Connecticut Warm Mix Asphalt (WMA)
Pilot Projects 2010 and 2011

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Disclaimer

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Standard Conversions

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

WMA overlays were placed in several pilot projects in Connecticut during the 2010 and 2011 construction seasons. These technologies included Sasobit®, Evotherm™, Advera®, Double-Barrel® Green foamed asphalt as well as SonneWarmix™. The research team observed placement and collected mix for laboratory testing. Laboratory testing consisted of rut testing and moisture susceptibility testing both with the Hamburg wheel-track test and with tensile strength testing. One of the pilot projects included SBS polymer modified asphalt binder. While the WMA mixes containing the polymer seemed to outperform the others overall in the laboratory, all of the WMA mixes appeared to perform satisfactorily in the laboratory. Temperature reductions were observed in the field. With the exception of a couple compaction related problems in the field (not believed to be caused by WMA technology) all mixes appeared to perform satisfactorily during placement. Upon revisit to the sites during 2013, all sections were still performing well. The research team recommends further monitoring of these sections during the coming years.

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Executive Summary

The use of Warm Mix Asphalt (WMA) is fast expanding in the United States. There are numerous benefits to the use of WMA technologies including reduced fuel consumption during production, reduced exposure to fumes due to the reduction in temperature during production and placement, and as an aid to achieving adequate compaction in the field especially with mixtures containing polymer modification.

Several pilot projects were constructed during 2010 and 2011 in Connecticut that utilized different WMA technologies for wearing surface replacement. Technologies that were piloted included Sasobit®, Evotherm™, Advera®, SonneWarmix™ and Astec Double-Barrell® foamed asphalt. Sasobit®, Evotherm™ and foaming were each used on two pilot projects, while Advera® and SonneWarmix™ were used on one pilot project.

CAP Lab personnel collected samples of all of the different mixes, along with samples of the control mix for each of the different projects, for performance testing in the laboratory. Laboratory testing consisted of rut testing as well as moisture induced damage testing via tensile strength ratio and Hamburg well track testing. CAP Lab personnel were also on hand for placement of the mixes for all but one of the pilot projects. Observations included ease of placement and compaction. Temperature monitoring of the material being placed was performed with an infrared temperature gun and a thermographic camera.

Results of laboratory testing as well as placement observations indicate that all of the WMA technologies show at least some benefit when it comes to temperature reduction. There were isolated issues with compaction in the field on two of the projects, but these issues were not necessarily caused by the WMA technology used. Laboratory test results indicate adequate performance in all cases, especially when the mixtures contain polymer modified asphalt binder. One of the pilot project mixes contained a polymer modified binder.

Continued performance monitoring of these overlays is recommended. Moving forward, this will yield answers to questions regarding the long term performance of these WMA technologies, and provide a platform from which decisions can be made regarding their use and specification in Connecticut.

Background

Asphalt pavements have been used in the United States for over 100 years. The asphalt binder and aggregates used in these pavements must be heated to a temperature that allows for proper construction. This heating is required to reduce the asphalt binder viscosity to allow the aggregates to become coated with a film of the liquid binder upon mixing. The result of this heating and mixing is a material called hot-mix asphalt (HMA) that is plastic enough to be loaded into haul units, transported, placed, and compacted to a specified density level before it reaches its cessation temperature. Typical HMA production temperatures are in the range of 300° to 330° F. HMA placement temperatures required to achieve the proper level of compaction are not typically below 265° F. The heating required for these steps involves the consumption of a great deal of fuel.

Warm Mix Asphalt (WMA) is intended to reduce the amount of heating that is required to produce asphalt pavement, while maintaining proper workability of the asphalt mixture for placement. Consequently, fuel consumption is reduced. This is accomplished with different techniques and asphalt binder additives that reduce the overall placement temperature of the asphalt pavement. There are many different WMA additives and technologies currently available. The intention is that WMA will perform comparably to HMA after it has been placed and compacted.

The reduction in the production temperatures has several benefits. First, there is a significant reduction in fossil fuel consumption and subsequent emissions from the burning of the fossil fuels. It also reduces the volatilization of compounds from the asphalt binder. This means there is very little “smoking” of the produced materials relative to the production and placement of HMA. This reduces worker exposure to these volatilized compounds from the asphalt binder. Figure 1 shows an example of the typical smoking that is seen during the placement of HMA.

Figure 1. Example of HMA Smoking

The use of WMA has the added benefit of increasing the chances of success when paving in colder weather. The greater the temperature differential between the ambient air temperature and paving mixture, the faster it will lose heat. Reduced WMA production temperatures will result in a mix that will not cool off as quickly as traditional HMA and will allow time to achieve compaction because it will still be workable at lower temperatures as compared to HMA. Also, if desired, WMA can be heated to typical HMA temperatures, which further increases the temperature window for compaction. Another benefit of WMA technologies is that they increase the workability of paving mixtures that contain polymer modified asphalt (PMA) binders. This makes placement of PMA pavements easier as they are typically more difficult to place due to the increased elastic behavior of the asphalt binder.

The use of WMA in the United States is still in its infancy, but is beginning to represent a significant proportion of the asphalt pavements being placed. WMA technology has a longer history in some European countries and is commonly used in these countries as the standard practice for producing asphalt pavements.

WMA technology is rapidly spreading across the United States and is poised to replace standard HMA in the coming years. WMA appears to be the future for asphalt pavement construction, as there are many benefits to using this technology, such as the environmental benefits and reduced human exposure benefits previously mentioned. This research investigated several different WMA technologies in the State of Connecticut that were used in pilot projects during the 2010 and 2011 construction seasons. This research utilized numerous different comparative analyses including temperature monitoring during placement, thermal imaging, acceptance test results and laboratory performance testing of sampled mixes. A brief survey of WMA specifications within regional State Departments of Transportation as well as a literature review of the various technologies from each manufacturer served as a prelude to the pilot projects analyses.

Research Objectives

Develop specification and quality assurance guidelines for WMA pavement.

Summary of Reviewed Literature

The Federal Highway Administration highlights several potential benefits to using WMA technologies, if those technologies can produce pavement products with the same quality and integrity as HMA (*FHWA, 2012*). Those benefits include reductions in energy consumption, workability during laydown and compaction, reduced emissions from burning fuels and reduced fumes and odors at both the production facility and the paving site. The reduction in fuel consumption could translate to cost impacts/reductions on transportation infrastructure projects.

Missouri Field Trials

A Missouri DOT resurfacing project conducted in May 2006 trialed three different WMA technologies (*Hurley et al, 2010*). The three trial technologies were Sasobit®, Aspha-min® and Evotherm™. The area where these sections were laid down accommodates ~21,000 Average Annual Daily Traffic (AADT). The overlay was a concrete structure which was originally overlaid with HMA. The cracks were sealed with a rubber crack sealer and HMA was laid down. After obtaining less than desirable smoothness results, it was the opinion of the contractor that if WMA was used, the reduction in temperature may lessen the expansion of the crack sealer and improve the overall smoothness. The use of these WMA products led to numerous performance tests in the laboratory including: tensile strength ratio (TSR) testing, Hamburg Wheel track testing, rut testing and dynamic modulus testing. Rut testing showed a slightly higher susceptibility for mix containing Aspha-min® than was indicated by the control mix. The Evotherm™ ET rut tests results were similar to that of the control while the Sasobit® mix rut depths were statistically lower than that of the control. The TSR results showed that the Evotherm™ ET and the Sasobit® (when compacted at lower temperatures) have an increased moisture damage susceptibility. This was not the case when examining the stripping inflection point results that demonstrated very minimal moisture susceptibility. The Evotherm™ ET and Sasobit® mixes had dynamic modulus results that were statistically similar to that of the control, while the Aspha-min® mix results had statistically lower results. The authors reported satisfactory field performance and minimal pavement distresses for all of the different mixes.

Colorado DOT Experimental Sections

The Colorado Department of Transportation (CDOT) utilized three different WMA technologies in experimental sections of I-70 in Silverthorne, which is located in a quite elevated region (8,800 – 11,100 feet above mean sea level) about 70 miles west of Denver. The region experiences very harsh winter weather with over 200 inches of annual snowfall (*Aschenbrener, 2011*). The technologies used were Advera®, Evotherm™ DAT and Sasobit® along with a HMA control section. The test sections were placed on separate days and 1000 tons of mix was placed with each technology along with a control strip of HMA for each section. Construction monitoring reports indicated that fuel consumption was comparable among the three different WMA technologies. In-place densities of all mixes, including the HMA controls, were within the 92% - 96% range specified by the contract. TSR testing was conducted on all mixes. Although the WMA mixes passed the specification requirement, results indicated that all three technologies may be more prone to moisture damage than the HMA controls. Laboratory indirect tensile testing of cores cut from the test sections after 2 and 3 years took place during year 3. The cores cut during year 2 were allowed to sit in the lab for 1 year. There was no significant difference in the strengths of any of the WMA specimens from the control HMA specimens for either year. The authors state that the WMA mixes in these test sections were compacted between 30° F and 50° F lower than the HMA control sections. After three years of evaluations conducted in the field, the authors report excellent performance from all test sections.

Maine DOT Warm Mix Trial

A pavement preservation WMA resurfacing project utilizing a product called SonneWarmix™ was undertaken by the Maine DOT in 2010 (*Thompson, 2012*), approximately one year prior to the construction of a similar section in Connecticut, which is part of this research. Located on Route 9 in Durham, ME, the project consisted of a shim and overlay. The entire project is just over 3.7 miles long and includes a HMA control section. The authors do not cite any placement issues with the mix. It is stated in this interim report that there were issues achieving the desired lower production temperatures of 260° F to 270° F and placement temperatures of 250° F to 260° F. Although these temperatures were not achieved, it was determined that moderate changes to the plant would negate these issues. The authors state that this overlay will be monitored and compared with other WMA sections placed in Maine over a five year period and performance will be compared. The authors report that with the exception of some scouring in the wheel path, to date, the mix is performing comparably with standard HMA mixes.

Vancouver Foaming Research

A research trial was performed in Vancouver, British Columbia to examine the performance properties of WMA produced utilizing the Double Barrel® Green process developed by Astec, Inc. (Middleton et al, 2008) This process is designed to mechanically foam asphalt utilizing the injection of small amounts of water into the asphalt binder stream. Mixes were also produced containing varying quantities of RAP and RAS to determine any effects. The authors present the findings of numerous performance tests which were conducted including asphalt binder testing, rut testing, moisture susceptibility and mix stiffness. The authors indicate that after the laboratory performance testing, the binder properties and actual mixture properties were similar to those of traditional HMA mixes. APA test results from the foamed asphalt mixes show satisfactory performance. Moisture susceptibility tests show no negative impacts on performance. The authors also state that the additions of RAP and/or RAS incorporated into the mechanically foamed mix showed no negative effect. In addition to the positive notes stated regarding the quality of the produced mixes from a laboratory testing performance standpoint, there were quantified environmental impacts as well. The authors indicate a 10% reduction in carbon dioxide, carbon monoxide and nitrogen oxides during the production utilizing the Double Barrel® Green process, as well as a 24% reduction in energy consumption.

There are numerous technologies available today for use in WMA. This literature review is limited to the technologies used on Connecticut pilot projects for the time period covered by this study. The number of WMA technologies is ever increasing, and it would be beyond the scope of this study to address all of them. The WMA pilot projects along with the associated technology used are shown in Table 1.

Table 1. Analyzed Warm Mix Technologies

WMA Technology
Sasobit®
*Mechanical Foaming
Evotherm™
Advera®
SonneWarmix™
Evotherm™
*Mechanical Foaming (SBS Polymer)
Sasobit® (SBS Polymer)

*Double Barrel Green® System from Astec Inc.

Information from Providers of WMA Technology

Basic information regarding the nature of each of the technologies investigated as part of this research is provided in the following paragraphs. This information was summarized from reviewed literature, which was made available by the providers of each technology and included in this section to give the reader some background on each WMA construction technology.

Sasobit®

Sasobit® is a hard F-T wax with a congealing point above 194° F according to the Material Safety Data Sheet. Manufacturers of Sasobit® (*Sasol*) indicate that plant mixing temperatures may be lowered from 300° F to 250° F allowing for as much as a 19% fuel savings. (*Sasol Wax 2012*). It is also indicated that these lower mixing temperatures lead to lower overhead costs, lower emissions outputs and also lower hardening due to oxidation from higher temperature exposure. Sasol states that blending may take place either at the terminal or at the HMA plant.

Evotherm™

Evotherm™, developed by MeadWestvaco Asphalt Innovations *(FHWA 2012,)* is a product which is derived from natural tree oils (*EVOTHERM™ Chemistry Series*). It contains surfactants which are intended to provide necessary adhesion between aggregate and binder at lower temperatures by replacing the required heat energy at the interface of the aggregate and binder with chemical energy. This chemical additive is described by the manufacturer as requiring no modifications to operations either at the production plant or at the job site and no need to modify an existing mix design (*Evotherm™, Warm Mix Asphalt*). The manufacturers claim that, with the use of Evotherm™, asphalt pavements can be produced at temperatures up to 100° F less than conventional HMA pavements and that some documented projects which utilized this product have realized between 30 and 60% reductions in fuel consumption during production.

Advera®

Advera® is a form of a zeolite (aluminosilicate) which is porous and retains water. Upon heating, this material releases chemically bound water which causes the liquid asphalt to foam. This foaming allows the aggregates in asphalt pavements to be coated at lower temperatures than are required for HMA. Manufacturers of Advera® indicate that asphalt pavements can be produced at

250° F or 50° to 70° F lower than standard HMA production temperatures (*Advera® WMA*). The manufacturer describes Advera® as producing a sustained time-release of moisture which in turn causes the foaming effect to last through mixing, transport and placement. Once the additive is in place after the mix has been compacted, it reabsorbs any residual water, binds it chemically and serves as mineral filler. The manufacturer indicates energy savings up to 30% during production.

SonneWarmix™

SonneWarmix™ is a paraffin hydrocarbon, which is blended with the selected PG binder at the terminal (*SonneWarmix™ Details*). This material is pre-blended and then supplied to the HMA producer so there are no modifications or added equipment necessary at the production plant. The manufacturer suggests that the typical production, placement and compaction temperatures for WMA using SonneWarmix™ is 50° F less than that which is required for production of HMA. This reduction in temperatures is stated by the manufacturer to reduce fuel consumption, reduce oxidative aging of the binder and also reduce emissions of greenhouse gasses (*SonneWarmix™ Data Sheet*).

Mechanically Foamed Asphalt

There are numerous ways to deliver mechanically foamed asphalt. This research focuses only on one method, which was available in CT during the aforementioned pilot projects. That system is the Double Barrel® Green System, which is manufactured by Astec Inc. This system utilizes a series of injectors and foaming chambers to add small quantities of water to the hot asphalt binder (*Astec Inc*). The addition of this small amount of water causes the asphalt to foam, allowing the aggregates to be coated with asphalt at much lower temperatures than are required for HMA production. The manufacturer indicates that benefits of this system include lower fuel consumption and reduced emissions.

Summary of Regional States Specifications/Experiences

Maine DOT

Maine DOT *Special Provision Section 401* specifies the submission of a JMF to establish a HMA control strip for any job that will utilize a WMA technology. This JMF must be submitted with the same aggregate source and percentages, as well as the same asphalt source and target percentage as the WMA JMF. This control strip is to be used for comparison purposes.

Maine DOT has approved four (4) different WMA technology options that contractors may choose from. They are:
Option A – *The use of organic additives such as a paraffin wax and or a low molecular weight esterified wax. Wax derived additives shall be introduced at the rate recommended by the manufacturer. Percentages shall be limited at a rate as to not impact on the binder's low temperature properties. Wax derived additives shall be introduced into the hot asphalt binder at the asphalt suppliers facility, or asphalt mixture plant and fully blended using a tank agitator / stirrer…*

Option B – *The use of a manufactured synthetic zeolite (Sodium Aluminate Silicate). Sodium aluminum silicate additives shall be introduced at a rate recommended by the manufacturer. Sodium aluminum silicate additives shall be introduced into the hot mix plant mixing chamber by mechanical means that can be controlled and tied directly to the hot mix asphalt plant rate of production…*

Option C – *The use of a chemical additive technology and a "Dispersed Asphalt Technology" delivery system. This process utilizes a dispersed asphalt phase (emulsion) in asphalt mixture plant at a rate recommended by the manufacturer. This additive shall be introduced into the hot mix plant mixing chamber by mechanical means that can be controlled an tied directly to the hot mix asphalt plant rate of production…*

Option D – *The use of a controlled asphalt foaming system. This process utilizes an injection system to introduce water to the asphalt stream and "expand" the asphalt prior to mixing with the aggregate in asphalt mixture plant at a rate recommended by the manufacturer. This shall be introduced into the plant mixing chamber by mechanical means that can be controlled and tied directly to the asphalt plant rate of production…*

All four of the available options also require that *…minimum placement temperatures shall be as per manufacturer recommendations. A Quality Control Plan shall be submitted for approval by the Department.* (*Maine DOT, 2010*)

New York State DOT

The New York State Department of Transportation (NYSDOT) issued an engineering instruction (*EI 12-008*) in April of 2012 stating that for any project submitted after September 6th, 2012, the contractor has the option to use an approved WMA technology. Their list of suitable WMA technologies includes three options: organic additives, chemical additives, and foaming processes. These were adopted from the NEAUPG Qualified Warm Mix Asphalt (WMA) Technologies list (March 2nd, 2012. (*NEAUPG, 2012*))

Option A- *Organic Additives(waxes); specifically SonneWarmix™ . (This is currently the only organic additive approved through NYSDOT)*

Option B- *Chemical Additives; options include Cecabase RT, Evotherm™ WMA, LEA-Lite (Low Emission Asphalt-Lite), and Rediset LQ.*

Option C- *Foaming processes; options include Advera®, ASTEC, LEA, AQUABlack, Meeker WMA, Accu-Shear, and Terex.*

MassDOT

The Massachusetts Department of Transportation released a Chapter 90 Warm Mix specification as an addition to their General Laws in the beginning of 2013 (*MAAPA, 2013*). This allows a 9.5 mm Superpave design with any WMA technologies approved and listed in the NEAUPG Qualified Warm Mix (WMA) Technologies list.

PennDOT

The Pennsylvania Department of Transportation (PennDOT) released a Standard Special Provision to include specifications regarding WMA. (*PennDOT, 2011*) Additional information was added to Section 409.2 to include WMA Technology Additives. The approved technologies can be found in Bulletin 15, which is a list composed of all approved construction materials from PennDOT Publication 35.

New Jersey DOT

In accordance with the New Jersey DOT (NJ DOT) Standard Specifications for Road and Bridge Construction (2007) section 902.07.02, one or more of the following types of warm mix asphalt additives may be used:

1) *Organic additives such as a paraffin wax or a low molecular weight esterified wax*
2) *Chemical additive that acts as a surfactant or dispersing agent*

In addition, it is specified that one does not use controlled asphalt foaming systems or any other steam injection processes or steam introducing additives (NJ DOT, 2007). The mix must be submitted for approval, including details of the type of additive, the manufacturer's recommendations for usage, recommended mixing and compaction temperatures, as well as details of a project that used the additive successfully in the United States.

2010 and 2011 Pilot Projects in Connecticut

This research covers pilot projects that were constructed during the 2010 and 2011 construction seasons. As stated, there were multiple technologies utilized over the course of those two construction seasons that were monitored, sampled and analyzed by the research team. The WMA pilot projects, along with the associated technology used, are shown in Table 2.

Table 2. Connecticut WMA Pilot Projects

Year	Town/City	Route	WMA Technology
2010	Meriden	70	Sasobit®®
2010	Meriden	70	*Mechanical Foaming
2011	Southbury	6	Evotherm™®
2011	Killingly	101	Advera®®
2011	Killingly	101	SonneWarmix™ ™
2011	New Hartford	219	Evotherm™®
2011	Farmington	I-84	*Mechanical Foaming (SBS Polymer)
2011	Farmington	I-84	Sasobit®® (SBS Polymer)

*Double Barrel Green® System from Astec Inc.

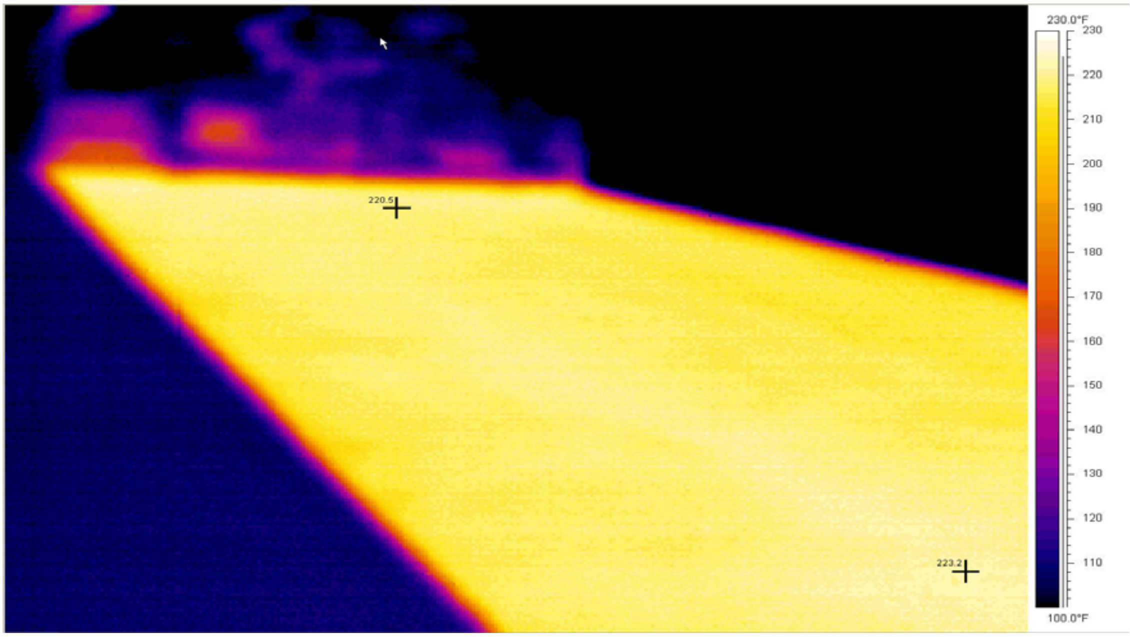
Project Field Details

CAP Lab personnel were on site for the construction of each of the projects. They monitored construction, recorded temperature data, obtained digital images, and observed if areas were milled and/or leveled prior to resurfacing. They collected detailed temperature information with a thermographic imaging camera loaned to the research team by the Connecticut DOT Division of Research.

The thermographic imaging camera records detailed temperature information and records and saves thermal images showing temperature gradients along with an adjustable scale on the image itself, similar to the image shown in Figure 2. The thermographic imaging camera is a FLIR Thermacam™ PM575.

CAP Lab personnel collected images in the field, brought them back to the lab, and processed and analyzed them using ThermaCAM Researcher 2000 software. Numerous examples of thermal images from each of the pilot projects, with the exception of Rt. 101 in Killingly, can be found in Appendix C. Due to logistical issues, the camera was not available during the construction of this project. These images display temperature information of the asphalt behind the screed, as well as the material being placed in the paver. Based on the scale adjustment to the right side of each image, the color gradients (or lack thereof) are indicative of temperature consistency.

Figure 2. Example Thermal Image



Construction of all of the Pilot projects involved a mix of different types/sizes of production plants, WMA technologies, haul distances and delivery temperatures. CAP Lab personnel monitored all of these. The specific details for each of the individual projects are shown in Table 3.

Table 3. Project Details

Route Number	Project Location	Placement Dates	WMA Technology	Material Transfer Vehicle	Plant Type	Haul Distance (Miles)	Mean Screed Temp.	Day/Night Paving
70	Meriden	July 2010	Sasobit®	Yes	Drum	12	230°	Day
70	Meriden	July 2010	*Mechanical Foaming	Yes	Drum	12	230°	Day
219	New Hartford	July 2011	Evotherm™	Yes	Batch	25	234°	Day
101	Killingly	August 2011	Advera®	Yes	Batch	20	N/A	Both
101	Killingly	August 2011	SonneWarmix™	Yes	Batch	20	N/A	Both
I-84	Farmington	August 2011	*Mechanical Foaming (SBS Polymer)	Yes	Drum	1	284°	Night
I-84	Farmington	August 2011	Sasobit® (SBS Polymer)	Yes	Drum	1	284°	Night
6	Southbury	September 2011	Evotherm™	Yes	Batch	2	284°	Night

As shown in Table 3, three of the pilot projects were constructed with more than one WMA technology. This was especially useful for comparative purposes with respect to each of the different technologies, as well as with the control HMA sections that were also constructed on each of the pilot projects. The following tables give brief descriptions of field density and truck temperature per project. With the exception of the Rt. 70 Meriden project, the temperature data was provided by ConnDOT on all of projects. These temperatures indicate the temperature of the material in the trucks immediately following loading at the production facility. The temperatures indicated for the Rt. 70 Meriden project were taken from the thermal images and represent the temperature at the screed immediately following placement.

Table 4. Rt. 70 Meriden Field Data

Paving Day	WMA Technology	Placement Temp (F)	Daily Mat Density (%)	Daily Joint Density (%)
7/20/10	Sasobit®	245	93.8	91.8
7/21/10	Mechanical Foaming	245	91.7	90.6
7/22/10	none - control	285	93.0	89.8

Table 5. Rt. 219 New Hartford

Paving Day	WMA Technology	Truck Temp (F)	Daily Mat Density (%)	Daily Joint Density (%)
7/26/11	Evotherm™	263	92.5	91.0
7/27/11	Evotherm™	250	92.0	90.0
7/28/11	Evotherm™	263		
7/29/11	Evotherm™	253	92.5	87.5
8/1/11	Evotherm™	265	90.5	87.4
8/2/11	Evotherm™	265	90.0	89.7
8/3/11	none – control	298	92.3	91.8

Table 6. Rt. 101 Killingly Field Data

Paving Day	WMA Technology	Truck Temp (F)	Daily Mat Density (%)	Daily Joint Density (%)
8/11/11	None - control	299	91.4	92.0
8/12/11	None - control	308	91.4	92.0
8/12/11	Advera®	280	91.9	91.3
8/13/11	Advera®	274	91.9	91.3
8/17/11	SonneWarmix™	272	91.6	92.3

Table 7. Rt. 6 Southbury Field Data

Paving Day	WMA Technology	Truck Temp (F)	Daily Mat Density (%)	Daily Joint Density (%)
9/2/11	None – control	305	92.3	90.8
9/11/11	Evotherm™	273	92.0	
9/12/11	Evotherm™	275	94.0	87.9
9/13/11	Evotherm™	280		
9/17/11	Evotherm™	280	92.6	89.0

I-84 Farmington Details

Among the pilot projects constructed during the 2010-2011 season, the I-84 Farmington project had the most tonnage. This project utilized SBS polymer modified asphalt and two different WMA technologies. Of note is that Hurricane Irene occurred during construction and there were two changes of liquid binder supplier terminals. The research team has decided to illustrate the details of this project in a separate section given the complexity of what occurred during construction. The breakdown of what transpired during the construction of that project is shown by date in Table 8.

Table 8. I-84 Farmington Field Data

Paving Day	WMA Technology	Binder Terminal Location	Average Daily Truck Temp (F)*	Daily Mat Density (%)*	Daily Joint Density (%)*
8/16/11	None – control	Paulsboro	338	92.9	90.2
8/17/11	Sasobit®	Gloucester City	315	90.5	88.6
8/18/11	Sasobit®	Gloucester City	335	90.0	88.7
8/22/11	Sasobit®	Gloucester City	360	91.1	88.4
8/23/11	Mechanical Foaming	Paulsboro	329	91.6	88.4
8/24/11	Mechanical Foaming	Paulsboro	309	91.7	88.5
8/25/11	Mechanical Foaming	Paulsboro	278	92.1	88.0
8/26/11	None – control	Paulsboro	330	92.4	
8/30/11	Mechanical Foaming	Paulsboro	294	93.0	90.3
8/31/11	Sasobit®	Paulsboro	304	92.5	89.3
09/01/11	Mechanical Foaming	Paulsboro	278	91.5	87.6
09/08/11	Sasobit®	Paulsboro	312	91.8	88.9
09/09/11	Sasobit®	Paulsboro	305	91.7	88.4

* **Data provided by ConnDOT**

The contractor had issues in achieving adequate compaction during the first few nights using Sasobit®. In response, binder supply terminal locations were changed. In addition, the contractor increased WMA temperatures in an attempt to achieve greater compaction. This became evident during the fourth night of construction. Although there were compaction problems during this project, the laboratory performance of the different mixes collected from this project all performed quite well in comparison with mixes collected from the construction of the other pilot projects. This is discussed in the testing sections below.

Sampling and Specimen Fabrication

At various times for each project, CAP Lab personnel monitored mix placement, and plant production to collect materials for testing in the laboratory. Each project included a HMA control strip that was sampled as well. Enough material was collected for fabrication of specimens for testing of:

- Moisture Susceptibility via Tensile Strength Ratio (TSR) - AASHTO T283
- Moisture Susceptibility via the Hamburg Rut Tester- AASHTO T324
- Rutting Susceptibility via Asphalt Pavement Analyzer (APA) – AASHTO T340

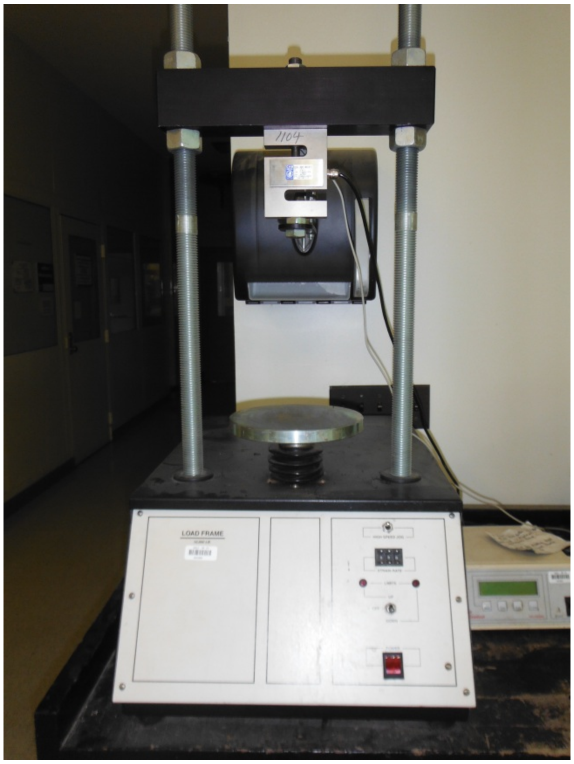
Some of the producers chose to produce trial blends of each mix prior to construction, which were tested by CAP Lab personnel. Pre-production testing included the three tests listed above. The results of all testing can be found in the testing results section below.

Materials were collected from trucks at a sampling stand at the production facility with the exception of Route 219 in New Hartford, where samples were collected directly from the jobsite at the paver screed auger. All samples were placed into new cardboard sample boxes, labeled and then transported back to the CAP Lab.

Once the materials had been collected and transported to the CAP Lab, specimen fabrication took place. All materials were heated to the production temperature, with one exception. The mechanically foamed material was heated to a higher than typical HMA production temperature because water is dissipated from the WMA during this process. Specimens were fabricated in the Superpave gyratory compactor to test heights of 95 mm for TSR testing, 75 mm for Hamburg testing and 75 mm for APA testing.

Tensile Strength Ratio Testing

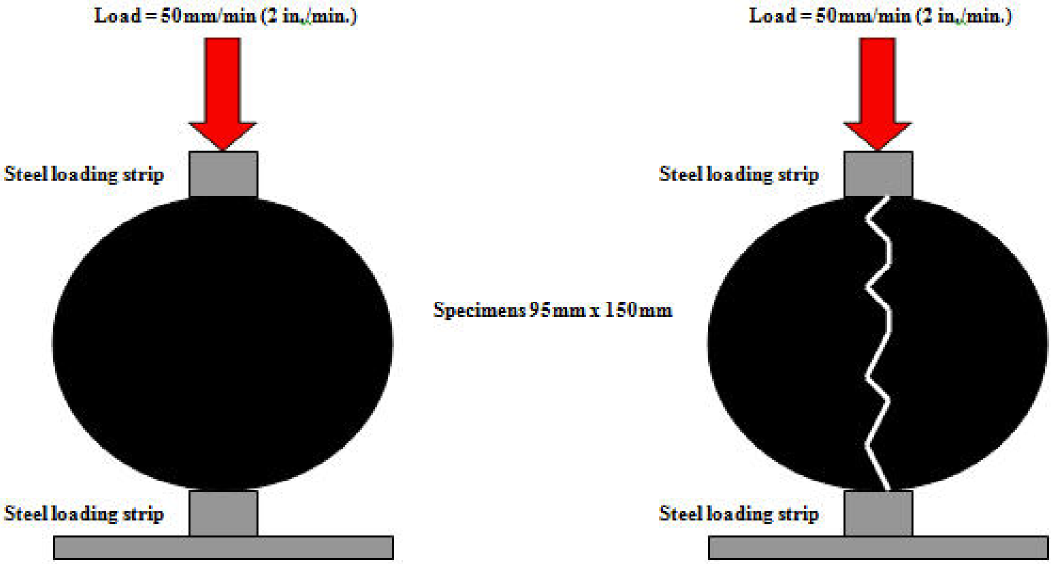
Figure 3. TSR Test Configuration



The tensile strength test measures the potential of a sample for stripping and moisture damage. Water tends to weaken the cohesive bond between the asphalt binder and the surface of the aggregate. The propensity of the mix to strip due to the effects of water is directly related to the strength (specifically tensile strength) of the mix. The TSR is the ratio of the tensile strength of a conditioned set of specimens to that of a set that has not been subjected to moisture or freezing. A high TSR value then would be indicative of mix that is not very susceptible to moisture induced damage while a lower value would be indicative of mix that is susceptible to moisture damage. ConnDOT specifications currently require a TSR value of no less than 80%, which is also the Superpave standard.

This test is performed by partially saturating a set of samples in a vacuum container for 5-10 minutes, and then running those samples through a freezing cycle for a minimum of 16 hours. Once the freezing cycle is complete, the sample is directly placed in a 60° C soaking cycle for 24 ± 1 hours. After the 60° C soaking phase, the sample is placed in a 25° C bath for 2 hours and finally tested for strength. Strength testing is conducted in the compression apparatus shown in Figure 3. The sample is locked in place and then an increasing load is applied at a constant rate until the sample breaks as shown in Figure 4.

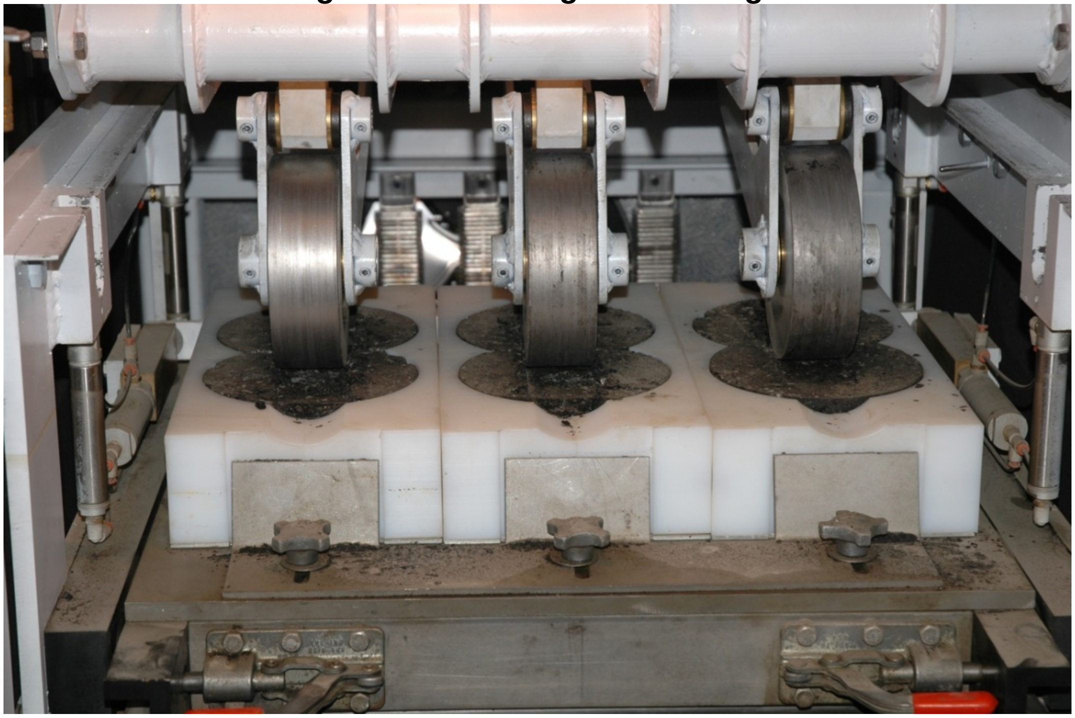
Figure 4. Tensile Strength Ratio Testing



The maximum load value is recorded, and once the sample is removed, it is observed for any possible stripping behavior. This is apparent by visible exposed aggregate, showing that the binder has separated from the aggregate surface.

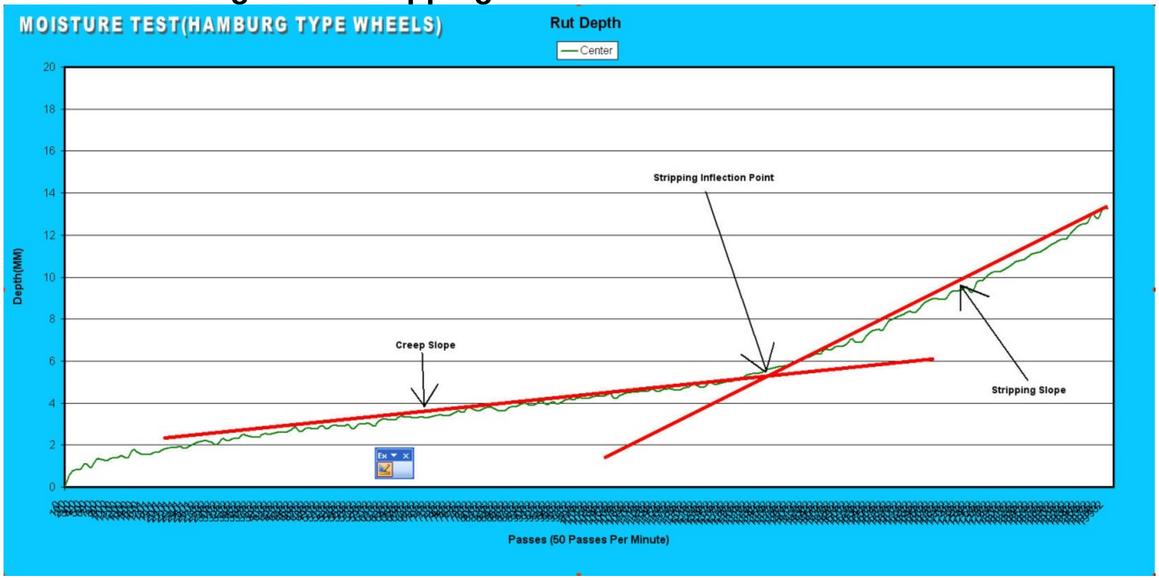
Hamburg Testing

Figure 5. Hamburg Test Configuration



The Hamburg test is a destructive test that involves heating a set of specimens to test temperature for a designated period of time under water and then running a loaded set of wheels across them, as shown in Figure 5, repeatedly while rut measurements are recorded and plotted. With this test, resistance to moisture damage can be observed by the overall rut depth of the specimens and by a stripping inflection point on the generated plot. The stripping inflection point is the point on the plot where the slope of the first steady state portion of the curve (the creep slope) intersects with the slope of the second steady state portion of the curve (the stripping slope). An example of this is illustrated in Figure 6.

Figure 6. Stripping Inflection Point Determination



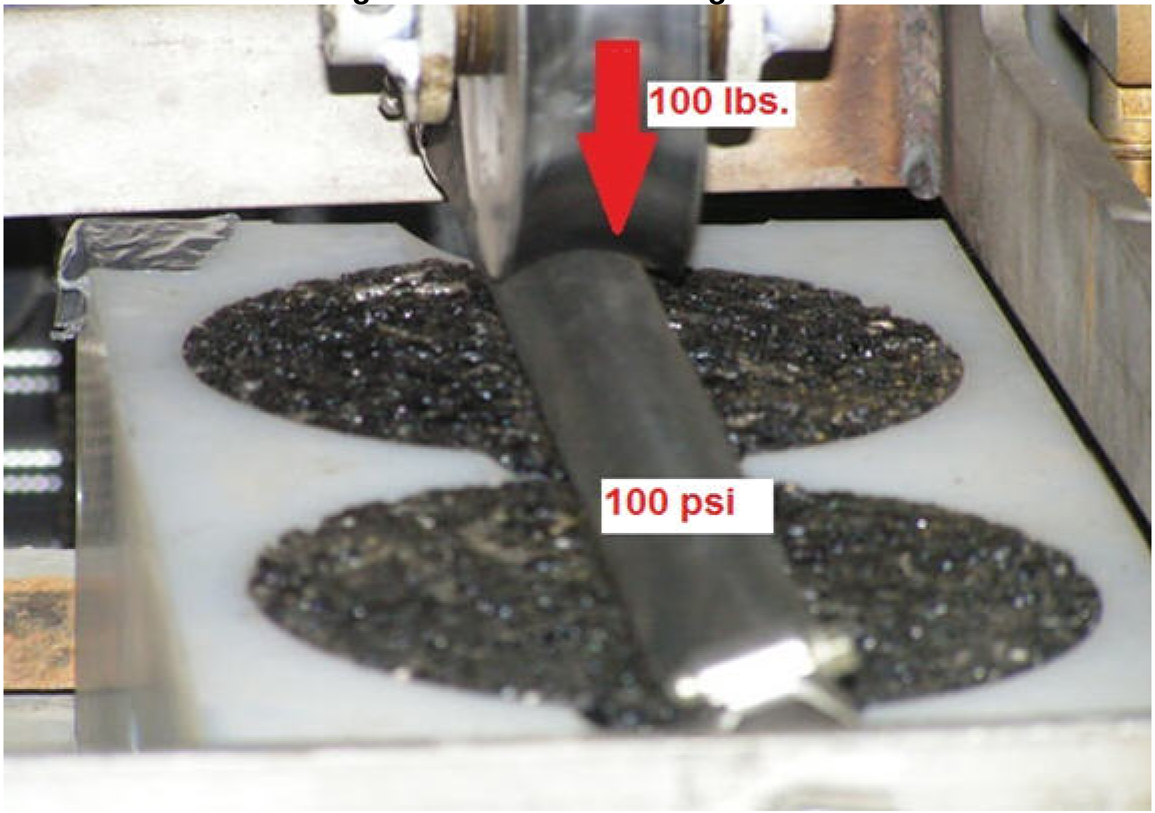
***Plot is intended as example of stripping inflection point. It does not reflect data collected as part of this research**

This change in slope, from creep slope to stripping slope, requires an increase in the rate of rutting at an advanced number of passes. This increased rate of rutting is caused by water breaking the asphalt-aggregate bond. The greater the number of cycles required to reach the stripping inflection point the less likely the material is to exhibit stripping and thus less susceptible to moisture induced damage. In many cases, it is not possible to see a stripping inflection point because the material exhibits no stripping. This was the case for most of the specimens tested as part of this research.

Asphalt Pavement Analyzer Testing

The research team conducted the rutting susceptibility testing with the Asphalt Pavement Analyzer (APA). The APA test involves laying a rubber pneumatic tube that is pressurized to 100 psi across the top center of the test specimens, as shown in Figure 7.

Figure 7. APA Test Configuration



The specimens are conditioned to temperature inside the unit for 6 to 24 hours. Once this has been achieved, the testing consists of applying a 100 lb. downward force onto the overlying pneumatic tubes via the wheels as shown in Figure 7. The wheels are then passed across the hoses a maximum of 8000 cycles. Rut depth measurements are taken via linear variable differential transformers LVDTs at different locations on the specimen.

For background information, as well as another basis for comparison, the research team investigated what some State Departments of Transportation are using as specification maximum rut testing values using the APA.

The Virginia Department of Transportation uses a maximum rut depth of 3.5 mm on roadways designed to be in service for more than 10 million ESALs, 5.5 mm for 3 to 10 million ESALs and 7.0 mm for 0 to 3 million ESALs. *(Virginia DOT, 2011)*

The Arkansas Department of Transportation specifies maximum rut depth based on the number of gyrations used in the mix design; maximum of 8.0 mm for 75 & 115 Gyrations, 5.0 mm for 160 & 205 Gyrations. *(Arkansas SHDT),*

The Georgia Department of Transportation specifies a maximum of 5.0 mm for most mixes. They specify higher maximum rut depths for lower volume mixes. *(Georgia DOT, 2008)*

The North Carolina Department of Transportation has specifications for APA rut depths ranging from 4.5 mm to 11.5 mm depending on the mix type. *(North Carolina DOT, 2006)*

TSR Test Results

TSR test results are shown in both Table 9 and Figure 8 below. The ConnDOT requirement for tensile strength ratio values as well as the Superpave standard is no less than 80%. With the exception of two of the WMA results (Advera® and Lab Fabricated Mechanical Foaming), all of the other WMA specimens met this requirement. The other two values that were less than 80% were HMA specimens. As seen in both Table 9 and Figure 8, the I-84 project in Farmington on average as well as the Evotherm™ on Rt. 219 in New Hartford outperformed all of the other projects with respect to tensile strength ratio testing. It is the opinion of the research team that this was a function of the addition of SBS polymer to the asphalt binder used on the I-84 mix and the anti-strip properties associated with the use of Evotherm™ on the Rt. 219 mix.

Table 9. TSR Results

HMA/WMA Technology	Placement Location	Placement Date	TSR
Sasobit® Plant Fabricated	70 Meriden	7/20/10	95.7
Sasobit® Lab Fabricated	70 Meriden	7/20/10	91.5
Foaming Plant Fabricated (2 days)*	70 Meriden	7/21/10	80.9
Foaming Plant Fabricated (7 days)*	70 Meriden	7/21/10	85.8
Foaming Lab Fabricated	70 Meriden	7/21/10	79.6
HMA Lab Fabricated	70 Meriden	7/22/10	94.2
Evotherm™	219 New Hartford	7/26/11	106.7
HMA	219 New Hartford	8/3/11	78.4
HMA	101 Killingly	8/12/11	92.1
Advera®	101 Killingly	8/15/11	65.9
SonneWarmix™	101 Killingly	8/16/11	86.9
HMA + SBS	EB I-84 Farmington	8/16/11	101.9
Sasobit® + SBS	EB I-84 Farmington	8/22/11	93.4
Foaming + SBS	EB I-84 Farmington	8/23/11	91.1
HMA + SBS	WB I-84 Farmington	8/26/11	95.4
Sasobit® + SBS	WB I-84 Farmington	8/31/11	93.4
HMA Pre-Prod.	6 Southbury		75.8
Evotherm™ Pre-Prod.	6 Southbury		86.8
HMA	6 Southbury	9/2/11	81.2
Evotherm™	6 Southbury	9/12/11	91.4

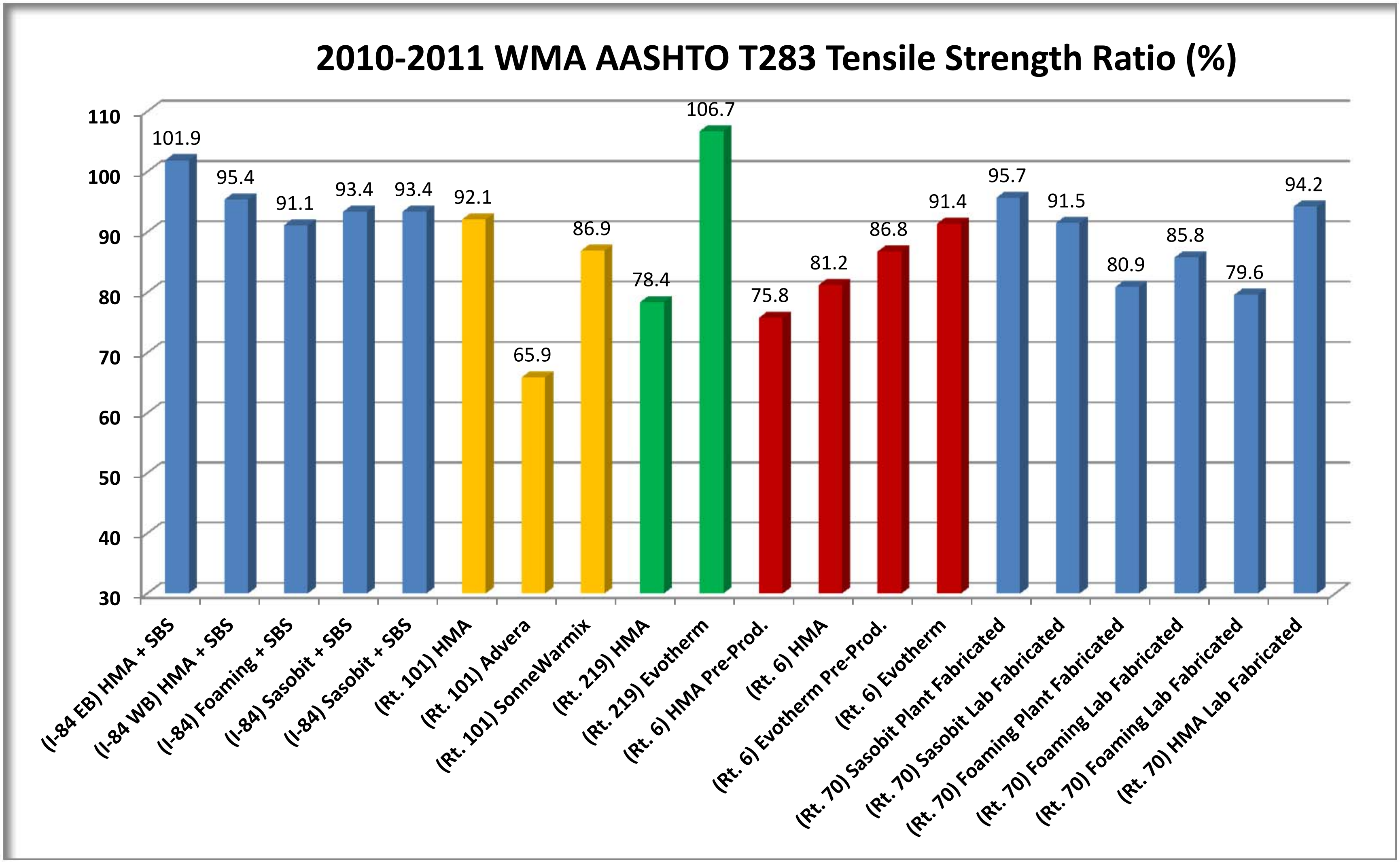
***See language below regarding foamed WMA specimen fabrication time**

It should be noted that there was some concern over the method in which to fabricate and test specimens produced using mechanical foaming during the 2010 pilot projects. Since the foaming process utilizes water, which generates foam that will collapse over time, the performance of the mix under test may be different depending upon handling. When the foamed asphalt is still present in the mix, the material may behave differently while being compacted, depending on the degree and/or uniformity of the dissipation of the foamed asphalt.

TSR results from the Rt. 70 Meriden project are presented in Table 9 above. These include test results for lab fabricated specimens that were made from mix that was allowed time to cool such that all of the foaming in the asphalt collapsed prior to making them. These also include test results for specimens that were compacted immediately after production and then sat for both 2 and 7 day periods prior to testing. Note that the TSR was 4.9% higher for specimens that sat for 7 days versus those that sat for 2 days. This may be an indication of the level of inconsistency that can be expected when fabricating plant produced WMA tensile strength ratio specimens while the material is still warm from production.

Considering these results, the research team recommends allowing mechanically foamed WMA time to cool such that all of the foaming in the asphalt collapses then reheating the material prior to specimen fabrication. The material is essentially the same as HMA at that point and should be heated to HMA temperature prior to compaction of specimens. It is the opinion of the research team that handling mechanically foamed WMA in this manner will lead to more consistent and repeatable performance testing results.

Figure 8. TSR, 2010-2011



Hamburg Rut Test Results

AASHTO T 324 requires that this test be run at a temperature in the range of 40°C to 50°C. The first specimens tested were the specimens from the Rt. 70 Meriden project, which took place in 2010. Those specimens were tested at 45°C. The results of those tests indicated no observable stripping inflection point, so the research team decided that all testing would be conducted at 50°C to provide a worst case scenario. Hamburg testing for that project was repeated at 50°C, and all subsequent testing was also conducted at 50°C. The results of Hamburg testing show that most of the mixes were not able to withstand the entire 20,000 passes. Among the mixes unable to withstand the entire 20,000 pass duration, the tests ranged from 4,520 passes to 18,439 passes.

There were two exceptions: the I-84 Farmington project and one of the mixes for Route 101 in Killingly. Both of these mixes were able to withstand the entire 20,000 passes. From a rut depth perspective, the I-84 Farmington project on average far outperformed the rest of the projects and WMA technologies. This is shown in Table 10 and Figures 9 and 10. The lower rut depth combined with the Hamburg test results for the I-84 project leads the research team to believe that the SBS polymer has a positive effect on the mix regardless of the type of WMA or HMA technology used. Excluding the I-84 Farmington Project, all other WMA technologies combined performed similarly from a rut depth perspective with a range of 3.8 mm among all tests excluding the I-84 Farmington Project.

Table 10. Hamburg Results

HMA/WMA Technology	Placement Location	Placement Date	Hamburg Rut Depth
Sasobit®	70 Meriden	7/20/10	12.504
Foaming	70 Meriden	7/21/10	10.280
HMA	70 Meriden	7/22/10	9.151
Evotherm™	219 New Hartford	7/26/11	12.452
HMA	219 New Hartford	8/3/11	13.023
HMA Pre-Prod.	101 Killingly		12.378
Advera® Pre-Prod	101 Killingly		12.082
SonneWarmix™ Pre-Prod	101 Killingly		12.99
HMA	101 Killingly	8/12/11	9.297
Advera®	101 Killingly	8/15/11	12.828
SonneWarmix™	101 Killingly	8/16/11	14.103
HMA + SBS	EB I-84 Farmington	8/16/11	4.954
Sasobit® + SBS	EB I-84 Farmington	8/22/11	5.669
Foaming + SBS	EB I-84 Farmington	8/23/11	3.662
HMA + SBS	WB I-84 Farmington	8/26/11	4.803
Sasobit® + SBS	WB I-84 Farmington	8/31/11	4.886
HMA Pre-Prod.	6 Southbury		12.191
HMA	6 Southbury	9/2/11	11.151
Evotherm™ Pre-Prod.	6 Southbury		13.767
Evotherm™	6 Southbury	9/12/11	12.994

***All Hamburg Rut Depth Values From Testing at 50°C**

Figure 9. Hamburg Rut Depths, 2010-2011

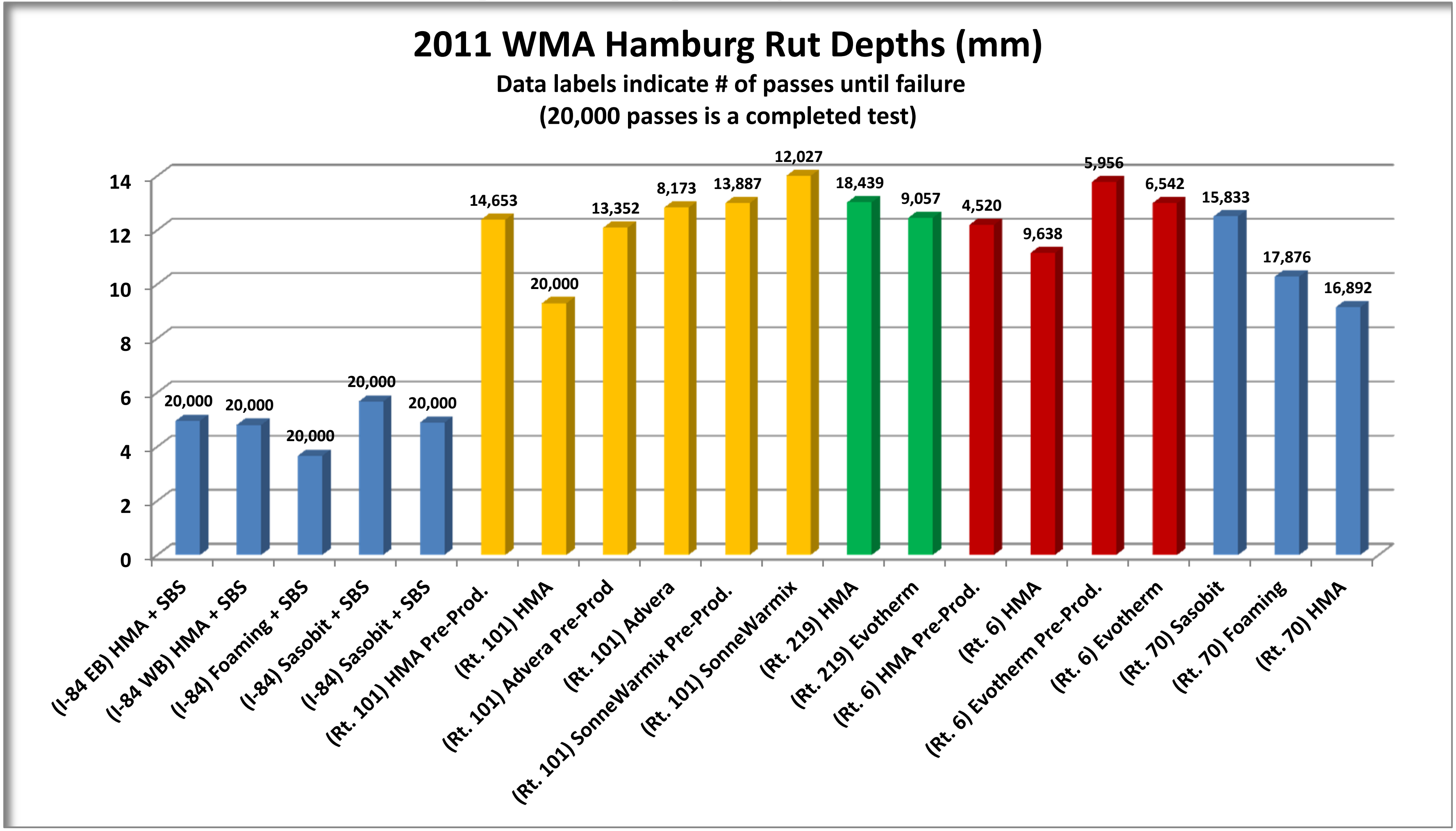
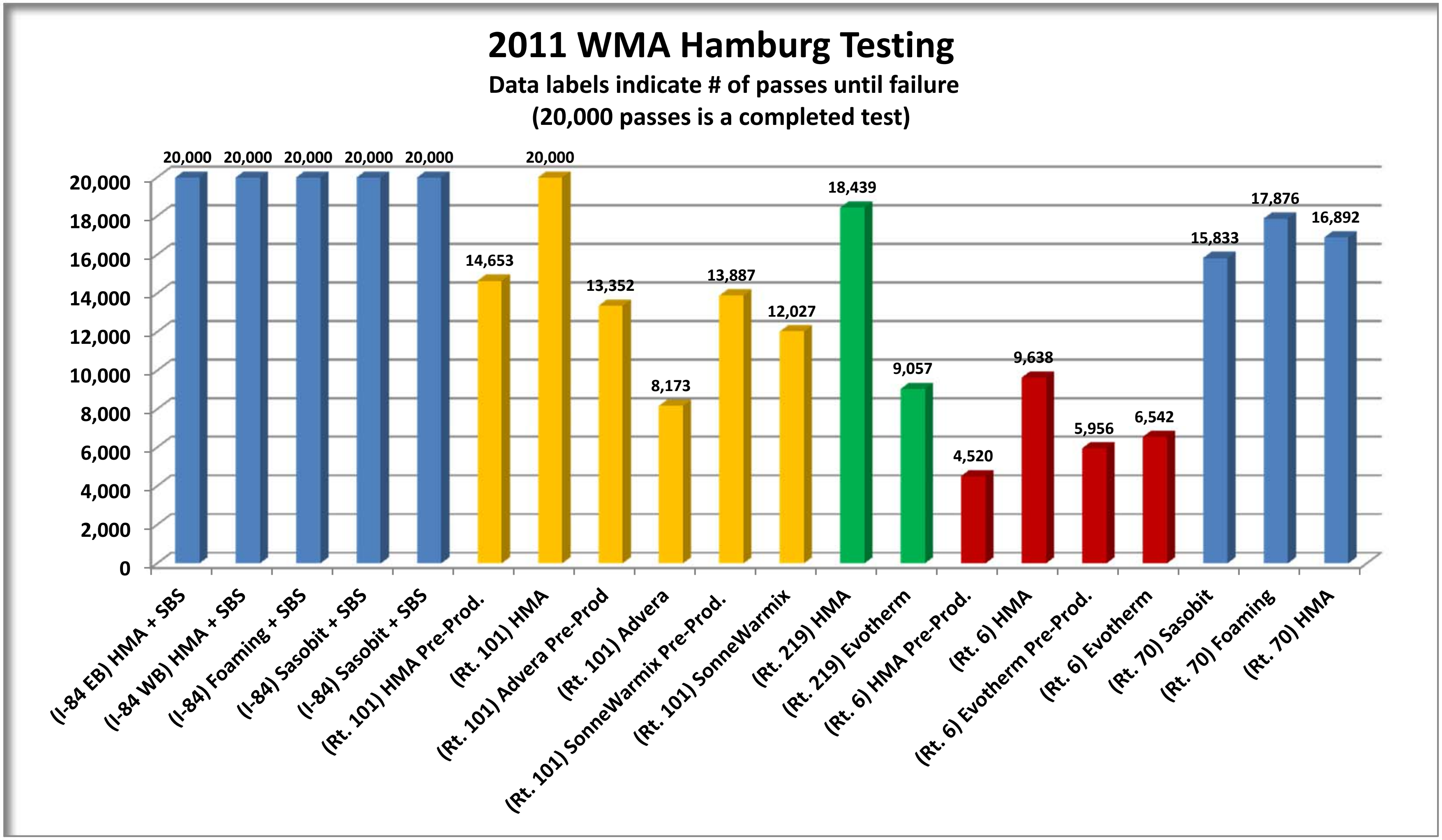


Figure 10. Hamburg Test, Number of Passes



Hamburg testing rut charts are provided in Appendix A. As shown in those charts, there is no indication of stripping inflection points on any of the mixes tested, with the exception of the pre-production HMA from the Rt. 101 Killingly project (Figure A.3). This chart shows just a slight indication of a slope change on two specimens in the 8,000 pass region. The production HMA Hamburg results for that project gave no indication of any stripping problems at all. Because of this and the fact that no other mixes tested during this research indicated any sort of change in slope on the Hamburg plots, it is the opinion of the research team that the pre-production HMA Hamburg testing plot results for the Rt. 101 Killingly project is an outlier and no cause for concern regarding stripping.

APA Test Results

The SonneWarmix™ pre-production trial mix had an elevated APA rut depth of 8.6 mm (Table 11). The research team feels this should not necessitate concern from a rutting perspective, since the SonneWarmix™ production mix rut depth value was 5.9 mm. This is more in line with the other WMA rut depth values and also more aligned with the rut depth specifications from other states, which were reviewed and discussed previously.

The highest rut depth value (9.1 mm) was measured on plant fabricated specimens from the Rt. 70 Meriden, Sasobit® mix; however, this should not be cause for concern because the lab fabricated specimens for that project registered a lower rut depth value of 4.8 mm, and perhaps the 9.1 mm rut depth was an outlier. Note that CAP Lab personnel made all of the plant and lab fabricated specimens.

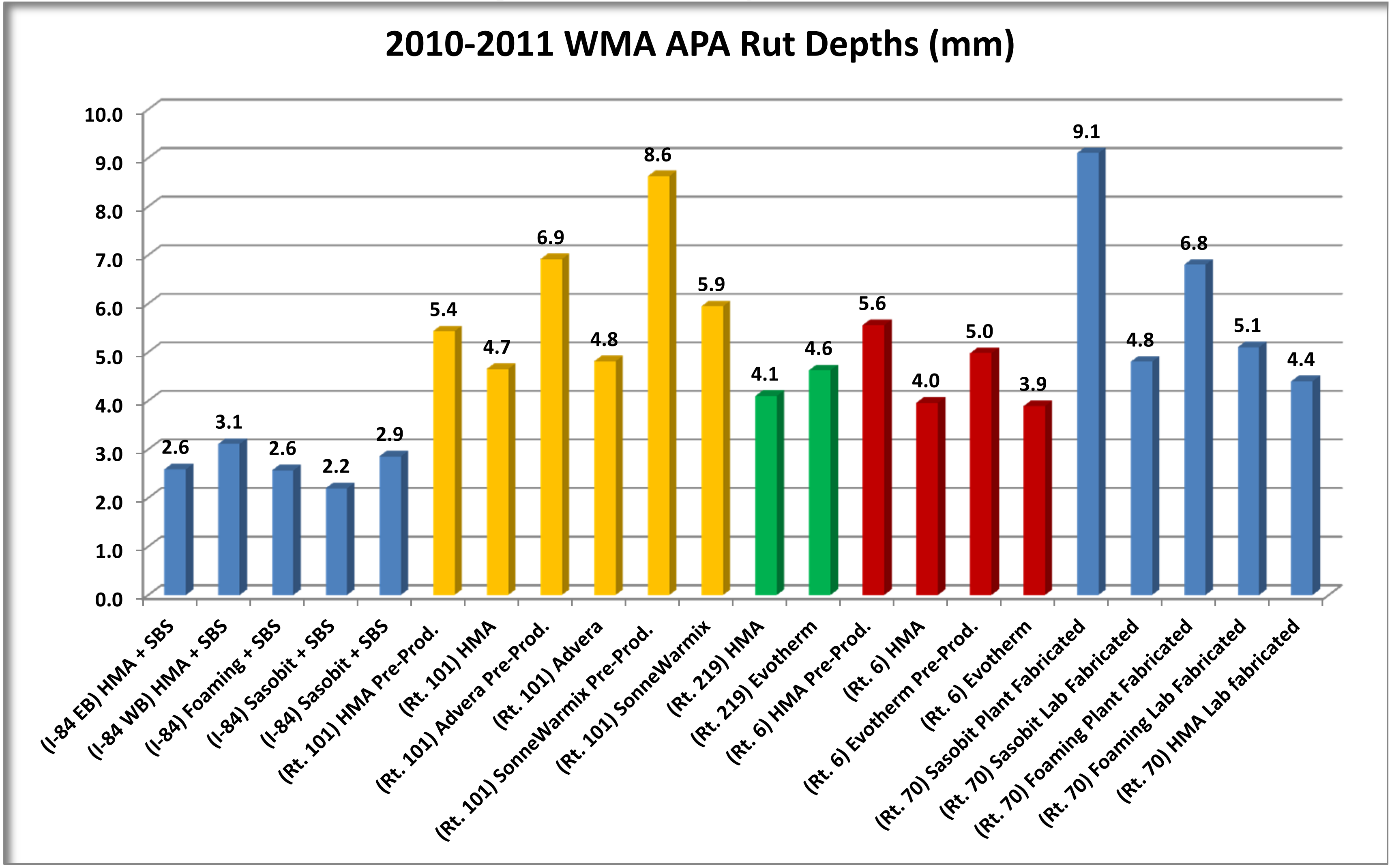
The I-84 Farmington project had significantly lower APA rut depths, ranging from 2.2 to 3.1 mm. This is likely the effect of the addition of SBS polymer to the asphalt binder that was used on that project. Other WMA APA rut depth measurements, ranging from 3.9 to 6.9 mm, were considerably lower than the two suspected outliers discussed above. Again, these rut depths were 8.6 mm for the SonneWarmix™ pre-production specimens and 9.1 mm for the Sasobit® plant fabricated specimens. All results are tabulated below in Table 11.

Table 11. APA Results

HMA/WMA Technology	Placement Location	Placement Date	APA Rut Depth
Sasobit® Plant Fabricated	70 Meriden	7/20/10	9.1
Sasobit® Lab Fabricated	70 Meriden	7/20/10	4.722
Foaming Plant Fabricated	70 Meriden	7/21/10	6.8
Foaming Lab Fabricated	70 Meriden	7/21/10	5.072
HMA Lab Fabricated	70 Meriden	7/22/10	4.437
Evotherm™	219 New Hartford	7/26/11	4.626
HMA	219 New Hartford	8/3/11	4.097
HMA Pre-Prod.	101 Killingly		5.43
Advera® Pre-Prod.	101 Killingly		6.914
SonneWarmix™ Pre-Prod.	101 Killingly		8.624
HMA	101 Killingly	8/12/2011	4.653
Advera®	101 Killingly	8/15/11	4.812
SonneWarmix™	101 Killingly	8/16/11	5.946
HMA + SBS	EB I-84 Farmington	8/16/11	2.588
Sasobit® + SBS	EB I-84 Farmington	8/22/11	2.195
Foaming + SBS	EB I-84 Farmington	8/23/11	2.565
HMA + SBS	WB I-84 Farmington	8/26/11	3.109
Sasobit® + SBS	WB I-84 Farmington	8/31/11	2.854
	Sasobit® 1 Wheel Stopped at 7778		
HMA Pre-Prod.	6 Southbury		5.557
Evotherm™ Pre-Prod.	6 Southbury		4.977
HMA	6 Southbury	9/2/11	3.959
Evotherm™	6 Southbury	9/12/11	3.889

***All APA testing was conducted at 64°C**

Figure 11. APA Rut Depths, 2010-2011



It should be noted that the APA was not functioning correctly when the Rt. 70 Meriden plant fabricated specimens were tested. The research team performed these rut depth measurements manually, which accounts for the reduced significant figures reported for those two sets of results. The individual plots of APA Rutting performance are shown in Appendix B. The Rt. 70 specimens that were fabricated at the production facility were unavailable, due to equipment malfunctions at that particular time.

Revisiting Construction Sites

During the spring and early summer of 2013, the research team revisited the construction sites that were part of this research, with the exception of I-84 in Farmington. Because I-84 is a high traffic, high speed, limited access interstate highway, revisiting was not practical. The research team was looking for any signs of early distress that could be attributed to the mix. This included both longitudinal and transverse cracking, thermal cracking, opening of joints and any other signs of premature failure. None were found during the visits to any of the pilot projects. Numerous digital images were taken during the revisits and general condition images from each of the projects (except I-84) are shown in Appendix D.

Conclusions

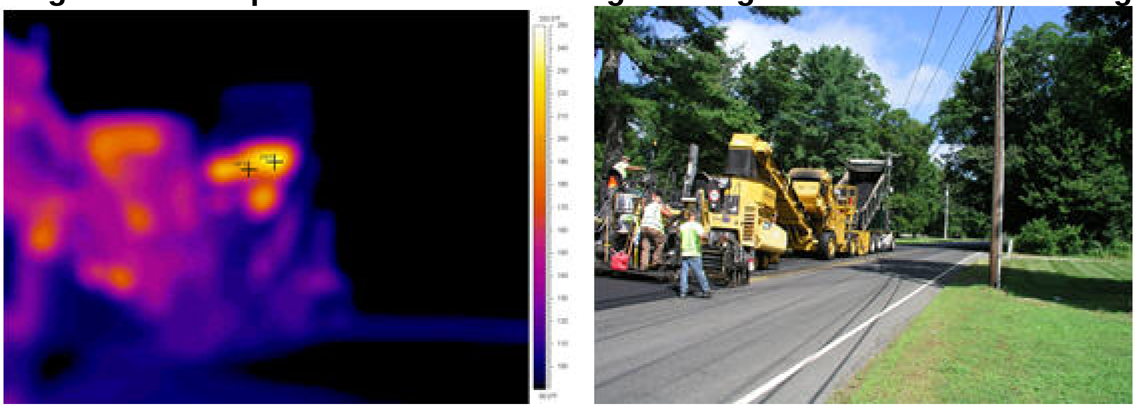
The research team was present for at least a portion of the construction for all of the projects analyzed, with the exception of Rt. 101 in Killingly. While a few isolated compaction issues presented themselves during some of these constructions, the only notable construction related difficulties observed by the research team occurred on I-84 in Farmington and on Rt. 219 in New Hartford (low joint density issues). All of the warm mix technologies certainly appear to have a profound workability attribute that counters the effects of the temperature reduction. The intention to reduce the amount of heat required to produce asphalt pavement, while maintaining proper workability for placement, was successful.

The combination of the SBS polymer and Sasobit that came from Gloucester City on the I-84 project appeared to cause of some of the compaction problems experienced on that project. By contrast, if the wearing surface performs exceptionally well over the coming years, this may also be a product of the SBS polymer. This may offset negative effects caused by poor compaction during construction.

The research team found that the mixes containing SBS performed superior to the mixes without polymer. The Hamburg and APA rut depths show that the SBS mixes outperformed all other mixes to a significant degree. Test sections on I-84 Farmington should be monitored on a year-by-year basis to examine the effects of the polymer. The effects of poor compaction in those sections should also be monitored to determine if the outstanding laboratory performance of the SBS polymer mixes translate to field performance.

From an environmental standpoint, the reduction in temperature of WMA mixes without question translates to a reduction in emissions. The research team noted, along with the reduction in temperatures, a significant reduction in the visually evident smoke (Figure 1) coming from the loads of mix during construction, as shown below in Figure 12. The thermal image and digital image were taken simultaneously on the Rt. 219 project.

Figure 12. Comparison Thermal and Digital Images of Evotherm™ Paving



The 2013 site visits revealed no indication that any of the mixes were underperforming in the field.

With the exception of Sasobit®, all of the WMA technologies used in these pilot projects are approved on the Northeast Asphalt User Producer Group Qualified Warm Mix Asphalt Technologies list. The list was adopted by the NEAUPG after ConnDOT had made the decision to use Sasobit® on these test sections as part of this research. It is currently ConnDOT practice to allow for the use of any of the WMA technologies listed on the NEAUPG qualified list.

Finally, it is the research team’s opinion that these test sections be monitored year-to-year to determine which of the WMA technologies outperform/underperform the others over time. This information may be useful to ConnDOT in determining if the use of any of the technologies listed on the NEAUPG Qualified Warm Mix Asphalt Technologies List should be discontinued due to underperformance. As an aid for future monitoring of these test surfaces, the ConnDOT mileage points for each of the individual test sections are outlined in Tables 12 and 13. The I-84 Farmington project was included in a separate table to include additional information (lane locations and liquid binder supplier location) due to the complexity of that project.

Table 12. Test Section Mileage Points*

Project	Surface	Start	End
Rt. 70 Meriden	**Sasobit**	9.69	9.22
	Foaming	9.22	8.62
	HMA	8.62	8.02
Rt. 6 Southbury	**HMA**	22.93	23.63
	Evotherm	23.63	25.94
Rt. 101 Killingly	**HMA**	5.21	7.3
	Advera	7.3	7.78
	Sonnewarm	7.78	9.55
Rt. 219 New Hartford	**Evotherm**	13.34	10.82
	HMA	10.82	10.48

*Mileage points were taken from the ConnDOT Photolog

Table 13. Test Section Mileage Points (I-84)*

Project	Surface	Start	End	Lane(s)	Binder Supplier Location
Rt. I-84 Farmington Eastbound	**HMA**	50.97	51.33	Curb to Curb	Paulsboro
	Sasobit	51.33	54.34	Left	Gloucester City
	Sasobit	51.33	53.78	Center	Gloucester City
	Foaming	53.78	54.34	Center	Paulsboro
	Foaming	51.33	54.34	Right	Paulsboro
Rt. I-84 Farmington Westbound	**HMA**	44.03	45.25	Left	Paulsboro
	Foaming	45.25	46.4	Left	Paulsboro
	Sasobit	46.4	47.29	Left	Paulsboro
	Foaming	44.03	45.11	Center	Paulsboro
	Sasobit	45.11	47.29	Center	Paulsboro
	Sasobit	44.03	47.29	Right	Paulsboro

*Mileage points were taken from the ConnDOT Photolog

Recommendations

The various Warm Mix technologies did not appear to create any significant differences as compared to the control HMA sections either during construction or during laboratory testing. The one exception was the I-84 Farmington project, but that issue was addressed during construction.

The majority of the laboratory testing focused on rutting and permanent deformation which would be the primary mechanism of concern for WMA as the reduced production temperature would reduce the hardening of the asphalt during construction. This reduction in asphalt hardening during construction, should allow the pavement to remain flexible longer which will delay the on-set of some of the distresses typically observed near the end of a pavement's service life.

Therefore, the Research Team has the following recommendations:

1. Allow the substitution of approved Warm Mix Technologies at the discretion of the asphalt mix producer
2. Allow the use of all three classifications of Warm Mix Technologies
3. Encourage the producers to reduce their production temperatures, but don't mandate the temperature reduction at the risk of not achieving density
4. When fabricating TSR specimens from foamed asphalt, allow the material to cool and then reheat before fabricating the TSR specimens

Starting in 2013, ConnDOT allowed asphalt mix producers to use Warm Mix Technologies that were on the Northeast Asphalt User Producer Group's approved Warm Mix list.

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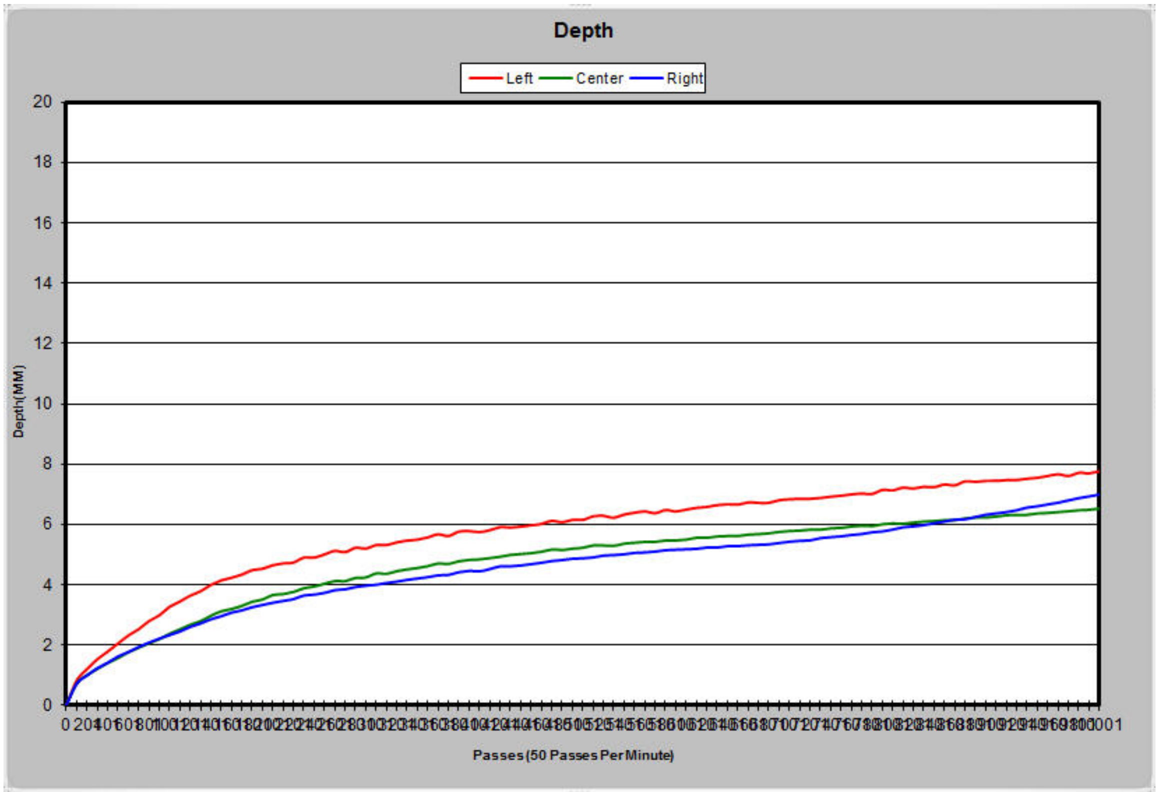
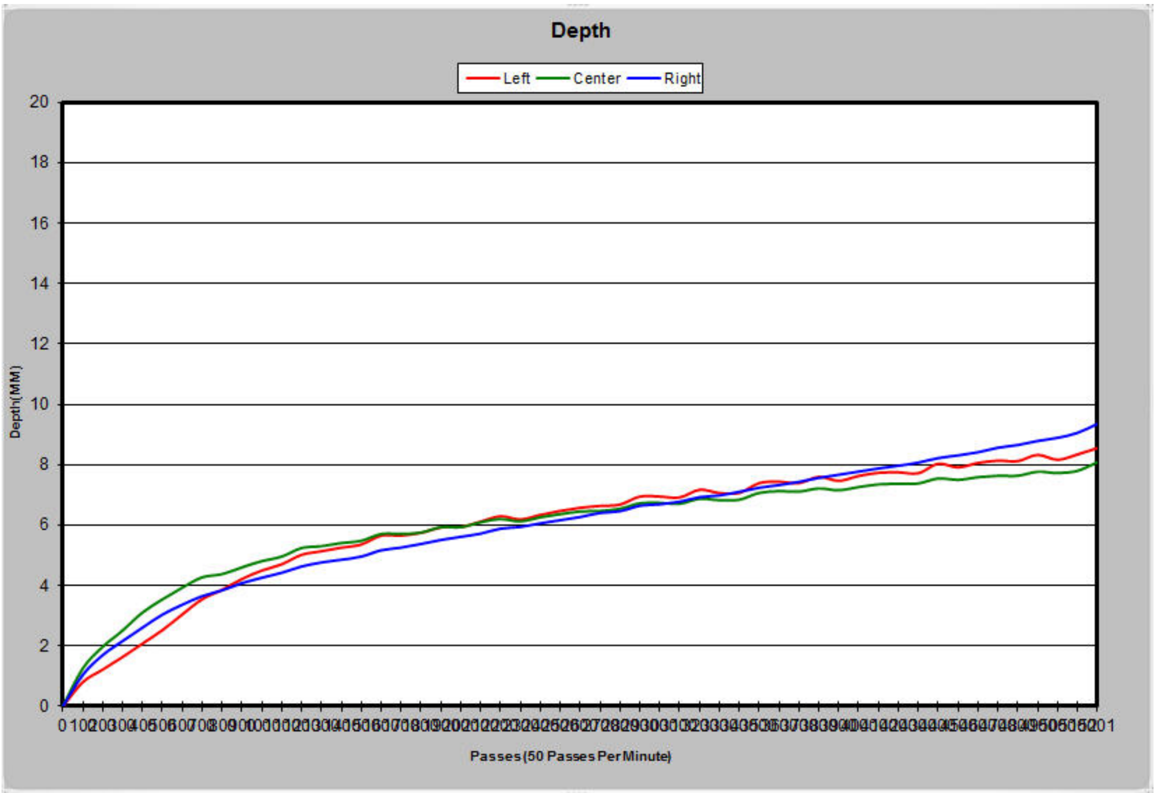
APPENDIX A. Hamburg Testing Rut Charts

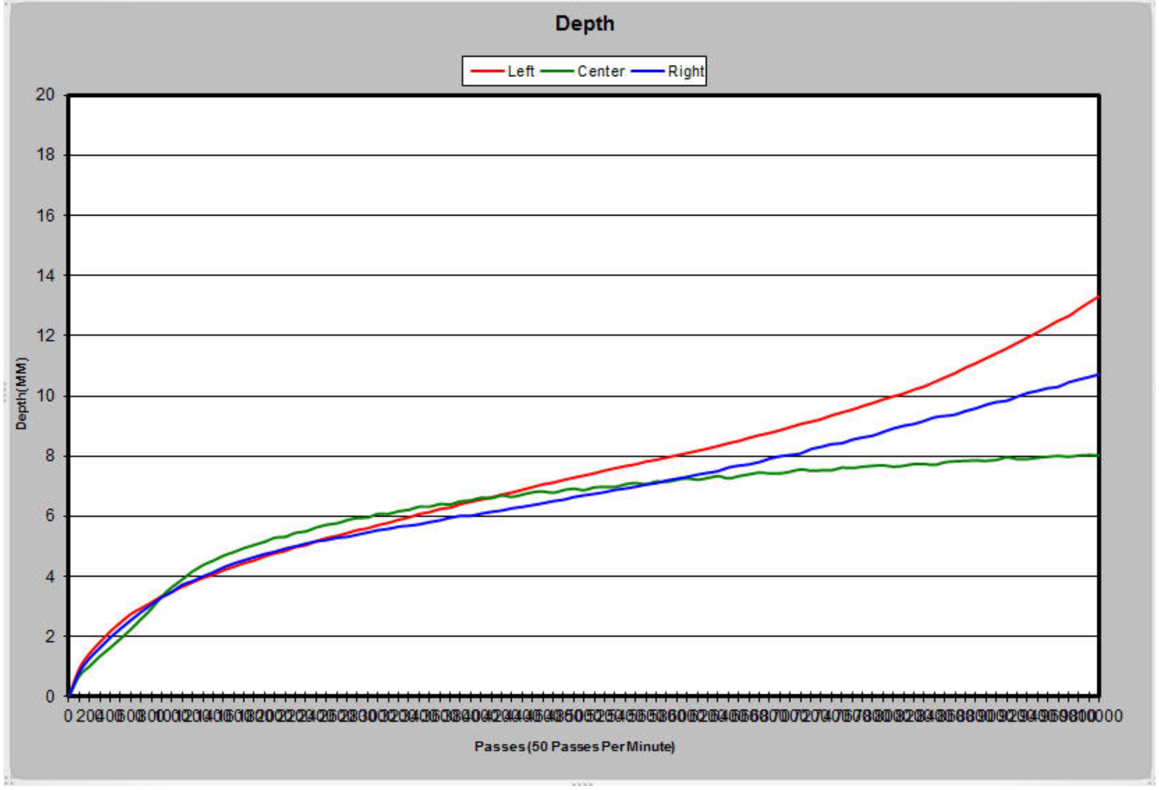
A.1 HMA - Rt. 219 New Hartford



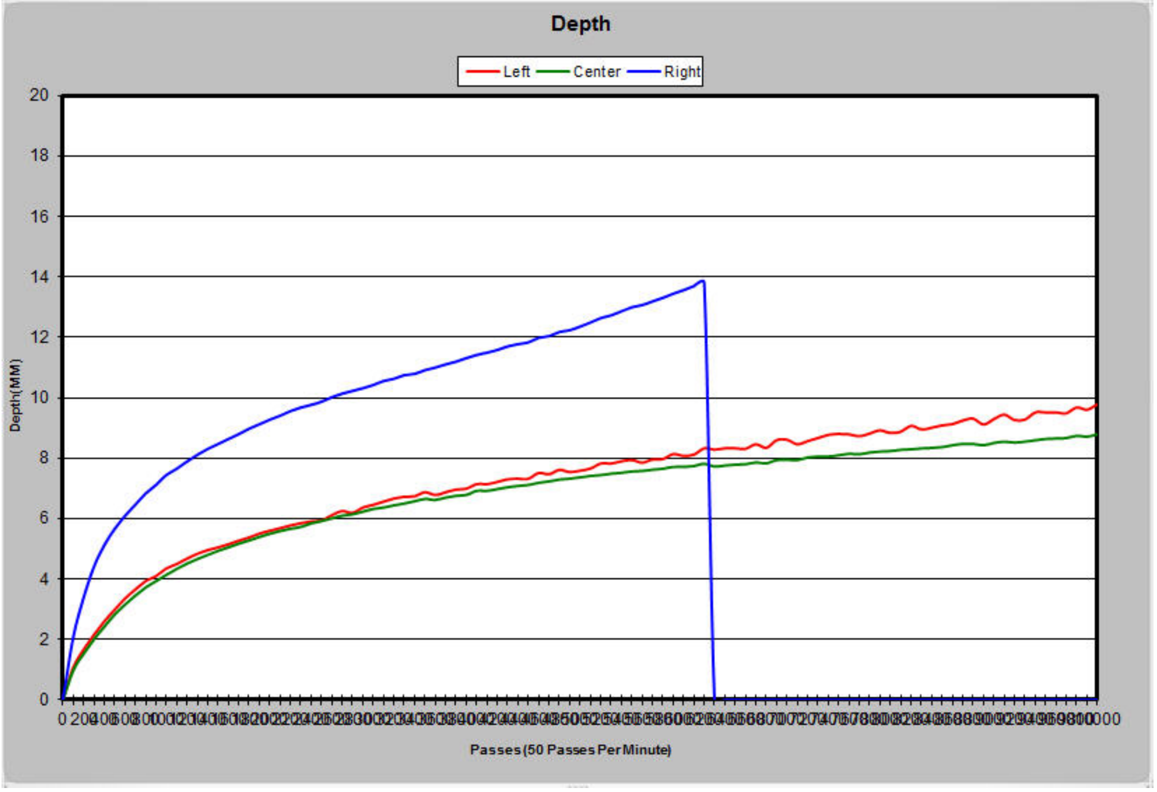
A.2 Evotherm™ – Rt. 219 New Hartford



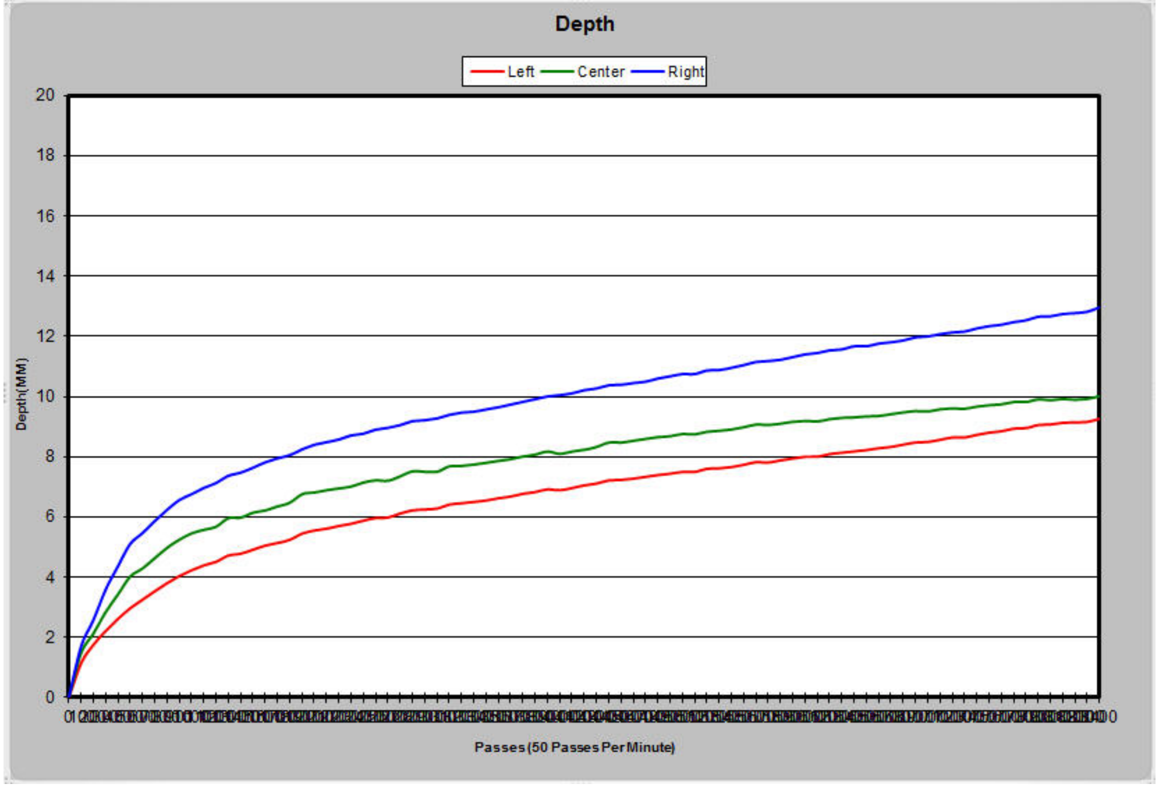
A.3 HMA (pre-production) – Rt. 101 Killingly



A.4 Advera® (pre-production) – Rt. 101 Killingly



A.5 SonneWarmix™ (pre-production) – Rt. 101 Killingly



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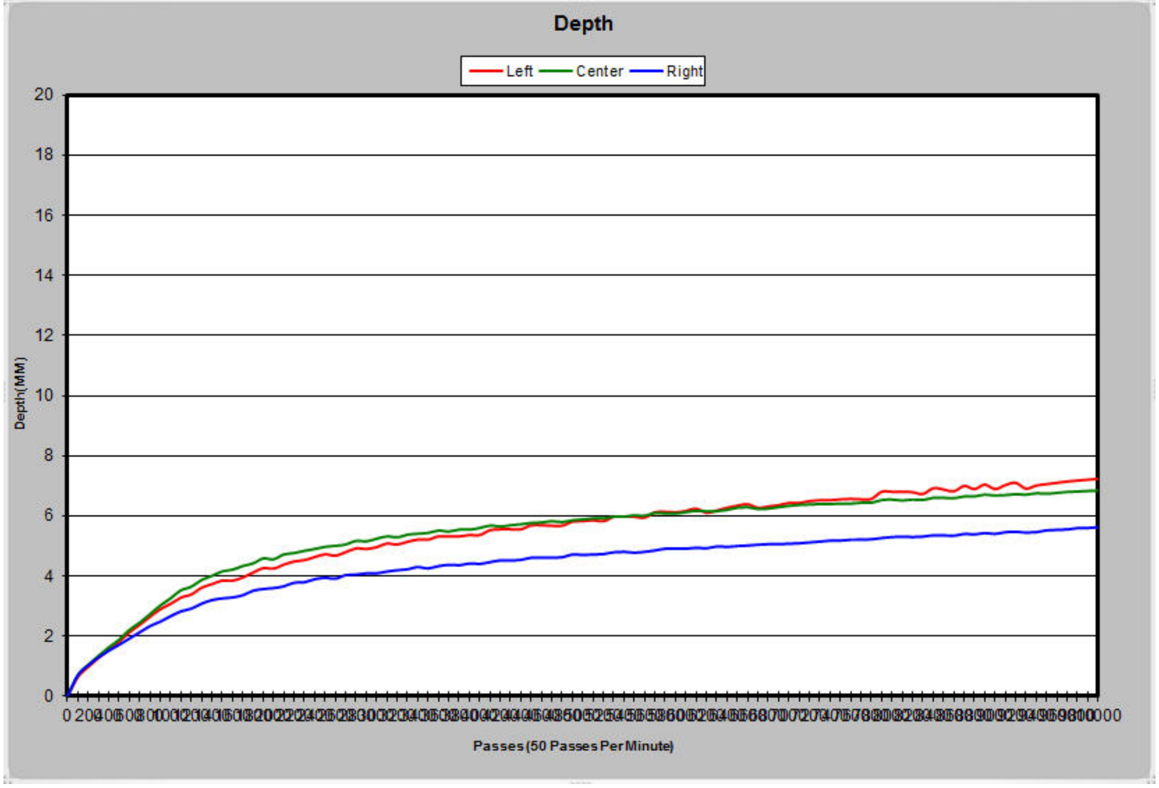
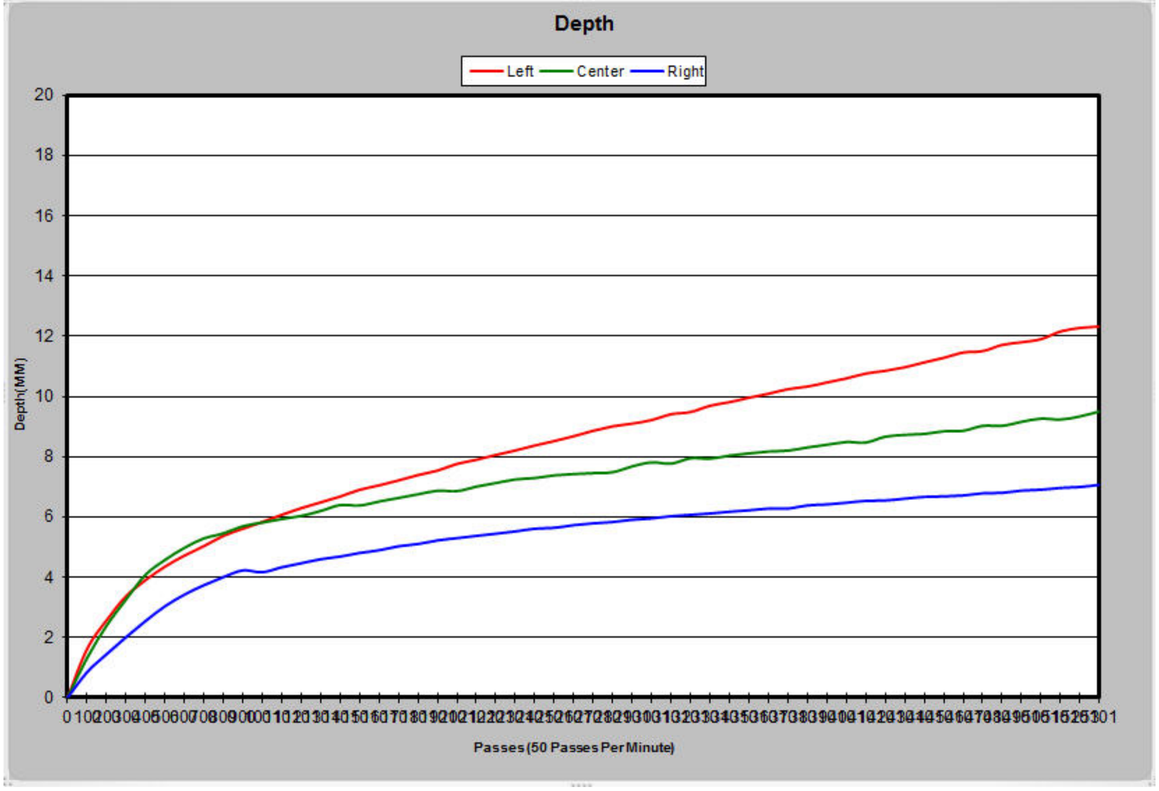
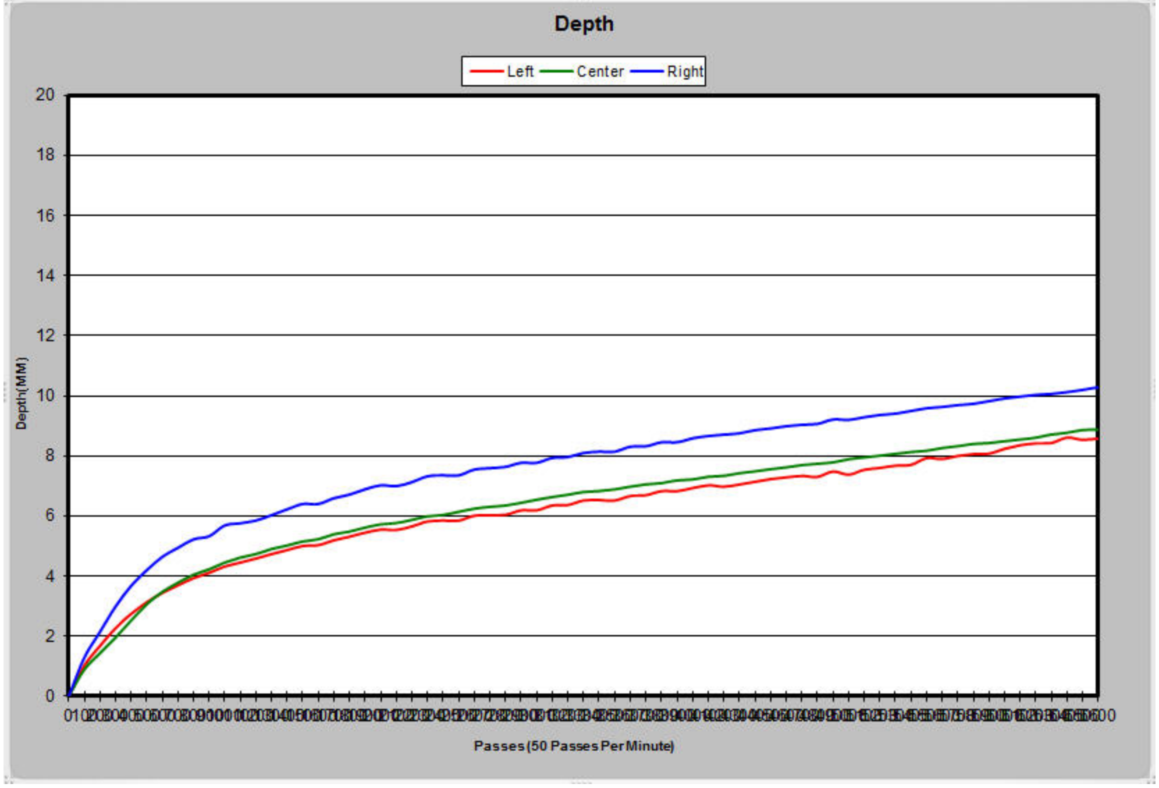


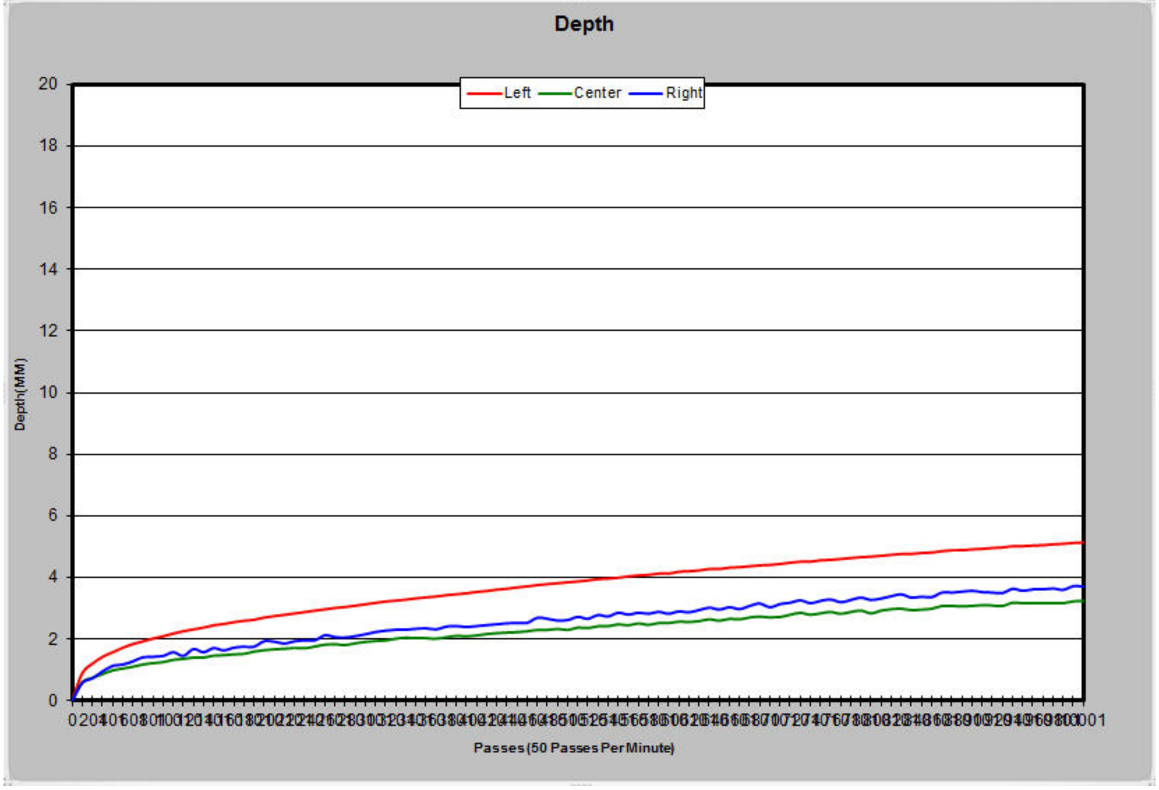
A.7 Advera® – Rt. 101 Killingly



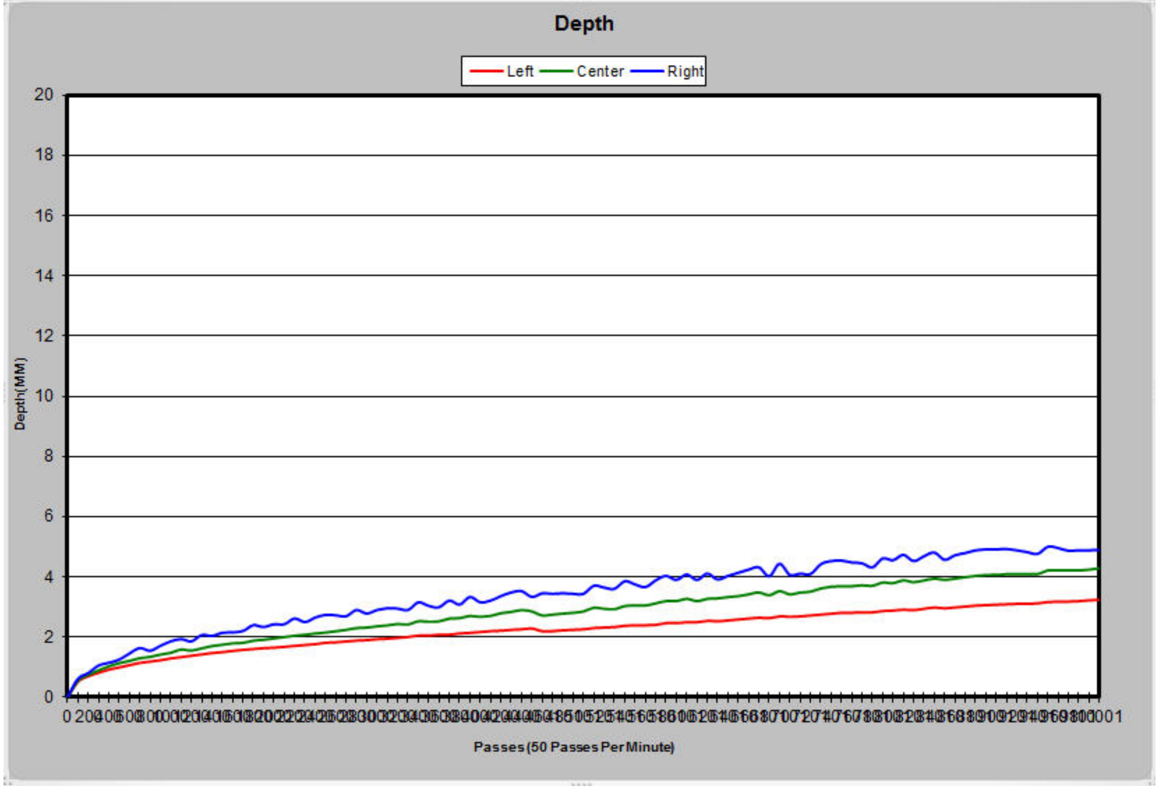
A.8 SonneWarmix™ – Rt. 101 Killingly



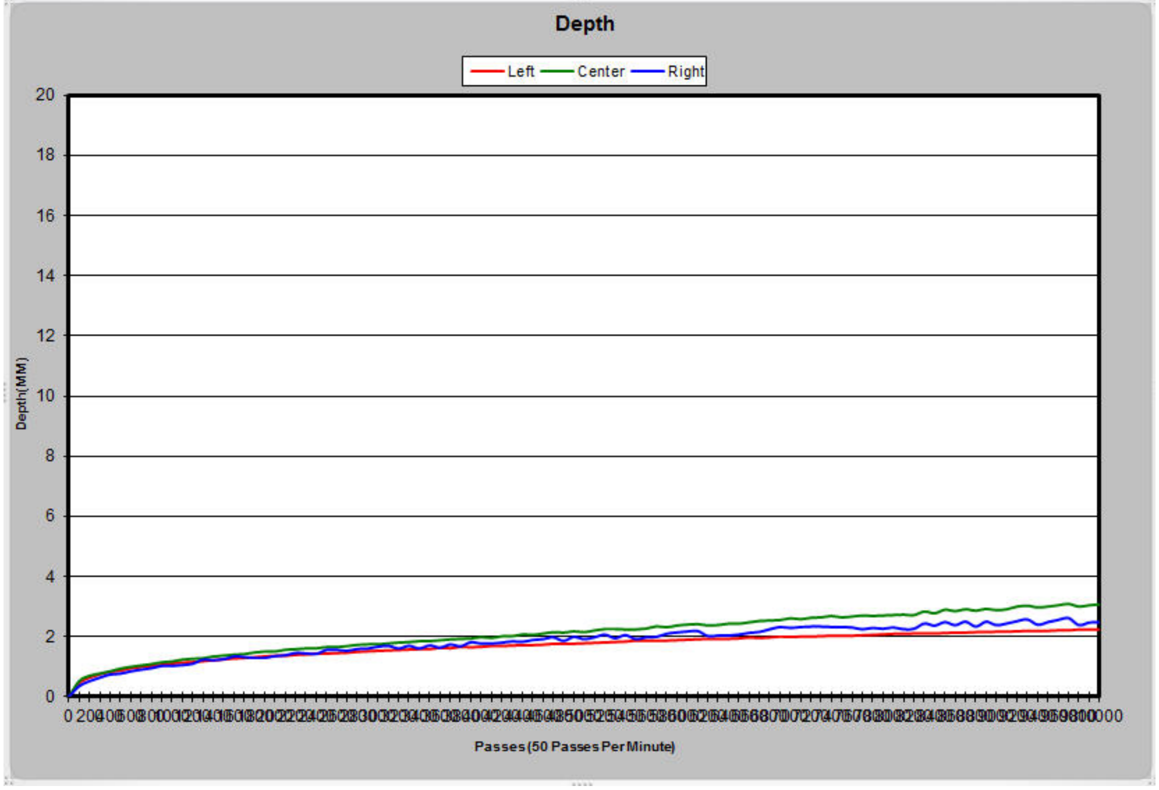
A.9 HMA + SBS – EB I-84 Farmington



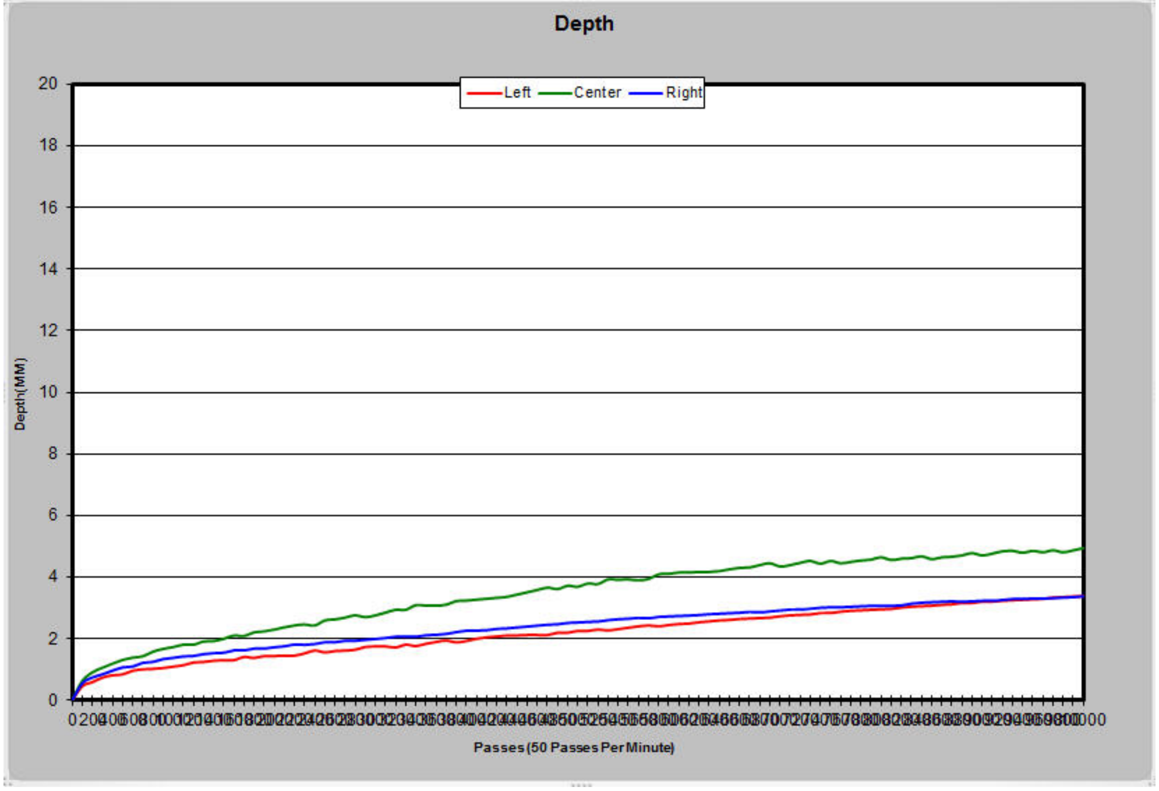
A.10 Sasobit® + SBS – EB I-84 Farmington



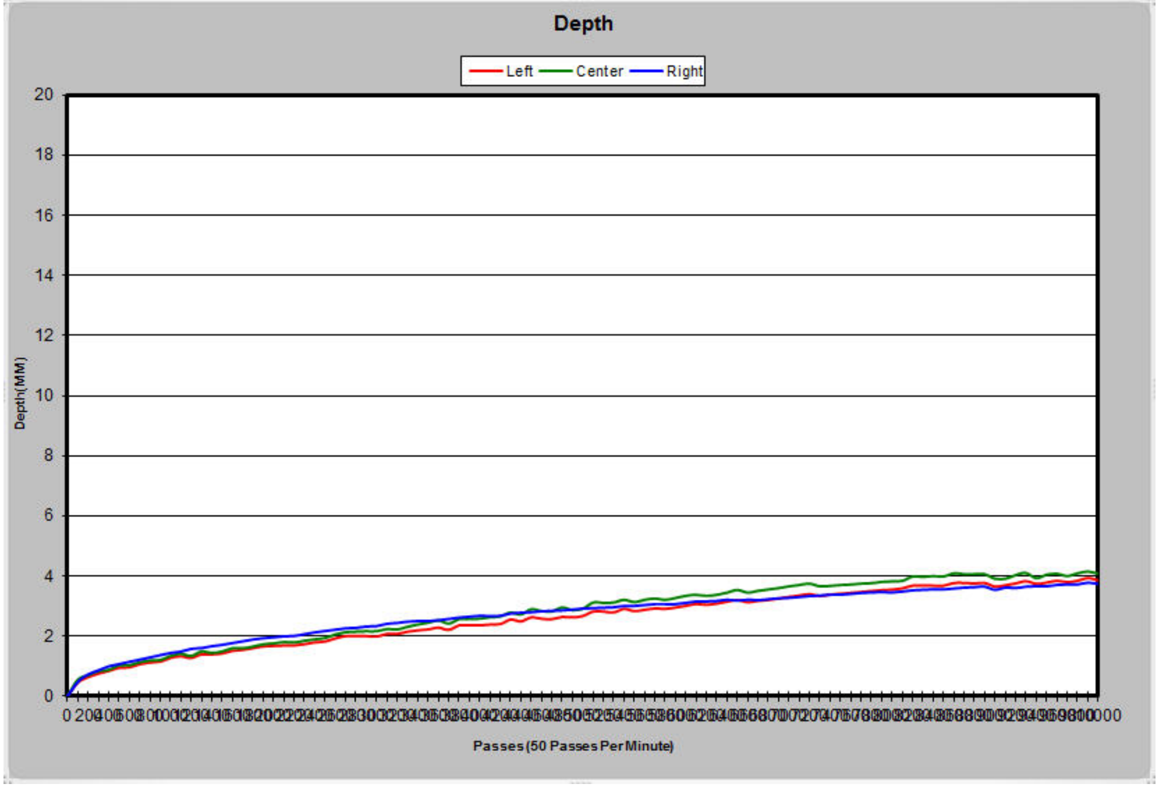
A.11 Foamed + SBS – EB I-84 Farmington



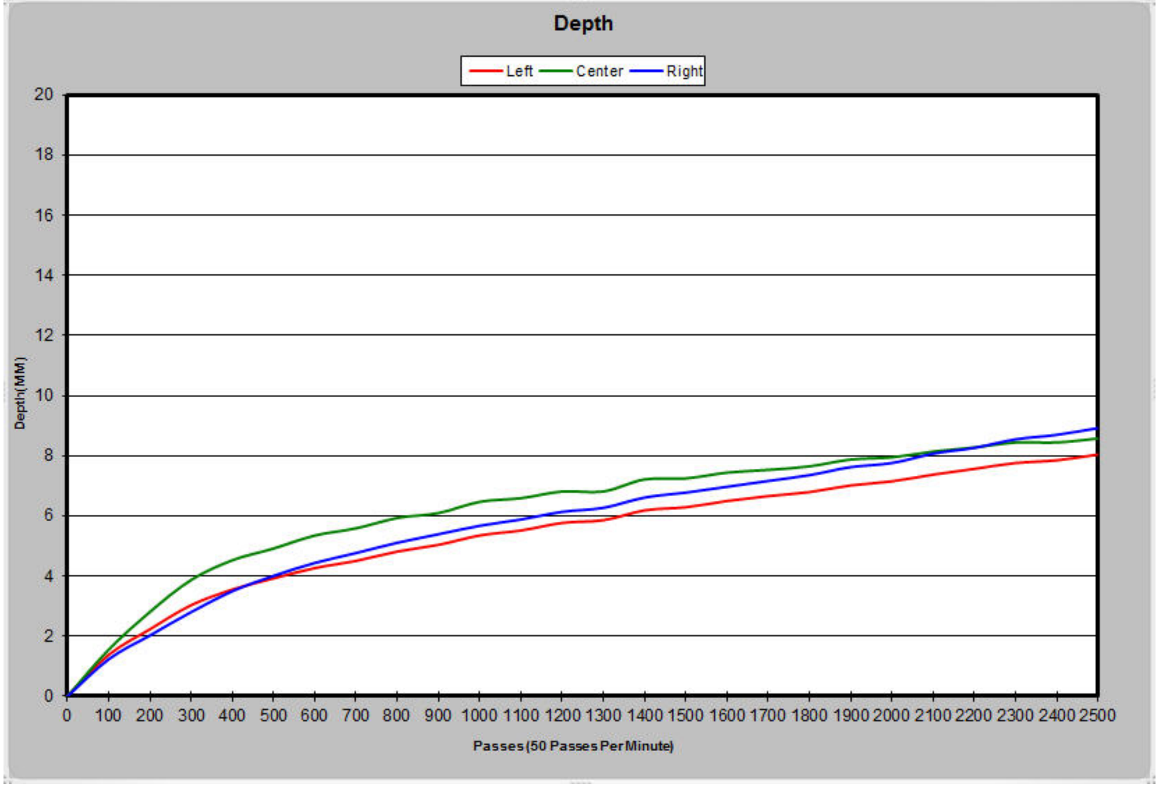
A.12 HMA + SBS – WB I-84 Farmington



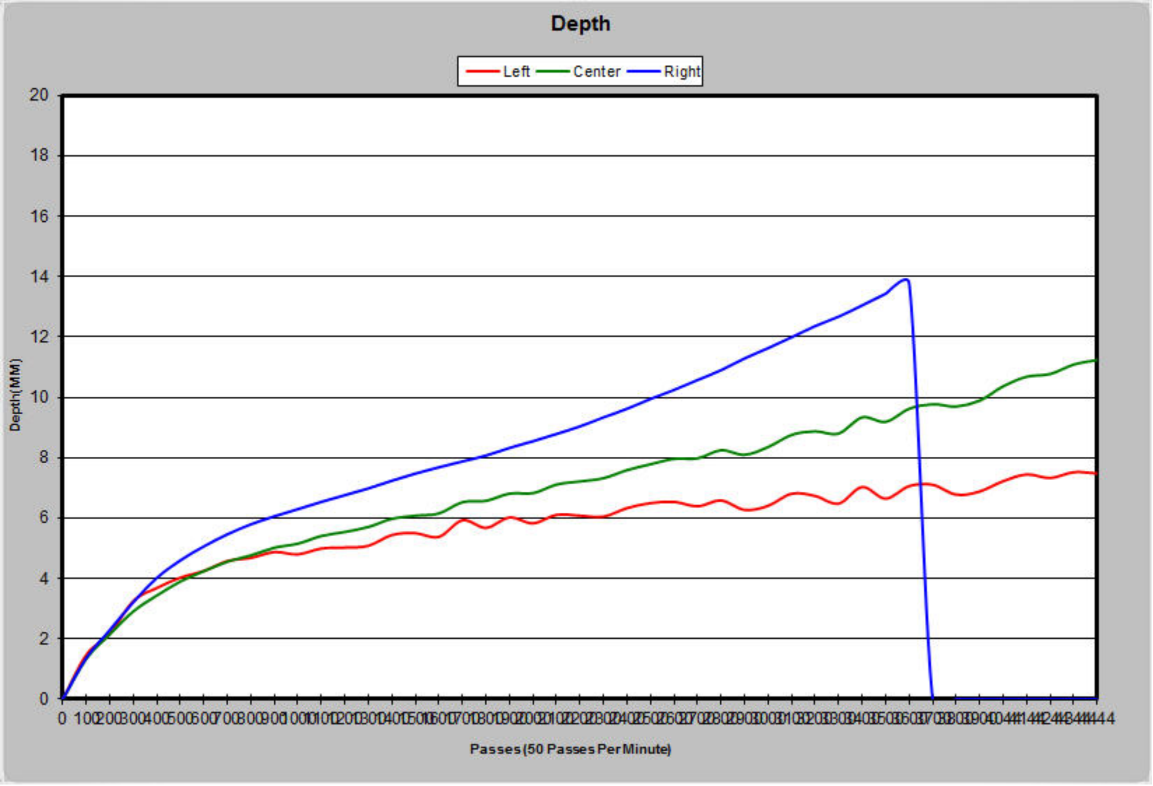
A.13 Sasobit® + SBS – EB I-84 Farmington



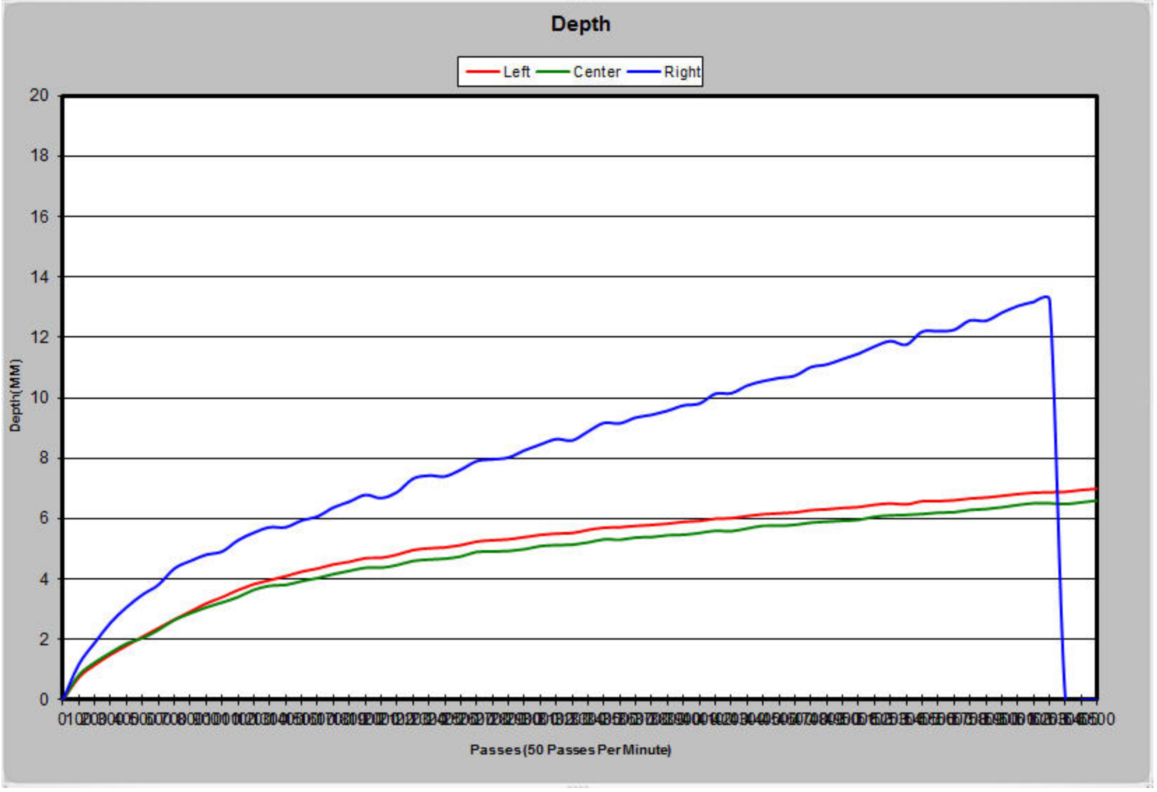
A.14 HMA (pre-production) – Rt. 6 Southbury



A.15 Evotherm™ (pre-production) – Rt. 6 Southbury



A.16 HMA – Rt. 6 Southbury



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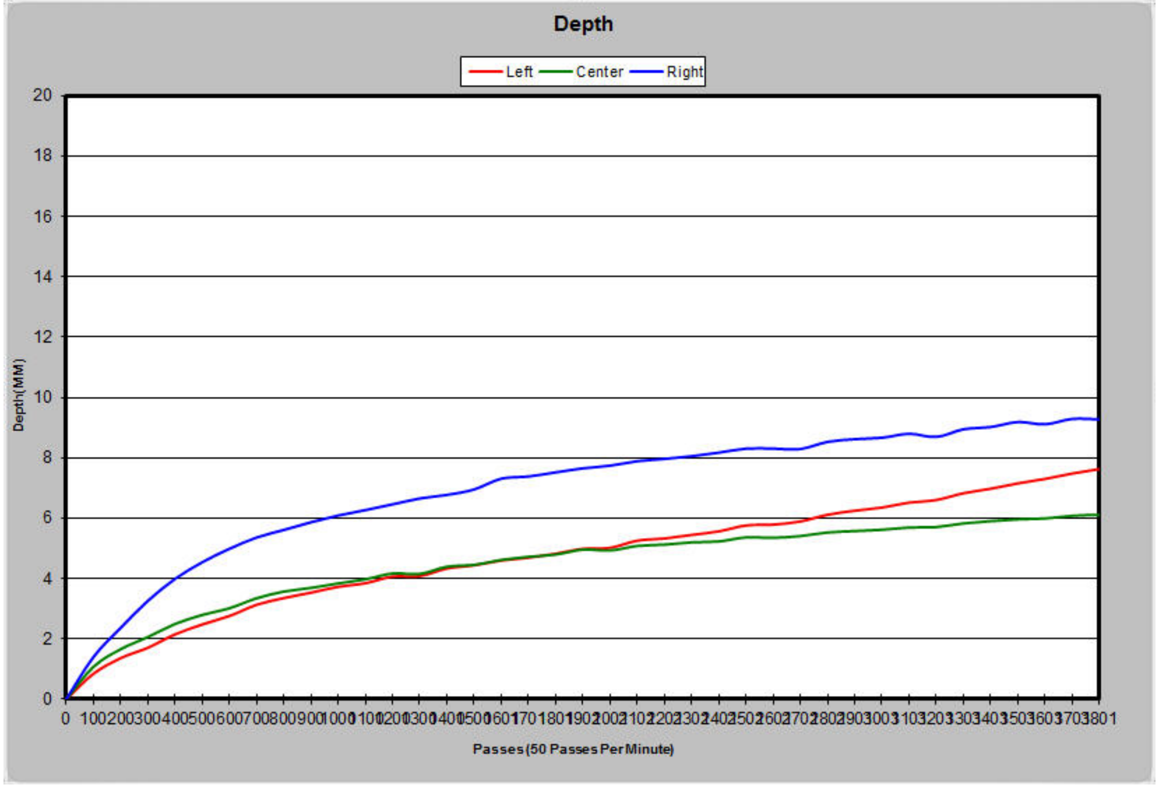
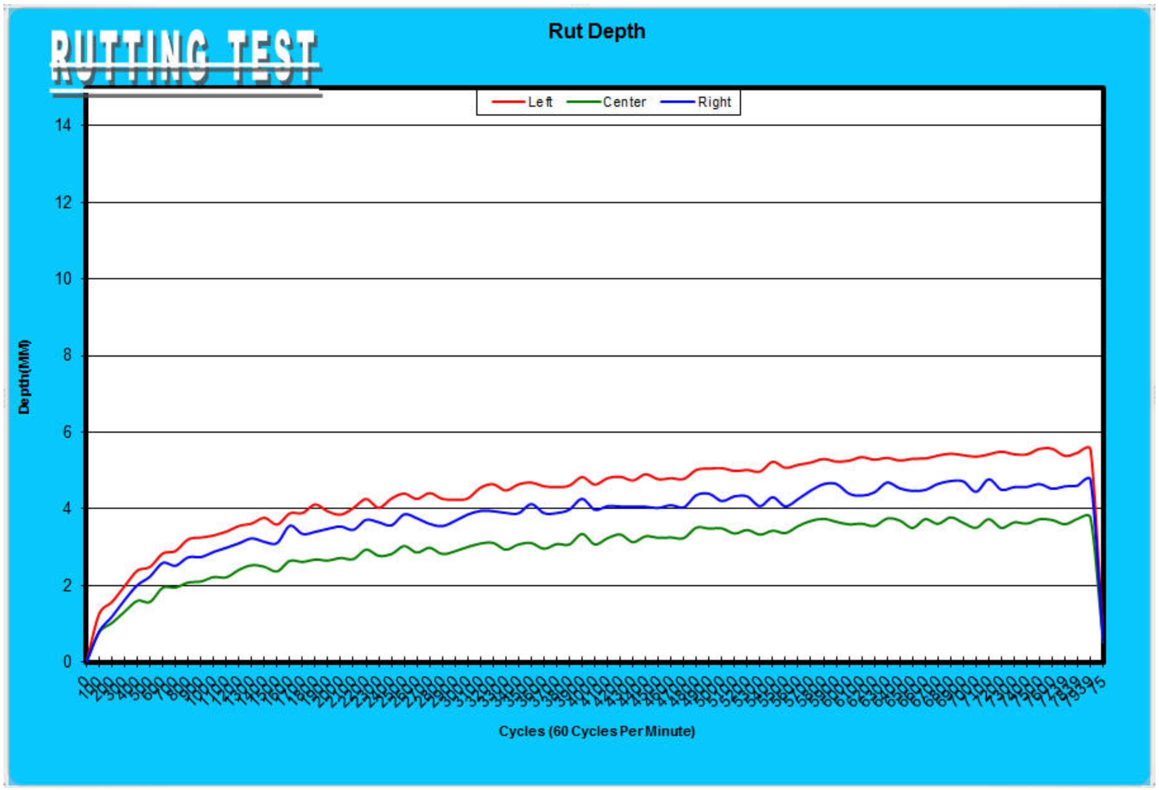


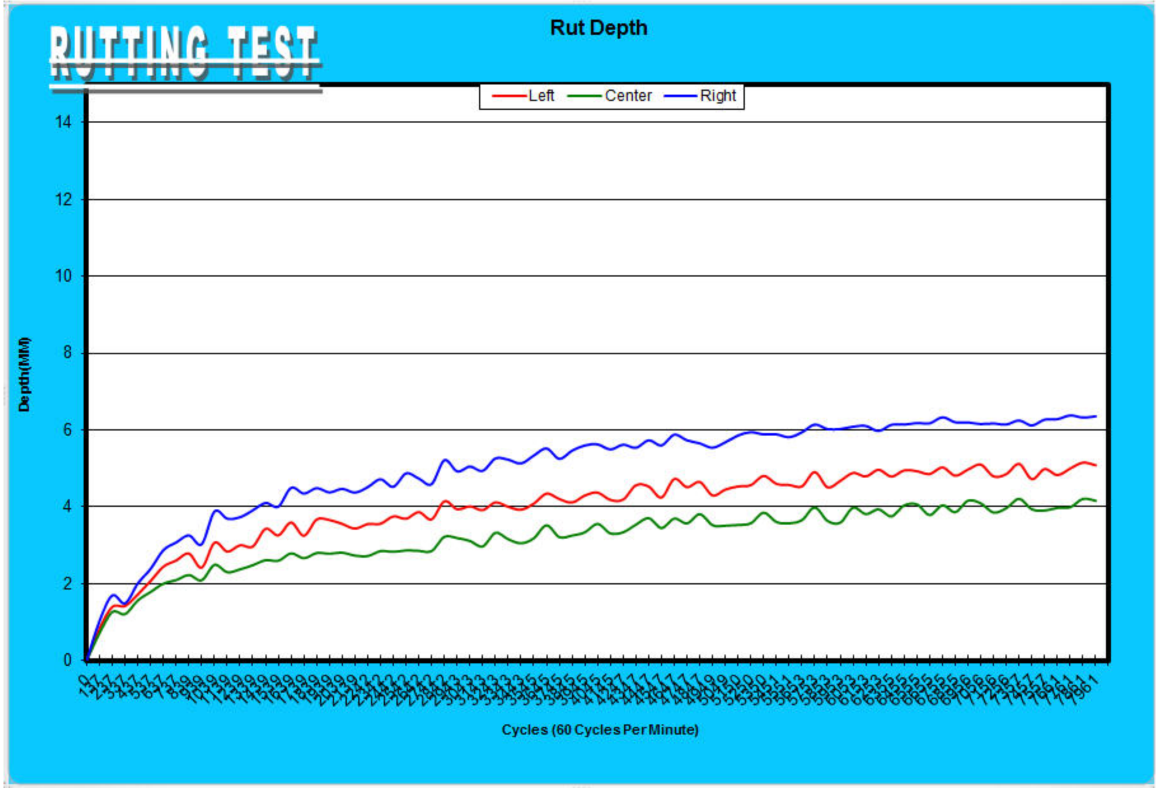
Note: The Hamburg charts for testing of the 2010 (Route 70, Meriden) sections were unavailable.

APPENDIX B. APA Testing Rut Charts

B.1 Sasobit® - Rt. 70 Meriden Lab Fabricated



B.2 Foamed - Rt. 70 Meriden Lab Fabricated



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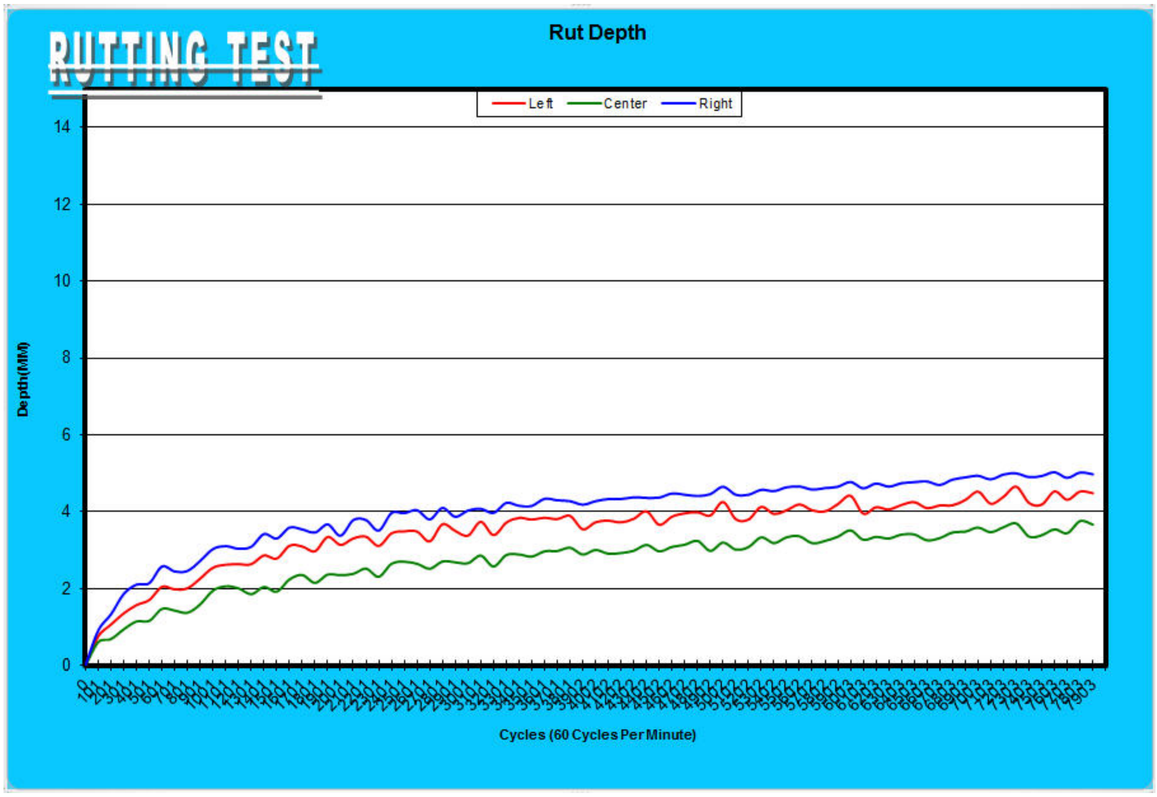
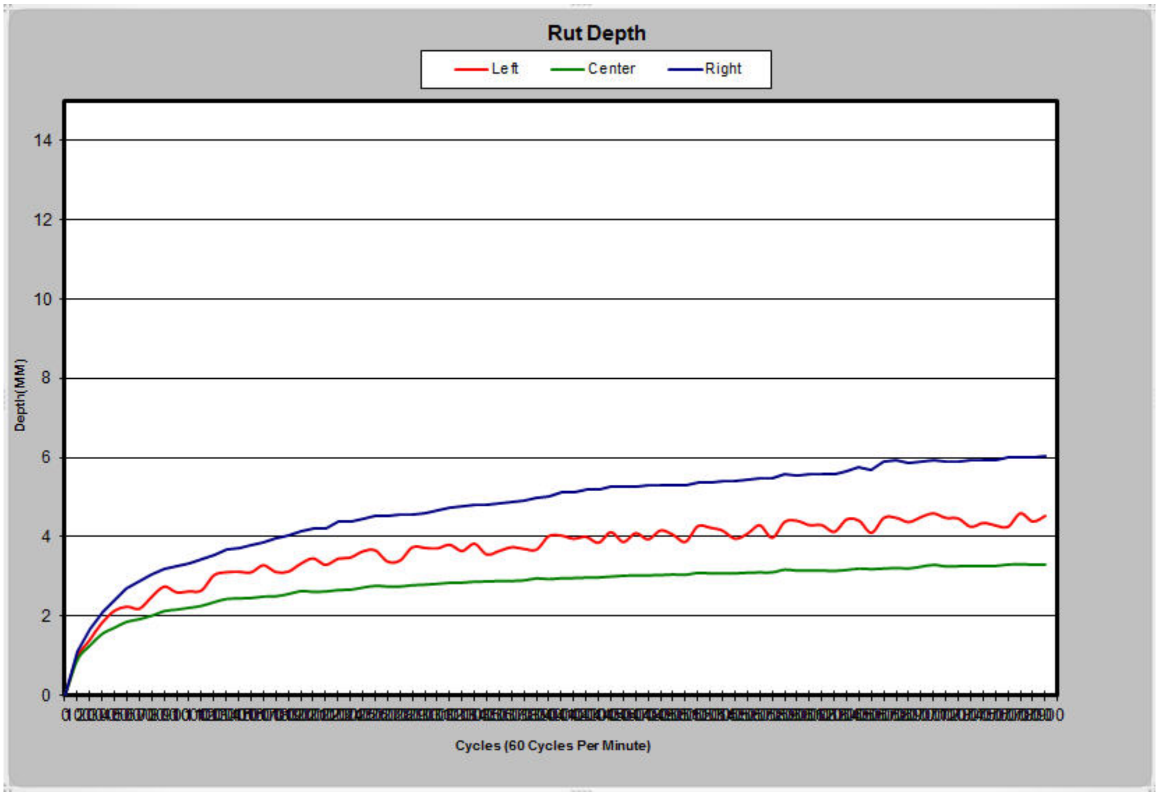


B.4 Evotherm™ - Rt. 219 New Hartford



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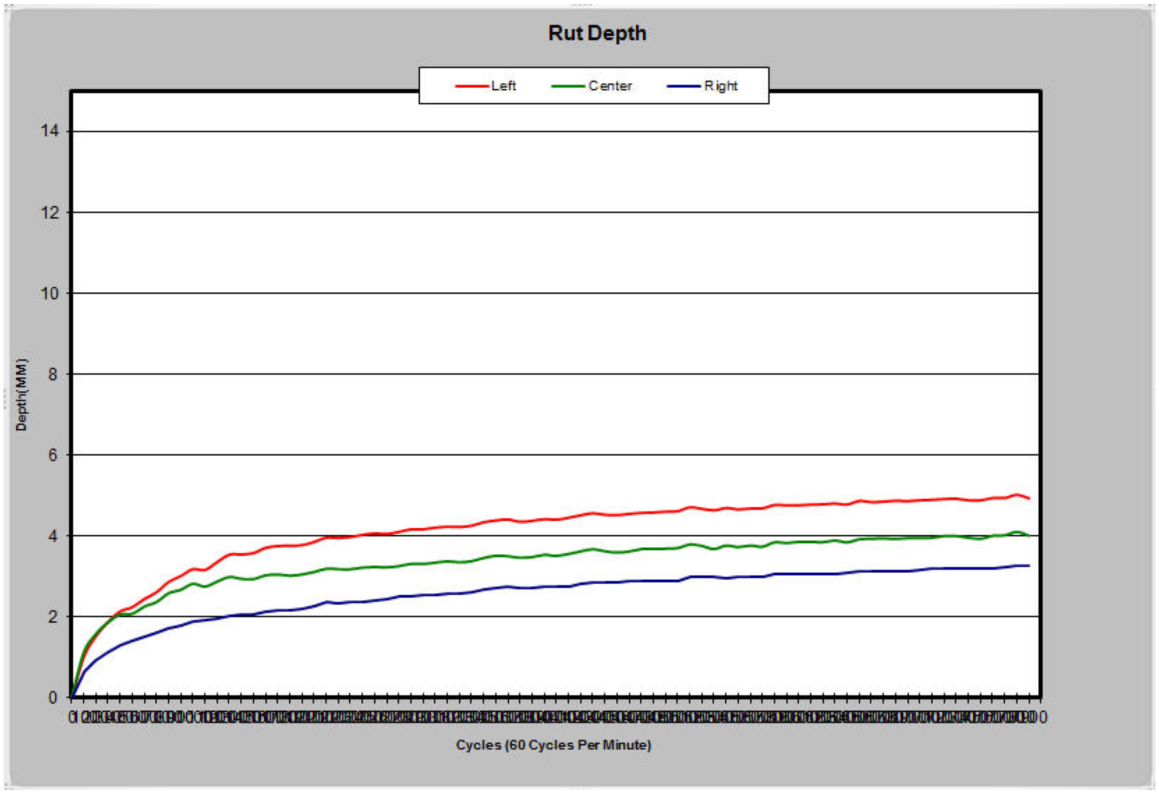
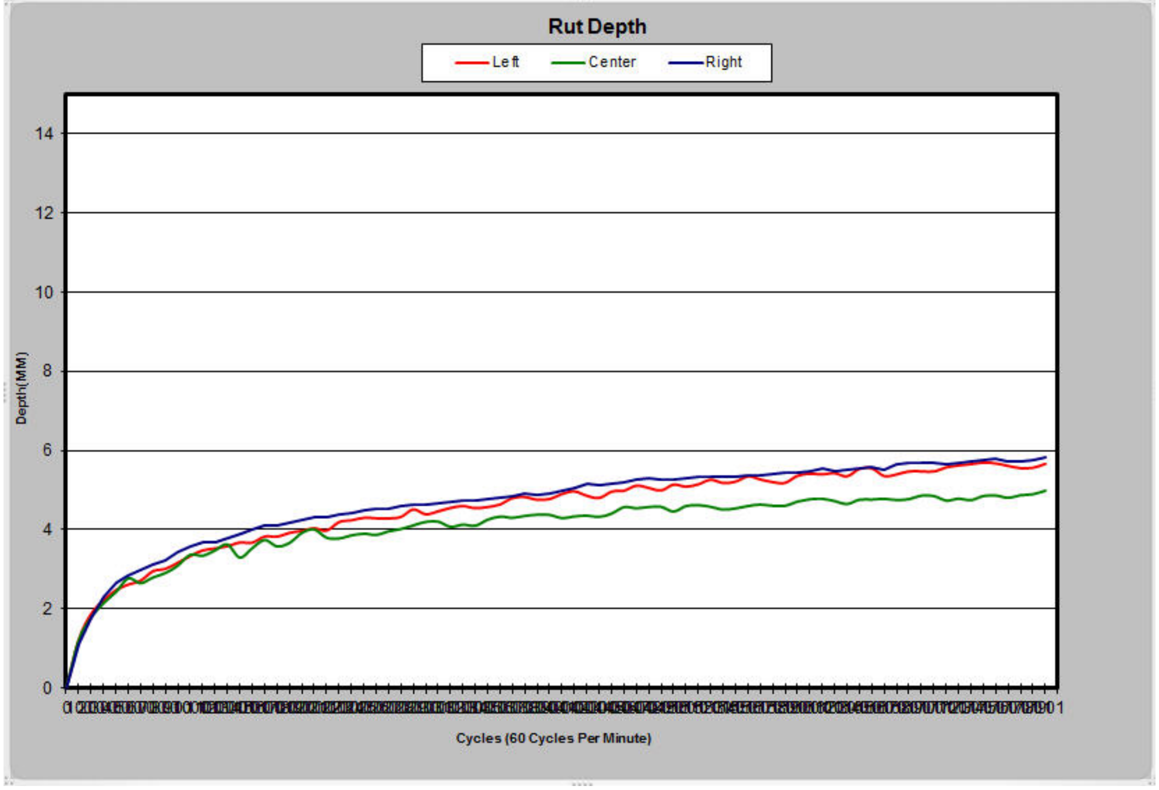
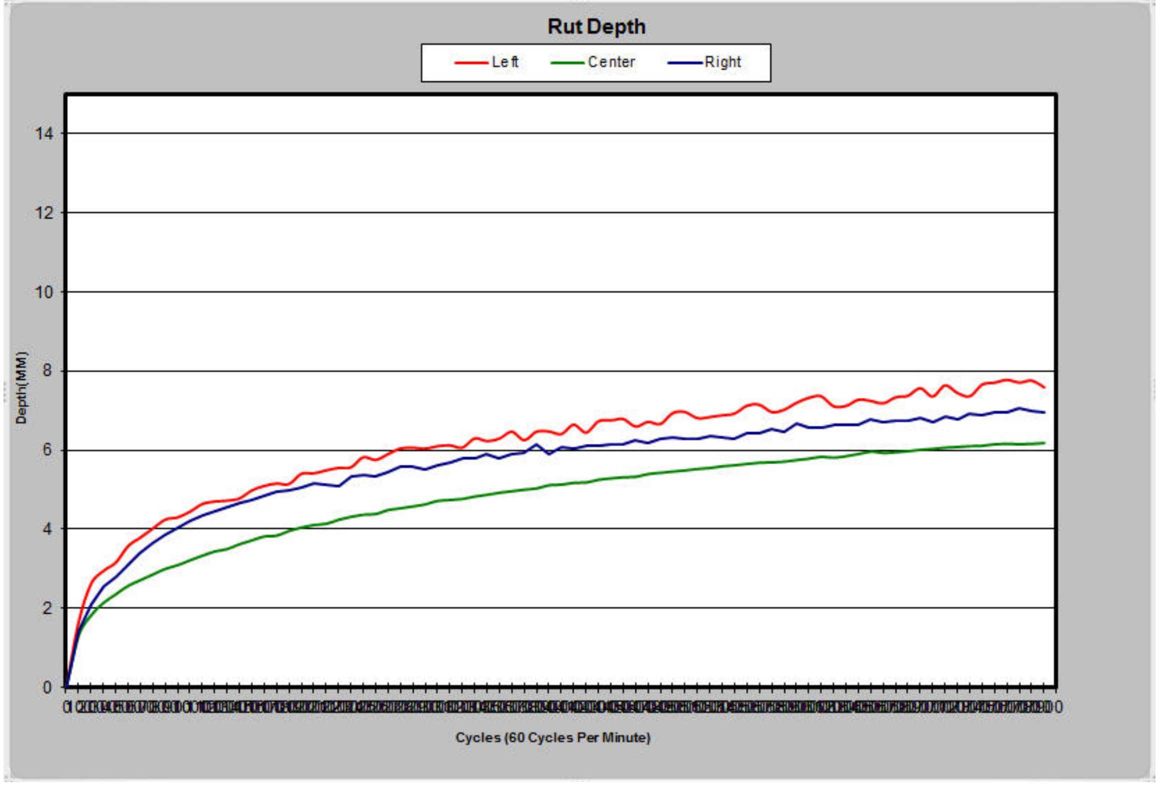


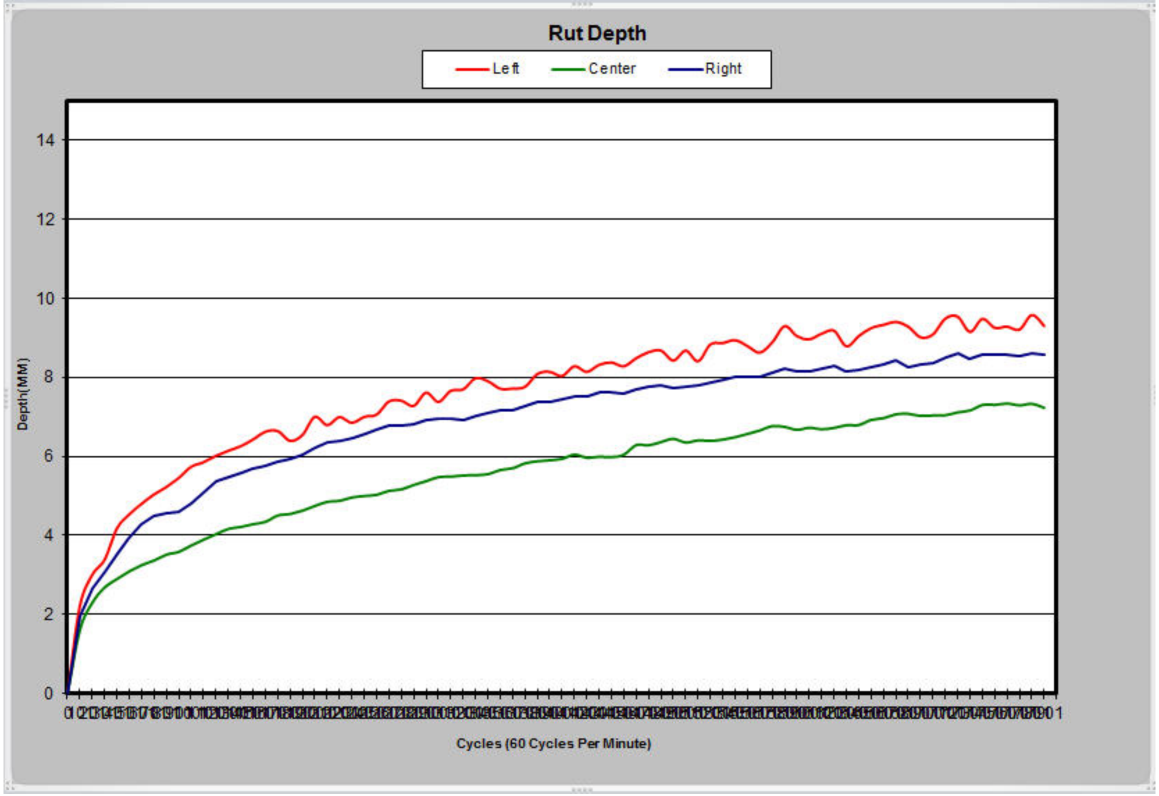
B.6 HMA (pre-production) – Rt. 101 Killingly



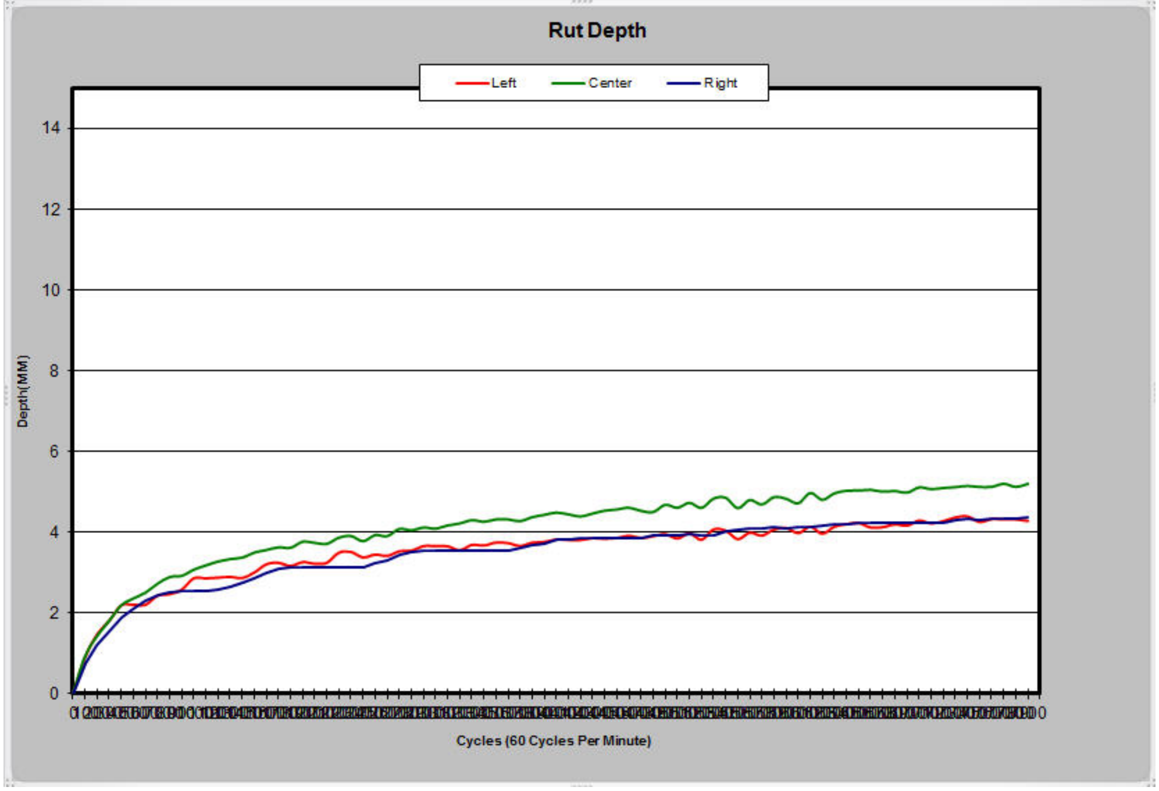
B.7 Advera® (pre-production) – Rt. 101 Killingly



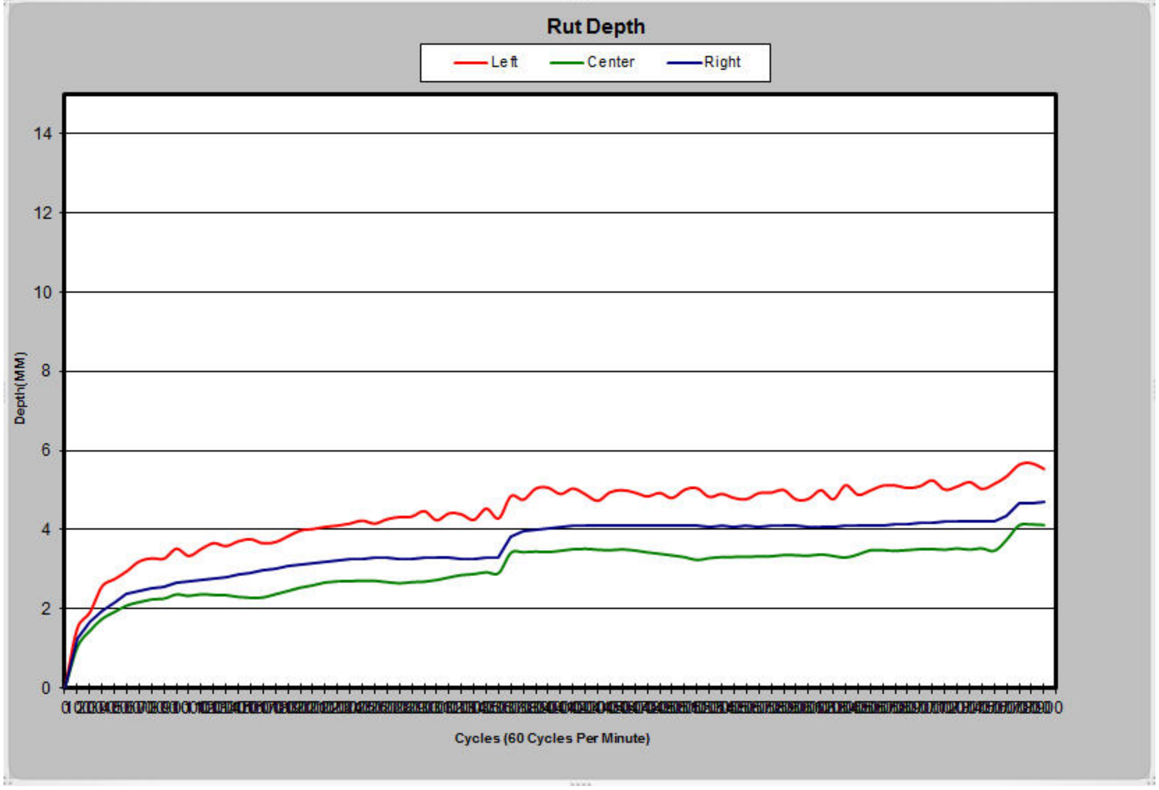
B.8 SonneWarmix™ (pre-production) – Rt. 101 Killingly



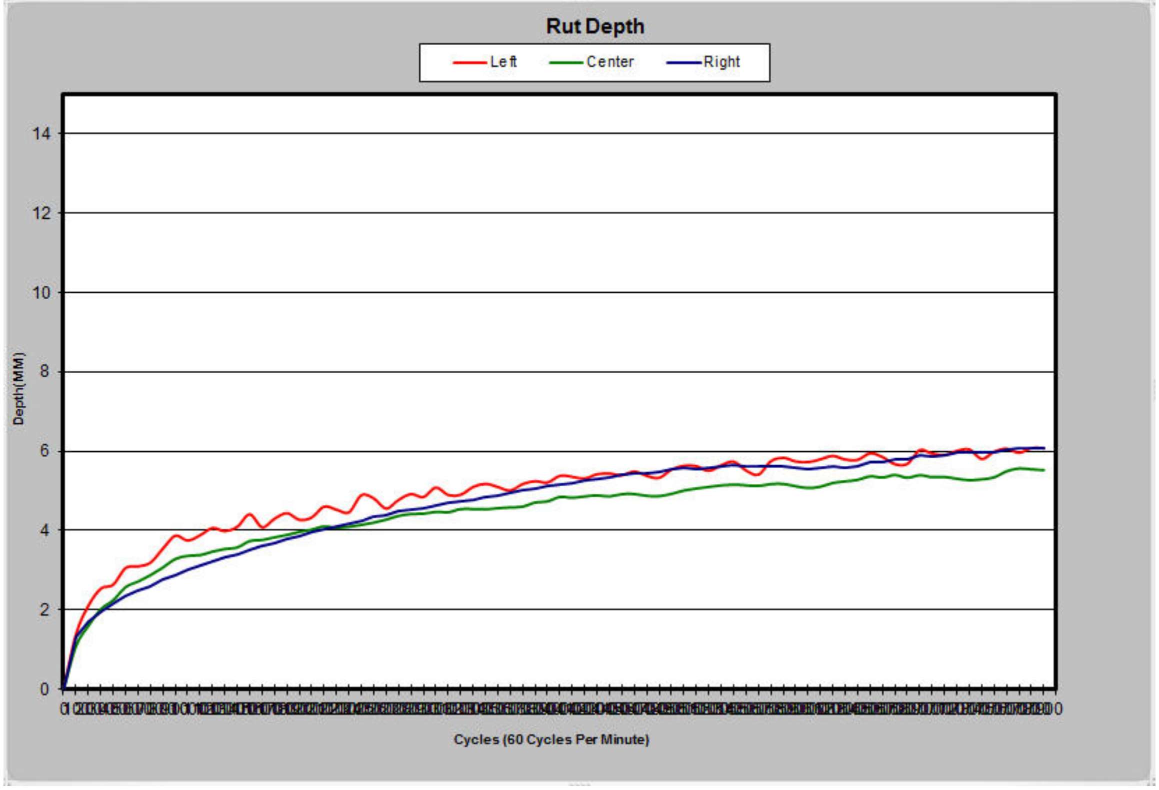
B.9 HMA – Rt. 101 Killingly



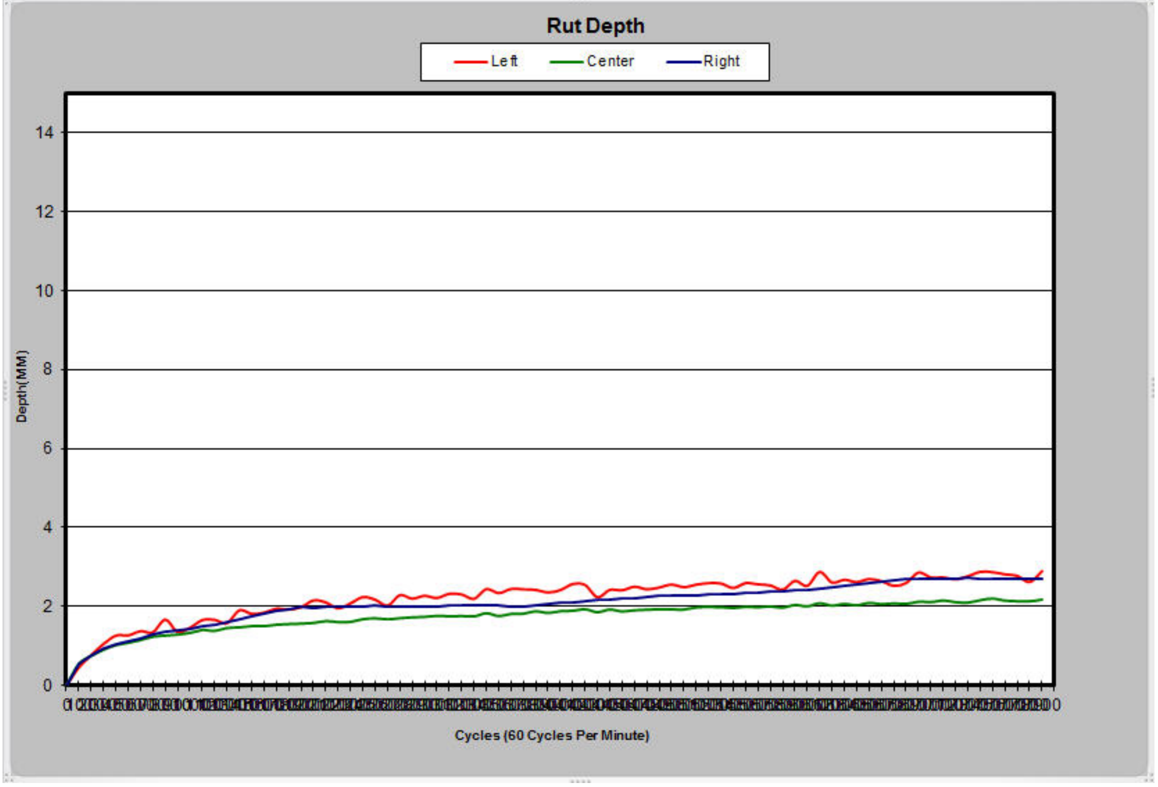
B.10 Advera® – Rt. 101 Killingly



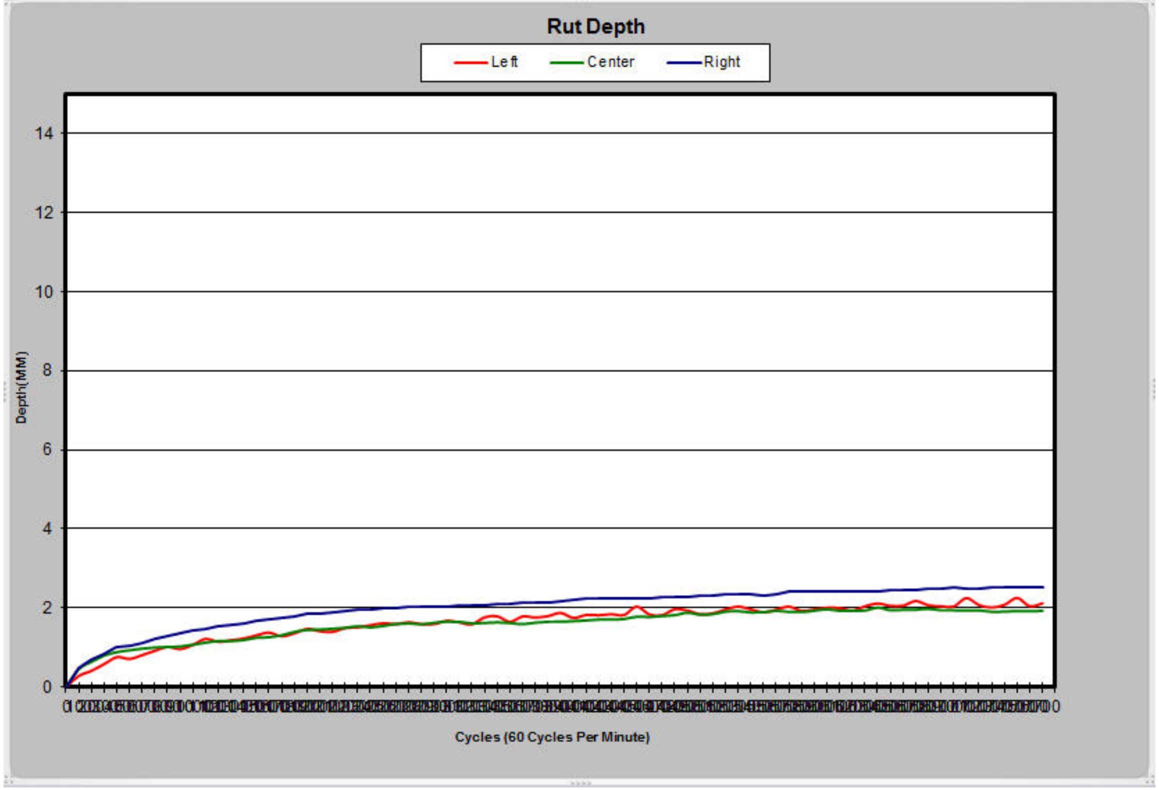
B.11 SonneWarmix™ – Rt. 101 Killingly



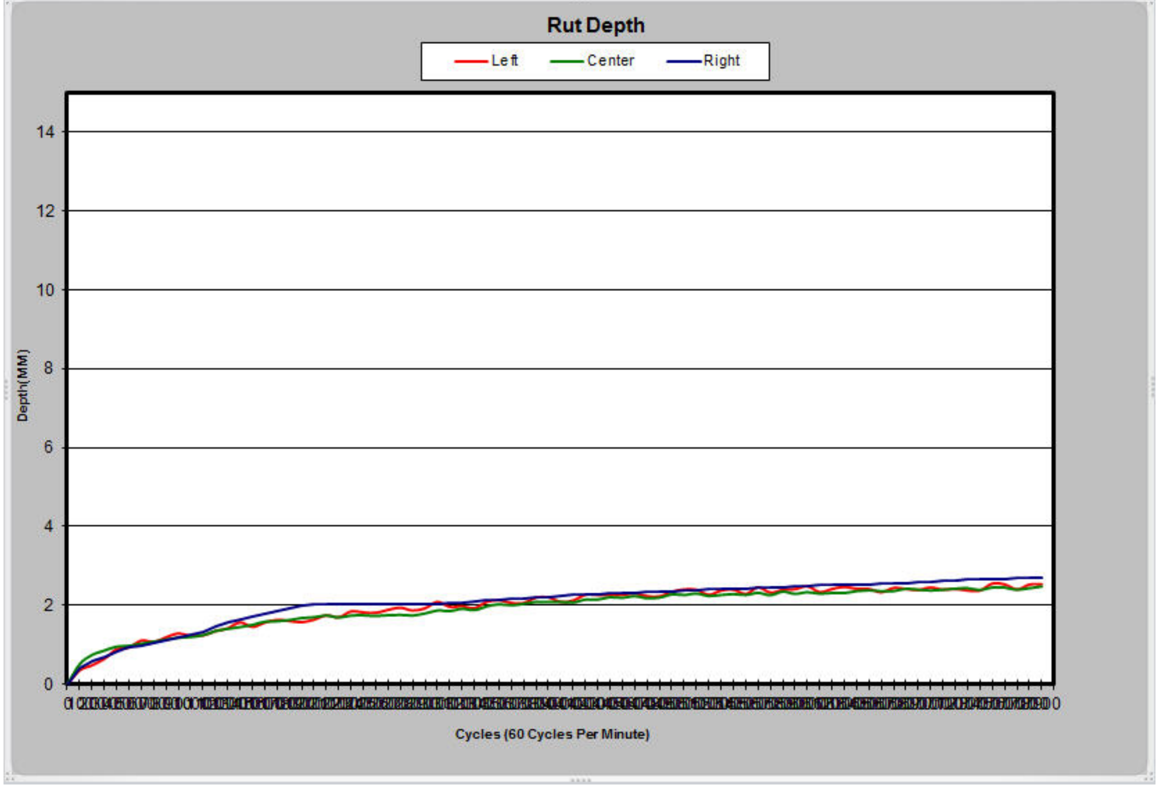
B.12 HMA + SBS – EB I-84 Farmington



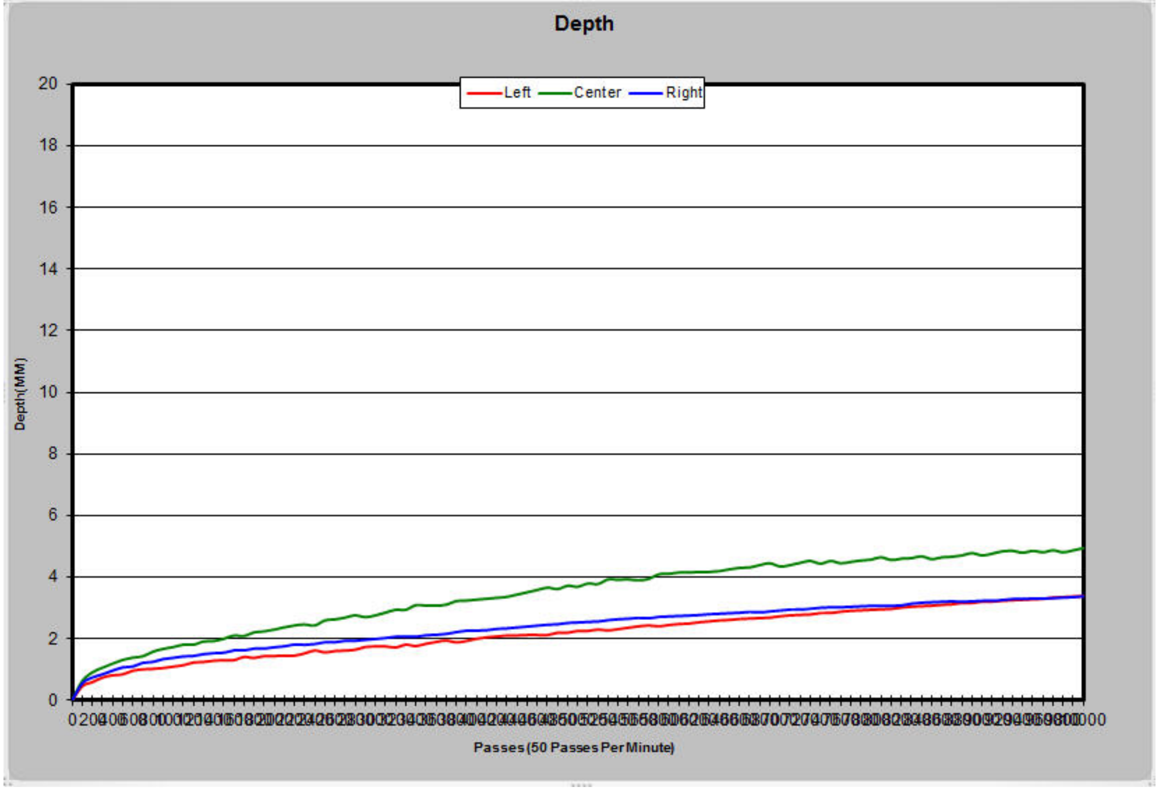
B.13 Sasobit® + SBS – EB I-84 Farmington



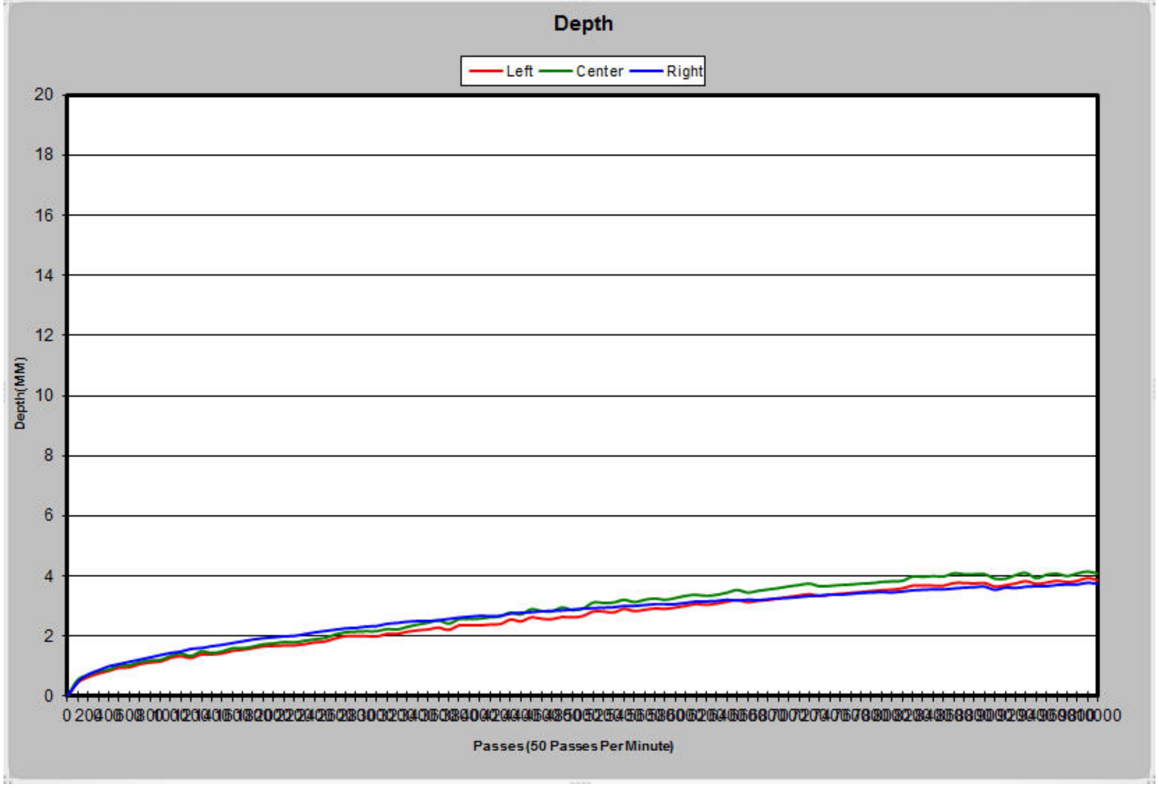
B.14 Foaming + SBS – EB I-84 Farmington



B.15 HMA + SBS – WB I-84 Farmington

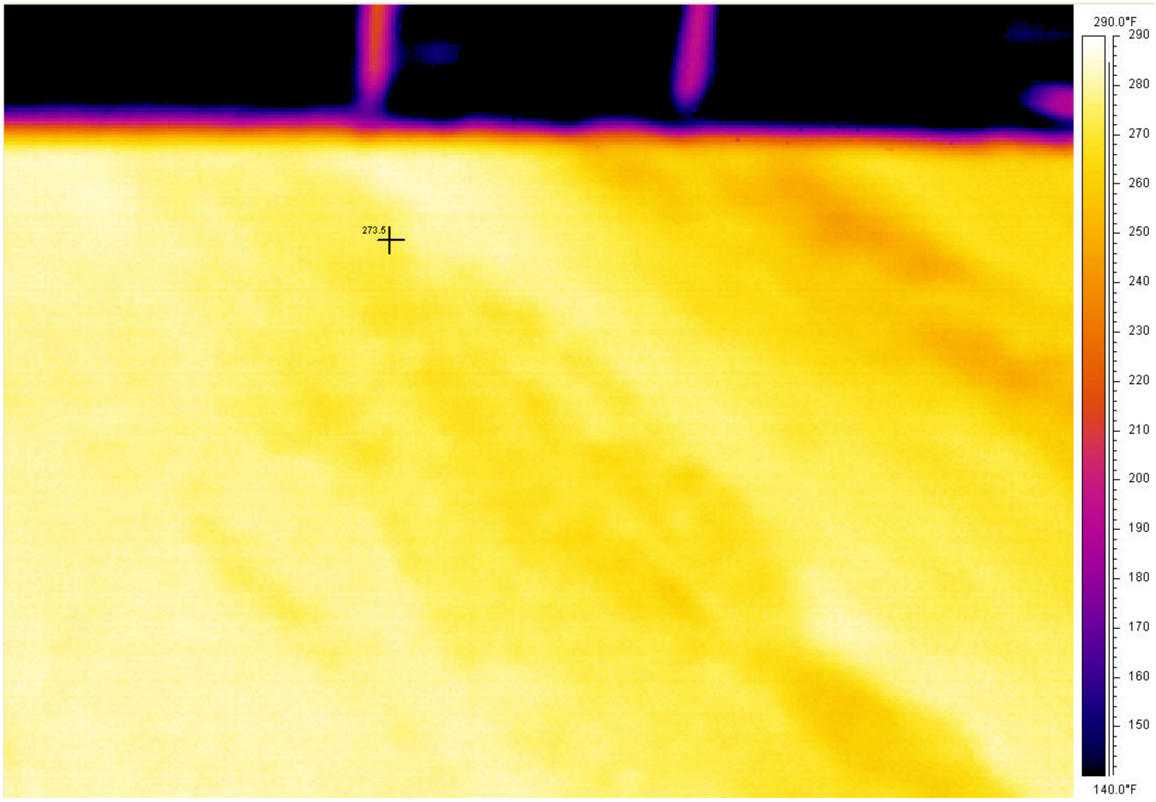


B.16 Sasobit® + SBS – WB I-84 Farmington

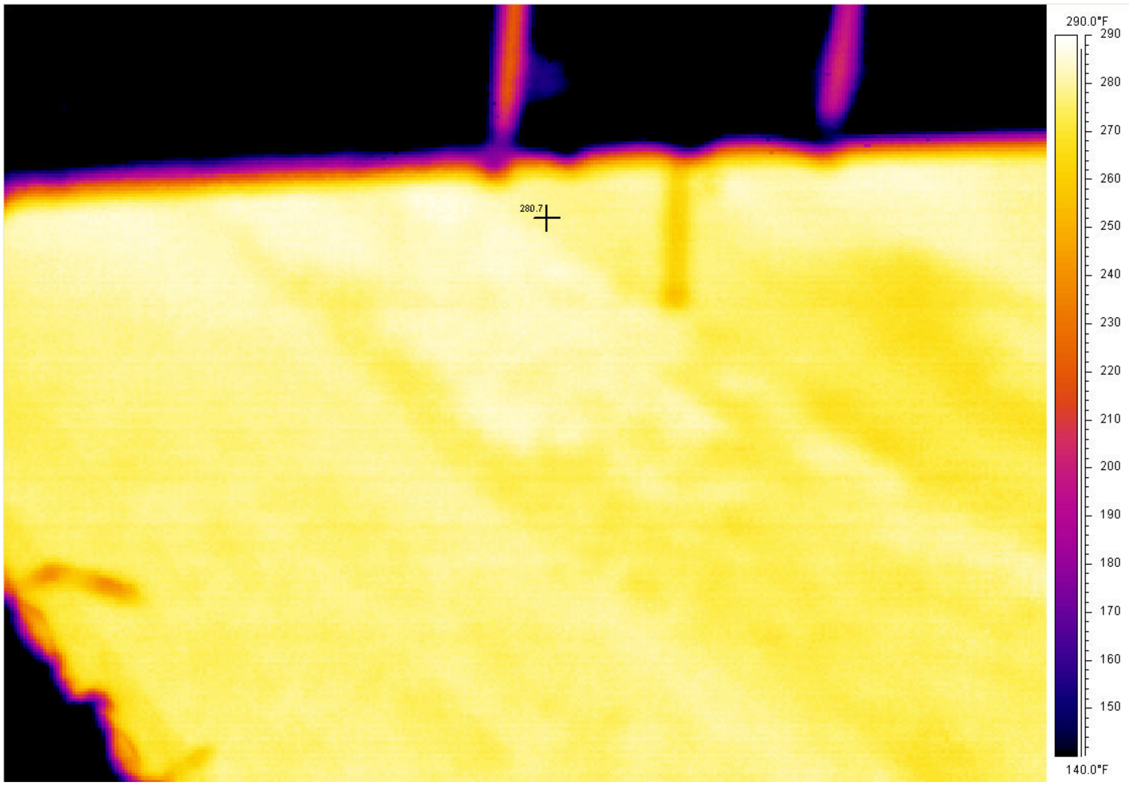


APPENDIX C. Thermographic Images

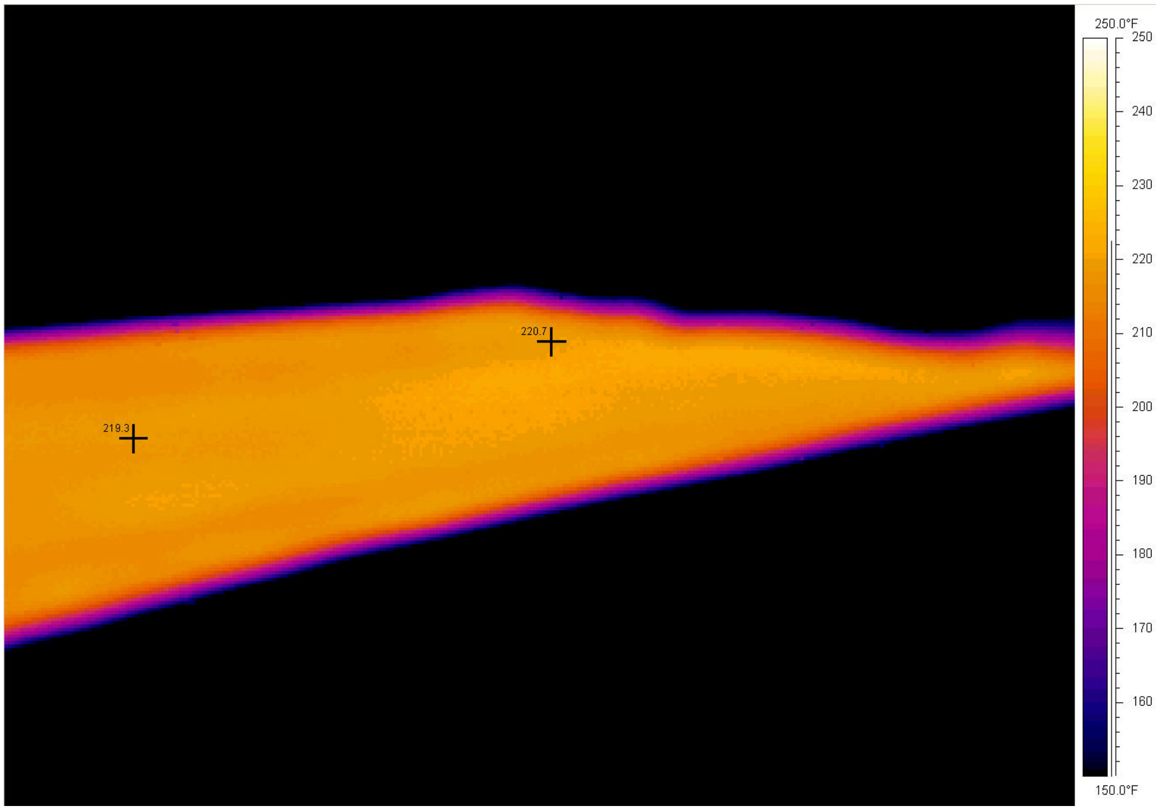
C.1-Route 6



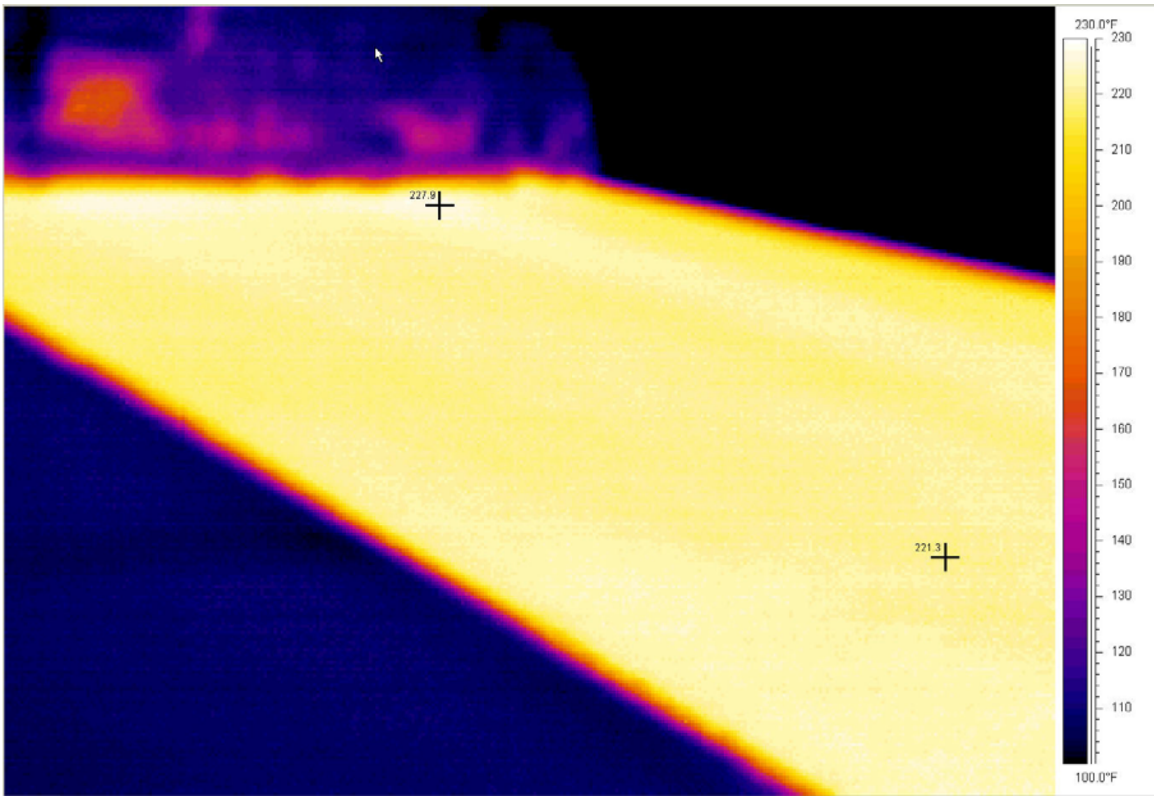
C.2-Route 6



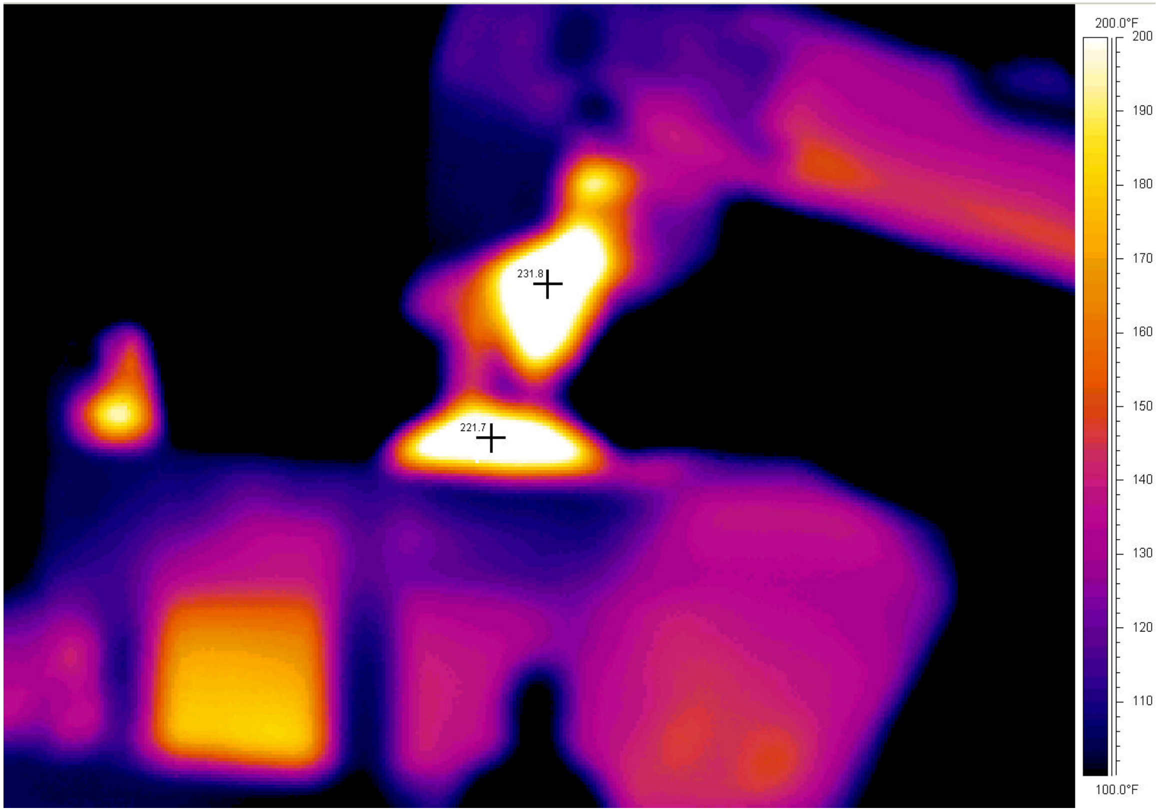
C.3-Route 70



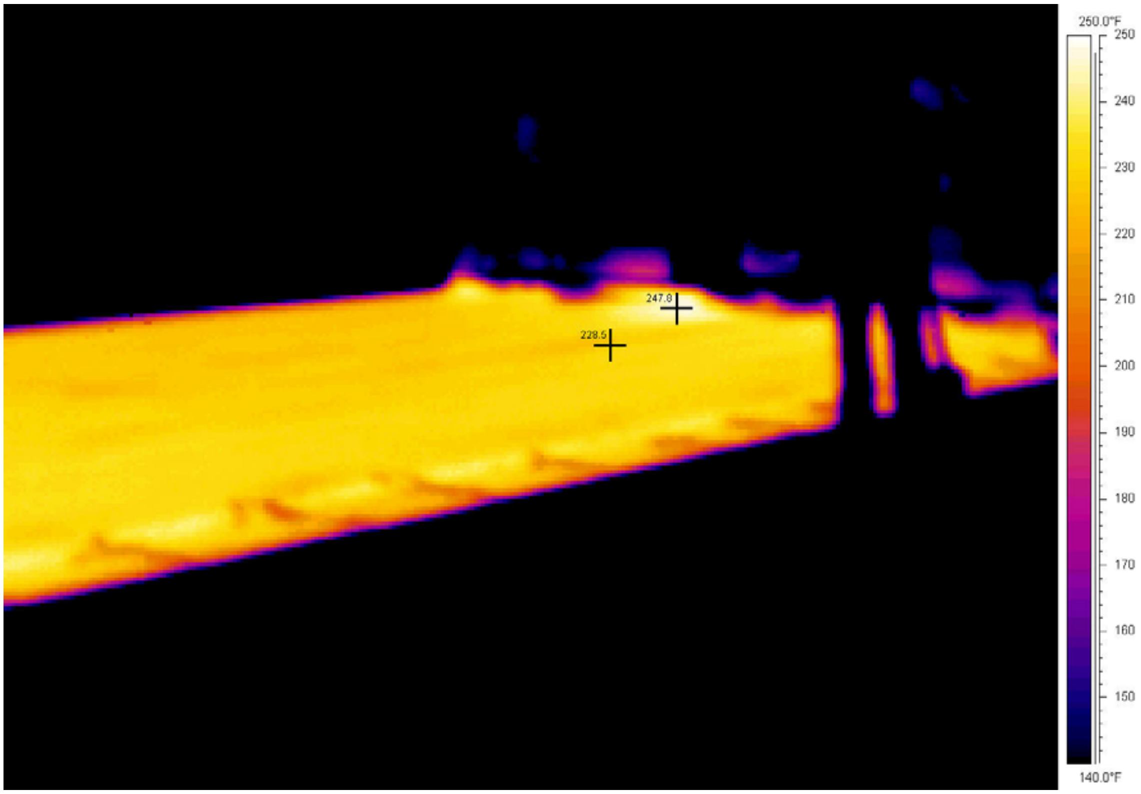
C.4-Route 70



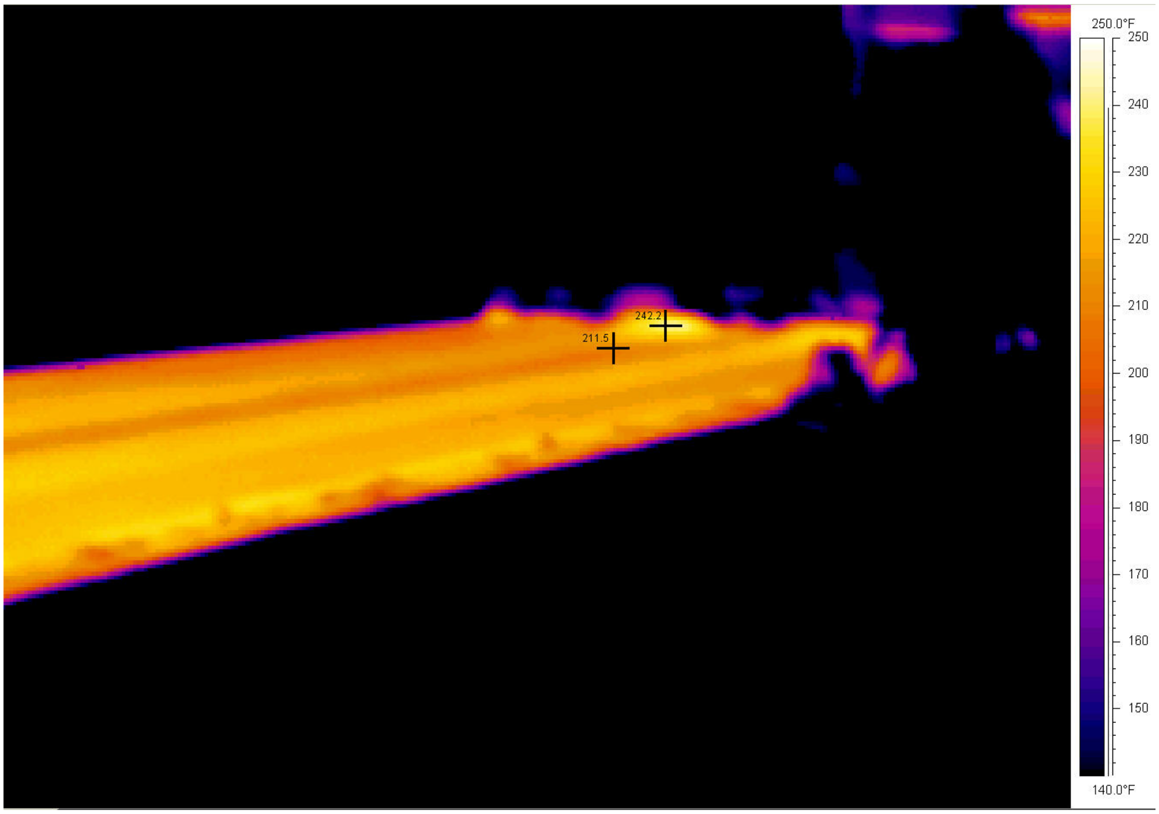
C.5-Route 70



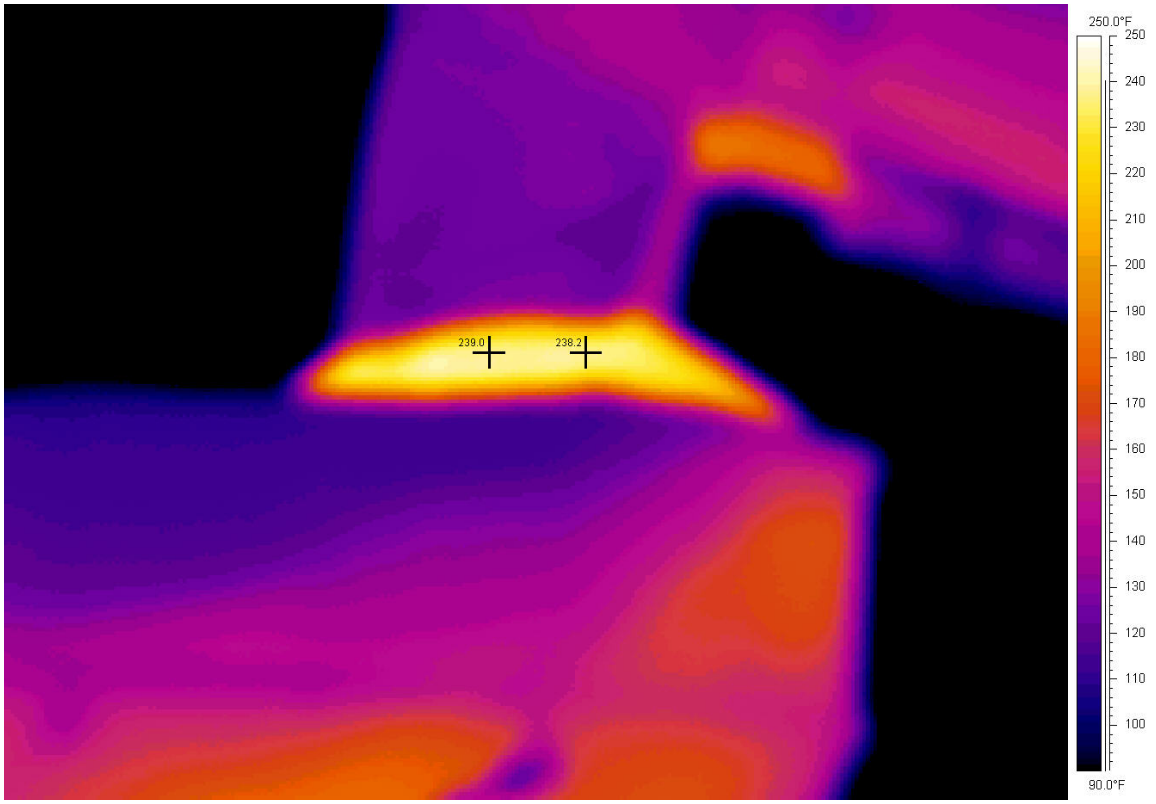
C.6-Route 219



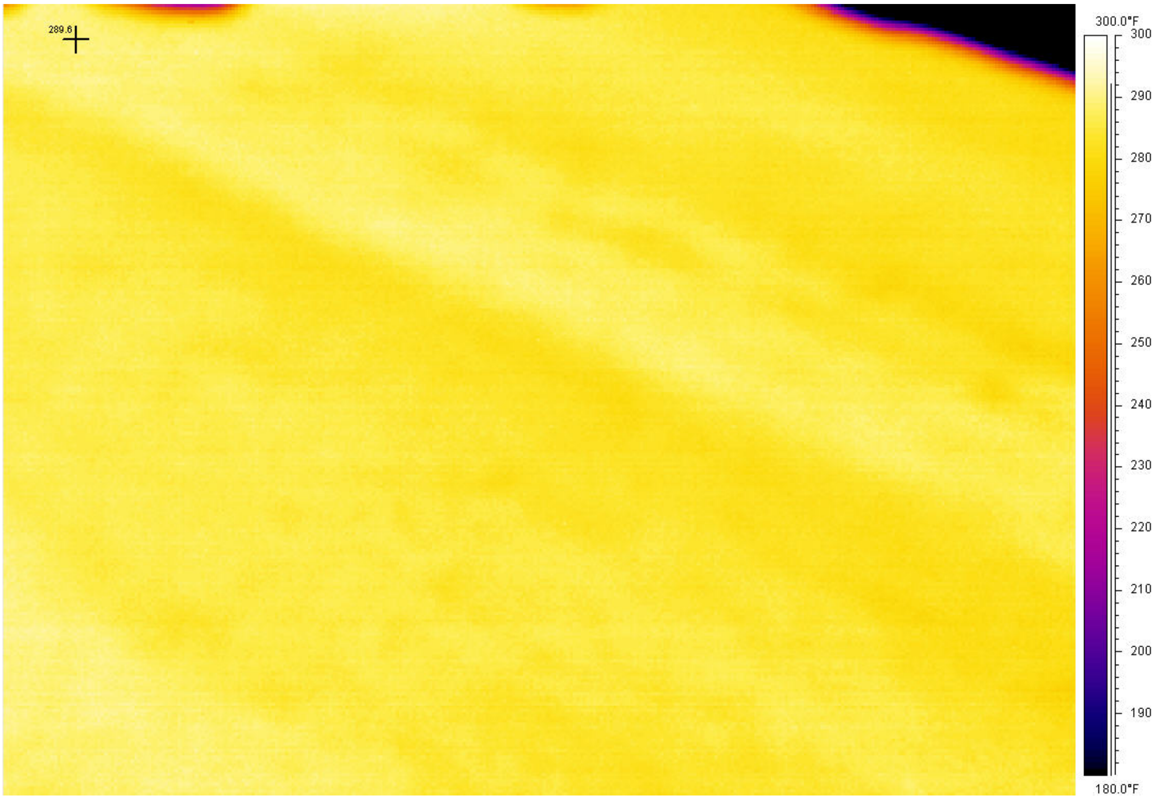
C.7-Route 219



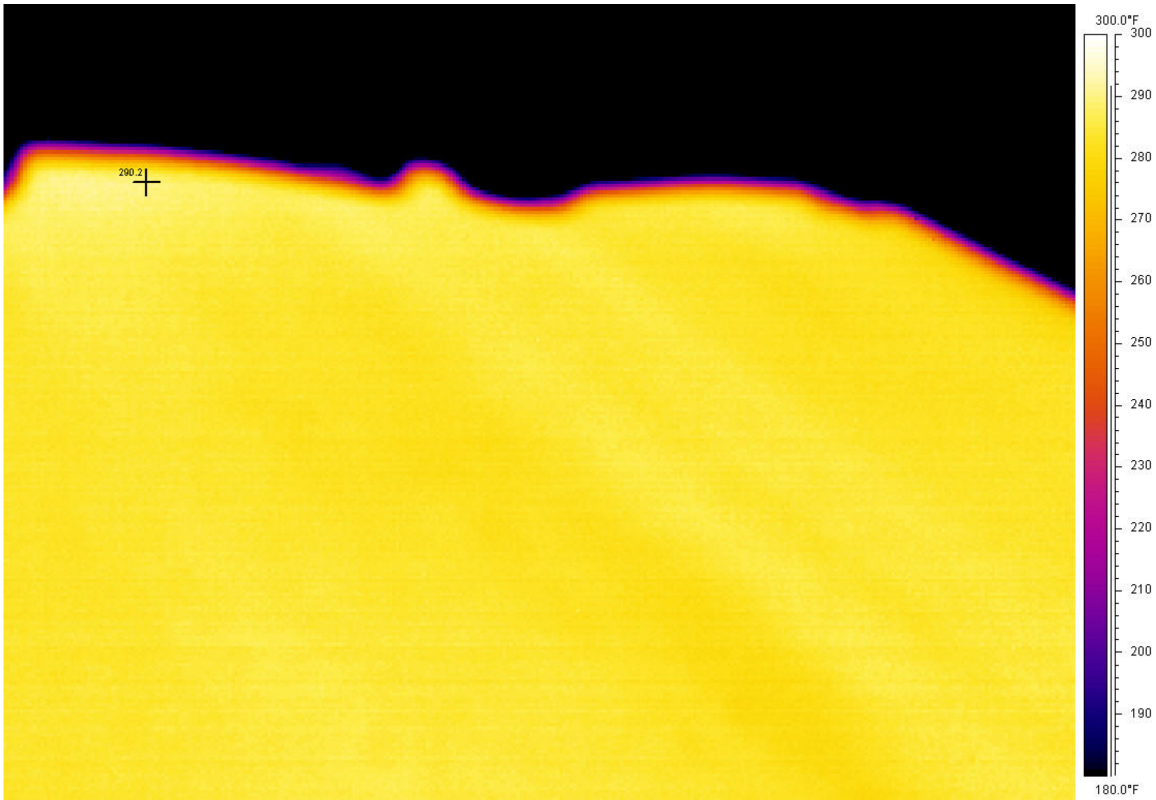
C.8-Route 219



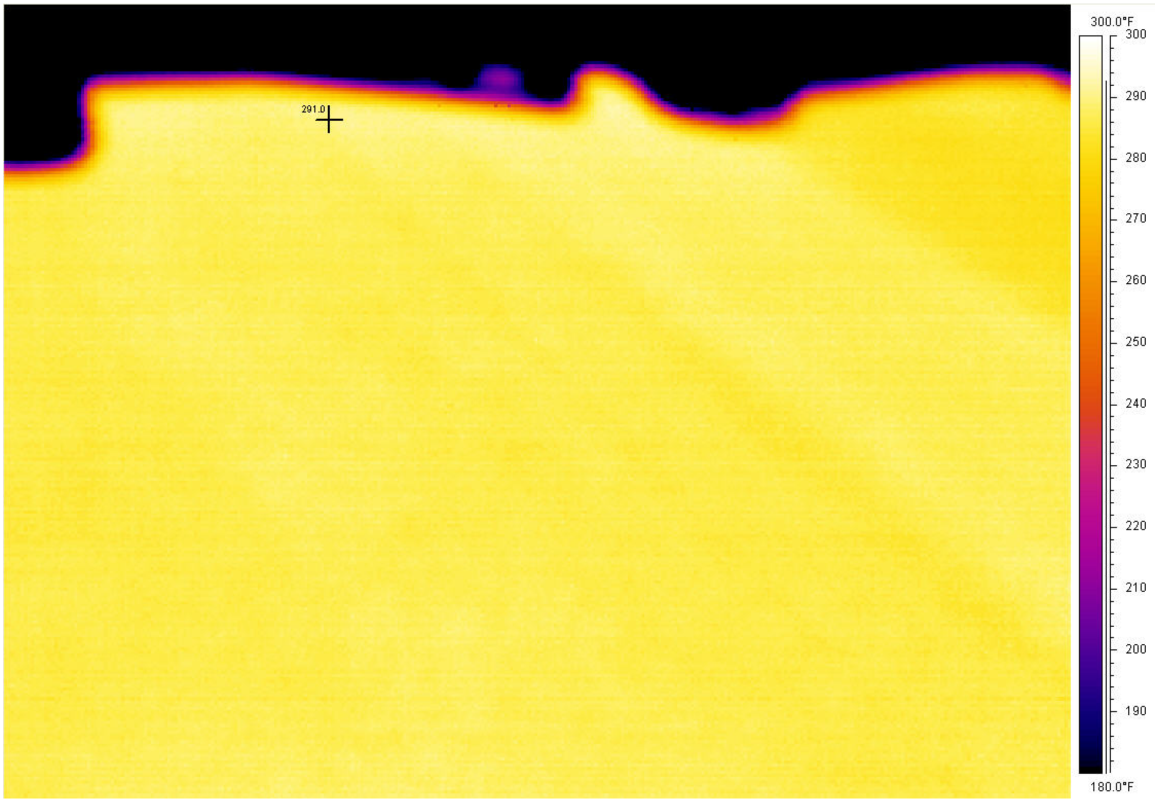
C.9 I-84



C.10 I-84



C.11 I-84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Appendix D. 2013 General Condition Images

D.1 Sasobit® - Rt. 70 Meriden

A.2 Mechanical Foaming – Rt. 70 Meriden

A.3 HMA – Rt. 70 Meriden

A.4 Evotherm™ – Rt. 219 New Hartford

A.5 HMA – Rt. 219 New Hartford

A.6 HMA – Rt. 101 Killingly

A.7 Advera® – Rt. 101 Killingly

A.8 SonneWarmix™ – Rt. 101 Killingly