.1 WMA Additives

Evothrm is a chemical warm mix additive that has been typically used by asphalt paving industry. It is a new generation WMA chemical additive that allows a temperature reduction in the range of 50 to 75°C lower than typical HMA. The addition of Evothrm helps to integrate recycled asphalt materials in asphalt mixtures easily (Kuang 2012). Evothrm is a typical WMA additive has been used in Rhode Island (RI).

1.3 Justification for and Significance of the Study

The use of RAP can reduce the need for virgin materials and is a sustainable rehabilitation technique. The recycling of old asphalt pavement materials can help in saving material, money and energy during production. Aggregate and binder from asphalt pavements can be recycled although such pavements have completed its service lives. The Rhode Island Department of Transportation (RIDOT) uses full depth reclamation (FDR) as one of its rehabilitation strategies and had several projects including Route 102 in Coventry and Foster from Harkney Hill road to the Old Plainfield Pike. RIDOT has been using FDRs in order to build stronger roads, have less physical maintenance and control costs (Lee et. al., 2017). Typically, the RI asphalt pavements are designed for 20 years for regular HMA pavements and generally consist of four layers (namely subgrade soils, granular subbase, granular or asphalt base, and asphalt surface). To maintain and rehabilitate pavement there needs to be a strategy to meet up the 20 years design life. However, at this time, there are no specific standard input material parameters to characterize the material so the performance can be predicted. The result of this research study will help to select the proper

material parameters to predict the better performance of asphalt pavement containing RAP.

1.4 Objectives of the Study

The primary objective of this study is to develop WMA mixtures with RAP in RI for better performance, and to investigate the feasibility of using a typical WMA additive, in a base layer. The specific objective of this research is as follows:

1. Compare the rheological properties of WMA asphalt binder with the straight one
2. Collect the existing data from the test sections of Route 102 including resilient moduli of subbase materials, pavement condition, material properties, and design parameters
3. Determine accurate material input parameters
4. Predict the performance of pavement structures with rehabilitation strategy used in Route 102 in terms of rutting, cracking and roughness Predict the performance of pavement structures with WMA containing RAP in terms of rutting, cracking and roughness
5. Develop guidelines for long-term evaluation.

1.6 Structure of the Study

This thesis consists of eight chapters. Chapter 1 shows the background of the research study with the significance of the research and discusses about the objectives of the study. Chapter 2 discusses the asphalt binder and material properties for HMA and WMA. Chapter 3 discusses about the volumetric design of HMA and WMA mixtures and evaluates the mechanical properties of HMA and WMA containing RAP. Chapter 4 discusses about the dynamic modulus and master curve of HMA and WMA mixtures. Chapter 5 discusses about RI Route 102 test sections and its details. Chapter 6 describes about input parameters

for ME Pavement software to predict the performance of asphalt pavement. Chapter 7 provides the performance prediction of RI Route 102 by PavementME. Finally, Chapter 8 provides conclusions and recommendations.

CHAPTER-2

EVALUATION OF ASPHALT BINDER

2.1 Materials and Sample Preparation

Rhode Island typically uses PG 58-28 as base binder when mixtures contain more than 15-25% RAP in accordance with RIDOT specification [RIDOT 2004]. In this study, straight Asphalt binder, of PG grading 58-28 without any polymer modification, was acquired from Bitumar in Providence(see Appendix D for material datasheet). This company is based in Quebec in Canada. Evotherm WMA was added by percentage of total sample weight, as prescribed by the manufacturer. WMA binders were prepared using a high shear mixer i.e., mechanical stirrer attached with heater. Asphalt was heated to 138°C (280°F) in the oven till the asphalt binder becomes liquid. Then, Asphalt binder was taken out from the oven and added the typical WMA additive slowly at a low mixing speed. The mixture was sheared with 150 rpm rotation speed for about 30 min to ensure that the blend became essentially homogenous. Figure 1 shows the production of WMA binder with the mechanical stirrer and heater. Heater is attached just to maintain the binder in liquid state and the temperature should not go above 280 °F.

According to the company recommendation about the dosage rates, samples were prepared (Table 1). The prepared sample can be found in Table 2 with details of mixing temperature.

Table 1 Recommendation by Producer

Additive	Dosage rate for study	Dosage rate recommended by Manufacturer
Evotherm	0.5%, 0.7% and 0.9%	(0.3 -75) %

Table 2 Material Preparation Details

Sample	Sample Name	Mixing Temperature
Neat Binder (PG 58-28)	0-0	310°F
Asphalt Binder with 0.5% Evotherm	0-5	280°F
Asphalt Binder with 0.7% Evotherm	0-7	280°F
Asphalt Binder with 0.9% Evotherm	0-9	280°F

a. Additive

b. Heating on oven before mixing

c. Mechanical Stirrer

Figure 1 Production of WMA Binder

2.2 Laboratory Testing Method

2.2.1 Dynamic Shear Rheometer (DSR) Test

DSR (figure 2) was used to determine the viscous and elastic behavior of asphalt binders at temperature starting from medium to high. The DSR is able to compute the complex shear modulus (G^*) and phase angle (δ). The complex shear modulus (G^*) is defined as the specimen's total resistance to deformation when repeatedly sheared, and the phase angle (δ), is the lag between the applied shear stress and the corresponding shear strain. In

Superpave instruction, high temperature grade has been defined as the temperature which $G^*/\sin \delta$ of bitumen before and after aging is more than 1.0 and 2.2 kPa. The test was performed at increasing temperatures until it fails. The larger the phase angle (δ), the more viscous the material would be. Phase angle (δ) limiting values are:

- Purely elastic material: $\delta = 0$ degrees
- Purely viscous material: $\delta = 90$ degrees

G^* and δ are used as predictors of potential HMA rutting and fatigue cracking.

Figure 2 Dynamic Shear Rheometer

2.2.2 Rolling Thin-Film Oven (RTFO) Test

RTFO was used to produce short term aged asphalt binder for physical property testing following AASHTO T 240 (Figure 3). Asphalt binder is exposed to oven temperature at 325°F (163°C) for 85 minutes to simulate manufacturing and placement aging. This aging

is expected to represent most conditions where the asphalt is considerably aged from the first exposure to the plant burner and contact with hot aggregates, throughout hauling and paving and until the final compaction takes place. Research leading to the development of the RTFO test indicated that aging of 85 min produces aging effects comparable to average field conditions.

Figure 3 Rolling Film Thin Oven

2.2.3 Multiple Stress Creep Recovery (MSCR) Test

MSCR test is the most recently developed test for binders to determine non-recoverable creep compliance (J_{nr}) which is the ratio of non-recoverable strain to applied stress. The procedures have been followed from AASTHO M332 which simulates the field loading condition which is why J_{nr} can be considered as rutting parameter. It provides high temperature binder specification that more accurately indicates the rutting performance of the asphalt binder. A major benefit of this MSCR test is that it eliminates the need to run tests such as elastic recovery, toughness and tenacity, and force ductility. This test is specifically designed to indicate the polymer modification of asphalt binders.

Using DSR, a 1 - second creep load is applied to the asphalt binder sample. This implies the sample is let to recover after the application of 1 - second load. A single MSCR test

yields meaningful information on performance and formulation of asphalt binder. Higher levels of stress and strain are applied to the binder that better represents the actual condition of pavement. By using the higher levels of stress and strain, the response of asphalt binder shows the stiffening effects and delayed elastic effects.

2.2.4 Pressure Aging Vessel (PAV)

PAV (Figure 4) provides simulated long-term aged asphalt binder for physical property testing. Asphalt binder is applied heat and pressure to simulate in-service aging over a 7 to 10-year period. The RTFO residue was aged in a PAV for 20 hours in a heated vessel pressurized at 100 °C to 305 psi (2.10 MPa) according to AASTHO R28. The PAV residue was tested in the DSR for $G^* \sin \delta$. The test was performed at decreasing temperatures until it failed the requirements of a maximum of 5,000 kPa. This test determines fatigue and low temperature cracking potential of asphalt pavement.

Figure 4 Pressure Aging Vessel

2.2.5 Bending Beam Rheometer (BBR) Test

BBR test (Figure 5) provides a measure of low temperature stiffness and relaxation properties of asphalt binders. These parameters reflect the asphalt binder's ability to resist low temperature cracking. PAV residue was tested at low temperature using the BBR to measure creep stiffness (S) and logarithmic creep rate (m) at 60 seconds as followed through AASTHO T313. The specification requires that the stiffness of the testing specimen (S) should be less than 300 MPa and the value of m should be greater than 0.300 in order to resist the low temperature cracking.

Figure 5 Bending Beam Rheometer

2.3 Test Results and PG Grading

Superpave performance grading (PG) is built around the concept that HMA asphalt binder's properties should be related to the conditions of its application. It was originally developed during the Strategic Highway Research Program (SHRP) in the early 1990's. PG specification classifies asphalt binders into performance grades which varies at 6°C intervals as per the service climate. For asphalt binders, two numbers are used to show Superpave performance grading– the first one for the average seven-day maximum pavement temperature (°C) and the second for the minimum pavement design temperature likely to be experienced (°C). Hence, a PG 58-22 suggests being used where the average seven-day maximum pavement temperature is 58°C and the expected minimum pavement temperature is -22°C.

According to AASHTO M 320-05 (figure 6), high temperature grade has been defined as the temperature which $G^*/\sin \delta$ of bitumen before and after aging is more than 1.0 and 2.2 kPa, respectively. The high temperature grade was established on the basis of this criteria. The low temperature grade was found after testing the PAV aged binders for $G^*\sin \delta$ and creep stiffness. The results of PG grading of Asphalt binder from DSR, RTFO, PAV and BBR are shown in Table 3 and hence with the help of PG grading sheet (figure 6), PG grades of asphalt binder were determined.

The manufacturer suggested that Evotherm does not adversely impact the asphalt binder performance grade at the recommended Evotherm dosages which is from 0.25% - 0.75% by weight of the total binder.

The original asphalt used had PG of grading 58-28 and the modified asphalt with Evotherm were evaluated if they met this grading requirement in reference to AASHTO M 320-05 (figure 6). Use of Evotherm from 0.5-0.7% was successful in lowering low temperature on the basis of PAV and had PG grading of 58-34. It was found that 0.5% and 0.7 % Evotherm enhanced low temperature performance. However, increasing the Evotherm to 0.9% (which is over recommended) performed as original binder.

Table 3 Results of PG Grading of Asphalt Binder

Asphalt Name	Description	PG Grade
0-0	PG 58-28 without additive	58-28
0-5	PG 58-28 with 0.5% additive	58-34
0-7	PG 58-28 with 0.7% additive	58-34
0-9	PG 58-28 with 0.9% additive	58-28

Performance Grade	PG 46			PG 52			PG 58			PG 64			PG 70			PG 76			PG 82								
	34	40	46	10	16	22	28	34	40	10	16	22	28	34	40	10	16	22	28	34	40	10	16	22	28	34	
Average 7-day Max Pavement Design Temperature, °C	< 46			< 52			< 58			< 64			< 70			< 76			< 82								
Min Pavement Design Temperature, °C	-34	-40	-46	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	
ORIGINAL BINDER																											
Flash Point Temp, T48, Min °C	230																										
Viscosity, ASTM D 4402: Max. 3 Pa s, Test Temp. °C	135																										
Dynamic Shear, TP 5 Min, 1Kpa G*/sinδ Test Temp @ 10 rad/s, °C	46			52			58			64			70			76			82								
ROLLING THIN FILM OVEN RESIDUE (T 240)																											
Mass loss, Max. percent	1.00																										
Dynamic Shear, TP 5 Min, 2.20 Kpa G*/sinδ Test Temp @ 10 rad/s, °C	46			52			58			64			70			76			82								
PRESSURE AGING VESSEL RESIDUE (PP 1)																											
PAV Aging Temperature °C	90			90			100			100			100 (110)			100 (110)			100 (110)								
Dynamic Shear, TP 5 Min, 5000 Kpa G*/sinδ Test Temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	34	31	28	25	22	19	37	34	31	28	34	31	28
Report																											
Physical Hardening																											
Creep Stiffness, TP 1 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP 3 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

Figure 6 PG Gradation Sheet (Extracted from AASHTO M 320-05, Standard

Specification for Performance Graded Asphalt Binder)

DSR Test results on Unaged Asphalt binder with and without additive

Table 4 DSR Results of unaged asphalt binders at 58 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G*/sin(delta) kPa	Pass / Fail
0-0	10	58	0.22	12	83.9	1.84	1.85	Pass
0-5	10	58	0.21	12	83.7	1.73	1.74	Pass
0-7	10	58	0.23	12	83.5	1.93	1.94	Pass
0-9	10	58	0.22	12	83.4	1.87	1.88	Pass

Table 5 DSR Results of unaged asphalt binders at 64 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G*/sin(delta) kPa	Pass / Fail
0-0	10	64	0.1	12	85.7	0.873	0.875	Fail
0-5	10	64	0.1	12	85.5	0.824	0.827	Fail
0-7	10	64	0.11	12	85.4	0.909	0.912	Fail
0-9	10	64	0.11	12	85.3	0.891	0.894	Fail

DSR on RTFO Residue

Table 6 DSR Results of RTFO aged residue asphalt binders at 58 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G*/sin(delta) kPa	Pass / Fail
0-0	10	58	0.8	10	74.9	8.04	8.33	Pass
0-5	10	58	0.63	10	75.7	6.32	6.52	Pass
0-7	10	58	0.7	10	75.4	6.97	7.2	Pass
0-9	10	58	1	10	72.5	9.94	10.4	Pass

Table 7 DSR Results of RTFO aged residue asphalt binders at 64 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G*/sin(delta) kPa	Pass / Fail
0-0	10	64	0.38	9.9	78	3.8	3.88	Pass
0-5	10	64	0.3	10	78.7	3.01	3.07	Pass
0-7	10	64	0.33	10.1	78.4	3.32	3.39	Pass
0-9	10	64	0.47	10	75.7	4.73	4.88	Pass

Table 8 DSR Results of RTFO aged residue asphalt binders at 70 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G*/sin(delta) kPa	Pass / Fail
0-0	10	70	0.18	10	80.8	1.84	1.87	Fail
0-5	10	70	0.15	10	81.4	1.47	1.48	Fail
0-7	10	70	0.16	10.0	81.1	1.61	1.63	Fail
0-9	10	70	0.23	10	78.8	2.31	2.36	Pass

MSCR Test on RTFO Residue

Table 9 MSCR Results of RTFO aged asphalt binders

Asphalt Binder	R _{0.1} (%)	R _{3.2} (%)	R _{diff} (%)	J _{nr 0.1} (kPa ⁻¹)	J _{nr 3.2} (kPa ⁻¹)	J _{nr diff} (%)
0-0	20.79	11.53	44.53	0.680	0.787	15.8
0-5	16.36	6.65	59.37	1.09	1.29	18.42
0-7	18.09	8.53	52.87	0.883	1.04	17.54
0-9	25.34	13.41	47.06	0.599	0.725	21.06

Where,

R_{0.1} -Average Percent Recovery at 0.1 kPa

R_{0.2} - Average Percent Recovery at 3.2 kPa

R_{diff} -Percent difference between average recovery at 0.1 kPa and 3.2 kPa

J_{nr 0.1} -Non-recoverable creep compliance at 0.1 kPa

J_{nr 3.2} -Non-recoverable creep compliance at 3.2 kPa

J_{nr diff} -Percent difference between non-recoverable creep compliance at 0.1kPa and 3.2 kPa

DSR Test on PAV Residue

Table 10 DSR Results of PAV Residue at 19 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G* sin(delta) kPa	Pass / Fail
0-5	10	19	17.55	1	53.5	1760	1410	Pass
0-9	10	19	57.44	1	39.6	5720	3640	Pass

Table 11 DSR Results of PAV Residue at 16 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G* sin(delta) kPa	Pass / Fail
0-0	10	16	47.04	1.0	47.8	4660	3460	Pass
0-5	10	16	28.26	1.0	50.9	2840	2200	Pass
0-7	10	16	36.07	1.0	49.4	3600	2740	Pass
0-9	10	16	84.49	1	37.4	8350	5070	Fail

Table 12 DSR Results of PAV Residue at 13 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G* sin(delta) kPa	Pass / Fail
0-0	10	13	73.86	1.0	45.1	7340	5210	Fail
0-5	10	13	45.09	1.0	48.2	4530	3380	Pass
0-7	10	13	58.12	1.0	46.5	5790	4200	Pass

Table 13 DSR Results of PAV Residue at 10 degree Celsius

Sample Name	Angular Frequency	Temp °C	Osc. Stress Pa	%Strain	Delta Degree	G* kPa	G* sin(delta) kPa	Pass / Fail
0-0	10	13	115.54	1.0	42.4	11400	7710	Fail
0-5	10	13	72.09	1.0	45.3	7190	5110	Fail
0-7	10	13	93.17	1.0	43.5	9200	6340	Fail

Bending Beam Rheometer Test Results

Table 14 BBR Results of PAV Residue of asphalt binder (PG 58-28)

t Time (s)	P Force (m-N)	D Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8	991	0.363	220	220	0.0	0.312
15	990	0.445	179	180	0.6	0.333
30	990	0.564	142	141	-0.7	0.355
60	989	0.726	110	110	0.0	0.378
120	987	0.950	83.8	83.8	0.0	0.400
240	986	1.262	63	63	0.0	0.423

Table 15 BBR Results of PAV Residue of asphalt binder (PG 58-28 with 0.5% additive)

t Time (s)	P Force (m-N)	D Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8	991	0.452	177	177	0.0	0.321
15	989	0.558	143	143	0.0	0.347
30	990	0.716	111	111	0.0	0.377
60	989	0.938	85	84.9	-0.1	0.406
120	988	1.256	63.4	63.5	0.2	0.435
240	988	1.715	46.5	46.5	0.0	0.465

Table 16 BBR Results of PAV Residue of asphalt binder (PG 58-28 with 0.7% additive)

t Time (s)	P Force (m-N)	D Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8	988	0.356	224	224	0.0	0.304
15	989	0.435	183	183	0.0	0.327
30	988	0.549	145	145	0.0	0.352
60	988	0.707	113	113	0.0	0.377
120	987	0.926	85.9	86	0.1	0.402
240	988	1.234	64.6	64.5	-0.2	0.427

Table 17 BBR Results of PAV Residue of asphalt binder (PG 58-28 with 0.9% additive)

t Time (s)	P Force (m-N)	D Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8	993	0.32	250	250	0.0	0.248
15	993	0.377	212	213	0.5	0.266
30	994	0.456	176	176	0.0	0.286
60	994	0.560	143	143	0.0	0.306
120	996	0.698	115	115	0.0	0.326
240	996	0.882	91.1	91.1	0.0	0.346

2.4 Analysis and Discussion

2.4.1 Resistance against Rutting

In order to resist rutting, an asphalt binder should be stiff (it should not deform too much) and it should be elastic (it should be able to return to its original shape after load deformation). Therefore, the complex shear modulus elastic portion, $G^*/\sin\delta$ (rutting parameter) should be high. When rutting is of greatest concern (during HMA pavement's early and mid-life), a minimum value for the elastic component of the complex shear modulus is specified. To get the overview, we can understand that the higher the G^* value, the stiffer the asphalt binder is (more resisting to deformation), and the lower the δ value, the greater the elastic portion of G^* is (recovering back to its original shape after deformation). Therefore, higher the rutting parameter, higher will be the performance against rutting (permanent deformation).

Figure 7 DSR Results on unaged Asphalt Binder

From results of the DSR on unaged binder as shown in figure 7, asphalt binder containing 0.7% and 0.9 % additive has the highest rutting parameter values compared to other binder. So, it concluded that (0.7-0.9) % WMA binder have better performance against rutting.

In the MSCR test, two separate parameters can be determined—non-recoverable creep compliance (J_{nr}) and percentage of recovery (R) during each loading cycle. Also, the MSCR test can be help determine the amount of recovery during the creep-recovery testing. In case the asphalt binder has a significant elastic component at the test temperature, it shows high delayed elastic response. In case the appropriate J_{nr} specification is met, then it can be expected that the binder will minimize its contribution to rutting.

For standard traffic loading, J_{nr} (at 3.2 kPa) is required to have a maximum value of 4.0 kPa⁻¹. Also, AASHTO MP19 maintains a requirement that the difference in J_{nr} values between 0.1 kPa and 3.2 kPa shear stress should not exceed a ratio of 0.75 and Table 9 shows that the results are in agreement with these conditions. Also, from MSCR results (Table 9), asphalt binder containing 0.9% additives showed the higher recovery percentage and also showed lesser non-recoverable creep compliance as compared with the regular asphalt binder.

2.4.2 Resistance against Fatigue Cracking

Fatigue damage in asphalt pavements is a complex phenomenon occurring from repeated bending that result in micro damage in asphalt pavement. This micro damage is a competitive process between micro cracking and healing, manifested as a reduction in stiffness of the asphalt pavement, degrading the load capacity and ability to resist further damage. Eventually micro cracks coalesce into macro cracks that appear in the wheel path. An asphalt binder should be elastic but not too stiff to withstand fatigue cracking which

is the reason for the complex shear modulus viscous portion, $G^*\sin\delta$ to be minimum. When fatigue cracking is of greatest concern (late in HMA pavement's life), a maximum value for the viscous component of the complex shear modulus is specified. From figure 8, it showed that 0.5% and 0.7% have lowest $G^*\sin\delta$ compared with the straight asphalt binder. Thus, it concluded that that (0.5-0.7) % WMA binders showed the better performance against fatigue cracking.

Figure 8 DSR Results on PAV Residue

2.4.3 Resistance against Low Temperature Cracking

The BBR test is used to find out the asphalt binder's creep stiffness with reference to time. This test is run on the long-term aged residue from the PAV as low temperature cracking is a common problem in older pavements. As temperature becomes low, then the asphalt binders start becoming stiffer. Stiffness can be understood as the limit an object would

withstand deformation under an applied force. Also, creep stiffness describes the strain in response to stress at low-temperature. And, as these creep stiffness are too high, cracking will occur. Here, a maximum creep stiffness value (300 MPa) was used as a higher creep stiffness value means higher thermal stresses. Similarly, a minimum m-value (0.300) was specified as a lower m-value means a smaller ability to relax stresses,. From results of BBR test as shown in figure 9, it was found that 0.5% WMA binder have less stiffness and high relaxation parameter (m-value) compared with straight asphalt binder and 0.7% WMA binder have almost same stiffness and same relaxation parameter (m-value) compared with straight asphalt binder.

Hence, It can be concluded that (0.5-0.7) % WMA additives contained binders showed better performance against lower temperature cracking. Also, from the above results in terms of rutting, fatigue cracking and thermal cracking, it was concluded that 0.7% Evothorm was the optimal dosage rate for further study.

Figure 9 BBR Results on Asphalt binder (PAV Residue)

CHAPTER 3

EVALUATION OF HMA AND WMA ASPHALT MIXTURES

3.1 Superpave Mix Design Method

One of the major output from the Strategic Highway Research Program (SHRP) was the Superpave mix design method. The Superpave mix design method was introduced to displace the Hveem and Marshall methods. The volumetric analysis which is common to the Hveem and Marshall methods also provides the basis for the Superpave mix design method. The Superpave system requires asphalt binder and aggregate selection into the mix design process and also considers traffic and climate as well. A gyratory compactor is used as compaction devices and the compaction effort in mix design is based on expected traffic is used in this method.

Under the SHRP, an initiative was undertaken to improve materials selection and mixture design by developing: A new mix design method that accounts for traffic loading and environmental conditions.

1. A new method of asphalt binder evaluation.
2. New methods of mixture analysis.

As SHRP was completed in 1993, it focused on these three aspects and termed it the Superior Performing Asphalt Pavement System (Superpave). Although the new methods of mixture performance testing have not yet been established, the mix design method is well-established.

The Superpave mix design method consists of 6 basic steps:

1. Aggregate selection.
2. Asphalt binder selection.
3. Sample preparation (including gyratory compaction).
4. Density and voids calculations.
5. Optimum asphalt binder content selection.
6. Performance Tests.

3.1.1 Aggregate Selection

Superpave specifies aggregate selection in two ways. Firstly, restrictions on aggregate gradation is made by means of broad control points and Second, “consensus requirements” is required on coarse and fine aggregate angularity, flat and elongated particles, and clay content. Other aggregate criteria calls “source properties” such as soundness, L.A. abrasion, and water absorption are used in Superpave. It is a common understanding that stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage affect the aggregate gradation (Roberts et al. 1996). Moreover, parameters such the maximum aggregate size can affect in compaction and lift thickness determination. Hence, Superpave mix design establishes aggregate gradation control points, through which aggregate gradations must pass.

Aggregate Blending It is not common to find a desired aggregate gradation from a single aggregate stockpile. Therefore, several different aggregate stockpiles are used and blended together in a ratio that may yield an acceptable final blended gradation. During this, it is

pretty normal that a Superpave mix design may use 3 or 4 different aggregate stockpiles. The present study used four types of aggregates sources and one RAP source. Within the Superpave mix design system, gradations are identified based upon nominal maximum aggregate size. Nominal maximum aggregate size (NMAS) is defined as one sieve size larger than the first sieve that retains more than 10 percent. In accordance with RIDOT specification, the mixes that contains RAP should have 19mm NMAS. Table 18 shows the blended aggregates with certain percentage that pass through the RIDOT specification. The color defines specific sources that are shown in the figure 10 and Figure 11 shows that the blended aggregates passed through RIDOT specification.

Table 18 Blend of Aggregates passed through RIDOT Specification

Sieve Size	K 3/4	K ½	K 3/8	K SS	RAP	Combined Aggregate	RIDOT Specification
25.4	100.0	100	100.0	100.0	100	100.0	100
19	89.4	100	100.0	100.0	100	97.9	98
12.7	20.6	93	100.0	100.0	99.5	82.6	80
9.51	3.3	39	95.8	100.0	89.5	65.5	62
4.76	1.1	5.5	38.8	96.9	62	40.9	40
2.38	1.1	2.5	11.2	83.8	44.5	28.6	26
1.19	1.1	2	5.8	71.9	33.5	22.9	20
0.595	1.1	1.5	4.2	52.5	26.5	17.2	15
0.297	0.6	1.5	3.1	23.1	20	9.7	10
0.149	0.6	1.5	2.3	7.5	14	5.2	6
0.075	0.6	1	1.5	2.5	8.5	2.8	3

Figure 10 Aggregates Gradation Chart

Figure 11 Blended Aggregates chart

3.1.2 Asphalt Binder Selection

As RIDOT specification (RIDOT, 2004) PG58-28 should be used to prepare asphalt mixture of class 19 with 20% RAP. Thus, the asphalt binder was used as shown in table 19.

Table 19 Sample Preparation

HMA Mixture	WMA Mixture
PG 58-28 without any rejuvenator and additives	PG 58-28 with 0.7% additive

When the binder and aggregates have been selected for the asphalt mixture, they are combined to produce the optimum mixture properties. Several trial blends are evaluated to determine the optimum binder content (OBC) mixture. The Superpave Gyratory Compactor (SGC) is used to do this and figure 12(a) shows the gyratory compactor machine which was used to make specimens for this study. The Superpave gyratory compactor is intended to the rolling effect of field paving on the mixture, and it is more consistent with the field stress state of the mixture, and closer to the actual engineering situation. In accordance to the AASTHO specification, there are some guidelines to make the specimens for specified traffic loading. This study includes the traffic loading less than 0.3 ESALs (million).

Figure 12 Samples Preparation with SGC

3.1.3 Density and Voids Analysis

All mix design methods use density and voids to determine basic HMA physical characteristics. Two different measures of densities are typically taken:

1. Bulk specific gravity (G_{mb}).
2. Theoretical maximum specific gravity (TMD, G_{mm}).

The theoretical maximum specific gravity (G_{mm}) was determined from loose asphalt mixture as shown in figure 13 in accordance with AASTHO T209. The bulk specific gravity (G_{mb}) was determined from fabricated asphalt mixture in accordance with AASTHO T166. Following the procedure, we measure the weight of sample in the dry condition (figure 14a), under water (figure 14b) and in the saturated surface dry condition, SSD (figure 14c). The measured data from both HMA specimen and WMA specimen can be

found in Appendix B.

These densities are then used to calculate the volumetric properties of the HMA. Measured void expressions are primarily:

- Air voids (V_a), sometimes expressed as voids in the total mix (VTM)
- Voids in the mineral aggregate (VMA)
- Voids filled with asphalt (VFA)

These volumetric properties are all included within the three specifications that is shown in table 11.

a. loose asphalt mixture

b. Rice Test for Gmm

Figure 13 Determination of Gmm

a Weight dry specimen

b Weight specimen under water

c Weight SSD specimen

Figure 14 Determination of Gmb

3.1.4 Selection of Optimum Asphalt Binder Content

The optimum binder content (OBC) is determined such that asphalt binder content results in 4 percent air voids at N_{design} . This asphalt content also must meet several other requirements:

Table 20 Minimum VMA Requirements and VFA Range Requirements (from RIDOT Specification)

Class of Mix	VMA	VFA	Air voids	Minimum OBC
19.0	14.5%	70% - 80%	4%	5.0

If these requirements could not be met, then the mix needs to be redesigned. But if requirement shown in the table 20 is not met but close, then slight adjustment is made to asphalt binder such that the air void content remains near 4 % but VFA is within limits. This is due to the fact VFA is considered more of a redundant term as it is a function of air voids and VMA (Roberts et al. 1996).

3.1.5 Analysis and Discussion

Figure 15 Chart showing asphalt binder content at 4% air voids

Figure 16 Chart showing VMA in different content of Asphalt Binder

Figure 17 Chart showing VFA in different content of Asphalt Binder

As required by the Superpave Mix Design, VFA%, VMA% and air voids were experimentally determined at different binder content. The graph is then plotted against VFA%, VMA% and air voids at different content of binder for HMA and WMA specimens can be found in the figure 15, 16 and 17. A curve was fitted for asphalt binder content and air voids and then, OBC is defined at the 4 % air voids. From the following graph, we can obtain that the OBC for HMA with RAP at 5.3 % and for WMA (0.7% additive) with RAP was at 5.6%. Hence, HMA-RAP required less 0.3% by volume compared with WMA-RAP.

3.2 Mechanical Properties and Strength

3.2.1 Tensile Strength Test

The tensile properties of bituminous mixtures are evaluated as it is closely associated with cracking. This done by applying the load to the cylindrical specimen along a diametric plane by introducing compressive load kept at a constant rate and acting parallel to and along the vertical diametrical plane of the specimen. The objective of such kind of configuration is to apply a uniform tensile stress perpendicular to the applied load and along the vertical diametrical plane. This will help in applying tension to the specimen by splitting along the vertical diameter.

Superpave mixed design method was used to prepare the specimen for performing this test. HMA specimens with 20% RAP and WMA ones with 20% RAP were prepared at OBC. They were continued at a temperature of 25°C for a period of 2 hours in air. These specimens were then mounted on conventional Marshall testing apparatus and loaded at a deformation rate of 51mm/min and the load at failure is recorded at each case as shown in figure 18.

A 13 mm (1/2 in.) wide strip loading is used for 101 mm (4 in.) diameter specimen to provide a uniform loading with which produces a nearly uniform stress distribution. The static indirect tensile strength of a specimen was determined using the procedure outlined in ASTM D 6931.

Figure 18 Indirect Tensile Strength Testing Machine

A loading rate of 51mm/minute is kept constant and tensile failure occurs in the specimen rather than the compressive failure. The peak load is noted, and it is divided by appropriate geometrical using the following equation:

$$S_t = \frac{2000 P}{\pi tD}$$

Where,

S_t = IDT Strength, kPa

P = Maximum load, N

t = Specimen height immediately before test, mm

D = Diameter Specimen, mm

The values of indirect tensile strength can be used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design, testing and estimating the resistance to cracking.

3.2.2 Results and Discussion

The indirect tensile strength results of HMA and WMA mixtures at unconditioned OBC samples are given in Table 21 and Table 22 respectively.

Table 21 Results of Indirect Tensile Strength Test of HMA Specimen

HMA Specimen #	Specimen Height (t), mm	Diameter Specimen, mm	Maximum load, N	IDT Strength, kPa
HMA #1	55.88	150	11676.8	873.34
HMA #2	48.26	150	10123.75	876.74
HMA #3	48.13	150	5224.3	453.63
HMA #4	50.8	150	6154.35	506.34

Table 22 Results of Indirect Tensile Strength Test of WMA Specimen

WMA Specimen #	Specimen Height (t), mm	Diameter Specimen, mm	Maximum load, N	IDT Strength, kPa
WMA #1	41.95	150	5255.45	523.6
WMA #2	50.8	150	6434.7	529.4
WMA #3	49.53	150	6483.65	547.1
WMA #4	48.26	150	8708.65	754.19

The above test results showed that the average tensile strength of HMA mixtures with 20% RAP is 677.51 kPa with standard deviation of 299.10 kPa, whereas, WMA is 588.57 kPa with standard deviation 110.86 kPa. The test results showed variation in strength results which could be attributed to sample preparation, material handling, instrumental handling and other potential sources of error. However, it was found that HMA mixtures have high average tensile strength compared with WMA mixtures.

CHAPTER-4

DYNAMIC MODULUS AND MASTER CURVE

4.1 Dynamic Modulus

Complex dynamic modulus (E^*) a property of viscoelastic materials which can be defined as the ratio of stress to strain under to periodic variation of stress. Due to such loading, the strain in a viscoelastic material is observed with a phase delay φ from the stress. Under such condition, stress is $\sigma = \sigma_0 \sin(\omega t)$ and strain is given by $\varepsilon = \varepsilon_0 \sin(\omega t - \varphi)$. Then the complex modulus can be computed as following:

$$E^* = \sigma/\varepsilon = \sigma_0 \sin \omega t / \varepsilon_0 \sin(\omega t - \varphi) \quad (1)$$

Where,

σ_0 = maximum stress,

ε_0 = maximum strain,

φ = phase lag between stress and strain in degrees,

ω = angular frequency in radians per second,

t = time in seconds, and

Dynamic modulus($|E^*|$) is the absolute value of complex modulus which can reveal the viscoelastic

behavior of any particular mix over a wide range of temperature and loading frequency.

To calculate this, a repeated load is applied at varying frequencies to a test specimen over a relatively short period of time and the corresponding strain is recorded. Figure 19 shows the stress and stress relationship under a sinusoidal loading.

Figure 19 Dynamic Modulus Test Curve

4.2 Master Curves

The mechanical behavior of viscoelastic materials is dependent on the temperature and frequency of loading. If for these variables, the material behaviors are viscoelastic, it is possible to characterize such material as rheologically simple and time temperature superposition can be used to show the effect of time and temperature under different loading conditions. It has been observed that the effects of temperature and time are equivalent and efforts to express the effect of both variables led to the introduction of theoretical master curves. This could be achieved by obtaining data at several temperatures and frequency and developing a master curve at a single reference temperature. The time temperature superposition is done such the a smooth function is plotted when data at various temperatures are shifted with respect to frequency (Dickinson and Witt 1974). It is understood that the greater the shift factor, the greater is the temperature dependency of the mix.

In the new M-E PDG, the viscoelastic behavior of HMA at different range of temperature and time rate of load, is established based on a master curve at a reference temperature .The

master modulus curve can be mathematically represented by a sigmoidal function defined from the following equation:

$$\text{Log } |E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log f_r)}} \dots\dots\dots (2)$$

Where,

f_r = shifted frequency at reference temperature

δ = minimum value of E^*

$\delta + \alpha$ = maximum value of E^*

β, γ = regression parameters of the sigmoidal function

The shift factor can be derived from following :

$$\alpha(T) = \frac{f_r}{f} \dots\dots\dots (3)$$

Where,

$\alpha(T)$ = shift factor as a function of temperature

f = frequency at desired temperature

f_r = shifted frequency at reference temperature

T = temperature of interest, °C

The relationship between the logarithm of the shift factor i.e. $\text{Log } \alpha(T_i)$ and the temperature in °C can be expressed with a polynomial which is as follows:

$$\text{Log } \alpha(T_i) = a T_i^2 + b T_i + c \dots\dots\dots (4)$$

Where,

$\alpha(T_i)$ = shift factor as a function of temperature T_i

T_i = temperature at any instant, °C

a, b and c = regression coefficients

4.3 Specimen Preparation for Asphalt Mixtures Performance Tester (AMPT)

For this study, four samples were prepared according to AASTHO 342-1 and the details of the four specimens can be found in the table 23. For AMPT testing, specimens should be prepared under some criteria. These criteria can be found in the table 24. Also, Details graph of each specimen at different temperature and frequencies are shown in Appendix C.

Table 23 Details of Four Types of Asphalt mixture Specimens

Sample A	Asphalt Binder PG 58-28	HMA mixtures for Base with 20% RAP
Sample B	Asphalt Binder PG 58-28 with 0.7% Evotherm	WMA mixtures for Base with 20% RAP
Sample C	Asphalt Binder PG 64-28	HMA mixtures for Base without RAP
Sample D	Asphalt Binder PG 64-28 with 0.7% Evotherm	WMA Mixtures for Base without RAP

Table 24 Criteria for AMPT Testing's Specimen

Criterion Items	Requirements
Size	Average diameter between 100 mm and 104 mm Average height between 147.5 mm and 152.5 mm
Gyratory Specimens	Prepare 175 mm high specimens to required air void content (AASHTO T 312)
Coring	Core the nominal 100 mm diameter test specimens from the center of the gyratory specimen. Check the test specimen is cylindrical with sides that are smooth parallel and free from steps, ridges and grooves
Diameter	The standard deviation should not be greater than 2.5 mm
End Preparation	The specimen ends shall have a cut surface waviness height within a tolerance of ± 0.05 mm across diameter The specimen end shall not depart from perpendicular to the axis of the specimen by more than 1 degree
Air Void Content	The test specimen should be within ± 1.0 percent of the target air voids
Replicates	For two LVDT's, two replicates with a estimated limit of accuracy of 13.1 percent
Sample Storage	Wrap specimens in polyethylene and store in environmentally protected storage between 5 and 26.7° C (40 and 80° F) and be stored no more than two weeks prior to testing

4.1.1 Results of Dynamic Modulus testing of four specimens

Table 25 Dynamic Modulus of Sample A (HMA specimen with RAP)

Dynamic Modulus						
T (°F)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
40 (4)	1,881,000	2,726,000	3,164,000	4,380,000	4,963,000	5,771,000
70 (21)	646,800	1,030,000	1,224,000	1,921,000	2,281,000	2,782,000
100 (37)	254,400	371,600	440,700	726,400	893,700	1,102,000
130 (54)	109,100	153,200	173,800	301,800	374,500	427,300

Table 26 Dynamic Modulus of Sample B (WMA specimen with RAP)

Dynamic Modulus						
T (°F)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
40 (4)	760,600	1,281,000	1,553,000	2,526,000	3,016,000	3,634,000
70 (21)	248,600	387,400	458,100	922,700	1,179,000	1,423,000
100 (37)	101,200	188,600	218,700	420,800	569,800	723,500
130 (54)	81,700	93,400	120,000	135,000	198,100	320,200

Table 27 Dynamic Modulus of Sample C (HMA Specimen)

Dynamic Modulus						
T (°F)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
40 (4)	2,271,000	3,570,000	4,212,000	6,015,000	6,838,000	7,923,000
70 (21)	442,900	864,100	1,137,000	2,096,000	2,632,000	3,365,000
100 (37)	138,900	206,600	243,700	511,700	696,600	904,300
130 (54)	91,600	123,100	137,100	270,900	367,400	452,400

Table 28 Dynamic Modulus of Sample D (WMA Specimen)

Dynamic Modulus						
T (°F)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
40 (4)	2,328,000	3,465,000	4,064,000	5,722,000	6,533,000	7,689,000
70 (21)	759,000	1,260,000	1,539,000	2,490,000	3,007,000	3,783,000
100 (37)	307,000	461,000	552,500	982,200	1,239,000	1,588,000
130 (54)	97,800	134,900	155,900	265,600	341,500	432,100

All Dynamic modulus are reported in psi.

Table 29 Master Curve Parameters

	δ	α	β	γ
HMA w RAP	4.568099	2.490947	-0.445790	-0.468820
WMA w RAP	4.629264	2.267807	0.0602610	-0.645040
HMA w/o RAP	4.84628	2.190182	-0.155180	-0.820180
WMA w/o RAP	4.088297	3.098425	-0.768200	-0.417560

4.4 Development of Master curves of four specimens

Figure 20 Master Curves and Shift factor plots of HMA and WMA specimen

From the table 25-28, it is seen that dynamic modulus of all WMA and HMA mixtures decreases significantly with the increase of temperature and exhibits frequency dependency under same temperature condition. Higher loading frequency means the higher dynamic modulus for asphalt mixtures, which illustrates the viscoelastic properties of that asphalt mixtures (Zhu et al 2011).

Figures of $|E^*|$ versus loading frequency where the $|E^*|$ data are shifted using a nonlinear optimization by solving shift parameters, and can be found in the Appendix C. In this study, 21 °C (70°F) is taken as the reference temperature and $|E^*|$ master curves of all mix were constructed at the reference temperature following the principle of time-temperature superposition. The data at various temperatures were shifted in line with frequency until the curve merges into a single sigmoidal function, representing the master curve (Figure 20). Least-squares method is used for solving the coefficients of the sigmoidal functions (α , β , γ and δ)(Table 29), and the coefficients of the second-order polynomial (a, b, and c) as Eq.4. And, the fitted master curves of each mixture can be found in the Appendix C. The shift factor is a function of temperature and is independent of strain level so it can be used within the linear viscoelastic range to be predict material behavior at any strain levels.

After that, figure 20 showed combined master curve of four different mix that were plotted in one graph. This figure showed that at high temperature and low frequency, HMA-RAP indicates highest reduced modulus and WMA without RAP has second highest modulus compared to other mix. So, it was concluded that WMA without RAP can be expected to improve performance against rutting compared with HMA without RAP and WMA-RAP. Again, at high frequency and low temperature, WMA-RAP indicates lowest reduced modulus compared with all other mix. We found out that WMA-RAP mixtures can be

expected to improve the performance against fatigue cracking compared with other mixtures, but was found to perform poor in rutting resistance than HMA and HMA-RAP.

CHAPTER 5

CASE STUDY OF REHABILITATION DESIGN OF RHODE ISLAND (RI) ROUTE 102

5.1 Rehabilitation Design of RI Route 102

Route 102 in Coventry, Rhode Island, was selected as a test road with two sections (HMA and WMA). The road had severe pavement distresses such as alligator cracking, block cracking, transverse cracking and longitudinal cracking and was not a candidate for a resurfacing. The road was selected for Full Depth Reclamation (FDR) in 2015 and has two sections; HMA and WMA (Evotherm has been used as warm mix additives). The project consisted of applying WMA additive to the pavement mixture for approximately one half of the 4.23 miles of roadway. Figure 21 shows the map of RI Route 102 sections.

Figure 21 Map of RI Route 102 sections

The project included the reclamation of an existing pavement structure and one section had placement of 3 inches of Class 19.0 WMA as base course and 2 inches of Class 12.5 WMA as surface course. The other section had placement of 3 inches of Class 19.0 HMA as base course and 2 inches of Class 12.5 HMA as surface course. The maximum sizes of base and surface aggregate were 19 mm (3/4 in.) and 12.5 mm (1/2 in.), respectively. Figure 21 shows cross section of HMA section (i.e. from 15 Perry Hill roads to the right as marked by red line segment in the figure) of Route 102 and cross section of WMA section (i.e. 174 Old Plainfield Pike to the left as marked by blue line segment in the figure)) of Route 102 after rehabilitation in 2015.

Figure 22 Cross section of HMA and WMA Section of Route 102

Table 29 shows the various soil types and properties, and American Association of State and Highway Transportation Officials (AASHTO) classifications of the soil ranges from A-2 to A-8 (Soil Survey of Rhode Island, 1981). Soils within Route 102 have severe frost action on all over the sections. Route 102 is comprised of very stony fine sandy soils; therefore, the plasticity index is NP-10. Areas of Route 102 contain wood bridge soil, Adrian soil, Canton soil and Leicester soil.

Table 30 Soil Classification of Route 102 (from Harkney Hill road to the Plainfield Pike)

Soil Index	Soil Name	AASHTO Classification	Liquid Limit	Plasticity Index	USDA Texture	Permeability (Inch/hour)	Depth (Inch)	Available water capacity (in/in)	Local Roads and streets
WoB	Wood Bridge	A-2, A-4	<30	NP-10	Very Stony fine sandy loam	0-7	0.6-6.0	0.08-0.23	Severe: Frost Action
Aa	Adrian	A-2, A-8			Loamy sand, fine sand	2-6	0-20	0.35-0.45	Severe: Frost Action, excess humus
ChB	Canton	A-2, A-4	<18	NP	Very stony fine sandy loam	2-6	3-22	0.13-0.2	Slight
Rf	Leicester	A-2, A-4	16-35	NP-10	Extremely stony fine sandy loam	0.6-6.0	0-4	0.06-0.24	Severe: Frost Action

5.2 Pavement Evaluation for Rehabilitation Design

Triaxial testing was performed on the subbase materials and subgrade soils before and after the FDR treatments to determine the resilient modulus. Appendix II shows the resilient modulus of subbase and Subgrade soil. The results of the material testing were used to predict the performance of each test section using AASHTOWare Pavement ME Design software.

The gradation sheet of Reclaimed base materials is shown on Table 30.

Table 31 Reclaimed Base Course Gradation

Sieve Size	3"	3/4 "	1/2"	3/8 "	#4	#40	#200
RIDOT Specification	95-100	90-80	-	-	-	-	12-3
Passing (g)	4482.0	4051.0	3510.0	3023.0	2234.0	174.0	31.0
% Passing	100.0%	90.4%	78.3%	67.4%	49.8%	3.9%	0.7%

The rheological properties of the regular asphalt binder used in the HMA sections is shown in Table 31 and the rheological properties of WMA asphalt binder used in WMA sections is shown in Table 32. These properties are in accordance with RIDOT specifications.

From the report of rheological properties of asphalt binder as shown in table 31 and 32, it showed that both WMA asphalt binder and HMA asphalt binder fails at same high and low temperature. Also, there is a little difference found in their modulus properties of binders before and after aging. It was found that asphalt rheological properties of both HMA and WMA are very similar but there are only difference in the mixing and compaction temperatures in the report of HMA and WMA asphalt binders.

Table 32 HMA Asphalt Binder Report (Source: RIDOT (Ref. 18))

Asphalt Binder		PG 64-28					
Type of Test		AASTHO Test	Result	Specification	Compaction Mix Data		
Original Binder	Rotational Viscometer	T 316	0.469 Pa.s	Max. 3Pa.s @ 135 °C		Min °C	Max °C
	Dynamic Shear Rheometer	T 315	1.320 kPa	Min. 1.0 kPa @ 64 °C	Compaction Range	144.7	149.7
	Fail Temperature		66.5 °C	Min. 64 °C	Mixing Range	156.1	161.6
RTFO Residue	Rolling Thin Film Oven Test	T 240 T 315		Max. 1.00 % Loss			
	Dynamic		3.657	Min. 2.20			

PAV Residue	Shear Rheometer		kPa	kPa @ 64 °C	
	Fail Temperature		68.3 °C	Min. 64 °C	
	Dynamic Shear Rheometer	T315	4332 kPa	Max. 5000 kPa @ 19 °C	
	Fail Temperature	T313	17.8 °C	Max. 22 °C	
	Bending Beam Rheometer		0.310 214 MPa	@ -18 °C Est. slope “m” Min. 0.3 @ 60s @ -18 °C Est. Stiffness Max. 300 MPa	

Table 33 WMA Asphalt Binder Report (Source: RIDOT (Ref. 18))

Asphalt Binder		PG 64-28 with 0.7% Evotherm					
Type of Test		AASTHO Test	Result	Specification	Compaction Mix Data		
Original Binder	Rotational Viscometer	T 316	0.383 Pa.s	Max. 3Pa.s @ 135 °C		Min °C	Max °C
	Dynamic Shear Rheometer	T 315	1.252 kPa	Min. 1.0 kPa @ 64 °C	Compaction Range	139.9	145.0
	Fail Temperature		65.9 °C	Min. 64 °C	Mixing Range	151.4	156.9
RTFO Residue	Rolling Thin Film Oven Test	T 240		Max. 1.00 % Loss			
	Dynamic Shear Rheometer	T 315	4.076 kPa	Min. 2.20 kPa @ 64 °C			
	Fail Temperature		68.9 °C	Min. 64 °C			
PAV Residue	Dynamic Shear Rheometer	T315	4780 kPa	Max. 5000 kPa @ 19 °C			
	Fail Temperature	T313	18.6 °C	Max. 22 °C			
	Bending Beam Rheometer		0.306 233 MPa	@ -18 °C Est. slope “m” Min. 0.3 @ 60s @ -18 °C Est. Stiffness Max. 300 MPa			

Volumetric Properties of HMA mixtures and WMA additives can be found on the Appendix IV and Appendix V. These properties showed the details of air voids, VMA, VFA, phase angle, modulus etc. From the Appendix IV and V, we can find that the OBC for WMA mixtures is 5.6% and OBC for HMA is 5.3%. These properties of both HMA and WMA mixtures were used as input parameters in the PavementME software for future prediction analysis in the pavement performance.

5.3 Field Pavement Evaluation and Data Compilation

Pavement performance is a function of its relative ability to serve traffic over a period. Originally, a pavement's relative ability to serve traffic was determined subjectively by visual inspection and experience. Typically, the preferred system uses objective measurements to quantify a pavement's condition and performance. Pavement Evaluation generally consists of the following:

1. Initial Pavement Assessment
2. Condition or Visual Survey
3. Present Serviceability Index (PSI)
6. Skid Resistance
7. International Roughness Index

5.3.1 Initial Pavement Assessment

Pavement condition assessment begins with an assembly of historic data. Historic data can be obtained from a windshield pavement condition field survey of the entire project followed by a detailed survey of selected areas of the project, by reviewing construction files and results from previous borings and laboratory results, by considering previous distress and profile surveys and pavement management records to establish performance

trends, and also by reviewing previous falling weight deflectometer reports. The inspection report of RI Route 102 before and after the rehabilitation works can be found in the Appendix III.

5.3.2 Current condition of Field visual Survey

A key factor in determining the condition or strength of the existing pavement layers is the result from a detailed pavement condition index survey. Pavement visual surveys are performed to identify the types, locations, and severities of distress. The survey should be performed on the pavement, shoulder, and on any drainage feature along the project site. To conduct the Condition survey, an inspection data sheet is used to determine the 19 different types of distresses, their severity, and their quantity. The most common distress types shown on the pavement are discussed below.

1. Alligator cracking (Bottom up cracking):

It is defined as a series of interconnected cracks (characteristically with an alligator pattern) that initiate at the bottom of the HMA layers. An example of a common alligator cracking is shown in Figure 23 and is also one of the most important outputs of PavementME, which determine the performance of pavement and is calculated as a percent of total lanes area.

Figure 23 Alligator Cracking (Source: Wikipedia.org)

2. Longitudinal Cracking (Top down Cracking): It is a form of fatigue or wheel load-related cracking that occurs within the wheel path and is defined as cracks predominantly parallel to the pavement centerline. Longitudinal cracks initiate at the surface of the HMA pavement and initially show up as short longitudinal cracks that become connected longitudinally with continued vehicle loadings. Raveling or crack deterioration may occur along the edges of these cracks, but they do not form an alligator cracking pattern. Longitudinal cracking (Figure 24) is also one of the outputs of PavementME and is calculated as a total feet per mile, including both wheel paths.

Figure 24 Longitudinal Cracking (Source: Louisiana DOT website)

3. *Thermal Transverse Cracking*: It is defined as non-wheel load-related cracking that is predominately perpendicular to the pavement centerline and caused by low temperature or thermal cycling. Thermal transverse cracking as shown in Figure 25 is also one of the outputs of PavementME and calculated in feet per 12-ft-wide lane.

Figure 25 Transverse Cracking (Source: Roadbotics)

It was predicted that WMA section would have better performance than HMA section. A

condition survey was conducted in 1st July 2019 and found in Appendix I. During inspection after a couple of years in service, no surface distresses were found on either of the HMA or WMA sections.

5.3.3 Present Serviceability Index

The present serviceability index (PSI) is based on the original AASHO Road Test Present Serviceability Rating (PSR). PSR is rating of pavement serviceability based on individual observation. Basically, the PSR was a ride quality rating that required a panel of observers to ride in an automobile over the pavement in question and that PSR is required to transit from a PSR serviceability measure to a PSI serviceability measure. The value of PSI ranges from 0 to 5. About one-half of the panel of raters found a PSR of 3.0 acceptable and a PSR of 2.5 unacceptable. Such information was useful in selecting “terminal” or failure serviceability (PSI) design input for empirical structural design equations. The PSI concept can be better understood by considering Figure 26. So, if the PSI value of pavement is 2 or less, then the maintenance or rehabilitation can be carried out to maintain road condition workable. The report of PSI value before and after the reconstruction can be found in Appendix III.

Figure 26 Concepts of Pavement Performance using Present Serviceability Index

5.3.4 Skid Resistance

Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface. Skid resistance is an important pavement evaluation parameter because inadequate skid resistance can lead to higher incidences of skid related accidents. Most agencies have an obligation to provide users with a roadway that is “reasonably” safe. Skid resistance measurements can be used to evaluate various types of materials and construction practices. Skid resistance changes over time. Typically, it increases in the first two years following construction as the asphalt binder coating the top layer of aggregate is worn away by traffic, and then decreases over the remaining pavement life as aggregates

become more polished. Skid resistance is also typically higher in the fall and winter and lower in the spring and summer. This seasonal variation can skew skid resistance data if not properly compensated.

5.3.5 International Roughness Index (IRI)

Pavement roughness is an expression of pavement surface irregularities that can adversely affect a vehicle's ride quality. Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle operating costs, fuel consumption, and maintenance costs. IRI is based on the accumulated suspension of a vehicle (inches or mm) divided by the distance traveled by the vehicle during the measurement (miles or kilometers). Figure 27 shows the scale of IRI that falls under different pavement categories.

Figure 27 International Roughness Index (IRI)

Roughness measurements can be made in a variety of ways and one of the most common methods is to use a profilograph and profiling devices. For pavement condition surveys, DOTs typically record the pavement's surface profile using laser equipment, which is mounted on a specially equipped collection van and then this equipment converts this profile into a roughness measurement. In addition to collecting profile data, these vans also record other types of distresses present in the pavement. For RI Route 102, RIDOT had done the Rideability test in 2015 and 2016. The report of Rideability can be found in Appendix VIII.

IRI is one of the outputs of PavementME and calculated in inch/mile. Thus, based on these outputs, RIDOT would be able to compare their field generated values to the predicted charts in order to track performance of the PavementME.

Average IRI (in./mi.) of 0.1 mile segments of Route 102							w/ 250mm filter			
			November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)	November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)
HMA	Northbound	LWP	60.50	60.95	0.45	0.74%	59.72	60.14	0.42	0.70%
		RWP	57.91	58.69	0.78	1.35%	57.15	57.97	0.82	1.44%
	Southbound	LWP	57.29	58.09	0.80	1.40%	56.61	57.43	0.82	1.45%
		RWP	54.72	54.76	0.03	0.06%	53.96	54.09	0.13	0.24%
WMA	Northbound	LWP	51.70	51.38	-0.32	-0.62%	51.02	50.69	-0.33	-0.64%
		RWP	45.15	45.21	0.06	0.12%	44.48	44.57	0.09	0.20%
	Southbound	LWP	50.33	50.88	0.55	1.10%	49.69	50.20	0.51	1.03%
		RWP	48.25	49.45	1.20	2.48%	47.63	48.84	1.21	2.54%
Average IRI Combining Northbound and Southbound Data							w/ 250mm filter			
			November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)	November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)
HMA	LWP	58.85	59.48	0.63	1.07%	58.12	58.74	0.63	1.08%	
	RWP	56.27	56.67	0.40	0.70%	55.51	55.97	0.46	0.84%	
WMA	LWP	50.99	51.12	0.13	0.25%	50.33	50.44	0.10	0.21%	
	RWP	46.75	47.39	0.64	1.38%	46.10	46.76	0.66	1.44%	
Average IRI Combining Wheel Paths							w/ 250mm filter			
			November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)	November 2015	September 2016	Δ IRI (2016 - 2015)	Δ IRI (% of 2015)
HMA			57.56	58.07	0.51	0.89%	56.81	57.36	0.55	0.96%
WMA			48.87	49.26	0.39	0.79%	48.22	48.60	0.38	0.80%

Figure 28 IRI Reports on RI Route 102 (in 2015 and 2016)

5.4 Analysis on RI Route 102

Table 34 Pavement Structural Health Index Report

Name of Pavement Distress	2018	
	WMA	HMA
Alligator cracking	100	100
Bleeding	100	100
Block Cracking	100	100
Edge Cracking	100	100
IRI	95.5	98.5
Longitudinal Cracking	84.5	70
Patching	99.5	100
Rutting	100	100
Transverse Cracking	100	99
PSHI	97.4	97.45

In 2015 and 2016, the field survey was done to evaluate IRI only which was used as pavement health index. The results show that no apparent differences were observed in the report. RIDOT later developed Pavement Structural Health Index (PSHI) as a unique pavement index to rate pavement structural health. PSHI relied on crack density (e.g., block, fatigue, transverse), smoothness, and rutting to indicate the relative roadway condition. The surveyed report in 2018 showed that the both sections HMA and WMA sections have about same value 97.45 and 97.4. Thus, it was concluded that both HMA and WMA sections have performed well till to this date, and we found no apparent differences in the pavement performance.

CHAPTER 6

INPUT PARAMETER TO PREDICT PAVEMENT PERFORMANCE

6.1. Background History of Pavement Design

American Association of State Highway Officials (AASHO) Road Test was conducted in Ottawa, IL (1958-1960) and represents the initiation of the modern empirical design approach. The information obtained from the AASHO Road Test was crucial in advancing knowledge of pavement structural design, performance, load equivalencies, climate effects, and much more. The basic performance information resulted in the performance equations and nomographs used in the 1993 American Association of State Highway and Transportation Officials (AASHTO) Guide. The 1993 AASHTO Guide has several older versions such as the 1961 interim guide and the 1986 guide which include material characterization information. Also, the 1993 AASHTO guide is based purely on empirical performance equations and nomographs used to calculate the structural number of different layers. The extensive and comprehensive 2002 AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG) includes analysis and design of new, reconstructed and rehabilitated asphalt and concrete pavements, evaluates existing pavements, sub-drainage design, recommendations for rehabilitation treatments and foundation improvements, recommendations for low volume road design, and life cycle cost analysis. The AASHTOWare Pavement ME Design (PavementME) is based on the 2002 AASHTO MEPDG and was used in this research study to evaluate and predict the performance of the RI Route 102 pavement test sections.

6.2. Introduction to AASHTOWare Pavement ME Design

The overall objective of AASHTOWare Pavement ME Design (PavementME) is to provide the highway community with a state-of-the-practice tool for the design and analysis of new and rehabilitated pavement structures, based on mechanistic-empirical principles. This means that the design and analysis procedure calculate predicted pavement responses (stresses, strains, and deflections) and uses those responses to compute incremental damage over time. This ME based procedure is shown in flowchart in Figure 29. When analyzing a pavement design project using PavementME, whether new construction overlay, or restoration, an iterative process that follows three basic steps is utilized:

Figure 29 Flowchart of ME Pavement Software

1. Create a trial design for the project.
2. Run the PavementME to predict the key distresses and smoothness for the trial design.
3. Review the predicted performance of the trial design against performance criteria and modify trial design as needed to produce a feasible design that satisfies the desired performance criteria.

6.3. Significance and Use of PavementME

The PavementME provides a uniform and comprehensive set of procedures for the analysis and design of new and rehabilitated flexible and rigid pavements. The PavementME design approach employs common design parameters for traffic, materials, subgrade, climate, and reliability for all pavement types, and is used to develop alternative designs using a variety of materials and construction procedures. The inputs generally used for PavementME are as follows:

1. General Project Information
2. Design Criteria and Reliability level
3. Truck Traffic data
4. Climate data
5. Material Properties

The general approach for determining inputs for materials in PavementME is a hierarchical (level) system which includes following 3 levels.

1. Level 1 input involves comprehensive laboratory tests
2. Level 2 inputs are estimated through correlations with other material properties that are commonly measured in laboratory or field.

3. Level 3 requires the designer to estimate the most appropriate design value of the material property based on experience with little or no testing.

In this research study, Level 1 input values were used which are described in later sections. The output from the PavementME at selected reliability level includes:

1. Permanent Deflection-Total pavement (in)
2. Asphalt Concrete bottom-up fatigue cracking (percent)
3. Asphalt Concrete thermal fracture (ft/mi)
4. Asphalt Concrete top-down fatigue cracking (ft/mi)
5. Permanent deformation Asphalt Concrete only (in)
6. International Roughness Index (IRI) or smoothness

6.4. Input data of RI Route 102 for PavementME

6.4.1. General Project Information

General project information includes input values such as design/analysis life and construction and traffic opening dates. Usually the design life of a new or rehabilitated pavement is the time from initial construction until the pavement has structurally deteriorated to a specified pavement condition, or the time when significant rehabilitation or reconstruction is needed. Generally, the design life for RI Route 102 was selected as 20 years. Construction and traffic opening dates for RI Route 102 were collected from RIDOT and are shown in the PavementME reports (Appendix VII).

6.4.2. Design Criteria and Reliability Level

Design performance and reliability greatly affect deterioration of an adequately performing

pavement. Performance criteria are used to ensure that a pavement design will perform satisfactorily over its design life. The designer selects performance threshold distress values to judge the adequacy of a trial design. Designer also specifies the desired level of reliability for each distress type and smoothness. The level of design reliability could be based on the general consequences of reaching the terminal condition earlier than the design life. For RI Route 102, the design criteria and reliability level are shown in Table 32.

Table 35 Design Criteria or Threshold values and Reliability level for RI Route 102

Distress Type	Performance Criteria	Reliability Level (%)
Permanent deflection- Total pavement (in.)	0.75	90
Asphalt concrete bottom-up fatigue cracking (percent lane area)	25	90
Asphalt concrete thermal fracture (ft/mi)	1000	90
Asphalt concrete top-down fatigue cracking (ft/mi)	2000	90
Permanent deformation Asphalt Concrete only (in.)	0.25	90
Terminal IRI (in/mi)	172	90

6.4.3. Truck Traffic Data

Truck traffic is a key data element for the structural design/analysis of pavement structures. PavementME uses the full axle-load spectrum data for each axle type for both new pavement and rehabilitation design periods. Traffic volume, lane distribution, volume adjustment factors (i.e., class distribution, traffic growth factors, etc.) and weight data are used as inputs along with some miscellaneous data such as tire pressure. The axle-load spectra are obtained from processing weighing-in-motion (WIM) data, which is measured

by a device usually embedded into a pavement used to calculate traffic flow.

For RI Route 102, all truck traffic data on June 2013 were collected from RIDOT Traffic section that includes data of average annual daily traffic (AADT), which is further broken down into vehicle classification, monthly adjustment factors, hourly adjustment factors, daily vehicle counts, and percent trucks in design direction. Average Annual Truck Traffic (AADTT) is calculated for Class 1 to Class 13 of the FHWA vehicle classification chart, which is shown in Figure 30. The RIDOT Traffic Report found that the percentage of combination unit trucks in AADT is 2% and the percentage of single unit trucks in AADT is 23%. The **K factor** is defined as the proportion of annual average daily traffic occurring in an hour, and the **D factor** expressed as a proportion of traffic moving in the peak direction during the design hour. The K factor value is 0.18 and D factor value is 0.54 for RI route 102. AADT data obtained from RIDOT for RI Route 102 are shown in Table 33.

Table 36 Vehicle classification of RI Route 102

VEHICLE CLASSIFICATION														
RI Route 102														
Time	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	Total
0:00	0	5	0	0	0	0	0	0	0	0	0	0	0	5
1:00	0	4	1	0	1	0	0	0	0	0	0	0	0	6
2:00	0	0	1	0	1	0	0	0	0	0	0	0	0	2
3:00	0	4	1	0	1	0	0	0	0	0	0	0	0	6
4:00	0	3	2	0	1	0	0	0	0	0	0	0	0	6
5:00	0	5	2	0	1	0	0	0	0	0	0	0	0	8
6:00	0	25	24	3	7	2	0	0	0	0	0	0	0	61
7:00	1	37	22	0	9	0	0	0	0	0	0	0	0	69
8:00	0	54	23	3	15	0	0	0	0	0	0	0	0	95
9:00	1	41	15	0	10	1	0	0	0	0	0	0	0	68
10:00	2	46	22	2	16	0	0	0	0	0	0	0	0	88
11:00	1	50	24	2	17	0	0	0	1	0	0	0	0	95
12:00	0	70	29	2	8	0	0	0	0	0	0	0	0	109
13:00	1	47	26	0	9	0	0	0	0	0	0	0	0	83
14:00	2	71	19	0	11	0	0	0	0	0	0	0	0	103
15:00	0	84	28	1	8	0	0	0	1	0	0	0	0	122
16:00	3	75	34	0	13	0	0	0	0	0	0	0	0	125
17:00	10	101	33	0	1	0	0	0	0	0	0	0	0	145
18:00	0	67	23	0	1	0	0	0	0	0	0	0	0	91
19:00	0	58	26	1	1	0	0	0	0	0	0	0	0	86
20:00	1	42	11	0	1	0	0	0	0	0	0	0	0	55
21:00	0	30	2	0	0	0	0	0	0	0	0	0	0	32
22:00	0	15	3	0	6	0	0	0	0	0	0	0	0	24
23:00	0	4	1	0	0	0	0	0	0	0	0	0	0	5
Total	22	938	372	14	138	3	0	0	2	0	0	0	0	1489
% of Total	1.48	63.00	24.98	0.94	9.27	0.20	0.00	0.00	0.13	0.00	0.00	0.00	0.00	

7-9 AM Peak Total	166	K Factor	0.18	% Single Unit Trucks in AADT	23.00%
12-2 PM Peak Total	195	D Factor	0.54	% Single Unit Trucks in Peak Hour	13.00%
4-6 PM Peak Total	271			% Combination Unit Trucks in Peak Hour	0.00%
Peak Hour	5:00 PM			%combination Unit Trucks in AADT	2.00%

6.4.4. Climate Data

Detailed climate data are required for predicting pavement distress with PavementME and include hourly temperature, precipitation, wind speed, relative humidity, and cloud cover. These data are used to predict the temperature and moisture content in each of the pavement layers as well as provide some of the inputs to the site factor parameter for the smoothness prediction models. All the climate data needed by PavementME are available from weather stations, generally located at airfields around the United States. PavementME has an extensive number of weather stations embedded in its software for ease of use and implementation. The longitude, latitude, elevation and number of months of available data are viewed by the user in selecting the weather stations to be used by the software to create a virtual weather station at the project location for the distress prediction. In this study, the educational version of PavementME was used for the RI Route 102 project, and Massachusetts is the nearest virtual weather station available in that educational version.

6.4.5. Material Properties

The PavementME software requires all material properties including rheological properties of asphalt binder, volumetric properties of HMA and WMA mixtures. The general approach for determining design inputs for materials in PavementME is a hierarchical (level) system as described in above section 6.3. For the RI Route 102 project, most of the input values used are Level 1, i.e., values obtained from comprehensive laboratory tests. Fundamental properties are required for all HMA and WMA mixture types or layers to execute PavementME. The input properties for all asphalt material types are grouped into volumetric and engineering properties. The volumetric properties (Superpave Mix Design) include

1. Air Voids
2. Effective Asphalt Content by volume
3. Aggregate gradation
4. Mix density
5. Asphalt grade

For RI Route 102 project all volumetric properties of HMA section and WMA section were determined at RIDOT material section and the reports are attached in the Appendix IV and V. The input data for resilient modulus for RI Route 102 are shown in Table 34.

Table 37 Summary of AASHTOWare Pavement ME Design inputs for RI Route 102

Layer Type	Thickness	Laboratory	Mr (psi)
Flexible	2	-	-
Flexible	3	-	-
Cold Recycled (FDR RAP)	8	RIDOT	41665
Non- Stabilized (Ex. Gravel borrow)	8	RIDOT	19005
Subgrade	Semi-infinite	Lee et al. (2003)	9304

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory test results and analyses made in this research study, the following conclusions can be made:

1. Use of Evotherm, WMA additive, enhanced the resistance properties of the asphalt binder against rutting, fatigue and low temperature cracking.
2. Combined Master Curves indicated that WMA-RAP can be expected to perform better in fatigue cracking resistance but may be expected to perform poor in rutting resistance than HMA and HMA-RAP. This indicated that fatigue cracking was not a problem with WMA-RAP mixtures whereas rutting resistance still requires further investigation and improvement.
3. There was an average decrease in 20 % of the tensile strength in WMA-RAP compared to HMA-RAP mixtures.
4. According to the case study of RI Route 102 in 2018, both HMA and WMA sections have performed well, and we found no apparent differences in the pavement performance.
5. This study also bolsters the argument that WMA additives reduce the production temperatures of the asphalt mixtures compared to the regular HMA reducing emissions and fuel demands.
6. The WMA additives could be used in mixtures with RAP for improved fatigue resistance performance. However, further study on the optimal Evotherm proportion under varying RAP content in RI is recommended.

7. For improved rutting resistance using Evotherm, there is a need for further investigation and improvement.
8. AASTHO PavementME software could be used for better performance prediction between HMA and WMA.
9. The pavement performance of HMA and WMA on RI Route 102 should be continuously monitored every year for the field scale future performance.

Appendix- I
Field Inspection Report on RI Route 102
2019

Appendix II

Resilient Modulus of Subgrade soil and Reclaimed Subbase layer

Table 1: Project Summary									
Project ID	Project Name	Location	Area (ha)	Volume (m³)	Start Date	End Date	Status	Remarks	Notes
1	Project A	Location A	100	10000	2020-01-01	2020-12-31	Completed		
2	Project B	Location B	200	20000	2021-01-01	2021-12-31	In Progress		
3	Project C	Location C	300	30000	2022-01-01	2022-12-31	Planned		
4	Project D	Location D	400	40000	2023-01-01	2023-12-31	Planned		
5	Project E	Location E	500	50000	2024-01-01	2024-12-31	Planned		
6	Project F	Location F	600	60000	2025-01-01	2025-12-31	Planned		
7	Project G	Location G	700	70000	2026-01-01	2026-12-31	Planned		
8	Project H	Location H	800	80000	2027-01-01	2027-12-31	Planned		
9	Project I	Location I	900	90000	2028-01-01	2028-12-31	Planned		
10	Project J	Location J	1000	100000	2029-01-01	2029-12-31	Planned		
11	Project K	Location K	1100	110000	2030-01-01	2030-12-31	Planned		
12	Project L	Location L	1200	120000	2031-01-01	2031-12-31	Planned		
13	Project M	Location M	1300	130000	2032-01-01	2032-12-31	Planned		
14	Project N	Location N	1400	140000	2033-01-01	2033-12-31	Planned		
15	Project O	Location O	1500	150000	2034-01-01	2034-12-31	Planned		
16	Project P	Location P	1600	160000	2035-01-01	2035-12-31	Planned		
17	Project Q	Location Q	1700	170000	2036-01-01	2036-12-31	Planned		
18	Project R	Location R	1800	180000	2037-01-01	2037-12-31	Planned		
19	Project S	Location S	1900	190000	2038-01-01	2038-12-31	Planned		
20	Project T	Location T	2000	200000	2039-01-01	2039-12-31	Planned		
21	Project U	Location U	2100	210000	2040-01-01	2040-12-31	Planned		
22	Project V	Location V	2200	220000	2041-01-01	2041-12-31	Planned		
23	Project W	Location W	2300	230000	2042-01-01	2042-12-31	Planned		
24	Project X	Location X	2400	240000	2043-01-01	2043-12-31	Planned		
25	Project Y	Location Y	2500	250000	2044-01-01	2044-12-31	Planned		
26	Project Z	Location Z	2600	260000	2045-01-01	2045-12-31	Planned		
27	Project AA	Location AA	2700	270000	2046-01-01	2046-12-31	Planned		
28	Project AB	Location AB	2800	280000	2047-01-01	2047-12-31	Planned		
29	Project AC	Location AC	2900	290000	2048-01-01	2048-12-31	Planned		
30	Project AD	Location AD	3000	300000	2049-01-01	2049-12-31	Planned		
31	Project AE	Location AE	3100	310000	2050-01-01	2050-12-31	Planned		
32	Project AF	Location AF	3200	320000	2051-01-01	2051-12-31	Planned		
33	Project AG	Location AG	3300	330000	2052-01-01	2052-12-31	Planned		
34	Project AH	Location AH	3400	340000	2053-01-01	2053-12-31	Planned		
35	Project AI	Location AI	3500	350000	2054-01-01	2054-12-31	Planned		
36	Project AJ	Location AJ	3600	360000	2055-01-01	2055-12-31	Planned		
37	Project AK	Location AK	3700	370000	2056-01-01	2056-12-31	Planned		
38	Project AL	Location AL	3800	380000	2057-01-01	2057-12-31	Planned		
39	Project AM	Location AM	3900	390000	2058-01-01	2058-12-31	Planned		
40	Project AN	Location AN	4000	400000	2059-01-01	2059-12-31	Planned		
41	Project AO	Location AO	4100	410000	2060-01-01	2060-12-31	Planned		
42	Project AP	Location AP	4200	420000	2061-01-01	2061-12-31	Planned		
43	Project AQ	Location AQ	4300	430000	2062-01-01	2062-12-31	Planned		
44	Project AR	Location AR	4400	440000	2063-01-01	2063-12-31	Planned		
45	Project AS	Location AS	4500	450000	2064-01-01	2064-12-31	Planned		
46	Project AT	Location AT	4600	460000	2065-01-01	2065-12-31	Planned		
47	Project AU	Location AU	4700	470000	2066-01-01	2066-12-31	Planned		
48	Project AV	Location AV	4800	480000	2067-01-01	2067-12-31	Planned		
49	Project AW	Location AW	4900	490000	2068-01-01	2068-12-31	Planned		
50	Project AX	Location AX	5000	500000	2069-01-01	2069-12-31	Planned		
51	Project AY	Location AY	5100	510000	2070-01-01	2070-12-31	Planned		
52	Project AZ	Location AZ	5200	520000	2071-01-01	2071-12-31	Planned		
53	Project BA	Location BA	5300	530000	2072-01-01	2072-12-31	Planned		
54	Project BB	Location BB	5400	540000	2073-01-01	2073-12-31	Planned		
55	Project BC	Location BC	5500	550000	2074-01-01	2074-12-31	Planned		
56	Project BD	Location BD	5600	560000	2075-01-01	2075-12-31	Planned		
57	Project BE	Location BE	5700	570000	2076-01-01	2076-12-31	Planned		
58	Project BF	Location BF	5800	580000	2077-01-01	2077-12-31	Planned		
59	Project BG	Location BG	5900	590000	2078-01-01	2078-12-31	Planned		
60	Project BH	Location BH	6000	600000	2079-01-01	2079-12-31	Planned		
61	Project BI	Location BI	6100	610000	2080-01-01	2080-12-31	Planned		
62	Project BJ	Location BJ	6200	620000	2081-01-01	2081-12-31	Planned		
63	Project BK	Location BK	6300	630000	2082-01-01	2082-12-31	Planned		
64	Project BL	Location BL	6400	640000	2083-01-01	2083-12-31	Planned		
65	Project BM	Location BM	6500	650000	2084-01-01	2084-12-31	Planned		
66	Project BN	Location BN	6600	660000	2085-01-01	2085-12-31	Planned		
67	Project BO	Location BO	6700	670000	2086-01-01	2086-12-31	Planned		
68	Project BP	Location BP	6800	680000	2087-01-01	2087-12-31	Planned		
69	Project BQ	Location BQ	6900	690000	2088-01-01	2088-12-31	Planned		
70	Project BR	Location BR	7000	700000	2089-01-01	2089-12-31	Planned		
71	Project BS	Location BS	7100	710000	2090-01-01	2090-12-31	Planned		
72	Project BT	Location BT	7200	720000	2091-01-01	2091-12-31	Planned		
73	Project BU	Location BU	7300	730000	2092-01-01	2092-12-31	Planned		
74	Project BV	Location BV	7400	740000	2093-01-01	2093-12-31	Planned		
75	Project BW	Location BW	7500	750000	2094-01-01	2094-12-31	Planned		
76	Project BX	Location BX	7600	760000	2095-01-01	2095-12-31	Planned		
77	Project BY	Location BY	7700	770000	2096-01-01	2096-12-31	Planned		
78	Project BZ	Location BZ	7800	780000	2097-01-01	2097-12-31	Planned		
79	Project CA	Location CA	7900	790000	2098-01-01	2098-12-31	Planned		
80	Project CB	Location CB	8000	800000	2099-01-01	2099-12-31	Planned		
81	Project CC	Location CC	8100	810000	2100-01-01	2100-12-31	Planned		
82	Project CD	Location CD	8200	820000	2101-01-01	2101-12-31	Planned		
83	Project CE	Location CE	8300	830000	2102-01-01	2102-12-31	Planned		
84	Project CF	Location CF	8400	840000	2103-01-01	2103-12-31	Planned		
85	Project CG	Location CG	8500	850000	2104-01-01	2104-12-31	Planned		
86	Project CH	Location CH	8600	860000	2105-01-01	2105-12-31	Planned		
87	Project CI	Location CI	8700	870000	2106-01-01	2106-12-31	Planned		
88	Project CJ	Location CJ	8800	880000	2107-01-01	2107-12-31	Planned		
89	Project CK	Location CK	8900	890000	2108-01-01	2108-12-31	Planned		
90	Project CL	Location CL	9000	900000	2109-01-01	2109-12-31	Planned		
91	Project CM	Location CM	9100	910000	2110-01-01	2110-12-31	Planned		
92	Project CN	Location CN	9200	920000	2111-01-01	2111-12-31	Planned		
93	Project CO	Location CO	9300	930000	2112-01-01	2112-12-31	Planned		
94	Project CP	Location CP	9400	940000	2113-01-01	2113-12-31	Planned		
95	Project CQ	Location CQ	9500	950000	2114-01-01	2114-12-31	Planned		
96	Project CR	Location CR	9600	960000	2115-01-01	2115-12-31	Planned		
97	Project CS	Location CS	9700	970000	2116-01-01	2116-12-31	Planned		
98	Project CT	Location CT	9800	980000	2117-01-01	2117-12-31	Planned		
99	Project CU	Location CU	9900	990000	2118-01-01	2118-12-31	Planned		
100	Project CV	Location CV	10000	1000000	2119-01-01	2119-12-31	Planned		

Appendix III
Pavement Condition Report

(Before the Rehabilitation Works) - Surveyed on June 2013

WMA Section	
Name of Pavement Distress	PSI
Alligator cracking	65
Bleeding	100
Block Cracking	0
Edge Cracking	95
IRI	66.5
Longitudinal Cracking	50
Patching	50
Rutting	78.5
Transverse Cracking	81
PSHI	97.4

HMA Section	
Name of Pavement Distress	PSI
Alligator cracking	60
Bleeding	100
Block Cracking	0
Edge Cracking	95
IRI	66
Longitudinal Cracking	45
Patching	74
Rutting	78
Transverse Cracking	65
PSHI	59.7

(After the Rehabilitation Works) - Surveyed on December 2018

WMA Section	
Name of Pavement Distress	PSI
Alligator cracking	100
Bleeding	100
Block Cracking	100
Edge Cracking	100
IRI	95.5
Longitudinal Cracking	84.5
Wheel Path Longitudinal Cracking	96.5
Patching	99.5
Rutting	100
Transverse Cracking	100
PSHI	97.4

HMA Section	
Name of Pavement Distress	PSI
Alligator cracking	100
Bleeding	100
Block Cracking	100
Edge Cracking	100
IRI	98.5
Longitudinal Cracking	70
Wheel Path Longitudinal Cracking	94.5
Patching	100
Rutting	100
Transverse Cracking	99
PSHI	97.45

November 23, 2015									
	Start Distance (ft)	Stop Distance (ft)	Length (ft)	Left Wheel Path - IRI (in/mi)	Right Wheel Path - IRI (in/mi)	w/ 250mm filter		Sample Rate	
						Left Wheel Path - IRI (in/mi)	Right Wheel Path - IRI (in/mi)	Start Distance (ft)	Stop Distance (ft)
WMA	25	553	528	78.43	79.61	77.73	78.80	25.033	553.0
	553	1081	528	47.04	45.99	46.66	45.39	553.062	1081
	1081	1609	528	45.24	44.66	44.65	43.83	1081.09	1609
	1609	2137	528	50.60	49.21	50.09	48.67	1609.12	2137
	2137	2665	528	50.40	55.78	49.76	55.05	2137.15	2665
	2665	3193	528	49.59	50.83	48.76	50.05	2665.18	3193
	3193	3721	528	44.03	44.77	43.42	43.94	3193.21	3721
	3721	4249	528	47.32	43.57	46.74	42.95	3721.24	4249
	4249	4777	528	52.03	44.20	51.18	43.52	4249.27	4777
	4777	5305	528	64.65	54.91	64.15	54.49	4777.3	5305
	5305	5833	528	49.83	38.39	49.00	37.76	5305.33	5833
	5833	6361	528	49.86	43.97	49.06	43.43	5833.36	6361
	6361	6889	528	43.96	39.18	43.52	38.70	6361.39	6889
	6889	7417	528	43.82	44.42	43.30	44.02	6889.42	7417
	7417	7945	528	42.59	42.87	41.98	42.44	7417.44	7945
	7945	8473	528	38.01	40.49	37.44	39.95	7945.47	8473
	8766.5	9294.5	528	58.89	54.36	57.95	53.63	8766.47	9294.5
	9294.5	9822.5	528	49.59	51.27	48.98	50.64	9294.5	9822.5
WMA Averages:				50.33	48.25	49.69	47.63		
HMA	11450	11978	528	57.55	47.83	57.05	47.32	11450	11978
	11978	12506	528	47.04	47.14	46.48	46.45	11978	12506
	12506	13034	528	50.28	49.22	49.90	48.71	12506.1	13034
	13034	13562	528	45.53	39.50	45.10	38.87	13034.1	13562
	13562	14090	528	45.47	41.96	44.93	41.37	13562.1	14090
	14090	14618	528	43.98	40.53	43.38	39.90	14090.2	14618
	14618	15146	528	44.81	47.13	44.08	46.42	14618.2	15146
	15146	15674	528	69.43	67.60	68.70	66.79	15146.2	15674
	15674	16202	528	67.60	64.13	66.98	63.74	15674.2	16202
	16202	16730	528	63.53	56.52	63.01	56.13	16202.3	16730
	16730	17258	528	70.58	56.82	69.98	56.38	16730.3	17258
	18617	19145	528	63.98	67.52	62.85	66.07	18617	19145
	19145	19673	528	52.74	50.26	51.64	49.07	19145.1	19673
	19673	20201	528	59.90	57.43	59.08	56.34	19673.1	20201
	20201	20729	528	55.36	53.69	54.63	52.93	20201.1	20729
	20729	21257	528	60.81	57.69	59.92	56.79	20729.2	21257
	21257	21785	528	55.34	62.07	54.63	61.02	21257.2	21785
	21785	22313	528	77.24	78.00	76.59	76.98	21785.2	22313
HMA Averages:				57.29	54.72	56.61	53.96		

September 22, 2016

Sample Rate adjusted to match 2015 distance*

w/ 250mm filter

Start Distance (ft)	Stop Distance (ft)	Length* (ft)	Left Wheel Path - IRI (in/mi)	Right Wheel Path - IRI (in/mi)	Left Wheel Path - IRI (in/mi)	Right Wheel Path - IRI (in/mi)
25.0	553.062	528.03	78.71	80.40	77.87	79.89
553.0	1081.09	528.03	46.57	48.76	46.13	48.12
1081.0	1609.12	528.03	45.14	46.81	44.50	45.95
1609.0	2137.15	528.03	52.68	50.51	52.05	49.90
2137.0	2665.18	528.03	51.66	55.35	51.04	54.72
2665.18	3193.21	528.03	50.63	53.86	49.83	53.04
3193.21	3721.24	528.03	46.42	50.16	45.69	49.25
3721.24	4249.27	528.03	48.47	45.03	47.76	44.39
4249.27	4777.3	528.03	50.43	43.32	49.62	42.72
4777.3	5305.33	528.03	66.05	56.15	65.52	55.69
5305.33	5833.36	528.03	47.38	36.71	46.70	36.21
5833.36	6361.39	528.03	48.90	44.89	48.15	44.38
6361.39	6889.42	528.03	43.10	38.82	42.65	38.49
6889.42	7417.44	528.03	44.49	44.51	44.01	44.18
7417.44	7945.47	528.03	44.62	42.38	43.97	41.94
7945.47	8473.5	528.03	39.96	41.31	39.32	40.76
8473.5	8999.5	528.03	60.06	60.04	58.75	58.97
8999.5	9527.53	528.03	50.58	51.04	50.03	50.46
			50.88	49.45	50.20	48.84
11450	11978	528.03	56.20	48.00	55.76	47.53
11978	12506.1	528.03	50.37	45.51	49.84	44.89
12506.1	13034.1	528.03	52.31	49.70	51.98	49.30
13034.1	13562.1	528.03	45.05	39.92	44.54	39.38
13562.1	14090.2	528.03	47.21	41.50	46.61	40.99
14090.2	14618.2	528.03	43.48	39.50	42.92	38.92
14618.2	15146.2	528.03	42.83	44.27	42.30	43.73
15146.2	15674.2	528.03	68.09	67.53	67.48	66.85
15674.2	16202.3	528.03	67.04	68.68	66.47	68.24
16202.3	16730.3	528.03	66.32	58.17	65.62	57.88
16730.3	17258.3	528.03	78.47	56.03	77.76	55.62
17258.3	17786.3	528.03	67.17	68.83	66.04	67.52
17786.3	18314.3	528.03	50.70	48.57	49.87	47.78
18314.3	18842.3	528.03	59.28	56.12	58.52	55.35
18842.3	19370.3	528.03	55.56	54.12	54.95	53.36
19370.3	19898.3	528.03	59.81	57.08	58.78	56.06
19898.3	20426.3	528.03	54.56	64.40	53.87	63.38
20426.3	20954.3	528.03	81.09	77.69	80.41	76.85
			58.09	54.76	57.43	54.09

Appendix IV

WMA Mixtures Properties of RI Route 102

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - PLANT BURNOFF AND GRADATION REPORT**

Counter No: 155190 Item No: Date: 9/11/2015
 RI Contract No: 2015-CH-014 Producer: JH Lynch CB Mix No: 113
 FAP No: Plant Location: Cumberland, RI Mix Class: 19.0 mm SP 24 % RAP

☒ Acceptance ☐ Independent ☐ Info Only ☐ P. Engineering

CA and FA Visually Checked Against Jar Samples ☒ Yes ☐ No ☐ Marshall: ☐ PG: PG 64-28 S WMA
 C.A. Producer: JH Lynch F.A. Producer: JH Lynch PUCK ID: 13

TEST #	TIME	TRUCK #	TEMP (°F)	WT. BEFORE BURNOFF (g)	WT. AFTER BURNOFF (g)	ASPHALT CONTENT (%)	AC SPEC	TOTAL WT. AFTER SIEVING (g)	LOSS AFTER SIEVING (g)
1	8:16 AM	NDF-3	300	2551.2	2406.5	5.6	5.6±0.3	2401.1	5.4

BURNOFF GRADATION (AASHTO T-30)											
SIEVE SIZE	1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	# 30	# 50	# 100	# 200
SPECIFICATIONS	100	90 - 100	90 MAX			21 - 31					≥ 2
WEIGHT PASSING (g)	2401.1	2390.5	2098.5	1617.5	905.8	565.8	378.2	276.9	195.3	128.9	72.70
WT PASSING + LOSS (g)	2406.5	2395.9	2103.9	1622.9	911.2	571.2	383.6	282.3	200.7	134.3	78.10
% PASSING W/ LOSS CORR	100	100	87	67	38	24	16	12	8	6	3.2

Meets Spec ☒ Does Not Meet Spec ☐ Not Applicable ☐

Bailey Method For 3/4" CA [Info Only]		G _{MB} : <u>2.499</u>	VMA: <u>13.5</u>	Dust to Asphalt Ratio: <u>0.83</u>
CA	FA _C	N/A	Va: <u>4.2</u>	
0.60	0.35	N/A	VFA: <u>68.9</u>	
0.75	0.50		Pbo: <u>3.84</u>	
Recommended Ratio: <u>0.60</u>	Results: <u>0.88</u>	FA _F	G _{MM} : <u>2.608</u>	
		0.35		
		0.50		
		0.42		

Sampled By: W. Robinson DATE: 9/11/15 Reviewed By: George Robinson DATE: 9/11/15
 Burnoff And Gradation By: ROBINSON

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - SUPERPAVE PUCK REPORT (AASHTO T-166)**

Counter No: 155190	Date: 9/1/2015
RI Contract No: 2015-CH-014	Mix No: 113
F.A.P. No:	Mix Class: 19.0 mm SP 24 % RAP
Producer: JH Lynch CB Plant Location: Cumberland, RI	P. Engineering
☒ Acceptance ☐ Independent ☐ Info Only	

Specimen Number	Asphalt (%)	Thick. (mm)	Weight		Volume (cc)	Bulk Specific Gravity	Unit Weight T _{hi} Mix (pcf)	G _{mm}	VMA	VA 4 ± 1	VFA	Pbe	% of Water Absorbed
			Air (g)	Water (g)									
13	5.57	119.400	4970.6	2893.5	1988.8	2.489	155.94	2.608	13.5	4.2	69.0	3.80	0.588

Meets Spec ☒ Does Not Meet Spec ☐ Not Applicable ☐

Remarks:

Plant Inspector: GARDEN Date: 9-11-15
 Reviewed By: George Nethune PE 10-8-15 Date:

ID# TP4 - 328

REV: 5/1/13

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - BSG AND GRADATION WORKSHEET**

Counter No: <u>155190</u>	Plant/Site: <u>LYNCH/Cumb.</u>	Date: <u>9/11/15</u>	
RI Contract No: <u>2015-CH-014</u>	HMA Temp: <u>300° / 8:45 AM</u>	Mix: <u>#113</u>	Ticket No: <u>74023</u>
Percent RAP: <u>24%</u>	Independent ☐ Superpave ☒ Marshall ☐	Info Only ☐ P. Engineering ☐	
Acceptance ☒			

Core No.	Thickness (mm)	Dry Wt (g)	Wt in Water (g)	SSD Wt (g)	G _{MB} A C-B	% Absorption C-A C-B X 100
13	119.4	4970.6	2993.5	4982.3	2499	

Burnoff: AC Determination

[A] Empty Cage Wt (g)	[B] Sample Wt Before Burnoff (g)	[C] Wt of Cage and Sample After Burnoff (g)	[D] = [C] - [A] Sample Wt After Burnoff (g)	% Wt Loss 100 X $\frac{B-D}{B}$	Binder Correction Factor (%)	[E] - [F] % AC
3301.9	2557.2	5708.4	2406.5	144.7	5.67 - 0.1	5.6%

Burnoff: Gradation Determination

Sieve Size	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Pan
Wt Retained (g)		10.6	307.6	783.6	1495.3	1835.3	2022.9	2124.2	2205.8	2272.2	2328.4	2401.1

ROBINSON
Sampled By (Print / Sign) _____ Date _____
ID# WP4 - 330

ROBINSON
Tested By (Print / Sign) _____ Date _____

GORDEN
Cores Made By (Print / Sign) _____ Date _____
REV 5/11/15

Pine Instrument Company
Gyratory Compaction Report

Specimen Height, Angle, Pressure vs. Gyration Number

Date: 09/11/15	Machine S/N: 8147
Time: 09:54	Mode: Set Heig
Filename: SEP11 01.DAT	Mold Diameter: 150 mm
Specimen ID: <u>13</u>	Avg Pressure: 599 kPa
Technician: _____	Avg Angle of Gyration: 1.16 deg

	0	1	2	3	4	5	6	7	8	9	
0	148.3	143.2	139.9	137.6	135.7	134.2	133.0	131.9	131.0	130.2	mm
	-----	1.16	1.15	1.16	1.16	1.15	1.16	1.16	1.16	1.16	deg
	596	570	564	579	593	598	600	600	600	600	kPa
10	129.5	128.8	128.2	127.7	127.2	126.7	126.3	125.9	125.5	125.1	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	600	600	600	600	600	600	600	600	600	600	kPa
20	124.8	124.5	124.2	123.9	123.6	123.4	123.1	122.9	122.7	122.5	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	600	600	600	600	600	599	599	599	599	599	kPa
30	122.3	122.1	121.9	121.7	121.5	121.4	121.2	121.0	120.9	120.7	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	599	599	598	599	599	599	599	599	599	599	kPa
40	120.6	120.4	120.3	120.2	120.1	119.9	119.8	119.7	119.6	119.5	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	599	599	599	600	600	600	600	600	600	600	kPa
50	119.4										mm
	1.16										deg
	600										kPa

Appendix V

HMA Mixtures Properties of RI Route 102

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - PLANT BURNOFF AND GRADATION REPORT**

Counter No: 155208		Item No: _____		Date: 9/18/2015	
RI Contract No: 2015-CH-014		Producer: JH Lynch CB		Mix No: 113	
FAP No: _____		Plant Location: Cumberland, RI		Mix Class: 19.0 mm SP 24 % RAP	
☒ Acceptance		☐ Independent		☐ Info Only	
☒ CA and FA Visually Checked Against Jar Samples		☒ Yes		☐ No	
C.A. Producer: JH Lynch		Superpave: ☒		Marshall: ☐	
		F.A. Producer: JH Lynch		PG: PG 64-28 S	
				PUCK ID: 24	

TEST #	TIME	TRUCK #	TEMP (°F)	WT. BEFORE BURNOFF (g)	WT. AFTER BURNOFF (g)	ASPHALT CONTENT (%)	AC SPEC	TOTAL WT. AFTER SIEVING (g)	LOSS AFTER SIEVING (g)
3	11:16 AM	NET-12	320	2501.2	2367.2	5.3	5.6 ± 0.3	2366.4	0.8

SIEVE SIZE	1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	# 30	# 50	# 100	# 200
SPECIFICATIONS	100	90 - 100	90 MAX			21 - 31					≥ 2
WEIGHT PASSING (g)	2366.4	2357.3	1923.0	1433.1	780.3	507.5	332.5	238.0	167.4	111.9	66.10
WT PASSING + LOSS (g)	2367.2	2358.1	1923.8	1433.9	781.1	508.3	333.3	238.8	168.2	112.7	66.90
% PASSING W/ LOSS CORR	100	100	81	61	33	21	14	10	7	5	2.8

Meets Spec ☒ Does Not Meet Spec ☐ Not Applicable ☐	Bailey Method For 3/4" CA (Info Only)		G _{MM} : 2.521 G _{SM} : 2.629	VMA: 12.4 Va: 4.1 VFA: 87.1 Pbe: 3.41	Dust to Asphalt Ratio: 0.82
	CA	FA _C			
	Recommended Ratio: Results:	0.60 0.75 0.72			

Sampled By: BOHANNON DATE: 9/18/15 Burnoff And Gradation By: ROBINSON DATE: 9/18/15
 Reviewed By: _____ DATE: _____

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - SUPERPAVE PUCK REPORT (AASHTO T-166)**

Counter No: 155208	Date: 9/18/2015
RI Contract No: 2015-CH-014	Mix No: 113
F.A.P. No:	Mix Class: 19.0 mm SP 24 % RAP
☒ Acceptance ☐ Independent ☐ Info Only ☐ P. Engineering	
Producer: JH Lynch CB Plant Location: Cumberland, RI	

Specimen Number	Asphalt (%)	Thick. (mm)	Weight		Volume (cc)	Bulk Specific Gravity	Unit Weight T _{RI} Mix (pcf)	VMA	VA 4 ± 1	VFA	P _{be}	% of Water Absorbed
			Air (g)	Water (g)								
24	5.26	119.900	4867.5	3002.7	4973.0	2.521	157.31	12.4	4.1	67.0	3.40	0.279

Meets Spec ☒ Does Not Meet Spec ☐ Not Applicable ☐

Remarks: _____

Plant Inspector: BOHANNON
 Date: 9/18/15
 Reviewed By: *Colleen Wehner*
 Date:

RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - BSG AND GRADATION WORKSHEET

Counter No: 155208
RI Contract No: 2015-CH-014
Percent RAP: 24%

Plant/Site: LYNCH/CUMBER
HMA Temp: 320° 11:16 A.M.
Independent ☐ Info Only ☐

Date: 9/18/15
113 19 mm SP
Ticket No: 74753 NET12
P. Engineering ☐ Acceptance ☒

HMA - BSG AND GRADATION WORKSHEET

Bulk Specific Gravity		Water Bath Temp:		Superpave ☒	Marshall ☐	..	
Core No.	Thickness (mm)	Dry Wt (g) [A]	Wt in Water (g) [B]	SSD Wt (g) [C]	$\frac{G_{MB}}{A}$ $\frac{A}{C-B}$	$\frac{\% \text{ Absorption}}{C-A} \times 100$ $\frac{C-A}{C-B} \times$	
24	119.9	4967.5	3008.7	4973.0	2.521	1573	

Burnoff: AC Determination

Burnoff: AC Determination						
[A]	[B]	[C]	[D] = [C] - [A] Sample Wt After Burnoff (g)	% Wt Loss $100 \times \frac{B-D}{B}$	Binder Correction Factor (%)	[E] - [F] % AC
Empty Cage Wt (g)	Sample Wt Before Burnoff (g)	Wt of Cage and Sample After Burnoff (g)				
3317.7	2501.2	5684.9	2367.2	5.36	- 0.10	5.26

Burnoff: Gradation Determination

Burnoff: Gradation Determination												
Sieve Size	1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	# 30	# 50	# 100	# 200	Pan
Wt Retained (g)	0	9.1	443.4	933.3	1586.1	1858.9	2033.9	2128.4	2199.0	2254.5	2300.3	2366.4

BOHANNON 9/18/15
Sampled By (Print / Sign) Date
104 WP4 - 330

Tested By	ROBINSON	Date	9/18/15
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9/19/15
Date
REV 4/1/15
Cores Made By (Print / Sign)
BOHANNON

1239

**RHODE ISLAND DEPARTMENT OF TRANSPORTATION
MATERIALS AND QUALITY ASSURANCE
HMA - RICE AND VOIDS WORKSHEET**

Counter No: 155208 Date: 9/18/15
 RI Contract No: 2015-CH-014 F.A.P. No: _____
 Producer: LYNCH Location: Cumb.
 Mix No: 113 Mix Class: 19mm SP

I. Superpave Sampling Procedure

1. Sample from truck in three equal increments. (AASHTO T-168)
2. Record temperature of mix in Truck. Temp: 320 (°F)
3. Split and quarter sample for testing. (AASHTO T-248)
4. Prepare sample for Ignition Oven.

NMAS	3/4"	1/2"	3/8"
Minimum Mass (g)	2000	1500	1200
5. Prepare sample for G_{mm} (Rice) test, spread out, and cool.

NMAS	3/4"	1/2"	3/8"
Minimum Mass (g)	2500	1500	1500
6. Prepare gyratory specimen. (AASHTO T-312)
 - 4800-5000g sample (approximation, adjustments may be needed)
 - Introduce sample to **heated mold** in one continuous motion.
 - Correctly place plates and paper disks.
 - Check for compaction temperature, and compact. Temp: 295 (°F)
 - Print height results. Puck ID: 24

II. G_{mm} Test Procedure and Calculation (Rice Test) (AASHTO T-209)

1. Submerge pycnometer in water bath until it stabilizes and record weight. B 1298.3 (g)
2. Tare pycnometer and place dry, cool, loose sample and record weight. A 2713.9 (g)
3. Add water until 1" above mix. Vacuum de-aerate at 25-30 mm Hg.
4. Agitate for 15 ± 2 minutes.
5. Submerge pycnometer and sample in bath for 10 ± 1 minutes. Record weight. C 2979.9 (g)

 G_{mm} Calculation

1. Subtract weight B from C. $C - B = D$ _____ (g)
2. Subtract D from weight A. $A - D = E$ _____ (g)
3. Take weight A and divide by E. A/E 2.629 G_{mm}
4. Theoretical Max density. $G_{mm} \times 62.4$ 164.0 lbs/ft³

Voids Calculation

1. Calculate G_{mb} for the Gyratory Puck (Bulk Specific Gravity) G_{mb} 2.521
2. Divide G_{mb} by G_{mm} $G_{mb} / G_{mm} = F$.959
3. Voids $(1 - F) \times 100$ 4.1

REHANNON
 Sampled/ Tested By
 (Print / Sign)

9/18/15
 Date

GN

Pine Instrument Company
Gyratory Compaction Report

Specimen Height, Angle, Pressure vs. Gyration Number

Date:	09/18/15	Machine S/N:	8147
Time:	08:28	Mode:	Set Height
Filename:	SEP18_01.DAT	Mold Diameter:	150 mm
Specimen ID:		Avg Pressure:	599 kPa
Technician:		Avg Angle of Gyration:	1.16 deg

	0	1	2	3	4	5	6	7	8	9	
0	145.8	140.9	137.7	135.4	133.6	132.1	130.9	129.8	128.9	128.1	mm
	----	1.17	1.17	1.15	1.16	1.16	1.16	1.16	1.16	1.16	deg
	596	570	567	579	593	598	600	600	600	600	kPa
10	127.3	126.7	126.1	125.6	125.1	124.6	124.2	123.8	123.4	123.1	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	600	600	600	600	600	600	600	600	600	600	kPa
20	122.7	122.4	122.1	121.8	121.6	121.3	121.1	120.8	120.6	120.4	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	600	600	600	600	600	600	599	599	599	599	kPa
30	120.2	120.0	119.8	119.6	119.5	119.3	119.2	119.0	118.9	118.7	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	599	599	598	599	599	599	599	599	599	599	kPa
40	118.6	118.4	118.3	118.2	118.1	117.9	117.8	117.7	117.6	117.5	mm
	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	deg
	599	599	600	600	600	600	600	600	600	600	kPa
50	117.4										mm
	1.16										deg
	600										kPa

Appendix VI

Traffic data of RI Route 102

HMA and WMA sections

VEHICLE CLASSIFICATIONS

STHW 102 VICTORY HW - BTW MAPLE VALLEY-FOSTER T/L (NORTH BOUND)

QTD PROJ LOG #:	000160 - 046	STATION NO:	600470000
ON STREET:	STHW 102 VICTORY HW	START DATE:	Tuesday, June 11, 2013
CROSS STREETS:	BTW MAPLE VALLEY-FOSTER T/L	VICINITY:	Rhode Island

Time	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	Total
0:00	0	4	0	0	0	0	0	0	0	0	0	0	0	4
1:00	0	4	0	0	0	0	0	0	0	0	0	0	0	4
2:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	3	0	0	0	0	0	0	0	0	0	0	0	3
4:00	0	1	0	0	0	0	0	0	0	0	0	0	0	1
5:00	0	1	0	0	0	0	0	0	0	0	0	0	0	1
6:00	0	11	9	3	0	1	0	0	0	0	0	0	0	24
7:00	0	9	4	0	1	0	0	0	0	0	0	0	0	14
8:00	0	17	8	0	3	0	0	1	0	0	0	0	0	29
9:00	0	20	6	0	1	1	0	0	0	0	0	0	0	28
10:00	2	34	5	0	1	0	0	0	0	0	0	0	0	42
11:00	1	26	7	0	2	0	0	0	1	0	0	0	0	37
12:00	0	47	11	1	1	0	0	0	0	0	0	0	0	60
13:00	1	27	10	0	1	0	0	0	0	0	0	0	0	39
14:00	1	47	8	0	3	0	0	0	0	0	0	0	0	59
15:00	0	56	10	1	3	0	0	0	1	0	0	0	0	71
16:00	3	55	14	0	1	0	0	0	0	0	0	0	0	73
17:00	1	63	14	0	1	0	0	1	0	0	0	0	0	80
18:00	0	47	2	0	0	0	0	0	0	0	0	0	0	49
19:00	0	38	6	0	1	0	0	0	0	0	0	0	0	45
20:00	1	32	3	0	1	0	0	0	0	0	0	0	0	37
21:00	0	22	0	0	0	0	0	0	0	0	0	0	0	22
22:00	0	15	3	0	0	0	0	0	0	0	0	0	0	18
23:00	0	2	0	0	0	0	0	0	0	0	0	0	0	2
TOTAL	10	501	120	5	20	2	0	2	2	0	0	0	0	742
% of Total:	1%	70%	16%	1%	3%	0%	0%	0%	0%	0%	0%	0%	0%	

7 - 9 AM Peak Total:	43	K Factor:	0.18	% Singl Unit Trucks in AADT	23.00%
12 - 2 PM Peak Total:	99	D Factor:	0.54	% Singl Unit Trucks in Pk Hr	13.00%
4 - 6 PM Peak Total:	153			% Comb Unit Trucks in Pk Hr	0.00%
				% Comb Unit Trucks in AADT	2.00%

FHWA Vehicle Classification Scheme

1	MOTORCYCLE	5	TWO AXLE, NO TIRE SINGLE UNIT	9	FIVE AXLE SINGLE TRAILER
2	PASSENGER CAR	6	THREE AXLE, SINGLE UNIT	10	SIX OR MORE AXLE, SINGLE TRAILER
3	FOUR TIRE, SINGLE UNIT	7	FOUR OR MORE AXLE, SINGLE UNIT	11	FIVE OR LESS AXLE, MULTI TRAILER
4	BUS	8	FOUR OR LESS AXLE, SINGLE TRAILER	12	SIX AXLE, MULTI TRAILER
				13	SEVEN OR MORE AXLE, MULTI TRAILER

QUALITY TRAFFIC DATA, LLC
 241 Boston Post Road West, Marlborough, MA 01752
 P: 877-852-4355 Fax: 877-877-3698 Info@QualityTrafficData.com

VEHICLE CLASSIFICATIONS

STHW 102 VICTORY HW - BTW MAPLE VALLEY-FOSTER T/L (SOUTH BOUND)

QTD PROJECT #:	800100 - 046	STATION NO:	600470060
ON STREET:	STHW 102 VICTORY HW	START DATE:	Tuesday, June 11, 2013
CROSS STREETS:	BTW MAPLE VALLEY-FOSTER T/L	VICINITY:	Rhode Island

Time	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	Total
0:00	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1:00	0	0	1	0	1	0	0	0	0	0	0	0	0	2
2:00	0	0	1	0	1	0	0	0	0	0	0	0	0	2
3:00	0	1	1	0	1	0	0	0	0	0	0	0	0	3
4:00	0	2	2	0	1	0	0	0	0	0	0	0	0	5
5:00	0	4	2	0	1	0	0	0	0	0	0	0	0	7
6:00	0	14	15	0	7	1	0	1	0	0	0	0	0	38
7:00	1	20	18	0	8	0	0	1	0	0	0	0	0	50
8:00	0	37	15	3	12	0	0	0	0	0	0	0	0	67
9:00	1	21	9	0	9	0	0	1	0	0	0	0	0	41
10:00	0	12	17	2	15	0	0	0	0	0	0	0	0	46
11:00	0	24	17	2	15	0	0	0	0	0	0	0	0	58
12:00	0	23	16	1	7	0	0	3	0	0	0	0	0	52
13:00	0	20	16	0	8	0	0	0	0	0	0	0	0	44
14:00	1	24	11	0	8	0	0	0	0	0	0	0	0	44
15:00	0	30	18	0	5	0	0	0	0	0	0	0	0	51
16:00	0	30	20	0	12	0	0	0	0	0	0	0	0	52
17:00	9	30	19	0	0	0	0	0	0	0	0	0	0	68
18:00	0	20	21	0	1	0	0	0	0	0	0	0	0	42
19:00	0	20	20	1	0	0	0	0	0	0	0	0	0	41
20:00	0	10	8	0	0	0	0	0	0	0	0	0	0	18
21:00	0	8	2	0	0	0	0	0	0	0	0	0	0	10
22:00	0	0	0	0	6	0	0	0	0	0	0	0	0	6
23:00	0	2	1	0	0	0	0	0	0	0	0	0	0	3
TOTAL	12	257	252	9	115	1	0	6	0	0	0	0	0	756
% of Total:	2%	47%	33%	1%	15%	0%	0%	1%	0%	0%	0%	0%	0%	

7 - 9 AM Peak Total:	123	D Factor:	0.98	% Good Unit Trucks in AADT:	23.00%
12 - 2 PM Peak Total:	90	D Factor:	0.94	% Long Unit Trucks in PM 10:	13.00%
4 - 6 PM Peak Total:	115			% Comb Unit Trucks in PM 10:	0.00%
				% Comb Unit Trucks in AADT:	2.00%

FHWA Vehicle Classification Scheme

1	MOTORCYCLES	5	TWO AXLE, SIX TIRE SINGLE UNIT	9	FIVE AXLE SINGLE TRAILER
2	PAVING/GR CARS	6	THREE AXLE, SINGLE UNIT	10	BOX OR WOMB AXLE, SINGLE TRAILER
3	FOUR TIRE, SINGLE UNIT	7	FOUR OR MORE AXLE, SINGLE UNIT	11	FIVE OR LESS AXLE, MULTI TRAILER
4	BUSES	8	FOUR OR MORE AXLE, SINGLE TRAILER	12	BOX AXLE, MULTI TRAILER
				13	MORE OR MORE AXLE, MULTI TRAILER

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241 Boston Post Road West, Marlborough, MA 01752
Ph: 877-852-4355 Fax: 877-877-3698 info@QualityTrafficData.com

VEHICLE CLASSIFICATIONS

STHW 102 VICTORY HW - BTW MAPLE VALLEY-FOSTER T/L (COMBINED)

QTD PROJ/LOC #:	900100 - 046	STATION NO:	900470060
ON STREET:	STHW 102 VICTORY HW	START DATE:	Tuesday, June 11, 2013
CROSS STREETS:	BTW MAPLE VALLEY-FOSTER T/L	VICINITY:	Rhode Island

Time	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	Total
0:00	0	5	0	0	0	0	0	0	0	0	0	0	0	5
1:00	0	4	1	0	1	0	0	0	0	0	0	0	0	6
2:00	0	0	1	0	1	0	0	0	0	0	0	0	0	2
3:00	0	4	1	0	1	0	0	0	0	0	0	0	0	6
4:00	0	3	2	0	1	0	0	0	0	0	0	0	0	6
5:00	0	5	2	0	1	0	0	0	0	0	0	0	0	8
6:00	0	25	24	3	7	2	0	1	0	0	0	0	0	62
7:00	1	37	22	0	9	0	0	1	0	0	0	0	0	70
8:00	0	54	23	3	15	0	0	1	0	0	0	0	0	96
9:00	1	41	15	0	10	1	0	1	0	0	0	0	0	59
10:00	2	46	22	2	16	0	0	0	0	0	0	0	0	86
11:00	1	50	24	2	17	0	0	0	1	0	0	0	0	95
12:00	0	70	29	2	8	0	0	3	0	0	0	0	0	112
13:00	1	47	26	0	9	0	0	0	0	0	0	0	0	83
14:00	2	71	19	0	11	0	0	0	0	0	0	0	0	103
15:00	0	54	28	1	8	0	0	0	1	0	0	0	0	122
16:00	3	75	34	0	13	0	0	0	0	0	0	0	0	125
17:00	10	101	33	0	1	0	0	1	0	0	0	0	0	146
18:00	0	67	23	0	1	0	0	0	0	0	0	0	0	91
19:00	0	58	26	1	1	0	0	0	0	0	0	0	0	86
20:00	1	42	11	0	1	0	0	0	0	0	0	0	0	55
21:00	0	30	2	0	0	0	0	0	0	0	0	0	0	32
22:00	0	15	3	0	6	0	0	0	0	0	0	0	0	24
23:00	0	4	1	0	0	0	0	0	0	0	0	0	0	5
TOTAL	22	936	372	14	136	3	0	6	2	0	0	0	0	1497
% of Total:	1%	63%	25%	1%	9%	0%	0%	1%	0%	0%	0%	0%	0%	

7 - 9 AM Peak Total:	166	K Factor:	0.18	% Singl Unit Trucks in AADT	23.00%
12 - 2 PM Peak Total:	195	D Factor:	0.54	% Singl Unit Trucks in Pk Hr	13.00%
4 - 6 PM Peak Total:	271			% comb Unit Trucks in Pk Hr	6.00%
Peak Hour:	5:00:00 PM			% comb Unit Trucks in AADT	2.00%

FHWA Vehicle Classification Scheme

1	MOTORCYCLES	5	TWO AXLE, SIX TIRE SINGLE UNIT	9	FOUR AXLE SINGLE TRAILER
2	PASSENGER CARS	6	THREE AXLE, SINGLE UNIT	10	BOX OR MORE AXLE, SINGLE TRAILER
3	FOUR TIRE, SINGLE UNIT	7	FOUR OR MORE AXLE, SINGLE UNIT	11	FIVE OR MORE AXLE, MULTI TRAILER
4	BUSES	8	FOUR OR MORE AXLE, SINGLE TRAILER	12	BOX AXLE, MULTI TRAILER
				13	SEVEN OR MORE AXLE, MULTI TRAILER

QUALITY TRAFFIC DATA, LLC

241 Boston Post Road West, Marlborough, MA 01752
Ph: 877-852-4355 Fax: 877-877-3698 Info@QualityTrafficData.com

Appendix VII
Classification of Soil of Route 102

Soil Classification of Route 102 (from Harkney Hill road to the Plainfield Pike)

Soil Index	Soil Name	AASTHO Classification	Liquid Limit	Plasticity Index	USDA Texture	Permeability (Inch/hour)	Depth (Inch)	Available water capacity (in/in)	Local Roads and streets
WoB	Wood Bridge	A-2, A-4	<30	NP-10	Very Stony fine sandy loam	0-7	0.6-6.0	0.08-0.23	Severe: Frost Action
Aa	Adrian	A-2, A-8			Loamy sand, fine sand	6-2	0-20	0.35-0.45	Severe: Frost Action , excess humus
ChB	Canton	A-2, A-4	<18	NP	Very stony fine sandy loam	2-6	3-22	0.13-0.2	Slight
Rf	Leicester	A-2, A-4	16-35	NP-10	Extremely stony fine sandy loam	0.6-6.0	0-4	0.06-0.24	Severe: Frost Action

(Source: Soil Survey of Rhode Island issued on 1981)

Appendix VIII
Reports of Rideability of RI Route 102

Appendix A

Rheological Properties of Asphalt Binder Test Report

Appendix A-1

Determining the Rheology Properties of Asphalt Binder Using a Dynamic Shear

Rheometer

Purpose of Test

This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. This test is appropriate for unaged and aged asphalt binders both.

During rheological evaluation of asphalt binder, the parameter $G^*/\sin \delta$ is derived assuming a stress-controlled behavior. Usually testings are done in constant stress mode for Superpave specification. The DSR can measure only two things: Torque and Displacement: rest all the other parameters are calculated. In Superpave specification testing, the binder is within the linear viscoelastic (LVE) regime. So in a constant stress mode, the DSR sets the torque such that the resulting strain is approximately 10-12% for soft materials (unaged, RTFO aged) and 1-2% for hard materials (PAV aged). The DSR sets this stress value automatically. So using the value of 10-12% or 1-2%, DSR is to set the torque (stress) so that material property is captured within LVE range.

Apparatus

The following apparatus used in this test

1. Dynamic Shear Rheometer (DSR) Test system which consists of Parallel metal plates, an environmental chamber, a loading device and a control data acquisition system.
2. Metal plates made from stainless steel or aluminum with smooth ground surface. One set made up of 8.00 ± 0.02 mm in diameter and the other one of 25.00 ± 0.05 mm in diameter.
3. Environmental Chamber used for controlling test temperature by heating or by cooling

to maintain a constant specimen environment. The temperature in the chamber may be controlled by the circulation of fluid such as water and conditioned gasses like nitrogen etc.

4. Temperature Controller capable of maintaining specimen temperatures within ± 0.1 °C.

5. Internal Temperature detector for the DSR used to control the temperature of specimen between two plates.

6. Loading Device apply a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/sec.

7. Control and data acquisition system which can provide a record of temperature, frequency, deflection angle and torque.

8. Specimen Mold

9. Specimen Trimmer

10. Wiping Material

11. Cleaning Solvents

12. Reference Thermometer

13. Optical Viewing Device

14. Electronic Thermometer

Test Procedure

1. This test is performed on unaged binders and binders that have been aged in a rolling thin film oven and pressure aging vessel.
2. At the beginning of the procedure, a 10 g sample is usually in a small container such as a “3” ounce tin. To prepare for testing heat the sample until it is sufficiently fluid to pour. The consistency should be less than 0.5 Pa-sec which is approximate consistency of motor oil. The sample should never be heated above 150°C.
3. Turn on the rheometer air system by opening the supply regulator. The regulator is a valve affixed to the central laboratory air system and is normally located close to the rheometer. In many cases, the valve is part of a combination regulator/water filter system and is not a part of rheometer itself. It is important that the rheometer air system be on prior to manipulation of the rheometer to prevent damage to any components. Turn on personal

computer system and temperature control system that circulates water.

4. Turn on rheometer and the attached computer. As we are using DSR by TA instruments so we used the Advanced Rheology Navigator software to run our test.

5. After initializing the software program do the calibration first with an operational thermometer and thermostat and check the calibrations with a testing material.

6. After doing calibration go to the main screen of the software then in scripts menu select utility scripts and then click on the zero gap option.

7. Once you click on the zero gap then software used you to attach 25 mm matching plates then select ok. Once you do that the upper head of the machine will start lowering its head to achieve 4500 microns value.

8. After that again from the script menu select original binder and enter your sample name and file name in the window then software will ask you about the range of temperature you want to run the test. In our case we put first temperature as 62°C and the second temperature as 68°C.

9. After that instrument will take some time to achieve the desired temperature and once again instrument will set zero gap.

10. In the mean while pour your sample into silicon made mold and give sample about 5 minutes to get cool and stiff.

11. After that software will ask you to load the sample simple remove the sample from mold and place it between two place and then select ok.

12. After doing that instrument will come down to achieve 1050 microns then software will ask you to trim the sample. Carefully by using trimming tools trim the sample from the sides of the plates and then select OK

13. Then instrument will go down further to 1000 microns and achieve desired temperature once again.

14. After that software will take 10 minutes to run the test at first given temperature and 10 more minutes to run the test for second given temperature.

15. After doing that software will tell you that test has been completed unscrew the plates and clean them by scraping using suitable liquid solvent like Black Jack asphalt and tar remover and in the end, it will print a 2 page report for you in which you can find the values of G^* , Phase angle and $G^*/\text{Phase angle}$.

Observations

After performing the above procedure, we have following observations.

It should be noted that in the report the operator name was TJB in some reports (Page 98-101) but they were mutually conducted by the author as well.

DSR Report

SAMPLE INFORMATION

Sample Name: 0.0 WMA
Operator: TJB
Project: WMA RESEARCH
Notes: PG 58-28 0.0% WMA
File Name: C:\ProgramData\TA Instruments\TRI\OS\Data\0.tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: Original Binder
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	0.22	12.0	83.9	1.84	1.85	Pass
2	10.0	64.0	0.10	12.0	85.7	0.873	0.875	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: 0.5 WMA
Operator: TJB
Project: WMA RESEARCH
Notes: 0.5% WMA
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\0.tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: Original Binder
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	0.21	12.0	83.7	1.73	1.74	Pass
2	10.0	64.0	0.10	12.0	85.5	0.824	0.827	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: 0.7 WMA TEST 2
Operator: TJB
Project: WMA RESEARCH
Notes: 0.7% WMA
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\0.tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: Original Binder
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	0.23	12.0	83.5	1.93	1.94	Pass
2	10.0	64.0	0.11	12.0	85.4	0.909	0.912	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: 0.9 WMA
Operator: TJB
Project: WMA RESEARCH
Notes: 0.9% WMA
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\0.tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: Original Binder
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	0.22	12.0	83.4	1.87	1.88	Pass
2	10.0	64.0	0.11	12.0	85.3	0.891	0.894	Fail

Analysis of Data Collection

By analyzing the data collected by performing DSR test on unaged sample that our test passed only on 58 °C. According to PG Binder grading system $G^*/\sin \delta$ value for unaged sample should have the value minimum 1.00 kPa. In our case temperature at 58 °C pass the criteria for PG grading system.

Possible sources of error

There might be following possible errors conducting DSR test.

- Calibration of the equipment
- Not enough trimming of the sample after loading between plates
- Not having enough good bulges as recommended by AASHTO specifications.

Conclusion

So, in the whole we can say that this method is used to measure the complex shear modulus (G^*) and Phase angle (sine delta) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry. The test temperature from this method is related to temperature experienced by the pavement in the geographical area for which asphalt binder is intended to be used. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region.

Appendix A-2

Using a Dynamic Shear Rheometer on Short term Aged Sample (RTFO) Test

Purpose of Test

This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. This test is appropriate for unaged and aged asphalt binders both.

Apparatus

The following apparatus used in this test

1. Dynamic Shear Rheometer (DSR) Test system which consists of Parallel metal plates, an environmental chamber, a loading device and a control data acquisition system.
2. Metal plates made from stainless steel or aluminum with smooth ground surface. One set made up of 8.00 ± 0.02 mm in diameter and the other one of 25.00 ± 0.05 mm in diameter.
3. Environmental Chamber used for controlling test temperature by heating or by cooling to maintain a constant specimen environment. The temperature in the chamber may be controlled by the circulation of fluid such as water and conditioned gasses like nitrogen etc.
4. Temperature Controller capable of maintaining specimen temperatures within $\pm 0.1^\circ\text{C}$.
5. Internal Temperature detector for the DSR used to control the temperature of specimen between two plates.
6. Loading Device apply a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/sec.
7. Control and data acquisition system which can provide a record of temperature, frequency, deflection angle and torque.

8. Specimen Mold
9. Specimen Trimmer
10. Wiping Material
11. Cleaning Solvents
12. Reference Thermometer
13. Optical Viewing Device
14. Electronic Thermometer

Preparation of Short-term Aged Sample using RTFO: -

1. For the preparation of aged sample we took three bottles of rolling thin film oven preheated at 163°C in oven and pour 35gms of asphalt binder preheated in an oven.
2. Then we placed the bottles into the oven back which was preheated at 163°C. After that we set the air pressure of 4 Psi, closed the door of the oven, Turn on the rotational and air button on the oven.
3. We placed our sample in the oven for 85 minutes. After that we removed the bottles pour a little amount of sample into the 8mm silicon made mold for DSR testing on aged sample and remaining into the container for PAV testing on aged sample.

Test Procedure

1. This test is performed on binders that have been aged in a rolling thin film oven.
2. Turn on the rheometer air system by opening the supply regulator. The regulator is a valve affixed to the central laboratory air system and is normally located close to the rheometer. In many cases, the valve is part of a combination regulator/water filter system and is not a part of rheometer itself. It is important that the rheometer air system be on prior

to manipulation of the rheometer to prevent damage to any components. Turn on personal computer system and temperature control system that circulates water.

3. Turn on rheometer and the attached computer. As we are using DSR by TA instruments so we used the Advanced Rheology Navigator software to run our test.

4. After initializing the software program do the calibration first with an operational thermometer and thermostat and check the calibrations with a testing material.

5. After doing calibration go to the main screen of the software then in scripts menu select utility scripts and then click on the zero-gap option.

6. Once you click on the zero gap then software used you to attach 25 mm matching plates then select ok. Once you do that the upper head of the machine will start lowering its head to achieve 4500 microns value.

7. After that again from the script menu select original binder and enter your sample name and file name in the window then software will ask you about the range of temperature you want to run the test. In our case we put first temperature as 62°C and the second temperature as 68°C.

8. After that instrument will take some time to achieve the desired temperature and once again instrument will set zero gap.

9. In the mean while pour your sample into silicon made mold and give sample about 5 minutes to get cool and stiff.

10. After that software will ask you to load the sample simply remove the sample from mold and place it between two plates and then select ok.

11. After doing that instrument will come down to achieve 1050 microns then software will ask you to trim the sample. Carefully by using trimming tools trim the sample from the

sides of the plates and then select OK

12. Then instrument will go down further to 1000 microns and achieve desired temperature once again.

13. After that software will take 10 minutes to run the test at first given temperature and 10 more minutes to run the test for second given temperature.

14. After doing that software will tell you that test has been completed unscrew the plates and clean them and in the end it will print a 2 page report for you in which you can find the values of G^* , Phase angle and $G^*/\text{Phase angle}$.

Observation: - After performing the above procedure, we have following observations.

DSR Report

SAMPLE INFORMATION

Sample Name: RTFO_0
Operator: NEHA
Project: Rheological Properties of WMA
Notes: RTFO RES PG 58-28 without Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\RTFO_0.tri
Time and Date: 6/19/2019 9:29:13 AM

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: RTFO Residue
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	52.0	1.75	10.0	71.7	17.4	18.4	Pass
2	10.0	58.0	0.80	10.0	74.9	8.04	8.33	Pass
3	10.0	64.0	0.38	9.9	78.0	3.80	3.88	Pass
4	10.0	70.0	0.18	10.0	80.8	1.84	1.87	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: RTFO_0.7
Operator: NEHA
Project: Rheological Properties of WMA
Notes: RTFO RES PG 58-28 with 0.5 Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\RTFO_0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: RTFO Residue
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	0.70	10.0	75.4	6.97	7.20	Pass
2	10.0	64.0	0.33	10.1	78.4	3.32	3.39	Pass
3	10.0	70.0	0.16	10.0	81.1	1.61	1.63	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: RTFO_0.9
Operator: NEHA
Project: Rheological Properties of WMA
Notes: RTFO RES PG 58-28 with 0.5 Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\RTFO_0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: RTFO Residue
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*/sin(delta) kPa	Pass/Fail
1	10.0	58.0	1.00	10.0	72.5	9.94	10.4	Pass
2	10.0	64.0	0.47	10.0	75.7	4.73	4.88	Pass
3	10.0	70.0	0.23	10.0	78.8	2.31	2.36	Pass
4	10.0	76.0	0.12	10.0	81.4	1.17	1.18	Fail

Analysis of Data Collection

By analyzing the data collected by performing DSR test on short term aged sample that our test passed on various temperature. According to PG asphalt binder grading system for sample under short term aging should have the value min 2.2 kPa.

Possible sources of error

There might be following possible errors conducting DSR test.

1. Calibration of the equipment
2. Not enough trimming of the sample after loading between plates
3. Not having enough good bulge as recommended by AASHTO specifications.

Conclusion

So, in the whole we can say that this method is used to measure the complex shear modulus (G^*) and Phase angle (sine delta) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry. The test temperature from this method is related to temperature experienced by the pavement in the geographical area for which asphalt binder is intended to be used. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region. To predict the highest temperature grade, we have to compare the results of unaged sample with results of short term aged sample report. Hence, from overall, we predicted that all HMA and WMA asphalt binders has the same final maximum temperature i.e. 58°C.

Appendix A-3

Using a Dynamic Shear Rheometer on Pressurized Aging Vessel Sample

Purpose of Test

This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. This test is appropriate for unaged and aged asphalt binders both.

Apparatus

The following apparatus used in this test

1. Dynamic Shear Rheometer (DSR) Test system which consists of Parallel metal plates, an environmental chamber, a loading device and a control data acquisition system.
2. Metal plates made from stainless steel or aluminum with smooth ground surface. One set made up of 8.00 ± 0.02 mm in diameter and the other one of 25.00 ± 0.05 mm in diameter.
3. Environmental Chamber used for controlling test temperature by heating or by cooling to maintain a constant specimen environment. The temperature in the chamber may be controlled by the circulation of fluid such as water and conditioned gasses like nitrogen etc.
4. Temperature Controller capable of maintaining specimen temperatures within $\pm 0.1^\circ\text{C}$.
5. Internal Temperature detector for the DSR used to control the temperature of specimen between two plates.
6. Loading Device apply a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/sec.
7. Control and data acquisition system which can provide a record of temperature, frequency, deflection angle and torque.

8. Specimen Mold
9. Specimen Trimmer
10. Wiping Material
11. Cleaning Solvents
12. Reference Thermometer
13. Optical Viewing Device
14. Electronic Thermometer

Preparation of Pressurized Aging Vessel (PAV) Sample:

1. Combine the hot residue from the RTFO into a single container, stir to blend, then transfer into TFOT pans for PAV conditioning.
2. Place the pan holder inside the pressure vessel. If an oven is used, place the pressure vessel inside the oven. If an integrated temperature control pressure vessel is used, turn on the heater. Select an aging temperature and preheat the pressure vessel to the aging pressure selected.
3. Place the TFOT pan on a balance and add 50 g of asphalt binder to the pan. This will yield approximately a 3.2 mm thick film of asphalt binder.
4. If the vessel is preheated to other than the desired aging temperature, reset the temperature control on the heating device to the aging temperature.
5. Place the filled pans in the pan holder and then place the pan holder with filled pans inside the pressure vessel and close the pressure vessel.
6. Connect the temperature transducer line and the air pressure supply line to the loaded pressure vessel's external connections.
7. Wait until the temperature inside the pressure vessel is within 20°C of the aging

temperature, apply an air pressure of 2.1 MPa and then start timing the test.

8. Maintain the temperature and air pressure inside the pressure vessel for 20 hours.

9. At the end of the 20 hour test period slowly begin reducing the internal pressure of the PAV, using the air pressure bleed valve. Adjust the bleed valve to an opening that requires 9 minutes to equalize the internal and external pressures on the PAV thus avoiding excessive bubbling and foaming of asphalt binder.

10. If the temperature indicated by temperature recording device falls above or below the target aging temperature 0.5°C for more than 10 minutes during the 20-hour aging period declare the test invalid and discard the material.

11. Remove the pan holder and pans from PAV, and place in an oven set at 163°C . Heat until sufficiently fluid to pour. Stir gently in the removal of air bubbles.

12. Pour a small amount of sample into rubber mold and allow sample to cool down for DSR testing.

Test Procedure

1. This test is performed on binders that have been aged in PAV.

2. Turn on the rheometer air system by opening the supply regulator. The regulator is a valve affixed to the central laboratory air system and is normally located close to the rheometer. In many cases, the valve is part of a combination regulator/water filter system and is not a part of rheometer itself. It is important that the rheometer air system be on prior to manipulation of the rheometer to prevent damage to any components. Turn on personal computer system and temperature control system that circulates water.

3. Turn on rheometer and the attached computer. As we are using DSR by TA instruments so we used the Advanced Rheology Navigator software to run our test.

4. After initializing the software program do the calibration first with an operational thermometer and thermostat and check the calibrations with a testing material.
5. After doing calibration go to the main screen of the software then in scripts menu select utility scripts and then click on the zero-gap option.
6. Once you click on the zero gap then software used you to attach 25 mm matching plates then select ok. Once you do that the upper head of the machine will start lowering its head to achieve 4500 microns value.
7. After that again from the script menu select PAV residue and enter your sample name and file name in the window then software will ask you about the range of temperature you want to run the test. In our case we put first temperature as 25°C and the second temperature as 22°C.
8. After that instrument will take some time to achieve the desired temperature and once again, instrument will set zero gap.
9. In the mean while pour your sample into silicon made mold and give sample about 5 minutes to get cool and stiff.
10. After that software will ask you to load the sample simple remove the sample from mold and place it between two place and then select ok.
11. After doing that instrument will come down to achieve 2050 microns then software will ask you to trim the sample. Carefully by using trimming tools trim the sample from the sides of the plates and then select OK
12. Then instrument will go down further to 2000 microns and achieve desired temperature once again.
13. After that software will take 10 minutes to run the test at first given temperature and 10

more minutes to run the test for second given temperature.

14. After doing that software will tell you that test has been completed unscrew the plates and clean them and in the end, it will print a 2-page report for you in which you can find the values of G^* , Phase angle and $G^*/\text{Phase angle}$.

Observation: -

After performing the above procedure we have following observations.

DSR Report

SAMPLE INFORMATION

Sample Name: PAV_RESidue_HMA
Operator: Neha
Project: PAV DSR
Notes: PG58-28 without Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\PAV_RESidue_HMA (1).tri
Time and Date: 7/3/2019 12:27:35 PM

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: PAV Residue
Geometry Diameter: 8.00 mm
Gap: 2000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*.sin(delta) kPa	Pass/Fail
1	10.0	16.0	47.04	1.0	47.8	4660	3460	Pass
2	10.0	13.0	73.86	1.0	45.1	7340	5210	Fail
3	10.0	10.0	115.54	1.0	42.4	11400	7710	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: PAV_Residue_WMA_0.5
Operator: Neha
Project: PAV DSR
Notes: PG58-28 with 0.5% Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\PAV_Residue_WMA_0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: PAV Residue
Geometry Diameter: 8.00 mm
Gap: 2000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*.sin(delta) kPa	Pass/Fail
1	10.0	22.0	10.84	1.0	56.1	1080	898	Pass
2	10.0	19.0	17.55	1.0	53.5	1760	1410	Pass
3	10.0	16.0	28.26	1.0	50.9	2840	2200	Pass
4	10.0	13.0	45.09	1.0	48.2	4530	3380	Pass
5	10.0	10.0	72.09	1.0	45.3	7190	5110	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: PAV_Residue_WMA_0.7_01
Operator: Neha
Project: PAV DSR
Notes: PG58-28 with 0.7% Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\PAV_Residue_WMA_0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: PAV Residue
Geometry Diameter: 8.00 mm
Gap: 2000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*.sin(delta) kPa	Pass/Fail
1	10.0	16.0	36.07	1.0	49.4	3600	2740	Pass
2	10.0	13.0	58.12	1.0	46.5	5790	4200	Pass
3	10.0	10.0	93.17	1.0	43.5	9200	6340	Fail

DSR Report

SAMPLE INFORMATION

Sample Name: PAV_Residue_WMA_0.9
Operator: Neha
Project: PAV DSR
Notes: PG58-28 with 0.9% Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\PAV_Residue_WMA_0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: PAV Residue
Geometry Diameter: 8.00 mm
Gap: 2000 μ m

RESULTS

	Angular Freq. rad/s	Temp. °C	Osc. Stress Pa	% Strain	Delta degrees	G* kPa	G*.sin(delta) kPa	Pass/Fail
1	10.0	22.0	38.77	1.0	41.8	3870	2580	Pass
2	10.0	19.0	57.44	1.0	39.6	5720	3640	Pass
3	10.0	16.0	84.49	1.0	37.4	8350	5070	Fail

Analysis of Data Collection

By analyzing the data collected by performing DSR test on long term aged sample that our test passed on 25°C temperature. According to PG grading system sample with long term aging should have $G^*\sin \delta$ value less than 5000 kPa. In our case at 25°C passed the criteria.

Possible sources of error

There might be following possible errors conducting DSR test.

1. Calibration of the equipment
2. Not enough trimming of the sample after loading between plates
3. Not having enough good bulge as recommended by AASHTO specifications.

Conclusion

So, in the whole we can say that this method is used to measure the complex shear modulus (G^*) and Phase angle (sine delta) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry. The test temperature from this method is related to temperature experienced by the pavement in the geographical area for which asphalt binder is intended to be used. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region.

Appendix A-4

Evaluating the Elastic Behavior of Asphalt Binders Using the Multiple Stress Creep Recovery (MSCR) Test

Purpose of Test

This test is used to evaluate the elastic response of an asphalt binder using shear creep and recovery at a specified temperature.

Apparatus

The following apparatus used in this test

1. Dynamic Shear Rheometer (DSR) Test system which consists of Parallel metal plates, an environmental chamber, a loading device and a control data acquisition system.
2. Metal plates made from stainless steel or aluminum with smooth ground surface. One set made up of 8.00 ± 0.02 mm in diameter and the other one of 25.00 ± 0.05 mm in diameter.
3. Environmental Chamber used for controlling test temperature by heating or by cooling to maintain a constant specimen environment. The temperature in the chamber may be controlled by the circulation of fluid such as water and conditioned gasses like nitrogen etc.
4. Temperature Controller capable of maintaining specimen temperatures within $\pm 0.1^\circ\text{C}$.
5. Internal Temperature detector for the DSR used to control the temperature of specimen between two plates.
6. Loading Device apply a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/sec.
7. Control and data acquisition system which can provide a record of temperature, frequency, deflection angle and torque.

8. Specimen Mold
9. Specimen Trimmer
10. Wiping Material
11. Cleaning Solvents
12. Reference Thermometer
13. Optical Viewing Device
14. Electronic Thermometer

Test Procedure

1. This test is performed on aged in a rolling thin film oven.
2. At the beginning of the procedure, a 10 g sample is usually in a small container such as a “3” ounce tin. To prepare for testing heat the sample until it is sufficiently fluid to pour. The consistency should be less than 0.5 Pa-sec which is approximate consistency of motor oil. The sample should never be heated above 150°C.
3. Turn on the rheometer air system by opening the supply regulator. The regulator is a valve affixed to the central laboratory air system and is normally located close to the rheometer. In many cases, the valve is part of a combination regulator/water filter system and is not a part of rheometer itself. It is important that the rheometer air system be on prior to manipulation of the rheometer to prevent damage to any components. Turn on personal computer system and temperature control system that circulates water.
4. Turn on rheometer and the attached computer as followed same procedure followed in RTFO aged sample.
5. The sample is tested in creep and recovery at two stress levels. The stress levels used are 0.1 kPa and 3.2 kPa.

6. The creep portion of the test lasts for one second which is followed by nine-second recovery. The ten creep and nine recovery cycles at each shear level (0.1 and 3.2 kPa). Two parameters are derived from MSCR test: non recoverable creep compliance (J_{nr}) and percent recovery (R).

Observations: After performing the above procedure, we have following observations.

Multiple Stress Creep and Recovery (MSCR)

SAMPLE INFORMATION

Sample Name: MSCR-0
 Operator: Neha
 Project: AMRL SPRING 2019
 Notes: RTFO RESidue MSCR -withot Evotherrn
 File Name: C:\ProgramData\TA Instruments\TRIOS\Data\MSCR-0.tri
 Time and Date: 6/19/2019 1:08:59 PM

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
 Model: RIDOT DSR
 Bearing Type: Air/Magnetic
 Temperature Control: Dry Asphalt System
 Test: MSCR
 Geometry Diameter: 25.00 mm
 Gap: 1000 μ m

RESULTS

Test Temperature:	58.0°C
$R_{0.1}$ - Average Percent Recovery at 0.100kPa:	20.79%
$R_{3.2}$ - Average Percent Recovery at 3.200kPa:	11.53%
R_{diff} - Percent difference between average recovery at 0.100kPa and 3.200kPa:	44.53%
$J_{nr 0.1}$ - Non-recoverable creep compliance at 0.100kPa:	0.680kPa ⁻¹
$J_{nr 3.2}$ - Non-recoverable creep compliance at 3.200kPa:	0.787kPa ⁻¹
$J_{nr diff}$ - Percent difference between non-recoverable creep compliance at 0.100kPa and 3.200kPa:	15.80%

The binder is not modified with an acceptable elastomeric polymer.

INDIVIDUAL CYCLE DATA

Cycle #	E0	Ec	Er	E1	E10
11	0.688212	0.774055	0.756346	0.0858429	0.0681339
12	0.756346	0.842175	0.824419	0.0858290	0.0680730
13	0.824419	0.910364	0.892331	0.0859441	0.0679112
14	0.892331	0.978454	0.960460	0.0861232	0.0681298
15	0.960460	1.04638	1.02845	0.0859200	0.0679915
16	1.02845	1.11428	1.09646	0.0858242	0.0680107
17	1.09646	1.18215	1.16445	0.0856846	0.0679851
18	1.16445	1.25007	1.23239	0.0856258	0.0679390
19	1.23239	1.31801	1.30020	0.0856277	0.0678082
20	1.30020	1.38576	1.36782	0.0855668	0.0676212
21	1.36782	4.21134	3.87685	2.84353	2.50903
22	3.87685	6.71756	6.38772	2.84071	2.51087
23	6.38772	9.22711	8.89920	2.83938	2.51148
24	8.89920	11.7394	11.4116	2.84016	2.51240
25	11.4116	14.2541	13.9266	2.84252	2.51498
26	13.9266	16.7711	16.4435	2.84451	2.51690
27	16.4435	19.2934	18.9664	2.84994	2.52288
28	18.9664	21.8215	21.4934	2.85518	2.52708
29	21.4934	24.3489	24.0224	2.85546	2.52892
30	24.0224	26.8776	26.5513	2.85525	2.52894

Ec and Er values determined by extrapolation

Multiple Stress Creep and Recovery (MSCR)

SAMPLE INFORMATION

Sample Name: MSCR-0.5
Operator: Neha
Project: AMRL SPRING 2019
Notes: RTFO RESidue MSCR -withot Evotherrn
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\MSCR-0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: MSCR
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

Test Temperature:	58.0°C
$R_{0.1}$ - Average Percent Recovery at 0.100kPa:	16.36%
$R_{3.2}$ - Average Percent Recovery at 3.200kPa:	6.65%
R_{diff} - Percent difference between average recovery at 0.100kPa and 3.200kPa:	59.37%
$J_{nr 0.1}$ - Non-recoverable creep compliance at 0.100kPa:	1.09kPa ⁻¹
$J_{nr 3.2}$ - Non-recoverable creep compliance at 3.200kPa:	1.29kPa ⁻¹
$J_{nr diff}$ - Percent difference between non-recoverable creep compliance at 0.100kPa and 3.200kPa:	18.42%

The binder is not modified with an acceptable elastomeric polymer

INDIVIDUAL CYCLE DATA

Cycle #	E0	Ec	Er	E1	E10
11	1.09545	1.22582	1.20444	0.130365	0.108989
12	1.20444	1.33497	1.31369	0.130529	0.109250
13	1.31369	1.44401	1.42278	0.130324	0.109095
14	1.42278	1.55329	1.53190	0.130506	0.109121
15	1.53190	1.66218	1.64093	0.130271	0.109030
16	1.64093	1.77113	1.74978	0.130194	0.108846
17	1.74978	1.88000	1.85865	0.130218	0.108875
18	1.85865	1.98898	1.96755	0.130324	0.108900
19	1.96755	2.09763	2.07638	0.130072	0.108828
20	2.07638	2.20649	2.18522	0.130112	0.108835
21	2.18522	6.60107	6.30408	4.41585	4.11886
22	6.30408	10.7195	10.4260	4.41539	4.12193
23	10.4260	14.8456	14.5527	4.41954	4.12669
24	14.5527	18.9756	18.6821	4.42288	4.12936
25	18.6821	23.1077	22.8146	4.42564	4.13249
26	22.8146	27.2434	26.9488	4.42885	4.13422
27	26.9488	31.3771	31.0831	4.42833	4.13428
28	31.0831	35.5094	35.2161	4.42630	4.13309
29	35.2161	39.6424	39.3476	4.42622	4.13145
30	39.3476	43.7731	43.4796	4.42551	4.13199

Ec and Er values determined by extrapolation

Multiple Stress Creep and Recovery (MSCR)

SAMPLE INFORMATION

Sample Name: MSCR-0.7
 Operator: Neha
 Project: AMRL SPRING 2019
 Notes: RTFO Residue MSCR -withot Evotherm
 File Name: C:\ProgramData\TA Instruments\TRIOS\Data\MSCR-0 (1).tri
 Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
 Model: RIDOT DSR
 Bearing Type: Air/Magnetic
 Temperature Control: Dry Asphalt System
 Test: MSCR
 Geometry Diameter: 25.00 mm
 Gap: 1000 μ m

RESULTS

Test Temperature:	58.0°C
$R_{0.1}$ - Average Percent Recovery at 0.100kPa:	18.09%
$R_{3.2}$ - Average Percent Recovery at 3.200kPa:	8.53%
R_{diff} - Percent difference between average recovery at 0.100kPa and 3.200kPa:	52.87%
$J_{nr 0.1}$ - Non-recoverable creep compliance at 0.100kPa:	0.883kPa ⁻¹
$J_{nr 3.2}$ - Non-recoverable creep compliance at 3.200kPa:	1.04kPa ⁻¹
$J_{nr diff}$ - Percent difference between non-recoverable creep compliance at 0.100kPa and 3.200kPa:	17.54%

The binder is not modified with an acceptable elastomeric polymer.

INDIVIDUAL CYCLE DATA

Cycle #	E0	Ec	Er	E1	E10
11	0.887131	0.994896	0.975689	0.107765	0.0885579
12	0.975689	1.08371	1.06434	0.108023	0.0886522
13	1.06434	1.17243	1.15277	0.108091	0.0884244
14	1.15277	1.26094	1.24127	0.108178	0.0884990
15	1.24127	1.34922	1.32964	0.107951	0.0883716
16	1.32964	1.43731	1.41788	0.107669	0.0882421
17	1.41788	1.52528	1.50603	0.107405	0.0881503
18	1.50603	1.61356	1.59418	0.107529	0.0881523
19	1.59418	1.70201	1.68240	0.107825	0.0882232
20	1.68240	1.79045	1.77052	0.108048	0.0881158
21	1.77052	5.39752	5.08453	3.62700	3.31401
22	5.08453	8.71940	8.41016	3.63487	3.32563
23	8.41016	12.0429	11.7341	3.63272	3.32393
24	11.7341	15.3619	15.0530	3.62786	3.31896
25	15.0530	18.6816	18.3726	3.62858	3.31959
26	18.3726	22.0064	21.6976	3.63374	3.32497
27	21.6976	25.3321	25.0221	3.63445	3.32450
28	25.0221	28.6601	28.3502	3.63797	3.32806
29	28.3502	31.9824	31.6728	3.63226	3.32265
30	31.6728	35.3061	34.9967	3.63325	3.32384

Ec and Er values determined by extrapolation

Multiple Stress Creep and Recovery (MSCR)

SAMPLE INFORMATION

Sample Name: MSCR-0.9
Operator: Neha
Project: AMRL SPRING 2019
Notes: RTFO RESidue MSCR -withot Evotherm
File Name: C:\ProgramData\TA Instruments\TRIOS\Data\MSCR-0 (1).tri
Time and Date:

DSR/TEST SPECIFICATIONS

Manufacturer: TA Instruments
Model: RIDOT DSR
Bearing Type: Air/Magnetic
Temperature Control: Dry Asphalt System
Test: MSCR
Geometry Diameter: 25.00 mm
Gap: 1000 μ m

RESULTS

Test Temperature:	58.0°C
$R_{0.1}$ - Average Percent Recovery at 0.100kPa:	25.34%
$R_{3.2}$ - Average Percent Recovery at 3.200kPa:	13.41%
R_{diff} - Percent difference between average recovery at 0.100kPa and 3.200kPa:	47.06%
$J_{nr 0.1}$ - Non-recoverable creep compliance at 0.100kPa:	0.599kPa ⁻¹
$J_{nr 3.2}$ - Non-recoverable creep compliance at 3.200kPa:	0.725kPa ⁻¹
$J_{nr diff}$ - Percent difference between non-recoverable creep compliance at 0.100kPa and 3.200kPa:	21.06%

The binder is not modified with an acceptable elastomeric polymer

INDIVIDUAL CYCLE DATA

Cycle #	E0	Ec	Er	E1	E10
11	0.609968	0.690236	0.670242	0.0802676	0.0602736
12	0.670242	0.750634	0.730133	0.0803923	0.0598911
13	0.730133	0.810431	0.790117	0.0802983	0.0599844
14	0.790117	0.870480	0.850233	0.0803632	0.0601153
15	0.850233	0.930464	0.910427	0.0802314	0.0601948
16	0.910427	0.990484	0.970050	0.0800563	0.0596228
17	0.970050	1.05032	1.02966	0.0802699	0.0596122
18	1.02966	1.10966	1.08934	0.0799957	0.0596764
19	1.08934	1.16932	1.14908	0.0799838	0.0597420
20	1.14908	1.22894	1.20856	0.0798642	0.0594834
21	1.20856	3.86867	3.50059	2.66010	2.29203
22	3.50059	6.16563	5.80309	2.66503	2.30250
23	5.80309	8.47369	8.11384	2.67060	2.31075
24	8.11384	10.7871	10.4282	2.67327	2.31435
25	10.4282	13.1061	12.7475	2.67795	2.31926
26	12.7475	15.4295	15.0719	2.68207	2.32441
27	15.0719	17.7564	17.3995	2.68452	2.32767
28	17.3995	20.0857	19.7286	2.68615	2.32910
29	19.7286	22.4182	22.0626	2.68961	2.33401
30	22.0626	24.7531	24.3968	2.69046	2.33413

Ec and Er values determined by extrapolation

Analysis of Data Collection

Modified binder shows higher percent of recovery compare with the regular asphalt binder.

Possible sources of error

There might be following possible errors conducting DSR test.

1. Calibration of the equipment
2. Not enough trimming of the sample after loading between plates
3. Not having enough good bulge as recommended by AASHTO specifications.

Conclusion

So, in the whole we can say that this method is used to measure the presence of elastic response in an asphalt binder under shear creep and recovery at two stress levels at 58 °

C. Hence, the addition of additives improves the recovery and rutting properties.

Appendix A-5

Determining the Flexural Creep Stiffness of Asphalt Binder using Bending Beam Rheometer

Purpose of Test

This test method covers the determination of the flexural creep stiffness or compliance of asphalt binder by means of a bending beam rheometer. It is applicable to material having flexural stiffness value from 20 MPa to 1 GPa values in the range of (50 nPa⁻¹ to 1 nPa⁻¹) and can be used with unaged material or with material aged using RTFOT or PAV test.

This test apparatus is designed to test within the temperature range of -36°C to 22°C.

Apparatus

The following apparatus used in this test.

1. Bending Beam Rheometer Test System (Figure B-6-1)
2. Loading Frame
3. Loading System
4. Sample supports
5. Loading Shaft
6. Controlled Temperature fluid bath
7. Data Acquisition System
8. Thermometers
9. Test Beam molds

Preparation of Asphalt Binder Beam:-

Prepare the asphalt sample by heating in oven. Pour the sample in standard aluminum mold. Allow the sample to cool down at room temperature for 45 minutes then trim it from the top after then put in the refrigerator to cool down. Set the temperature of the water bath inside the BBR system for your test temperature in our case we set the temperature at -18°C. Once asphalt in the mold gets hard remove from the mold and place the asphalt binder beam in the water bath for one hour to equalize temperature.

Test Procedure: -

First step to run BBR test is to do calibrations for Load, Deflection and Temperature. Use zero and load gauges on the BBR machine to lower or raise the shaft. Apply pressure of 40 psi to BBR machine. For load calibrations apply four different 100g weight on the machine on a thick beam and save the readings in the software. Similarly save the deflection calibration as instructed by software. After doing calibration run a confidence test on a thin beam by applying four different 100g weights and save the results in the software. Once it done then place the asphalt binder beam under the loading machine and run the test from the software and software will calculate the stiffness and deflection values of the beam in a given interval of time that is 240 seconds and Load.

Observations:

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 218
Operator : TJB	Min. Temp (°C) : -18.1	Conf Date : 07/03/2019
Specimen : PG 58-28 0% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 11:09:00 AM	Temp Cal Date : 07/03/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/03/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.81
File Name : 19070301	Beam Width (mm) : 12.70	Cal Date : 07/03/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	991	0.363	220	220	0.000	0.312
15.0	990	0.445	179	180	0.559	0.333
30.0	990	0.564	142	141	-0.704	0.355
60.0	989	0.726	110	110	0.000	0.378
120.0	987	0.950	83.8	83.8	3.64e-006	0.400
240.0	986	1.262	63	63	0.000	0.423

A = 2.59 B = -0.245 C = -0.0374 R² = 0.999997

Force (t=0.0s) = 38 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 990 mN Deflection (t=0.5s) = 0.162 mm

Max Force Deviation (t=0.5 - 5.0s) = -0, +3 mN
 Max Force Deviation (t=5.0 - 240.0s) = -2, +3 mN

Average Force (t=0.5 - 240.0s) = 988 mN
 Maximum Force (t=0.5 - 240.0s) = 991 mN
 Minimum Force (t=0.5 - 240.0s) = 986 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 218
Operator : TJB	Min. Temp (°C) : -18.1	Conf Date : 07/03/2019
Specimen : PG 58-28 0% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 11:16:43 AM	Temp Cal Date : 07/03/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/03/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.81
File Name : 19070302	Beam Width (mm) : 12.70	Cal Date : 07/03/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	989	0.399	200	200	0.000	0.293
15.0	989	0.484	165	165	0.000	0.316
30.0	989	0.607	131	131	0.000	0.341
60.0	989	0.774	103	103	0.000	0.366
120.0	988	1.009	79	79.1	0.127	0.391
240.0	987	1.330	59.8	59.8	-1.28e-006	0.416

A = 2.53 B = -0.218 C = -0.0415 R² = 0.999991

Force (t=0.0s) = 39 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 986 mN Deflection (t=0.5s) = 0.182 mm

Max Force Deviation (t=0.5 - 5.0s) = -2, +1 mN
 Max Force Deviation (t=5.0 - 240.0s) = -1, +2 mN

Average Force (t=0.5 - 240.0s) = 988 mN
 Maximum Force (t=0.5 - 240.0s) = 990 mN
 Minimum Force (t=0.5 - 240.0s) = 986 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 210
Operator : TJB	Min. Temp (°C) : -18.0	Conf Date : 07/05/2019
Specimen : PG 58-28 0.5% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 11:51:43 AM	Temp Cal Date : 07/05/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/05/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.91
File Name : 19070501	Beam Width (mm) : 12.70	Cal Date : 07/05/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	989	0.463	172	172	0.000	0.338
15.0	988	0.574	139	139	0.000	0.356
30.0	986	0.740	107	108	0.935	0.376
60.0	985	0.966	82.2	82.3	0.122	0.396
120.0	984	1.278	62.1	62.1	-2.46e-006	0.417
240.0	987	1.724	46.2	46.2	1.65e-006	0.437

A = 2.51 B = -0.277 C = -0.0336 R² = 0.999997

Force (t=0.0s) = 41 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 992 mN Deflection (t=0.5s) = 0.197 mm

Max Force Deviation (t=0.5 - 5.0s) = -0, +6 mN
 Max Force Deviation (t=5.0 - 240.0s) = -2, +4 mN

Average Force (t=0.5 - 240.0s) = 986 mN
 Maximum Force (t=0.5 - 240.0s) = 992 mN
 Minimum Force (t=0.5 - 240.0s) = 984 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 210
Operator : TJB	Min. Temp (°C) : -18.1	Conf Date : 07/05/2019
Specimen : PG 58-28 0.5% WMA	Max. Temp (°C) : -18.0	Force Const (mN/bit) : 0.151
Test Time : 11:56:53 AM	Temp Cal Date : 07/05/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/05/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.91
File Name : 19070502	Beam Width (mm) : 12.70	Cal Date : 07/05/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	991	0.452	177	177	0.000	0.321
15.0	989	0.558	143	143	0.000	0.347
30.0	990	0.716	111	111	0.000	0.377
60.0	989	0.938	85	84.9	-0.118	0.406
120.0	988	1.256	63.4	63.5	0.158	0.435
240.0	988	1.715	46.5	46.5	0.000	0.465

A = 2.5 B = -0.232 C = -0.0488 R² = 0.999995

Force (t=0.0s) = 38 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 988 mN Deflection (t=0.5s) = 0.196 mm

Max Force Deviation (t=0.5 - 5.0s) = -1, +3 mN
Max Force Deviation (t=5.0 - 240.0s) = -2, +2 mN

Average Force (t=0.5 - 240.0s) = 989 mN
Maximum Force (t=0.5 - 240.0s) = 992 mN
Minimum Force (t=0.5 - 240.0s) = 987 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 210
Operator : TJB	Min. Temp (°C) : -18.1	Conf Date : 07/05/2019
Specimen : PG 58-28 0.7% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 12:09:36 PM	Temp Cal Date : 07/05/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/05/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.91
File Name : 19070504	Beam Width (mm) : 12.70	Cal Date : 07/05/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	988	0.356	224	224	0.000	0.304
15.0	989	0.435	183	183	0.000	0.327
30.0	988	0.549	145	145	0.000	0.352
60.0	988	0.707	113	113	0.000	0.377
120.0	987	0.926	85.9	86	0.116	0.402
240.0	988	1.234	64.6	64.5	-0.155	0.427

A = 2.59 B = -0.229 C = -0.0415 R² = 0.999998

Force (t=0.0s) = 33 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 982 mN Deflection (t=0.5s) = 0.162 mm

Max Force Deviation (t=0.5 - 5.0s) = -5, +3 mN
 Max Force Deviation (t=5.0 - 240.0s) = -6, +3 mN

Average Force (t=0.5 - 240.0s) = 987 mN
 Maximum Force (t=0.5 - 240.0s) = 990 mN
 Minimum Force (t=0.5 - 240.0s) = 981 mN

Project : WMA Target Temp (°C) : -18.0 Conf Test (GPa) : 210
 Operator : TJB Min. Temp (°C) : -18.0 Conf Date : 07/05/2019
 Specimen : PG 58-28 0.7% WMA Max. Temp (°C) : -18.0 Force Const (mN/bit) : 0.151
 Test Time : 12:02:08 PM Temp Cal Date : 07/05/2019 Defl Const (µm/bit) : 0.141
 Test Date : 07/05/2019 Soak Time (min) : 60.0 Cmpl (µm/N) : 6.91
 File Name : 19070503 Beam Width (mm) : 12.70 Cal Date : 07/05/2019
 BBR ID : 3654-A3612 Thickness (mm) : 6.35 Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	992	0.338	237	237	0.000	0.312
15.0	991	0.413	193	193	0.000	0.333
30.0	991	0.526	152	152	0.000	0.356
60.0	991	0.677	118	118	0.000	0.380
120.0	990	0.888	89.9	89.9	1.70e-006	0.404
240.0	990	1.185	67.4	67.4	2.26e-006	0.427

A = 2.62 B = -0.241 C = -0.0391 R² = 0.999995

Force (t=0.0s) = 38 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 988 mN Deflection (t=0.5s) = 0.151 mm

Max Force Deviation (t=0.5 - 5.0s) = -2, +2 mN
 Max Force Deviation (t=5.0 - 240.0s) = -1, +2 mN

Average Force (t=0.5 - 240.0s) = 990 mN
 Maximum Force (t=0.5 - 240.0s) = 992 mN
 Minimum Force (t=0.5 - 240.0s) = 988 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 218
Operator : TJB	Min. Temp (°C) : -18.1	Conf Date : 07/03/2019
Specimen : PG 58-28 0.9% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 11:23:24 AM	Temp Cal Date : 07/03/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/03/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.81
File Name : 19070303	Beam Width (mm) : 12.70	Cal Date : 07/03/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	993	0.320	250	250	0.000	0.248
15.0	993	0.377	212	213	0.472	0.266
30.0	994	0.456	176	176	0.000	0.286
60.0	994	0.560	143	143	0.000	0.306
120.0	996	0.698	115	115	0.000	0.326
240.0	996	0.882	91.1	91.1	-1.67e-006	0.346

A = 2.59 B = -0.188 C = -0.0331 R² = 0.999994

Force (t=0.0s) = 36 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 987 mN Deflection (t=0.5s) = 0.163 mm

Max Force Deviation (t=0.5 - 5.0s) = -8, +0 mN
 Max Force Deviation (t=5.0 - 240.0s) = -3, +1 mN

Average Force (t=0.5 - 240.0s) = 995 mN
 Maximum Force (t=0.5 - 240.0s) = 996 mN
 Minimum Force (t=0.5 - 240.0s) = 987 mN

Project : WMA	Target Temp (°C) : -18.0	Conf Test (GPa) : 218
Operator : TJB	Min. Temp (°C) : -18.2	Conf Date : 07/03/2019
Specimen : PG 58-28 0.9% WMA	Max. Temp (°C) : -17.9	Force Const (mN/bit) : 0.151
Test Time : 11:28:32 AM	Temp Cal Date : 07/03/2019	Defl Const (µm/bit) : 0.141
Test Date : 07/03/2019	Soak Time (min) : 60.0	Cmpl (µm/N) : 6.81
File Name : 19070304	Beam Width (mm) : 12.70	Cal Date : 07/03/2019
BBR ID : 3654-A3612	Thickness (mm) : 6.35	Software Version : BBRw 1.24

WARNING! - Temperature out of tolerance (± 0.1 °C)

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value
8.0	1000	0.312	258	258	0.000	0.242
15.0	1000	0.366	220	220	0.000	0.260
30.0	999	0.441	183	183	0.000	0.279
60.0	999	0.538	150	150	0.000	0.299
120.0	999	0.665	121	121	0.000	0.319
240.0	1000	0.839	96.1	96.2	0.104	0.338

A = 2.6 B = -0.183 C = -0.0325 R² = 0.999983

Force (t=0.0s) = 37 mN Deflection (t=0.0s) = 0.000 mm
 Force (t=0.5s) = 993 mN Deflection (t=0.5s) = 0.160 mm

Max Force Deviation (t=0.5 - 5.0s) = -6, +1 mN
 Max Force Deviation (t=5.0 - 240.0s) = -1, +1 mN

Average Force (t=0.5 - 240.0s) = 999 mN
 Maximum Force (t=0.5 - 240.0s) = 1000 mN
 Minimum Force (t=0.5 - 240.0s) = 993 mN

Analysis of Data Collection

According to PG grading system m-value for asphalt binder sample should be minimum 0.3. By analyzing the data obtained from BBR test at two different temperature of -18°C (as attached report shows) of all asphalt binder samples. We came to know that all asphalt binder is good for -28°C and added Evotherm can go down one more temperature grade.

Possible sources of error

There might be following possible errors conducting BBR test.

1. Calibrating temperature to -18°C and -12°C inside water bath due to some external factors.
2. Calibrating load values due to the sensitivity of machine
3. No proper cleaning of shaft which have to stand on asphalt binder beam.

Conclusion

Overall, we can say that BBR test is good to use for testing temperature experienced by pavement in the geographical area for which asphalt binder is intended to use. The flexural creep stiffness or flexural creep compliance determined from this test describe the low temperature, stress-strain time response of asphalt binder at the test temperature within the linear viscoelastic response range. Finally looking at the chart given by FHWA as shown in above Figure, we can predict the PG grading of all regular and modified asphalt binder and discussed in the above page.

Appendix B
Superpave Mix Design

Preparation of Super Pave Volumetric Design for Hot Mixed Asphalt Mixtures and Warm Mixed Asphalt Mixtures

Purpose of test

The objective of the lab was to use optimum gradation provided to determine optimum binder content from samples compacted using the Superpave Gyrotory Compactor.

Apparatus

Gyrotory Compactor, Computer, Mixer, Oven, Mixing Tools, Containers, Scales, Vacuum Device, Vibratory Device & Gloves.

Test procedure

1. Sample Preparation and Compaction:

a. Weigh out 4600 g of aggregate for each of the eight specimens for HMA asphalt mixtures and eight specimens for WMA asphalt mixtures were prepared.

Prepare loose mix as per Marshall Design Method, using 4.5%, 5.0%, 5.5% and 6.0% asphalt content (AC) by weight for a set of two specimens.

b. Marshall Design method involves curing loose aggregate mix in oven at 135°C for approximately 24 hours. Heat the Asphalt binder for an hour to reach its liquid state and weigh the % to be added to the heated aggregate mix. Mix them in the mixer

c. Leave the mix in the oven for 4 hours to ensure aging of the sample.

d. Also at the same time, leave the gyrotory mold and base plates in the oven to be heated up.

e. Turn on the Super pave Gyrotory Compactor and the computer associated with it.

Pull up the Excel program with the Samples in the columns

f. After time is due, remove the 6" diameter SGC mold and fill the mold with the asphalt

mix. Place two paper plates on the base and top plate.

g. Set the SGC pressure to 600 kPa, the angle of gyration to 1.25° and speed of gyration is standardized at 30 rpm.

h. Place the mold with the asphalt mix inside and hit Enter on SGC screen to start the compactor. At the same time, select Specimen 1 in Excel sheet and click “Launch Comm. Module”. The data starts generating in the column.

i. After achieved maximum gyrations of 205, extract the compacted mold and place it between piers to extract the sample.

j. Make a note of the %AC used for the sample on the paper circular disc and repeat the process for each sample at its varying asphalt content percentage.

k. Calculate the optimum trial blend. The end result is a creation of 4 sets of 2 samples with optimum trial blend, as per Marshall Mix Design with 4600 g of aggregate. % AC will equal the estimated binder content minus 0.5%, as is, plus 0.5%, and plus 1.0%.

l. Clean the work area and calculate optimum asphalt content.

2. Specific Gravity of Coarse Aggregate:

a. Weigh out 2000 g sample of coarse aggregate blend in question and submerge overnight for nearly 15 hours.

b. Determine submerged mass.

c. Dry sample with a towel such that no film remains on the surface of the aggregate.

Determine the mass and is called as Saturated Surface Dry mass.

d. Oven-dry the sample overnight at 110°C and determine the mass.

3. Specific Gravity of Fine Aggregate:

a. Weigh out 1000 g of the fine aggregate blend in question.

b. Determine mass of pycnometer filled with water at 23°C

c. Determine mass of pycnometer filled with the aggregate and water to the calibration line.

d. Allow surface of sample to dry using a blow dry until the sample just fails the cone and determine the SSD mass.

e. Combine Gsb of Fine and Coarse values

4. Specific Gravity of Compacted Mix

a. Determine the compacted sample weight in air after being retrieved from the SGC mold.

b. Submerge the sample for 15 to 30 minutes after the sample reaches room temperature.

Determine the submerged mass.

c. Remove the sample from the water and dry the surface using a cloth so that no water film stays on the surface. Determine the mass again.

d. Multiply by a correction factor as needed for the temperature.

5. Specific gravity of Loose Mix

a. Retrieve 1000 g of HMA sample prior to its compaction. This requires careful planning

of preparing a HMA over 5100 g for every sample and separating 500 g from each.

b. Cure the sample for 2 hours at 230°F and let it cool to 25°C.

c. Weigh the container to be used

d. Fill the container with water and make a note of the weight

e. Add the sample to the water in the container.

f. Place the container with the sample on the vibratory device. Fasten the lid and start the vibratory device making sure the vacuum is attached.

g. Let it run for 15 minutes so that the air between the HMA mixtures is removed.

h. Weight the container with the water and sample.

Results and Discussion

Different results at various content of binder can be shown below with the calculation of determination of VMA, VFA , air voids and optimum binder content. Then the following measured data are plotted in various asphalt binder content and discussed in the above section. As we know that optimum binder content is defined as the asphalt binder content that results in the 4 percent air voids.

From the above mentioned graph results, we can conclude that the optimum binder content for HMA with RAP is at 5.3 percent and the optimum binder content for WMA (0.7% Evotherm) with RAP is at 5.6%.

45%

HMA Asphalt Content, Gradation & Marshall Volumetrics Test Report (T 110, T 164, T 30, T 166, T 209, PP 19, T 245)

Date/Time:	3/12/2019 9:24:15	Lab Location:	Johnston
Weather:	N/A	Material:	RIDOT 19mm 20% RAP
Project:	19mm Virgin Richmond Sand	Sample #:	#1 Lab Design for Optimum AC
Contractor:	D'Ambra Construction	Sample Location:	Lab
Plant Type:	Drum	Sampled By / NETTCP #:	Masoud Faramarzi / Neha Shrestha

Moisture Content (T 110)	Asphalt Content of HMA by Ignition Oven Method	Feeder #	Material	Blend %
Sample Wet Mass (A):	Mixture Mass on Ticket:	2364.0	1	Stone Sand Keating
Sample Dry Mass (B):	Weight Loss:	113.9	2	Asphalt Sand Richmond
Water Mass (C): (A - B)	Percent Loss:	4.82	3	3/8"
% Moisture (M): (100*((A-B)/B))	Temp. Comp:	0.13	4	1/2"
	Calibration Factor:	0.00	5	3/4"
	%PG Binder (Pb):	4.64	PG Binder	PG 58 - 28
	PG Binder JMF:	4.5	RAP	RAP
	PG Binder Master Range:	4.5 - 6.0	MF	MF
HMA Temperature				
Sample Temp, °F:	300			100.0

Mechanical Analysis of Extracted Aggregate (T 30)							
Sieve	Mass Retained	Percent Retained	Percent Passing	Job Mix Formula	+/- Tolerance	Variance	Master Range
37.5 mm (1 1/2")							
25 mm (1")	0.0	0.0	100.0	100		0.0	100
19 mm (3/4")	13.6	0.5	99.4	98	7	1.4	90 - 100
12.5 mm (1/2")	195.9	8.7	91.3	80		11.3	
9.5 mm (3/8")	609.3	27.1	72.9	62		10.9	
4.75 mm (#4)	1362.2	60.1	39.9	40		-0.1	
2.36 mm (#8)	1629.5	72.4	27.6	26	5	1.6	21 - 31
1.18 mm (#16)	1760.5	78.2	21.8	20		1.8	
600 µm (#30)	1881.5	83.6	16.4	15		1.4	
300 µm (#60)	2005.8	89.1	10.9	10		0.9	
150 µm (#100)	2092.4	93.0	7.0	6		1.0	
75 µm (#200)	2158.0	95.9	4.1	3	2	1.1	
PAN	2249.7	100.0					
TOTAL:	2253.5	100.2					

Bulk Specific Gravity of Compacted HMA (T 166)					
Specimen #	Mass in Air	Mass in H ₂ O	SSD Mass	Volume	Gmb
A	4843.5	2883.7	4887.7	2024.0	2.393
B	4836.1	2878.0	4895.6	2017.6	2.397
C					
					Avg. Gmb
					2.395
					Unit Weight
					149.4

Specimen #	Wt. in Air	Bowl Cal.	Wt. After Vac.	Volume		Gmm	Unit Weight
A	2505.1	1369.3	2894.2	980.2	2.556	2.556	159.5
B	2506.1	1369.3	2894.2	980.2	2.556	2.556	154

Volumetric Analysis (PP 19)					HMA Marshall Stability and Flow (T 245)				
Specimen #	Gsb. Of PGAB	% Air Voids	VMA	VFA	Dial Reading	Corr. Factor	Stability	Corr. Stability	Flow
A	1.034	6.4	17.1	62.8		error			
B	1.034	6.2	17.0	63.4		error			
C	1.034								
	Average:	6.3	17.0	63.1			Average:		

Comments: PG 64-28 Manual Calculation for % AC is 4.65. (4.6)
 #1 Gyration Sample: 4851.2 g @ 285°F. Height: 118.7
 #2 Gyration Sample: 4851.0 g @ 285°F. Height: 118.1

Tested by: Masoud Faramarzi / Neha Shrestha	Reviewed by: Christopher Sharples / Timothy Bernard
Date: 3/15/2019	Certification #: 768m / 1158m
	Date: 3/12/2019

HMA Asphalt Content, Gradation & Marshall Volumetrics Test Report (T 110, T 164, T 30, T 166, T 209, PP 19, T 245)

5.0%

Date/Time:	3/12/2019 10:42:46	Lab Location:	Johnston
Weather:	N/A	Material:	RIDOT 19mm 20% RAP
Project:	19mm Virgin Richmond Sand	Sample #:	#2 Lab Design for Optimum AC
Contractor:	D'Ambra Construction	Sample Location:	Lab
Plant Type:	Drum	Sampled By / NETTCP #:	Masoud Faramarzi / Neha Shrestha
Moisture Content (T 110)			
Sample Wet Mass (A):		Mixture Mass on Ticket:	2228.0
Sample Dry Mass (B):		Weight Loss:	128.7
Water Mass (C): (A - B)		Percent Loss:	5.78
% Moisture (M): (100*((A-B)/B))	0	Temp. Comp:	0.10
		Calibration Factor:	0.00
		%PG Binder (Pb):	5.62
		PG Binder JMF:	
		PG Binder Master Range:	4.5 - 6.0
HMA Temperature			
Sample Temp, °F:	285		
			100.0

Mechanical Analysis of Extracted Aggregate (T 30)							
Sieve	Mass Retained	Percent Retained	Percent Passing	Job Mix Formula	+/- Tolerance	Variance	Master Range
37.5 mm (1 1/2")							
25 mm (1")	0.0	0.0	100.0	100		0.0	100
19 mm (3/4")	7.7	0.4	99.6	98	7	1.6	90 - 100
12.5 mm (1/2")	25.5	1.2	98.8	80		18.8	
9.5 mm (3/8")	427.7	20.4	79.6	62		17.6	
4.75 mm (#4)	1117.9	53.3	46.7	40		6.7	
2.36 mm (#8)	1433.1	68.3	31.7	26	5	5.7	21 - 31
1.18 mm (#16)	1584.1	75.5	24.5	20		4.5	
600 µm (#30)	1709.8	81.4	18.6	15		3.6	
300 µm (#60)	1836.2	87.5	12.5	10		2.5	
150 µm (#100)	1228.5	58.5	41.5	6		35.5	
75 µm (#200)	1996.5	95.2	4.8	3	2	1.8	
PAN	2066.4	99.9					
TOTAL:	2103.3	100.2					

Bulk Specific Gravity of Compacted HMA (T 166)									
Specimen #	Mass in Air	Mass in H ₂ O	SSD Mass	Volume	Gmb				
A	4844.1	2860.4	4865.0	2007.6	2.413				
B	4797.8	2825.5	4834.7	2008.2	2.389				
C									
Specimen #	Wt. in Air	Bowl Cal.	Wt. After Vac.	Volume	Gmm	Unit Weight			
A	2495.8	1369.3	2883.3	981.8	2.542	158.6			
B	2495.8	1369.3	2883.3	981.8	2.542	154			
HMA Marshall Stability and Flow (T 245)									
Specimen #	Gsb. of PGAB	% Air Voids	VMA	VFA	Dial Reading	Corr. Factor	Stability	Corr. Stability	Flow
A	1.034	5.1	18.2	72.1		error			
B	1.034	6.0	19.0	68.3		error			
C	1.034								
Average:		5.5	18.6	70.2			Average:		

Comments: PG 64-28 Manual Calculation for % AC is 5.58 (5.6)
 #1 Gyrotory Sample: 4843.5g @ 285°F. Height: 117.9
 #2 Gyrotory Sample: 4845.1g @ 285°F. Height: 117.9

Tested by: Masoud Faramarzi / Neha Shrestha
 Reviewed by: Christopher Shumles / Timothy Sarand
 Certification #: 788m / 1168m
 Date: 3/12/2019
 Date: 3/12/2019

55%

Mechanical Analysis of Extracted Aggregate (T 30)							
Sieve	Mass Retained	Percent Retained	Percent Passing	Job Mix Formula	+/- Tolerance	Variance	Master Range
37.5 mm (1 1/2")							
25 mm (1")	0.0	0.0	100.0	100		0.0	100
19 mm (3/4")	0.1	0.0	100.0	98	7	2.0	90 - 100
12.5 mm (1/2")	244.6	12.0	88.0	80		8.0	
9.5 mm (3/8")	704.9	34.5	65.5	62		3.5	
4.75 mm (#4)	1322.3	64.7	35.3	40		-4.7	
2.36 mm (#8)	1528.7	74.7	25.3	26	5	-0.7	21 - 31
1.18 mm (#16)	1624.5	79.4	20.6	20		0.6	
600 µm (#30)	1723.2	84.3	15.7	15		0.7	
300 µm (#50)	1830.3	89.5	10.5	10		0.5	
150 µm (#100)	1907.2	93.3	6.7	6		0.7	
75 µm (#200)	1960.5	95.9	4.1	3	2	1.1	
PAN	2045.1	100.0					
TOTAL:	2048.8	100.2					

Specimen #	Wt. in Air	Bowl Cal.	Wt. After Vac.	Volume		Gmm	Unit Weight		
A	2505.8	1369.3	2884.7	990.4	2.530	2.530	157.9		
B	2506.8	1369.3	2884.7	990.4	2.530	2.530	154		
Volumetric Analysis (PP 19)					HMA Marshall Stability and Flow (T 245)				
Specimen #	Geb. Of PGAB	% Air Voids	VMA	VFA	Dial Reading	Corr. Factor	Stability	Corr. Stability	Flow
A	1.034	3.8	16.2	76.6		error			
B	1.034	3.7	16.1	77.3		error			
C	1.034								
Average:		3.7	16.1	76.9			Average:		

Certification # 765m / 1156m

6%.

Date/Time:	3/13/2019 9:44:03	Lab Location:	Johnston			
Weather:	N/A	Material:	RIDOT 19mm 20% RAP			
Project:	19mm Virgin Richmond Sand	Sample #:	#4 Lab Design for Optimum AC			
Contractor:	D'Ambra Construction	Sample Location:	Lab			
Plant Type:	Drum	Sampled By / NETTCP #:	Masoud Faramarzi / Neha Shrestha			
Moisture Content (T 110)		Asphalt Content of HMA by Ignition Oven Method		Feeder #	Material	Blend %
Sample Wet Mass (A):	0	Mixture Mass on Ticket:	2304.0	1	Stone Sand Keating	
Sample Dry Mass (B):		Weight Loss:	155.8	2	Asphalt Sand Richmond	16.0
Water Mass (C): (A - B)		Percent Loss:	5.76	3	3/8"	26.0
% Moisture (M): (100*((A-B)/B))		Temp. Comp:	0.10	4	1/2"	20.0
		Calibration Factor:	0.00	5	3/4"	18.0
		%PG Binder (Pb):	6.61	PG Binder	PG 58 - 28	6.0
		PG Binder JM/F:		RAP	RAP	20.0
HMA Temperature		PG Binder Master Range:	4.5 - 6.0	M/F	M/F	
Sample Temp. °F:	285					100.0

Mechanical Analysis of Extracted Aggregate (T 30)

Sieve	Mass Retained	Percent Retained	Percent Passing	Job Mix Formula	+ / - Tolerance	Variance	Master Range
37.5 mm (1 1/2")							
25 mm (1")	0.0	0.0	100.0	100		0.0	100
19 mm (3/4")	0.1	0.0	100.0	98	7	2.0	90 - 100
12.5 mm (1/2")	144.0	6.7	93.3	80		13.3	
9.5 mm (3/8")	520.2	24.2	75.8	62		13.8	
4.75 mm (#4)	1183.5	55.1	44.9	40		4.9	
2.36 mm (#8)	1456.1	67.8	32.2	26	5	6.2	21 - 31
1.18 mm (#16)	1592.0	74.1	25.9	20		5.9	
600 µm (#30)	1920.2	89.4	10.6	15		-4.4	
300 µm (#60)	1952.4	90.9	9.1	10		-0.9	
150 µm (#100)	1953.1	90.9	9.1	6		3.1	
75 µm (#200)	2030.7	94.5	5.5	3	2	2.5	
PAN	2148.3	100.0					
TOTAL:	2152.6	100.2					

Bulk Specific Gravity of Compacted HMA (T 166)

Specimen #	Mass in Air	Mass in H ₂ O	SSD Mass	Volume	Gmb	Avg. Gmb	Unit Weight
A	4768.9	2634.4	4781.2	1946.8	2.450		
B	4836.8	2883.2	4843.3	1960.1	2.468	2.459	153.4
C							

Specimen #	Wt. in Air	Bowl Cal.	Wt. After Vac.	Volume		Gmm	Unit Weight		
A	2499.1	1369.3	2869.3	999.1	2.501	2.501	156.1		
B	2499.1	1369.3	2869.3	999.1	2.501	2.501	154		
	Volumetric Analysis (PP 19)				HMA Marshall Stability and Flow (T 245)				
Specimen #	Gov. Of PGAB	% Air Voids	VMA	VFA	Dial Reading	Corr. Factor	Stability	Corr. Stability	Flow
A	1.034	2.1	17.7	88.3		error			
B	1.034	1.3	17.1	92.1		error			
C	1.034								
	Average:	1.7	17.4	90.2			Average:		

Comments: PG 64-28 Manual Calculation for % AC is 6.58 (6.6)
#1 Gyrotory Sample: 4851.5 g @ 285°F. Height: 114.0
#2 Gyrotory Sample: 4859.0 g @ 285°F. Height: 113.3

Tested by: Masoud Faramarzi / Neha Shrestha

Reviewed by: Christopher Sharples / Timothy Barard

Superpave Mix Design for WMA (OBC)

Densification Data for blend 1, 4.5% asphalt content							Densification Data for blend 2, 4.5% asphalt content						
Specimen 1							Specimen 2						
Wm= Mass of dry specimen for 4.5 % AC=						4647	Wm= Mass of dry specimen for 4.5 % AC=						4678
Bulk specific gravity of stones= Gsb=						2.65	Bulk specific gravity of stones= Gsb=						2.65
Aggregate Content = Ps=						0.955	Aggregate Content = Ps=						0.955
Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.585	Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.585
Bulk specific gravity of Mixture= Gmb (Meas) =						2.313	Bulk specific gravity of Mixture= Gmb (Meas) =						2.324
							Ratio		Percentage				
%Gmm @ N (ini) =							0.7494		74.9368%				
%Gmm @ N (des) = Average %Gmm =							0.8969		89.6905%				
Va= % Air Voids = 100- %Gmm @ N (des)=							0.1031		10.3095%				
VMA % = 100- (%Gmm @ N (des)*Gmm (Meas) * Ps)/Gsb=							0.16		16.4465%				
VFA%= 100*(VMA -Va)/VMA=							0.37		37.3151%				
Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm	Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm
1= N (INI)	152.8	2698.83	1.721857	1.1235334	1.934564136	0.748381	1= N (INI)	154.8	2734.155	1.710949	1.13368	1.939669251	0.750356
50 = N (DES)	127.8	2257.268	2.058684	1.1235334	2.313	0.894778	50 = N (DES)	129.2	2281.995	2.049961	1.13368	2.324	0.899033
50 = N (MAX)	127.8	2257.268	2.058684	1.1235334	2.313	0.894778	50 = N (MAX)	129.2	2281.995	2.049961	1.13368	2.324	0.899033
AVERAGE % Gmm=							Ratio		Percentage				
							0.8969		89.69%				
Air Voids %							Ratio		Percentage				
							0.1031		10.31%				

Superpave Mix Design for WMA (OBC)

Densification Data for blend 1, 5% asphalt content							Densification Data for blend 2, 5.0% asphalt content						
Specimen 1							Specimen 2						
Wm= Mass of dry specimen for 5.0 % AC=						4594	Wm= Mass of dry specimen for 5.0 % AC=						4582.5
Bulk specific gravity of stones= Gsb=						2.65	Bulk specific gravity of stones= Gsb=						2.65
Aggregate Content = Ps=						0.950	Aggregate Content = Ps=						0.950
Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.456	Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.456
Bulk specific gravity of Mixture= Gmb (Meas) =						2.275	Bulk specific gravity of Mixture= Gmb (Meas) =						2.320
							Ratio		Percentage				
%Gmm @ N (ini) =							0.8011		80.1059%				
%Gmm @ N (des) = Average %Gmm =							0.9355		93.5464%				
Va= % Air Voids = 100- %Gmm @ N (des)=							0.0645		6.4536%				
VMA % = 100- (%Gmm @ N (des)*Gmm (Meas) * Ps)/Gsb=							0.18		17.6368%				
VFA%= 100*(VMA -Va)/VMA=							0.63		63.4084%				
Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm	Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm
1= N (INI)	140.1	2474.516	1.856524	1.08108802	2.0071	0.817209	1= N (INI)	152	2684.7	1.706895	1.129382	1.928	0.784909
50 = N (DES)	123.6	2183.085	2.104361	1.08108802	2.275	0.926303	50 = N (DES)	126.3	2230.774	2.05422	1.129382	2.32	0.944625
50 = N (MAX)	123.6	2183.085	2.104361	1.08108802	2.275	0.926303	50 = N (MAX)	126.3	2230.774	2.05422	1.129382	2.32	0.944625
AVERAGE % Gmm=							Ratio		Percentage				
							0.9355		93.55%				
Air Voids %							Ratio		Percentage				
							0.0645		6.45%				

Superpave Mix Design for WMA (OBC)

Densification Data for blend 1, 5.5% asphalt content							Densification Data for blend 2, 5.5% asphalt content						
Specimen 1							Specimen 2						
Wm= Mass of dry specimen for 5.5 % AC=						4591	Wm= Mass of dry specimen for 5.5 % AC=						4579
Bulk specific gravity of stones= Gsb=						2.65	Bulk specific gravity of stones= Gsb=						2.65
Aggregate Content = Ps=						0.945	Aggregate Content = Ps=						0.945
Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.435	Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.435
Bulk specific gravity of Mixture= Gmb (Meas) =						2.311	Bulk specific gravity of Mixture= Gmb (Meas) =						2.260
							Ratio		Percentage				
%Gmm @ N (ini) =							0.7937		79.3677%				
%Gmm @ N (des) = Average %Gmm =							0.9386		93.8604%				
Va= % Air Voids = 100- %Gmm @ N (des)=							0.0614		6.1396%				
VMA % = 100- (%Gmm @ N (des)*Gmm (Meas) * Ps)/Gsb=							0.18		18.4982%				
VFA%= 100*(VMA -Va)/VMA=							0.67		66.8096%				
Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm	Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm
1= N (INI)	134.2	2370.308	1.936879	1.00733689	1.951090164	0.801269	1= N (INI)	134.6	2377.373	1.926076	0.99379	1.914115899	0.786085
50 = N (DES)	113.3	2001.161	2.294168	1.00733689	2.311	0.949076	50 = N (DES)	114	2013.525	2.274121	0.99379	2.26	0.928131
50 = N (MAX)	113.3	2001.161	2.294168	1.00733689	2.311	0.949076	50 = N (MAX)	114	2013.525	2.274121	0.99379	2.26	0.928131
AVERAGE % Gmm=							Ratio		Percentage				
							0.9386		93.86%				
Air Voids %							Ratio		Percentage				
							0.0614		6.14%				

Superpave Mix Design for WMA (OBC)

Densification Data for blend 1, 6.0% asphalt content							Densification Data for blend 2, 6.0% asphalt content						
Specimen 1							Specimen 2						
Wm= Mass of dry specimen for 6.0 % AC=						4593.5	Wm= Mass of dry specimen for 6.0 % AC=						4595
Bulk specific gravity of stones= Gsb=						2.65	Bulk specific gravity of stones= Gsb=						2.65
Aggregate Content = Ps=						0.940	Aggregate Content = Ps=						0.940
Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.378	Specific Gravity OF Mixture Measured= Gmm (Meas) =						2.378
Bulk specific gravity of Mixture= Gmb (Meas) =						2.326	Bulk specific gravity of Mixture= Gmb (Meas) =						2.289
							Ratio		Percentage				
%Gmm @ N (ini) =							0.8205		82.0528%				
%Gmm @ N (des) = Average %Gmm =							0.9704		97.0353%				
Va= % Air Voids = 100- %Gmm @ N (des)=							0.0296		2.9647%				
VMA % = 100- (%Gmm @ N (des)*Gmm (Meas) * Ps)/Gsb=							0.18		18.1491%				
VFA%= 100*(VMA -Va)/VMA=							0.84		83.6648%				
Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm	Gyrations	Ht, mm	Vmx	Gmb (est)	"C"	Gmb (corr)	%Gmm
1= N (INI)	134.2	2370.308	1.937934	1.01332341	1.963754098	0.825801	1= N (INI)	134.6	2377.373	1.932806	1.003038	1.938677563	0.815255
50 = N (DES)	113.3	2001.161	2.295417	1.01332341	2.326	0.978133	50 = N (DES)	114	2013.525	2.282068	1.003038	2.289	0.962574
50 = N (MAX)	113.3	2001.161	2.295417	1.01332341	2.326	0.978133	50 = N (MAX)	114	2013.525	2.282068	1.003038	2.289	0.962574
AVERAGE % Gmm=							Ratio		Percentage				
							0.9704		97.04%				
Air Voids %							Ratio		Percentage				
							0.0296		2.96%				

Appendix C
Dynamic Modulus of Asphalt Mixtures

Determining Dynamic Modulus of Asphalt Mixtures

Specimen Preparation:

Four Samples were prepared for dynamic modulus testing with four different asphalt binders as shown in table 1. Test samples were prepared in accordance with the requirements of AASHTO T 342-1.

Table 1: Asphalt Mixtures specimen details

Sample A	Asphalt Binder PG 58-28	HMA mixtures for Base with 20% RAP
Sample B	Asphalt Binder PG 58-28 with 0.7% Evotherm	WMA mixtures for Base with 20% RAP
Sample C	Asphalt Binder PG 64-28	HMA mixtures for Base without RAP
Sample D	Asphalt Binder PG 64-28 with 0.7% Evotherm	WMA Mixtures for Base without RAP

Sample Requirements:

The AASHTO T 342-11 requirements for dynamic modulus test samples are provided in Table 2. Dynamic modulus testing requires a 150 mm high by 100 mm diameter sample, of a target air void content, be cored from 175 mm high by 150 mm diameter sample. There is no simple conversion factor for compaction of a 175 mm high, 150 mm diameter SGC compacted sample to a cored dynamic modulus (E^*) sample with a given target air void content. The two samples will not have the same VTM due to a density gradient present in SGC compacted samples. A trial and error procedure is required to determine the density or void content of the larger sample required to produce a cored and sawed test sample of the intended void content.

Recommended target air void contents for all base samples are 4-7%. For this project, the asphalt mixture test samples were compacted to a void content of $4.5 \pm 1\%$ VTM. After several trials, it was determined that a 175 mm high by 150 mm diameter sample compacted

to $6.0 \pm 1\%$ VTM would yield a dynamic modulus test sample of the target $4.5 \pm 1\%$ void content.

Table 2: Criteria for acceptance of Dynamic Modulus test Specimen

Criterion Items	Requirements
Size	Average diameter between 100 mm and 104 mm Average height between 147.5 mm and 152.5 mm
Gyratory Specimens	Prepare 175 mm high specimens to required air void content (AASHTO T 312)
Coring	Core the nominal 100 mm diameter test specimens from the center of the gyratory specimen. Check the test specimen is cylindrical with sides that are smooth parallel and free from steps, ridges and grooves
Diameter	The standard deviation should not be greater than 2.5 mm
End Preparation	The specimen ends shall have a cut surface waviness height within a tolerance of ± 0.05 mm across diameter The specimen end shall not depart from perpendicular to the axis of the specimen by more than 1 degree
Air Void Content	The test specimen should be within ± 1.0 percent of the target air voids
Replicates	For two LVDT's, two replicates with a estimated limit of accuracy of 13.1 percent
Sample Storage	Wrap specimens in polyethylene and store in environmentally protected storage between 5 and 26.7° C (40 and 80° F) and be stored no more than two weeks prior to testing

Batching:

A 6500 -6800 gram batch of aggregate, batched to the desired gradation, was required to produce a 175 mm high by 150 mm diameter test specimen with $6.0 \pm 1\%$ VTM. When the compacted sample was cored to 100 mm diameter and sawed to the required sample height of 150 mm, the required target void content of $4.5 \pm 1\%$ VTM was obtained.

Mixing:

All samples were mixed in a bucket mixer. The asphalt cement was stirred occasionally to prevent localized overheating while being heated to the mixing temperature of 325° F for HMA mixtures and 280 ° F for WMA mixtures. The aggregates were heated for a minimum

of four hours at the respective mixing temperature. Approximately one hour before mixing, the compaction molds, spoons and spatulas were placed in the oven and brought to the mixing temperature. For mixing, the aggregates were placed in the bucket mixer and added the desired amount of asphalt binder. The mixture was mixed until well coated, approximately two minutes.

Compaction:

After mixing, the mixture was placed in a large flat pan and placed in an oven set at the respective compaction temperature for two hours in accordance with AASHTO R 30. The samples were compacted in a 150 mm diameter mold to a height of 175 mm using a Pine SGC. To produce the required 175 mm high by 150 mm diameter sample with a void content of $6.0 \pm 1 \%$, 6500 g of aggregate were required. Twenty-five gyrations were applied to reach a height of 175 mm. A compacted specimen is shown in the given Figure.

Coring and Sawing:

After compaction, the samples were extruded from the compaction molds, labeled and allowed to cool to room temperature. Next, the compacted samples were cored and sawed to obtain a 150 mm tall by 100 mm diameter test sample with $4.5 \pm 1 \%$ air voids. The samples were cored using a diamond studded core barrel to obtain the required diameter of 100 mm. The cored samples were then sawed to obtain the required 150 mm height. The cored and sawed samples were washed to eliminate all loose debris. After cleaning, the samples were tested for bulk specific gravity in accordance with AASHTO T 166.

Restraining Collar

Coring the Specimens

100mm x152mm Specimens

Setting up Testing Method:

Specimens were tested for dynamic modulus per AASHTO TP 62-03. The procedure is briefly explained in Figure E5. The test parameters are provided in following flowchart.

Data collection

Sample A

Sample B

Sample D

Master Curves using Excel solver

1. Sample A (HMA with 20% RAP)

2. Sample B (WMA with RAP)

3. Sample C (HMA without RAP)

4. Sample D (WMA without RAP)

PERFORMANCE PREDICTION OF REHABILITATED RI ROUTE 102

WITH AASHTOWare PAVEMENTME ME DESIGN

The Output from PavementME software generally consists of six types of distress types which are as follows:.

1. Permanent Deformation-Total Pavement (in.)
2. AC bottom-up fatigue cracking (percent)
3. AC thermal fracture (ft/mile)
4. AC top-down fatigue cracking (ft/mile)
5. Permanent deformation-AC only (in.)
6. Terminal IRI (in./mile)

The above mentioned distresses would be compared with targeted value specified by standard and selected reliability levels. If the predicted distresses and achieved reliability are within the target values it shows the criterion has been met, otherwise failed. To achieve good results and longer life for pavement all distress types should meet the criteria.

The above chapter 6 described input parameters required to predict the performance of pavements. The input parameter for RI Route sections were ready to upload. However, the University of Rhode Island has expired AASTHO MEPavement software both “Educational version” and “Licence Version”. URI Department is in process to renew the both version. But, it is going to take a while due to process.

Since, the predicted performance of rehabilitated sections in RI Route 102 could not be evaluated in this study. Hence, the study of HMA section and WMA section in RI Route 102 can be studied in future and evaluate the performance of WMA with RAP over

HMA with and without RAP.

Also, we can evaluate the performance of WMA and HMA section in each distress and then we can study about how we can address the distress in both sections and how we can make the sustainable pavement.

Appendix D
Bitumar Asphalt Material Datasheet

PG 58-28

Characteristics	Methods	Units	Specifications Requirements	
			Min	Max
High Temperature Rating - T_{high}	-	°C	58	-
Low Temperature Rating - T_{low}	-	°C	-	-28

Original Binder				
Specific Gravity @ 25°C (77°F)	AASHTO T228	g/cm ³	Report	
Flash Point	AASHTO T48	°C (°F)	230 (446)	-
Viscosity @ 135°C (275°F)	AASHTO T316	Pa.S	-	3.0
Viscosity @ 165°C (329°F)	AASHTO T316	Pa.S	Report	
Dynamic Shear, $G^*/\sin\delta$, 10 rad/s @ 58°C	AASHTO T315	kPa	1.00	-

Rolling Thin-Film Oven Residue				
Mass Change	AASHTO T240	%	-	1.00
Dynamic Shear, $G^*/\sin\delta$, 10 rad/s @ 58°C	AASHTO T315	kPa	2.20	-

Pressure Aging Vessel Residue				
PAV Aging Temperature	AASHTO R28	°C (°F)	100 (212)	
Dynamic Shear, $G^*/\sin\delta$, 10 rad/s @ 19°C	AASHTO T315	kPa	-	5000
Creep Stiffness, 60s @ -18°C	Modulus (S)	AASHTO T313	Mpa	300
	Slope (m)	AASHTO T313	-	0.300

Meets AASHTO M320 - 2015

Date of revision : August 15, 2016

By : M. Florant

Source: <http://www.bitumar.com/medias/files/sheets/PRO%20PG%2058-28.pdf>

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