Rubber Asphalt Study for Wisconsin

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16. Abstract

This study investigated the usage of ground tire rubber (GTR) in Wisconsin asphalt pavements. A special provision (SPV) was drafted outlining mix design guidance when using terminal and dry process GTR. The SPV also included a performance testing regime including Hamburg Wheel Tracking, Disk-Shaped Compact Tension (DCT), and Illinois Flexibility Index (I-FIT) tests. Short and long-term aging was also performed on DCT and I-FIT samples to determine long term performance. Test strips were constructed on USH 51 consisting of a control, terminal blend, terminal blend hybrid, and dry process sections. A preliminary pavement distress survey was performed to quantify pavement distresses before construction of the overlay test sections. After the construction of the test section, approximately 1 year later, another pavement distress survey was performed. A cost benefit analysis was performed comparing bid prices with improved performance compared to the control. All GTR mixtures showed varying degrees of increased performance and may be an option for WisDOT when implementing a future Balanced Mix Design (BMD) approach to asphalt mixtures.

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Definitions

ABR	Asphalt Binder Replacement
AC	Asphalt Content
BMD	Balance Mix Design
BME	Behnke Materials Engineering (Research Lab)
CRM	Crumb Rubber Modifier
CSBG	Combined State Binder Group
DCT	Disk-Shaped Compact Tension Test
DP	Dry Process (Elastiko)
DSR	Dynamic Shear Rheometer
FRAP	Fractionated Recycled Asphalt Pavement
GTR	Ground Tire Rubber
HWT	Hamburg Wheel Tracking Test
IDEAL-CT	Indirect Tensile Asphalt Cracking Test
I-FIT	Illinois Flexibility Index Test
JMF	Job Mix Formula
PG	Performance Grade
PWL	Percent within Limits
RAM	Recycled Asphalt Materials
RAP	Recycled Asphalt Pavement
RAS	Recycled Asphalt Shingles
RFP	Request for Proposal
RMB	Rubber Modified Binder
SAM	Super Air Meter
SBR	Styrene Butadiene Rubber
SBS	Styrene Butadiene Styrene
SGC	Superpave Gyratory Compactor
SMA	Stone Matrix Asphalt
SPV	Special Provision
TB	Terminal Blend (Seneca)

TBH	Terminal Blend Hybrid (Ingevity)
Va	Air Voids
VMA	Voids in Mineral Aggregate
WisDOT	Wisconsin Department of Transportation

1. Introduction

1.1 History

Ground tire rubber (GTR) has been available in the United States for many years now with modern usage starting in the early 1960's by Charles McDonald, a Materials Engineer for the City of Phoenix in Arizona. McDonald developed a surface patching material using a highly elastic recycled tire rubber binder with an aggregate topping. This work was expanded into larger surface treatment projects as well as crack relief and open-graded surfaces courses, and as a result, these initial developments aided in the propagation of asphalt rubber modifications [1]. Asphalt pavements that have been modified with GTR have shown improved rutting resistance, skid resistance, ride quality, and pavement life while showing decreased moisture susceptibility, cracking potential, and noise levels [1, 2, 3, 4]. Cracking resistance and pavement life are increased with the addition of rubber to the asphalt because it slows oxidative aging and therefore the brittleness of the asphalt cement which generally increases with oxidative aging [2].

Initially, the push to use tires in asphalt was primarily a means of disposing of piles of scrap tires, and for many agencies, their first experience using crumb rubber modifier (CRM) and GTR in asphalt came from the mandate included in the Intermodal Surface Transportation Efficiency Act of 1991 subsection 1038(d). This mandate required states to use a minimum amount of rubber from recycled tires in asphalt surfacing operations beginning in 1994. The requirement was lifted soon after in 1995, but by then many rubber modified asphalt pavements were placed and national research on their performance began [1, 2].

Throughout the years there have been differing nomenclatures to describe rubber products, however, there is no uniform consensus between using CRM or GTR. For all intents and purposes, they are just different names for the same product. Going forward, GTR will be used to identify these materials in this research report.

1.2 Grinding Processes

Today's GTRs are highly controlled materials. Modern passenger and truck tires are made up of roughly the same compositions, 14-27% natural rubber, 14-27% synthetic rubber, 28% carbon black, 14-15% steel fabric, and 16-17% processing oils [1]. Processing no longer involves just grinding up stockpiles of old tires and then adding the GTR to the asphalt, but rather the process is now carefully planned and monitored. Refinements to the processing of ground tire rubber has produced products which are clean and very consistent. There are two common processes for producing the small tire particles: ambient grinding and cryogenic fracturing [1, 3]. Both processes begin by cutting tires into pieces that are approximately 50 mm (approx. 1.97 in) in size. Cryogenic methods then freeze and fracture the tires pieces into particles that are cubical and smooth and can range from 75 μm (approx. 0.003 in) up to 4-5 mm (approx. 0.16 -0.20 in) in size. Ambient grinding, as opposed to cryogenic fracturing, breaks the large tire pieces into smaller particles using shredders. The particles are rougher in texture with more surface area than cryogenically produced GTR with particle sizes again ranging from 75 μm (approx. 0.003 in) up to 4-5 mm (approx. 0.16 -0.20 in) in size [1]. The differences in resultant rubber products from ambient and cryogenic fracturing are shown below in **Figure 1**. Additionally, processing also includes the removal of the tires' reinforcing wires and fibers via magnets and aspiration [2].

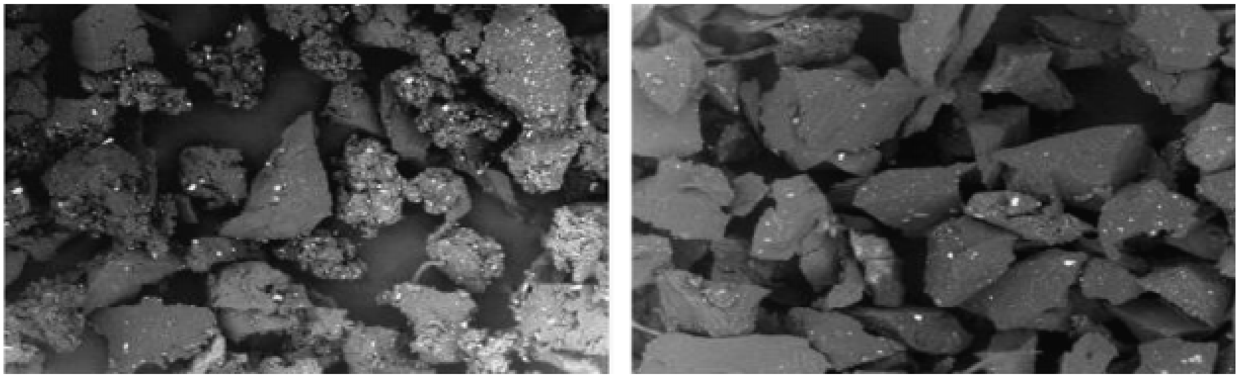


Figure 1: Rougher ambiently ground rubber (left) and smoother cryogenically fractured rubber (right). Size can vary from passing 75 µm sieve to 4-5 mm [1]

1.3 Blending Processes

After the GTR has been processed either cryogenically or via ambient grinding, these particles are then introduced into the asphalt through one of two different methods, dry process, or wet process. Incorporating the rubber by dry process involves mixing the GTR into the mixture as a small portion of the aggregate or filler material directly through an auger at the asphalt plant. The blending of the GTR and asphalt binder occurs in the mixing chamber of the asphalt plant, and subsequent paving process. Wet process, on the other hand, incorporates the rubber by blending the rubber with the liquid asphalt as a separate operation. During the wet process, the GTR and asphalt binder are blended at elevated temperatures either on-site in a pug mill at the asphalt plant, or off-site at a terminal/refinery prior to being shipped to the asphalt plant.

One of the primary concerns with blended GTR asphalt material is how to quantify, control and accommodate for swelling. When GTR is mixed with asphalt it undergoes a diffusion-induced volume expansion process [5], commonly referred to as swelling. Swelling occurs in four stages [6] where:

- Stage 0: The asphalt maltenes are diffused into and absorbed by the GTR,
- Stage 1: The GTR swells and forms a gel like substance,
- Stage 2: The swelling reaches an equilibrium, and then
- Stage 3: The rubber disintegrates as shown in **Figure 2** below.

The amount of swelling is dependent on the unique properties of the asphalt, the temperature and the viscosity of the binder [3].

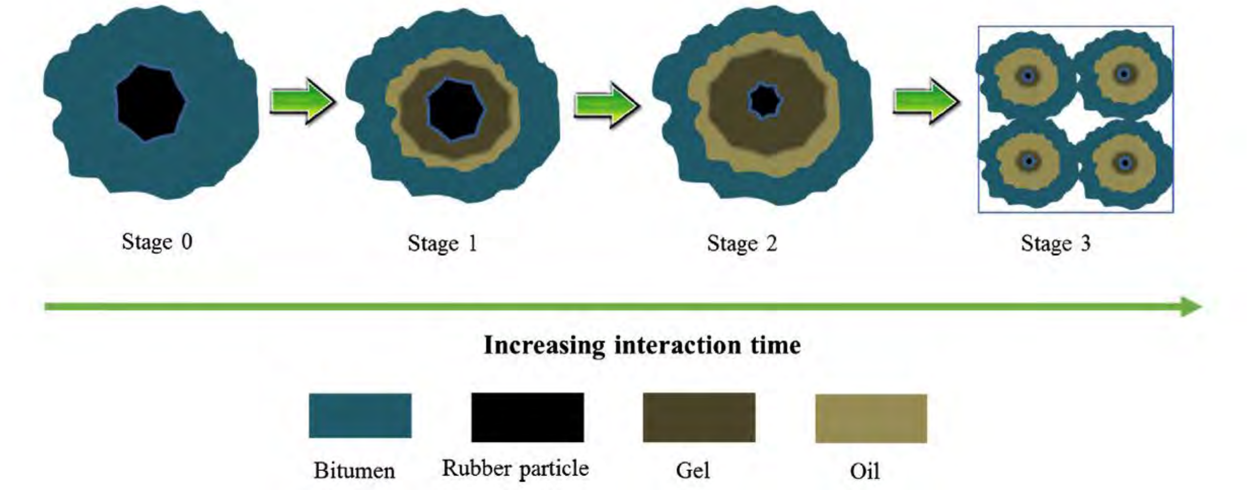


Figure 2: Schematic Representation of the Asphalt Rubber Interaction Process [6]

There are several key factors to note about swelling [6]:

1. Truck tire rubber will swell more than car tire rubber,
2. Increased temperature will decrease the swelling time, and
3. Small rubber particles will swell faster than larger rubber particles.

This research will not attempt to quantify the volume of swelling, rather determine mix design parameters to control and accommodate for swelling.

Depending on the selected process for each product – dry or wet/terminal process – swelling is controlled differently. Wet and terminal processes are both typically blended at 176.7-204.4°C (350-400°F) for extended periods of time [7], however, the difference is in the location of blending. The wet process could be processed at the plant (in a pug mill) whereas the terminal process occurs at an asphalt terminal. The important difference is the accessibility to a lab. The terminal process has an advantage if the supplier has a lab onsite to ensure the swelling process is complete before shipping to the plant. Some suppliers use a DSR to monitor several metrics over time. Once the DSR metrics have leveled out, the swelling process has completed. For the wet process, there is typically no access to a lab to ensure completion of the swelling, so an arbitrary mixing time is usually specified to quantify the swelling process. Either way, most of the time, when using the wet/terminal process, the swelling has been completed prior to incorporating the rubber modified binder (RMB) into the asphalt plant.

During the dry process, GTR is incorporated directly into the asphalt plant and blended in the mixing chamber with the asphalt and aggregate. The GTR will begin to swell as soon as it comes into contact with the asphalt binder. Like the wet/terminal process, there is an arbitrary amount of time that is needed for the swelling process to complete, however with the dry process this occurs during the mixing, shipping, paving and compacting processes. The main complication with the dry process and swelling, starts with the mix design (See Section 3.3.1 Design Constraints). A mix design has two main functions; to replicate the plant production process, and to determine adequate aggregate components and the optimized AC to ensure volumetric and performance properties. To replicate the plant process, the mix designer will mix an aggregate blend with varying ACs (usually ranging from 5.0% - 6.0% by weight in increments of 0.5%) to determine the optimum AC. The optimum AC is achieved when asphalt fills in the Voids in the Mineral Aggregate (VMA), to the required percentage (required by specifications) that relates to performance and durability parameters. The problem when swelling occurs during the mixing and compaction of a mix design, is that swelling will directly affect the void space between the aggregate particles (otherwise known as VMA) and change the "optimum" AC for the mix design. Because of this, there are considerations that have to be made during the mix design process to try to simulate the swelling process that occurs during mixing and compaction of the mixture, to ensure the correct optimum AC and long term performance and durability.

1.4 Wisconsin Experience

In 2015 WisDOT was invited to participate in an Illinois Tollway test section using a dry process GTR mixture. Performance testing included rutting and cold temperature cracking potential. This project is being monitored visually for performance. Considering there are GTR suppliers in Wisconsin and GTR mixtures being placed just south of the border, WisDOT would like to take advantage of GTR availability and investigate the potential mixture improvements.

WisDOT is currently researching and working towards a Balanced Mix Design (BMD) specification which will include performance testing. The investigation of GTR mixtures will compliment this progression in that GTR mixtures may be an option to provide increased performance.

2. Research Objectives

To date, WisDOT has not specified or placed GTR mixtures in Wisconsin. For this research, WisDOT has committed to a pilot project which includes multiple GTR mixtures and a control WisDOT High Traffic (HT) mixture using a PG 58-28H asphalt binder.

The first objective of this research, as defined in the RFP, is to complete a specification for GTR mixtures.

- Determine equivalent performance.
- Identify the performance and laboratory binder testing required to work with these mixtures, including specification limits for acceptance of materials.
- Write a WisDOT Special Provision (SPV) that will be incorporated into a contract, to specify GTR mixtures that will be equivalent to a standard WisDOT HT mixture. Please note, a WisDOT HT mixture contains polymer (see 2d. below).

Equivalent performance is a metric designed to level the playing field. While more GTR may produce extraordinary performance results, we want to evaluate GTR mixtures that are similar to a standard WisDOT HT mixture. To do so, specifications are written to ensure equivalency.

The second objective of this research is to create specifications for the test sections:

- A dry process rubber modified asphalt mix.
- A terminally blended wet process rubber modified asphalt mix.
- A terminally blended wet process rubber and polymer (hybrid) modified asphalt mix.
- An asphalt mix with an H (AASHTO M332 - Heavy) designation binder.

It is important that the specification is written clearly so the GTR suppliers and asphalt contractor are providing accurate bids. To do so, additional testing is needed to designate the amount of GTR for each mixture. Additionally, the specification must include other testing parameters and methods:

- Verification of rubber mix designs in the lab.
- Verification of rubber modified binder.
- Test procedures for incorporation of each product into the mix in the lab.
- Test procedures for testing field production mixes both in the lab and density in the field.
- Performance testing thresholds for acceptance.
- Specification language to allow for contractor choice while maintaining equivalent performance.

When the test sections and testing are completed, another research objective is to perform a cost/benefit estimate for the proposed recommendations using bidding documents from the demonstration test sections.

Lastly, the researcher is to identify the unique challenges of working with rubber modified mixtures. In the end, WisDOT should have a comprehensive report on how to specify and incorporate GTR into WisDOT mixtures – including challenges, improvements and lessons learned.

3. Develop a WisDOT Special Provision for GTR

An objective of this research was to create a special provision that included all the needed information for a contractor to bid on a project with three GTR test sections and one control test section. Considering there have been no WisDOT GTR projects to date, this specification must include the following key components:

1. Specific GTR mixtures (Performance Grade (PG) and GTR Materials),
2. Mix design considerations for GTR mixtures,
3. Performance testing requirements for the GTR mixtures, and
4. Performance testing procedures.

Since an additional objective of this research was to create cost/benefit analysis, it was important to keep each test section similar. To do so, the concept of equivalent performance was used. It was decided that each GTR test section would be of equal or better performance than the control test section. The performance tests chosen in the study were: Binder PG, Hamburg Wheel Tracking Test (HWT), Illinois Flexibility Index (I-FIT), Disk-Shaped Compact Tension Test (DCT) and Recovered Binder PG.

3.1 Binder PG – Equivalent Performance

When it comes to specifications, WisDOT considers “modifiers” separate from “additives.” A modifier is defined as a product that will change the binder PG, whereas an additive is a product that is added to the mixture that does/should not change the PG. Examples of WisDOT defined additives (according to Standard Section 460.2.4) are: hydrated lime or liquid antistripping agent, Stone Matrix Asphalt (SMA) stabilizer, warm mix asphalt additive or process. While the wet/terminal blend GTR process could be considered a modifier or an additive, the dry process GTR can only be considered an additive because of how it is added to the mixture in a separate process.

When writing a GTR specification, the wet/terminal blend can be quantified by a PG (similar to a virgin asphalt modified with a polymer). The addition of GTR to a virgin asphalt will result in a higher PG, again, similar to a polymer. Please note, some considerations must be made for PG testing of rubber (see section 3.1.2 Binder Grading and Testing), to make up for the size of the rubber particles in the asphalt. The benefit to specifying a wet/terminal blend by a PG is so the Agency can verify the supplied product at the plant during production, by taking a sample from the tank or in-line.

Because the nature of the product is different, the dry process GTR must also be specified differently. Since the dry process GTR is mixed in the asphalt plant, along with the aggregate and various recycled materials, there is no way to verify the PG of the RMB. Therefore, it is better to specify the virgin asphalt PG, along with the percentage of GTR that will be introduced to the plant. This way, the Agency can verify the virgin PG grade by taking a sample at the plant during production and verify the percent rubber going into the plant by looking at the plant computer in the control house.

While each process must be specified differently, in order to maintain equivalent performance, the RMBs had to be designated such that they produced a similar PG (AASHTO M 320 / Combined State Binder Group (CSBG)). Please note the control mixture design for the research test strips will use a PG 58-28H, which requires the use of a polymer.

3.1.1 Illinois Tollway Specification

The Illinois Tollway began experimenting with GTR as far back as 2006 and has since been successfully using the material, thus making them a prime candidate for review due to their proximity and experience. The Illinois Tollway Special Provisions table (**Table 1**) is based on the amount of recycle used in the blends. The sections highlighted in yellow are applicable to Wisconsin since WisDOT allows up to 30% binder replacement in surface mixes. The table suggests that an SBS/SBR PG 70-28, a GTR PG 70-28, and a PG 58-28 with 10% dry process GTR are expected to produce similar performance.

Table 1: Illinois Tollway Special Provision for Recycled Asphalt Materials, Asphalt Binder Replacement, and Asphalt Binder Requirements

Reclaimed Asphalt Material (as permitted in Tollway Tables 7 & 8)		RAP[1/]/FRAP/RAS	FRAP/RAS	Category 1[2/] FRAP with RAS
ABR		**0-17%**	**18-33%**	**34-50%**
Allowable Mix Options	SMA and IL-4.75[3/]	SBS/SBR 70-28 GTR PG 70-28 PG 58-28 10% Dry GTR		SBS/SBR 64-34 GTR PG 64-34 PG 52-34[5/] 10% Dry GTR
	Unmodified SMA and Binder & Surface Course	PG 58-28[6/]		PG 52-34[4/5/6/]
	Asphalt Stabilized Subbase and STS	PG 58-28[6/7/]		

1/ Recycled Asphalt Pavement (RAP) not allowed in SMA.
2/ Category II is allowed in Binder and Surface Course, Sustainable Temporary Surface, and Asphalt Stabilized Subbase.
3/ IL-4.75 Asphalt Binder Replacement (ABR) cannot exceed 33%.
4/ Up to 60% ABR on N50 IL 19.0 mm Binder.
5/ PG 46-34 shall be considered an equivalent to PG 52-34.
6/ Alternate Grades or Modifiers may be considered with approval of the Engineer.
7/ Up to 65% ABR on Asphalt Stabilized Subbase and Sustainable Temporary Surface.

The suggested equivalency in **Table 1** had to be confirmed and compared to the proposed control PG 52-28H, before proceeding with a special provision for the proposed test strips. This confirmation testing was performed and summarized in section 3.1.2 Binder Grading and Testing.

3.1.2 Binder Grading and Testing

Binder testing was needed to validate the specification limits provided by the Tollway and ensure equivalent performance. Several blends were prepared with differently graded base binders as well as different percentages of rubber to produce binders of similar performance using each of the rubber products and production processes. Two blends were terminally processed, one of which was a rubber/polymer hybrid. The terminally blended nonhybrid produced by Seneca will be referred to as “TB”, and the terminally blended hybrid binder, produced by Seneca using Ingevity’s Evoflex, will be referred to as “TBH” here on out. One blend was produced using dry process rubber from Elastiko and that blend will be referred to as “DP”, for “dry process” here on out.

The rubber modified binders were tested in a dynamic shear rheometer to determine their performance grades. However, the DSR testing standard limits the maximum particle size to 250 µm (approx. 0.010 in) when using a 1 mm (approx. 0.040 in) parallel plate testing gap (or 1/4 the gap between the parallel plates). If the particle sizes exceed this limit, the DSR may not accurately measure the bulk properties of the binder as the results will be influenced by particle to particle interactions between the DSR plates. The rubber used to produce terminally modified binders typically use rubber sieved with #30 screen or smaller which equates to particles up to 600 µm (approx. 0.024 in) in size, which is greater than the 250 µm (approx. 0.010 in) maximum particle size requirement. Therefore, to mitigate the particle interaction issue the testing gap between the parallel plates can be increased to accommodate the larger rubber particles [1].

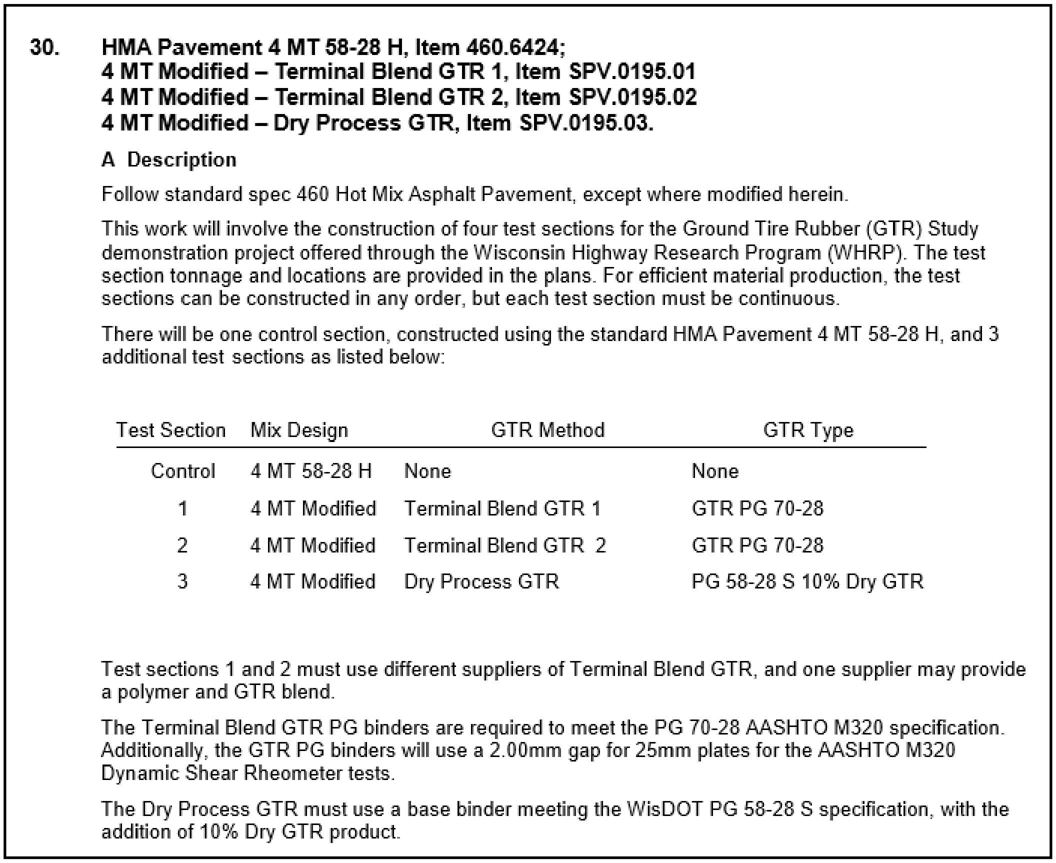
The results from testing of the rubber modified binders are shown below in **Table 2**. The lines highlighted show combinations that produced the most similar PG performance to the control PG 58-28H binder. Percent recoveries appearing in red text fell short of meeting the "Heavy Traffic" grade specified as a minimum of 30% recovery at 3.2 kPa in the Multiple Stress Creep-Recovery (MSCR) DSR test as outlined in the CSBG specification used in Wisconsin. It is worth noting that all the binder combinations tested did meet the "Heavy Traffic" grade when using the AASHTO M 332 specification which requires that the Jnr (non-recoverable creep compliance) at the 3.2 kPa stress level of the test be less than or equal to 2.0 kPa^{-1} as opposed to qualifying the binder based on percent recovery and Jnr. A discussion with WisDOT resulted in the determination that, for this research, the difference in AASHTO M 332 grading are not exclusionary and are for informational purposes only. Since the base binder could not change, the only adjustments that could be made to modify the binders is the rubber dosage. While it would be ideal to have all of the properties nearly identical, this is currently not possible with the available rubber modifications being used. For example, increasing the dosage of rubber to increase the %Recovery parameter may cause the binder to achieve a higher high temperature PG, no longer classifying the same as the control binder. Therefore, the parameter chosen to be held nearly constant was the PG.

Table 2: Equivalent Performance Binder Testing Results

WHRP Binder Summary

ID	Type	Binder	High Temp PG (°C)	Low Temp PG (°C)	Jnr @ 3.2 kPa @ 58°C	% Recovery @ 3.2 kPa @ 58°C
180101	Base (Poly)	PG 58-28H (Control)	**68.7**	**-32.1**	0.36	64.4
180104	Terminal	PG 58-28 + 12% TB (Seneca)	**70.3**	**-30.8**	0.73	28.0
180100	Terminal	PG 46-34 + 12% TB (Seneca)	69.2	-39.3	0.97	27.9
180119	Terminal	PG 58-28S + 10% Evoflex/TBH (Ingevity)	**70.4**	**-30.6**	0.44	41.4
180099	Terminal	PG 46-34 + 15% Evoflex/TBH (Ingevity)	66.6	-39.5	0.46	65.8
180118	Dry	PG 58-28S + 10% DP (Elastiko)	**68.8**	**-30.4**	0.53	20.5
180103	Dry	PG 58-28H + 10% DP (Elastiko 100)	78.8	-32.9	0.11	75.2

From this testing the binders and their dosage rates of rubber modification were selected based on their equivalent performance and added to the SPV. An excerpt of the SPV specification of the binders is shown below in **Figure 3**.



30. HMA Pavement 4 MT 58-28 H, Item 460.6424;
4 MT Modified – Terminal Blend GTR 1, Item SPV.0195.01
4 MT Modified – Terminal Blend GTR 2, Item SPV.0195.02
4 MT Modified – Dry Process GTR, Item SPV.0195.03.

A Description

Follow standard spec 460 Hot Mix Asphalt Pavement, except where modified herein.

This work will involve the construction of four test sections for the Ground Tire Rubber (GTR) Study demonstration project offered through the Wisconsin Highway Research Program (WHRP). The test section tonnage and locations are provided in the plans. For efficient material production, the test sections can be constructed in any order, but each test section must be continuous.

There will be one control section, constructed using the standard HMA Pavement 4 MT 58-28 H, and 3 additional test sections as listed below:

Test Section	Mix Design	GTR Method	GTR Type
Control	4 MT 58-28 H	None	None
1	4 MT Modified	Terminal Blend GTR 1	GTR PG 70-28
2	4 MT Modified	Terminal Blend GTR 2	GTR PG 70-28
3	4 MT Modified	Dry Process GTR	PG 58-28 S 10% Dry GTR

Test sections 1 and 2 must use different suppliers of Terminal Blend GTR, and one supplier may provide a polymer and GTR blend.

The Terminal Blend GTR PG binders are required to meet the PG 70-28 AASHTO M320 specification. Additionally, the GTR PG binders will use a 2.00mm gap for 25mm plates for the AASHTO M320 Dynamic Shear Rheometer tests.

The Dry Process GTR must use a base binder meeting the WisDOT PG 58-28 S specification, with the addition of 10% Dry GTR product.

Figure 3: SPV Excerpt Specifying Equivalent Binders based on Testing

3.1.3 GTR Product Quality

The physical GTR products are not equivalent. Dependent on the process, the grinding and final gradation is different. That being said, the rubber product physical qualities also needed to be specified. Again, the Illinois Tollway specification provides robust and proven guidance for accomplishing this. As part of the Illinois Tollway Approved List of Asphalt Binder and Mixture Modifiers section on modifier product requirements (previously located in the SPV), rubber processing and gradation requirements are defined.

Per the Tollway specification, when using a terminally blended asphalt, the GTR shall be produced from processing automobile and/or truck tires using the ambient grinding method. Rubber that has been sourced from heavy equipment tires, or that is uncured or de-vulcanized shall not be permitted. The rubber should not exceed 1/16 inch in length (approx. 1.59 mm or approx. #12 sieve) and must not contain any free metal. Detection of free metal particles shall be determined by passing a magnet through a 2 oz. (approx. 56.7 g) sample. Metal embedded in the rubber particles, however, will be permitted. When storing the rubber, it shall be stored in a dry location that is protected from the rain. When the rubber is combined with the asphalt, the moisture content of the rubber shall not cause foaming of the blend. When tested in accordance to AASHTO T-27, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates, a 2 oz. (approx. 56.7 g) samples of the rubber shall conform to the following gradation requirements shown in **Table 3**.

Table 3: GTR Gradation Requirements for Terminal Process

Sieve Size	Percent Passing
No. 8 (2.36 mm)	100
No. 16 (1.18 mm)	98 ± 2
No. 30 (600 µm)	95 ± 5
No. 50 (300 µm)	50 ± 10
No. 100 (150 µm)	10 ± 5
No. 200 (75 µm)	2 ± 2

Additionally, a mineral powder (such as talc) meeting AASHTO M17, Standard Specification for Mineral Filler for Bituminous Paving Mixtures, requirements may be added, up to a maximum of 4% by weight of GTR particles, to reduce sticking and caking of the GTR particles. The GTR shall have a specific gravity of 1.15 ± 0.05 when tested in accordance with ASTM D1817, Standard Test Method for Rubber Chemicals-Density.

When using a dry process rubber modified asphalt mixture, the dry process GTR shall be produced from processing automobile and/or truck tires by ambient or cryogenic grinding methods. Rubber that has been sourced from heavy equipment tires, or that is uncured or de-vulcanized shall not be permitted. The rubber should not exceed 1/20 in. in diameter (1.27 mm or approx. #14 sieve) and must not contain any free metal. Detection of free metal particles shall be determined by passing a magnet through a 2 oz. (approx. 56.7 g) sample. Metal embedded in the rubber particles, however, will be permitted. The dry process GTR shall be packaged and shipped in closed-top, water resistant bulk bags. The dry process GTR bags shall be stored in a dry location protected from the rain before use in the field. When the GTR is combined with the asphalt cement and aggregate, the moisture content of the GTR shall not cause foaming of the blend. When tested in accordance with AASHTO T-27 (Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates), a 2 oz. (approx. 56.7 g) sample of the dry process GTR shall conform to the following gradation requirements shown in **Table 4**.

Table 4: GTR Gradation Requirements for Dry Process

Sieve Size	Percent Passing
No. 20 (841 µm)	100
No. 30 (600 µm)	99 ± 1
No. 40 (300 µm)	60 ± 10
No. 100 (150 µm)	10 ± 5

Additionally, a mineral powder (such as talc) meeting AASHTO M 17, Standard Specification for Mineral Filler for Bituminous Paving Mixtures, requirements may be added, up to a maximum of 4% by weight of GTR particles, to reduce sticking and caking of the GTR particles. The GTR shall have a specific gravity of 1.15 ± 0.05 when tested in accordance with ASTM D1817, Standard Test Method for Rubber Chemicals-Density.

Since, these GTR product quality specifications are used in a neighboring state to acquire rubber products, we knew they would be available for use in Wisconsin, and suppliers would be able to supply conforming materials. Therefore, these product specifications were incorporated into the SPV used to construct the test sections.

3.2 Mix Design – Equivalent Performance

Unlike traditional mix designs there are unique challenges when working with GTR modified asphalt mixtures. The primary challenge arises from swelling and the stages of swelling during mixing and compacting. Because the swelling process can affect the void spacing in the mix (and therefore the VMA), it is important that rubber modified asphalt mix designs are all created the same way to ensure the proper optimum asphalt content is selected. This may require mix design adjustments to ensure reproducible test results between the contractor and research lab.

Please note that swelling is of greater concern during the mix design process for fine graded mixtures than coarse graded mixtures or SMA mixtures. Coarse graded and SMA mixtures have larger void spacing between the aggregate particles, therefore swelling can mostly occur within the aggregate structure. The concern with fine graded mixtures, since the void space between particles is so small, is that swelling will actually push apart the aggregate particles creating additional VMA. During the mix design process, if VMA is too high the designer will add either dust or asphalt. The following design modifications are to ensure that additional dust or asphalt are not added unnecessarily.

3.2.1 Design Constraints

Dry process rubber has been used in dense-graded, open-graded, or gap-graded mixtures, and is used as a substitute for a small portion of the fine aggregates – usually 1 to 3% by weight of the total aggregates in the mixture [3, 8] or 15 to 22% be weight of asphalt binder [9]. The rubber is blended with the aggregates before the asphalt cement is finally added to the rubber/aggregate mixture. The recommended production temperature is 148.9-176.7°C (300-350°F) for effective blending of the rubber [7]. Once blended with the GTR and aggregates the asphalt reacts with the GTR and swells. This swelling and softening of the rubber particles occurs when the GTR particles absorb some of the oils and asphalt binder during blending. The absorption of these lighter fraction oils and subsequent swelling of the rubber particles produces a binder with increased viscosity that also produces a thicker film to coat the aggregates [9].

Working with dry process rubber requires extra considerations in the lab. The swelling of the rubber will still be happening in the cylindrical specimens (sometimes referred to as “pucks” or “pills”) that are used to test bulk specific gravity (Gmb). If the swelling is allowed to continue, the Gmb value will be skewed (not accurate, or not representative of what is in the field). Since the Gmb is used to determine optimum AC content in a mix design, it is very important to ensure these values are accurate. This may require increased additional time in the gyratory mold until swelling subsides before removing the specimen. In the field, the dry process rubber modified mixtures may require additional silo time for swelling to subside to avoid compaction and workability issues during placement. The additional lab “mold time” is to simulate what will happen in the silo and under the compaction of the rollers in the field. If the specimen is removed too soon, the swelling may permanently deform the sample and provide a Gmb that does not represent the field. This will result in an elevated VMA and subsequently affect the determination of the optimum AC content during the design process. Accommodations for swelling during the mix design process are evaluated in section 3.3.2 Lab Testing to Accommodate Design Constraints.

Terminally blended rubber modified binders are prepared and blended at the refinery or asphalt terminal. The constituent rubber and asphalt materials are heated to approximately 176.7-204.4°C (350-400°F) for extended periods of time and blended (45-60 minutes) [7]. This process dissolves the rubber into the asphalt and is considered a modification to the binder. Sometimes other additives are added in addition to the GTR. The terminal tests throughout production of the rubber modified binder using a DSR to detect when the properties have stabilized, and the swelling process has subsided. This process is advantageous because it does not require a change in the mix design process. The TB RMB is added to the aggregate in its post-swelled form.

3.2.2 Lab Testing to Accommodate Dry Process Design Constraints

To properly compensate for the swelling of dry process rubber modified binder, additional considerations during mix design had to be evaluated. After compacting specimens, the compaction force no longer exists on the top surface of the specimen since this is normally where the top plate rests on the specimen during compaction. Since this plate is not fixed, it is free to move as the specimen swells. This will permit elongation of the specimen during swelling and result in lower bulk specific gravity measurements (Gmb) which in turn can lead practitioners to believe they require more asphalt (or dust) to fill the voids in the aggregate structure.

After talking with other mix designers and reviewing the supplier’s recommendations, Behnke Materials Engineering (BME) felt it was necessary to experiment with applying varying confinement weights to the specimen to prevent swelling. To accomplish this, different weights were applied to the upper plate of the gyratory mold after compaction to provide confining pressure during the 30-minute (manufacturer recommended) rest period inside the mold. The mass of the top plate was 1,284 g. Specimens were then measured for degree of swelling by measuring the resultant change in height from the specified compaction height, and air voids. These results were compared against a control specimen that contained no rubber, did not swell, and had an air voids content of 3.3%. The results of this experiment are shown below in **Figure 4**.

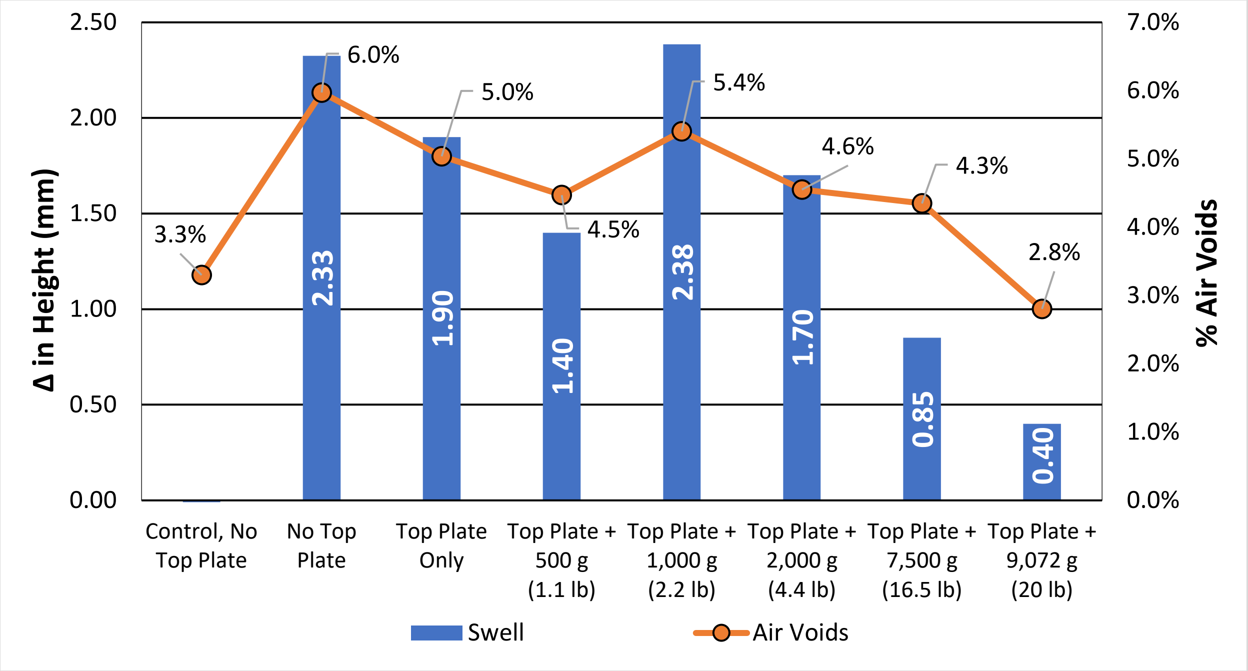
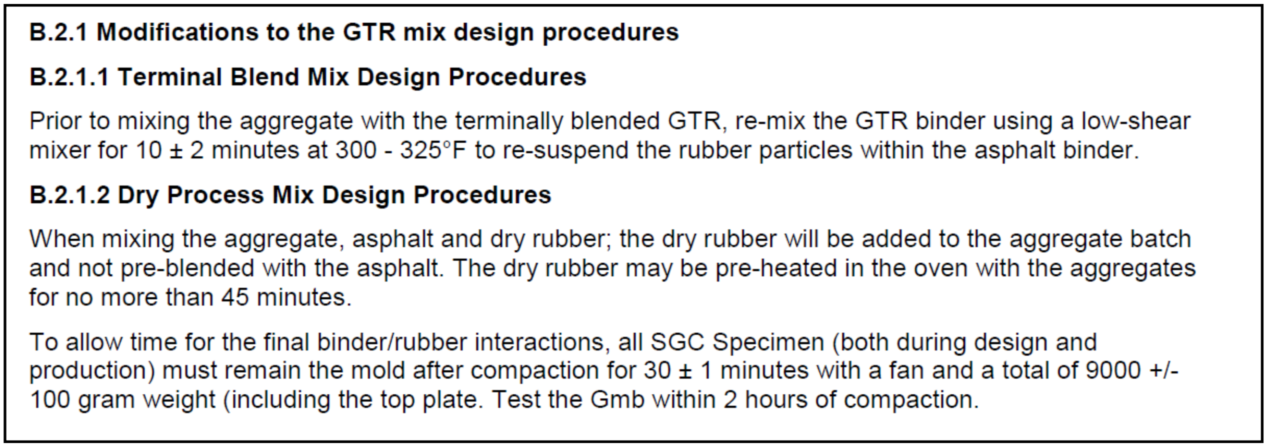


Figure 4: Gyratory Top Plate Confinement Results for Accommodating Swelling

Results from this experiment show that 20 lbs. (9,071.85 g) of confinement reduces swelling to less than 0.5 mm and nearly hits the minimum air void contents of 3.0%. Ultimately, the research team decided that 9,000 g (19.8 lbs) of confinement should be enough to minimize the swelling and hit the target air voids of 3.0% when producing gyratory specimens using dry process rubber. The SPV was then written to account for this by requiring 30 minutes of rest time in the gyratory mold post-compaction but before being extruded to maintain confinement to prevent deformation of the specimen. An excerpt of the SPV regarding modifications to the mix design procedure is shown in **Figure 5**.



B.2.1 Modifications to the GTR mix design procedures

B.2.1.1 Terminal Blend Mix Design Procedures

Prior to mixing the aggregate with the terminally blended GTR, re-mix the GTR binder using a low-shear mixer for 10 ± 2 minutes at 300 - 325°F to re-suspend the rubber particles within the asphalt binder.

B.2.1.2 Dry Process Mix Design Procedures

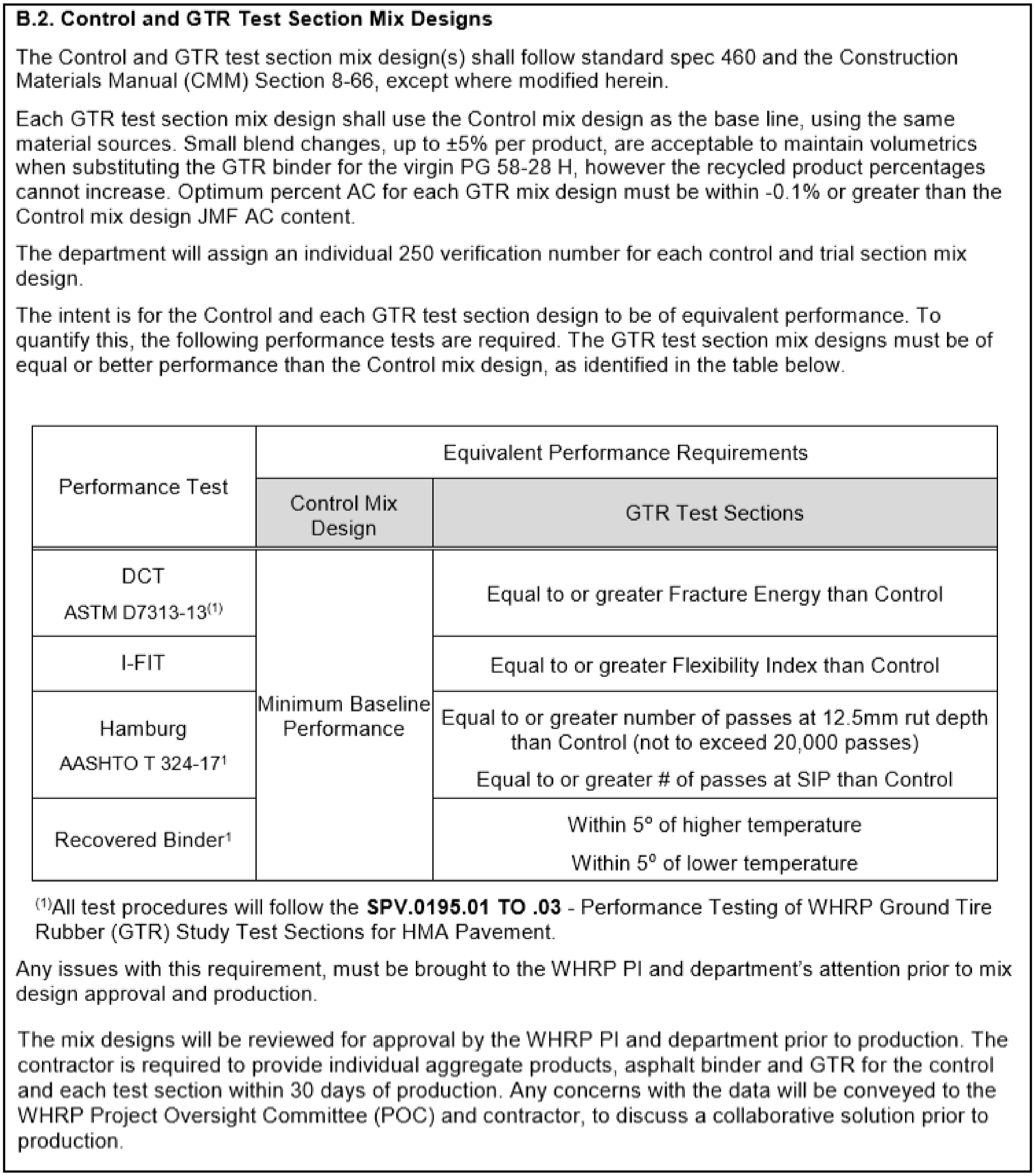
When mixing the aggregate, asphalt and dry rubber; the dry rubber will be added to the aggregate batch and not pre-blended with the asphalt. The dry rubber may be pre-heated in the oven with the aggregates for no more than 45 minutes.

To allow time for the final binder/rubber interactions, all SGC Specimen (both during design and production) must remain the mold after compaction for 30 ± 1 minutes with a fan and a total of 9000 +/- 100 gram weight (including the top plate. Test the Gmb within 2 hours of compaction.

Figure 5: SPV Except Specifying Confinement and Wait Time Requirements during Mix Design

3.2.3 Performance Testing – Equivalent Performance

One of the objectives of this research was equivalent performance and how to physically incorporate and specify rubber products into Wisconsin mixtures to ensure equality among the various products. To accomplish this, parameters were established for what is considered equivalent performance for all the performance tests. For this research, the binders had to be of nearly equivalent performance in terms of AASHTO M 320 performance grades and (in the case of Wisconsin) Combined State Binder Group specifications for PG+ traffic loading grading as previously discussed in Section 3.1. Additionally, the mixtures had to produce similar performance in several key areas – rutting and low and intermediate temperature cracking. This equivalent performance had to be achieved with only small changes to base mix design to ensure that confounding variables were not introduced. The following verbiage in **Figure 6** was included in the SPV to ensure similar or equivalent performance.



B.2. Control and GTR Test Section Mix Designs

The Control and GTR test section mix design(s) shall follow standard spec 460 and the Construction Materials Manual (CMM) Section 8-66, except where modified herein.

Each GTR test section mix design shall use the Control mix design as the base line, using the same material sources. Small blend changes, up to ±5% per product, are acceptable to maintain volumetrics when substituting the GTR binder for the virgin PG 58-28 H, however the recycled product percentages cannot increase. Optimum percent AC for each GTR mix design must be within -0.1% or greater than the Control mix design JMF AC content.

The department will assign an individual 250 verification number for each control and trial section mix design.

The intent is for the Control and each GTR test section design to be of equivalent performance. To quantify this, the following performance tests are required. The GTR test section mix designs must be of equal or better performance than the Control mix design, as identified in the table below.

Performance Test	Equivalent Performance Requirements	
	Control Mix Design	GTR Test Sections
DCT ASTM D7313-13(1)	Minimum Baseline Performance	Equal to or greater Fracture Energy than Control
I-FIT		Equal to or greater Flexibility Index than Control
Hamburg AASHTO T 324-17[1]		Equal to or greater number of passes at 12.5mm rut depth than Control (not to exceed 20,000 passes) Equal to or greater # of passes at SIP than Control
Recovered Binder[1]		Within 5° of higher temperature Within 5° of lower temperature

(1)All test procedures will follow the **SPV.0195.01 TO .03** - Performance Testing of WHRP Ground Tire Rubber (GTR) Study Test Sections for HMA Pavement.

Any issues with this requirement, must be brought to the WHRP PI and department's attention prior to mix design approval and production.

The mix designs will be reviewed for approval by the WHRP PI and department prior to production. The contractor is required to provide individual aggregate products, asphalt binder and GTR for the control and each test section within 30 days of production. Any concerns with the data will be conveyed to the WHRP Project Oversight Committee (POC) and contractor, to discuss a collaborative solution prior to production.

Figure 6: SPV Except Specifying Equivalent Performance

3.2.4 Wisconsin Modified Performance Testing Methods and Procedures

The following test methods and procedures were created to ensure consistent and repeatable testing of performance properties.

3.2.4.1 Reheating and Short- and Long-Term Aging Protocol (WHRP 0092-17-04)

To minimize the effects of confounding variables, the aging of the specimens needed to be controlled. Based on the results of earlier work performed during the Wisconsin Highway Research Program (WHRP) 0092-17-04: Field Aging and Oil Modification Study several factors were deemed important for consideration when trying to simulate short-term plant and long-term field aging in the lab [10].

To minimize the effects of confounding variables, the aging of the specimens needed to be controlled. Based on the results of earlier work performed during the Wisconsin Highway Research Program (WHRP) 0092-17-04: Field Aging and Oil Modification Study several factors were deemed important for consideration when trying to simulate short-term plant and long-term field aging in the lab [8].

Based on these considerations, the recommended procedures for reheating and short- and long-term aging were developed to be used in this study.

Reheating is to be performed by:

1. Placing an uncovered pan on the middle-center rack of an oven that is at 135°C (275°F) for 2 hours ± 5 minutes. The oven is not to be opened during this time and the samples are not to be stirred.
2. Once the reheating is complete, aging procedures (described below) can immediately follow without additional interference of the sample or the sample can be removed and compacted to specification.

Short-term oven aging (STOA) should first follow the reheating procedure above and then:

1. Keep the reheated pan in an oven set at 135°C (275°F) for 2 hour ± 5 minutes. Take the sample out of the oven and stir after 1 hour ± 5 minutes from the starting time of the aging process (which begins immediately after the reheating procedure has ended). Stirring should be completed within 1 to 2 minutes. Keep the oven closed before and after stirring throughout the aging time to avoid cooling of the oven.
2. Once aging time is achieved compact specimens according to specification.

Long-term oven aging (LTOA) should first follow the reheating procedure above and then:

1. Keep the reheated pan in an oven set at 135°C (275°F) for 6 hours ± 5 minutes. Take the sample out of the oven and stir after 1 hour ± 5 minutes from the starting time of the aging process (which begins immediately after the reheating procedure has ended). Stirring should be done within 1 to 2 minutes. Keep the oven closed before and after stirring throughout the aging time to avoid cooling of the oven.
2. Once aging time is achieved compact specimens to specification.

3.2.4.2 Hamburg Wheel Tracking Test (AASHTO T 324-17)

The Hamburg Wheel Tracking (HWT) test measures the rutting and moisture-susceptibility of a laboratory-compacted specimen of asphalt mixture, a saw-cut slab specimen, or a core taken from a compacted pavement using a loaded reciprocating steel wheel and is shown below in **Figure 7**.

Figure 7: Hamburg Wheel Tracking Testing Machine

The procedure was performed according to AASHTO T 324-17, where the only modification to the test procedure was a reduction to the testing temperature outlined below. Test specimens were:

- Short-term oven aged as described in section 3.3.4.1,
- Compacted to 7.0% ± 0.5% air voids using a gyratory compactor to 62 mm ± 2 mm (approx. 2.44 ± 0.08 in.) height with 150 mm (approx. 5.91 in.) diameters,
- and submerged in a water bath which is heated to testing temperature – in the case of this research, 46°C (114.8°F) for testing.

The wheels that track over the specimens are loaded at 705 N ± 4.5 N (158 lbs. ± 1.0 lb.) and reciprocate at a frequency of 52 ± 2 passes per minute. The test is complete when either 20,000 passes of the wheel have been completed or a 12.5 mm rut depth has been achieved, whichever comes first. Output data produced by the testing machine is then inserted into Iowa's Hamburg Wheel Tracking Device Report spreadsheet for analysis, which is made available by the Iowa DOT on their website at https://iowadot.gov/construction_materials/Hot-mix-asphalt-HMA. This spreadsheet analyzes the output data from the machine and summarizes average rut depths at various numbers of wheel passes, creep and stripping slope, and slope inflection point (SIP). In the settings tab on the spreadsheet, the measurement locations for rutting and SIP in both "poor" and "good" columns were set to sensors 3-9. Sensors 1-2 and 10-11 are deselected as they are in locations where the wheel begins to slow its travel as the machine finishes one reciprocation of the wheel before changing travel direction and may affect the quality of the results during analysis [11]. Lower rut depths indicate better performance.

3.2.4.3 Disk-Shaped Compact Tension Test (ASTM D7313-13)

The Disk-Shaped Compact Tension (DCT) test measures the low temperature fracture energy of circular specimens with a single edge notch loaded in tension. The measured fracture energy can be used to describe the cracking resistance of asphalt mixtures at low temperatures. The testing machine can be seen below in **Figure 8**.

Figure 8: Disk-Shaped Compact Tension Testing Machine

The procedure was performed according to ASTM 7313-13 with no modifications to the test procedure. Test specimens were:

- Short-term and long-term oven aged as described in section 3.3.4.1,
- After aging, specimens were compacted to 7.0% ± 0.5% air voids using a gyratory compactor to 150 mm (approx. 5.91 in.) height by 150 mm (approx. 5.91 in.) diameter.
- Samples were then cut using a masonry saw from the 150 mm height specimen to produce two 50 mm (approx. 1.97 in.) height samples.
- Air voids were then retested to ensure that the 50 mm (approx. 1.97 in.) specimens were still within the required 7.0% ± 0.5% air voids.
- This process was repeated to create a total of four specimens as required by the test.
- The holes are drilled into the specimens using a hole-saw and the notch is cut using a tile-saw according to specification.
- Clip-on gage points are then superglued to the specimen above and below the notch on the face perpendicular to the length of the notch.
- The fabricated specimens are then conditioned in a freezer for 14 hours at -18°C (-0.4°F) and then moved to the testing chamber and further conditioned at -18°C (-0.4°F) for 2 hours before testing.

Once loaded in the DCT fixture, the sample is loaded in tension at a rate of 0.017 mm/sec until the formation of a crack occurs through the notch. This is repeated four times with each specimen. Analysis involves taking the average of the four fracture energies and discarding the value furthest from the average. A new average is then calculated from the three specimens remaining, and this value is used to represent the fracture energy of the mixture. Higher fracture energy values indicate better performance.

3.2.4.4 Illinois Flexibility Index Test (Illinois Test Procedure 405)

The Illinois Flexibility Index (I-FIT) test measures fracture energy and post peak slope of asphalt mixtures using semicircular specimens at intermediate temperatures. These parameters are used to calculate the Flexibility Index (FI) which can be used to predict cracking resistance. The testing fixture and schematic can be seen below in **Figure 9**.

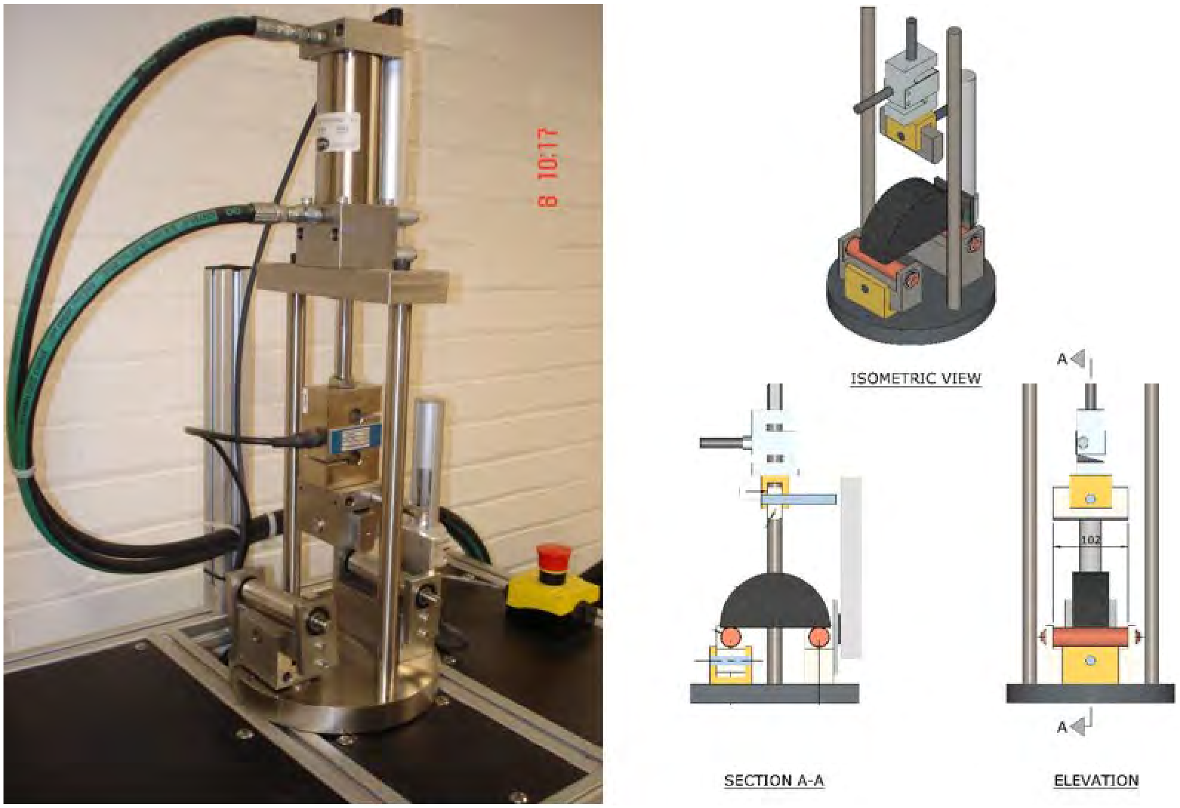


Figure 9: Illinois Flexibility Index Testing Fixture and Schematic

The procedure was performed according to Illinois Testing Procedure 405 with no changes to the procedure. Test specimens were:

- Short-term and long-term oven aged as described in section 3.3.4.1.
- After aging, specimens were compacted to 7.0% ± 0.5% air voids using a gyratory compactor to 150 mm (approx. 5.91 in.) height by 150 mm (approx. 5.91 in.) diameter.
- Samples were then cut using a masonry saw from the 150 mm (approx. 5.91 in.) height specimen to produce two 50 mm (approx. 1.97 in.) height samples.
- These samples are then cut in half again through the diameter to produce two semi-circular samples. This is done twice to produce a total of four semi-circular specimens.
- Notches are then cut into the samples using a tile saw.
- Before testing, samples are submerged in a water bath that is 25°C (77°F) for 2 ± 0.5 hours.

Then, the semi-circular notched specimens are loaded, notched side down centered on two rollers. A load is applied at 50 mm/min along the vertical radius of the specimen until a crack begins to form from the notch. Analysis involves taking the average of the four flexibility indices and discarding the value furthest from the average. A new average is then calculated from the three specimens remaining, and this value is used to represent the flexibility index of the mixture. Higher flexibility indices indicate better performance.

4. Project Start Up

The project location was USH-51. The stretch of USH-51 to be constructed is located just north of E. Philhower Road and continues north to W. Knilans Road (next to the Southern Wisconsin Regional Airport) northwest of Beloit Wisconsin.

4.1 Project Details

This project was let on March 6, 2019. A local contractor with a plant located on USH 51 was the lowest bidder. The project plans defined the limits of each test section, and the contractor submitted mix designs for verification. Additionally, prior to production the research team completed a survey of each test section.

4.1.1 Test Section Layout

Since this study included four (4) mixtures – a control, a terminal blend (TB), a terminal blend hybrid modified with rubber and polymer (TBH), and a dry process (DP) blend – there were four (4) test sections corresponding to each mixture. As previously mentioned, these test sections are located just north of E. Philhower Road and continues north to W. Knilans Road (next to the Southern Wisconsin Regional Airport) northwest of Beloit Wisconsin. The total length of roadway is approximately 23,000 ft. or about 4.4 mi. Test sections were broken into roughly equal lengths between 11,055 ft. and 11,745 ft. Two of these sections were in the northbound direction while the other two were in the southbound direction. Details of the project layout and stationing are shown below in **Table 5** and **Figure 10**. The test strip number in the table corresponds with the test strip number on the map.

Table 5: Details of the Test Strip Layout

Number	Test Strip	Type of Material	Stationing	Lane	Tonnage
1	Terminal Blend	Seneca	290+00 - 400+55	NB Outside Lane & Shoulders	1,867
2	Terminal Blend Hybrid	Ingevity	402+55 - 520+00	NB Outside Lane & Shoulders	1,937
3	Control	4 MT 58-28 H	290+00 - 400+55	SB Outside Lane & Shoulders	1,887
4	Dry-Process	Elastiko	402+55 - 520+00	SB Outside Lane & Shoulders	1,988

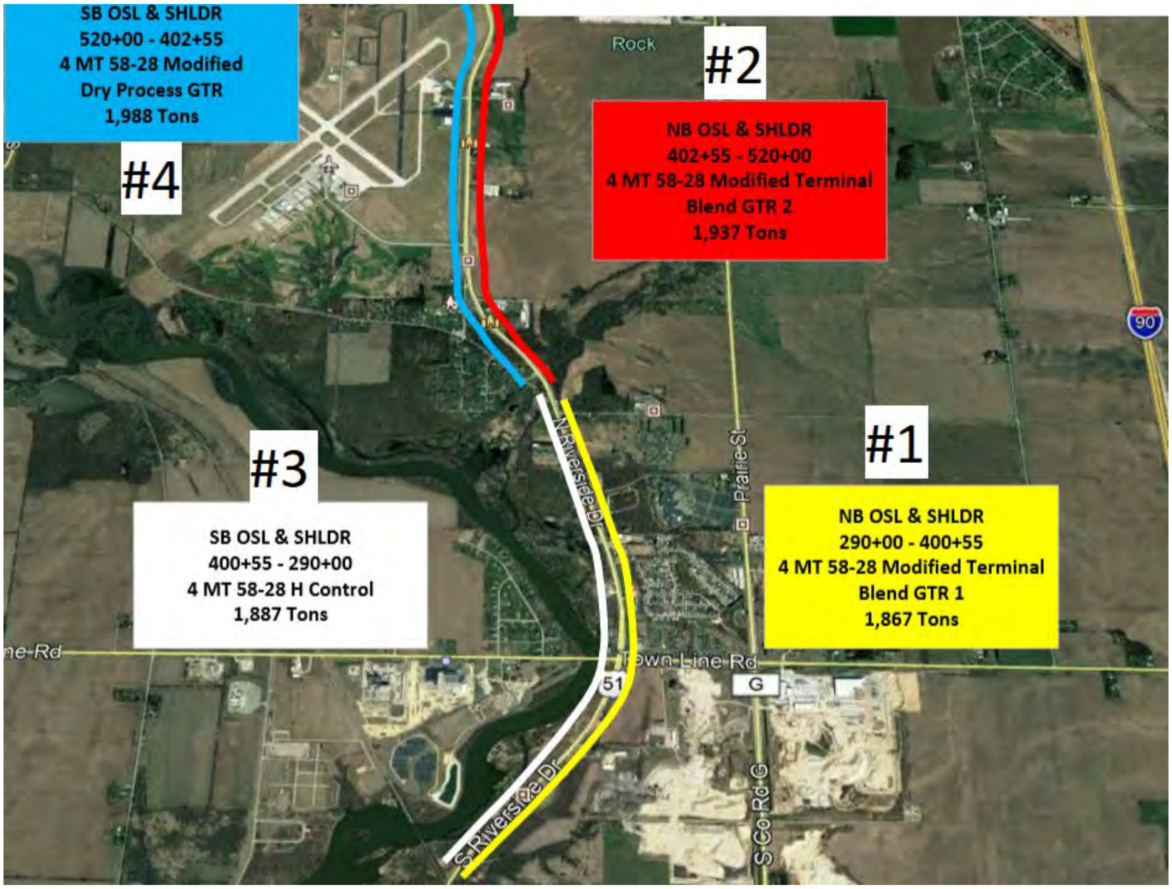


Figure 10: Map of the Test Strip Layout

4.2 Mix Design Verification

According to the SPV (see in Appendix section 13.1 for the full SPV) the contractor created mix designs that met the required criteria. Four mix designs were required: a control mix, a terminally blended mix, a terminally blended hybrid mix containing both rubber and polymer, and a dry process mix. All the mix design data can be found in the appendix in sections 13.2-13.5.

The contractor was able to select the rubber products that met the criteria outlined in the SPV. Ultimately, the contractor selected a terminal blend produced by Seneca (TB), a terminally blended hybrid produced by Seneca using Ingevity's Evoflex (TBH), and a dry process blend using Elastiko GTR (DP). The control was produced using a 58-28H binder that was modified with an undisclosed polymer.

The Job Mix Formula (JMF) for the control mix and rubber modified mixes are presented below in **Table 6**.

Table 6: JMF for Control and GTR Mixes

Sieve	**JMF - % Retained**			
	Control	**TB**	**TBH**	**DP**
3/4"	100%	100%		
1/2"	97.8%	96.6%		
3/8"	90.2%	86.2%		
#4	73.6%	67.3%		
#8	56.1%	53.2%		
#16	41.6%	40.3%		
#30	29.5%	28.6%		
#50	13.7%	13.4%		
#100	6.9%	7.5%		
#200	4.8%	5.5%		
%AC	5.7	5.8	5.8	5.9

The GTR mixtures (TB, TBH, and DP) all used the same JMF gradation, while the control used a slightly different JMF gradation. The GTR blends were all coarser and dirtier than the control mixture. The design ACs were as follows: 5.7% for the control, 5.8% for the TB and TBH, and 5.9% for the DP.

Once the mix designs were created, the contractor had to perform the performance testing outlined in the SPV which included Hamburg Wheel Tracking, Disk-Shaped Compact Tension, and Illinois Flexibility Index tests to verify the performance was greater than or equal to that of the control mixture. The results of the contractor’s testing are shown below in **Figure 11**, **Figure 12**, and **Figure 13**. These results show the contractor’s mix design results (orange) as well as the results performed by the researcher, BME (blue), to verify the contractor’s results.

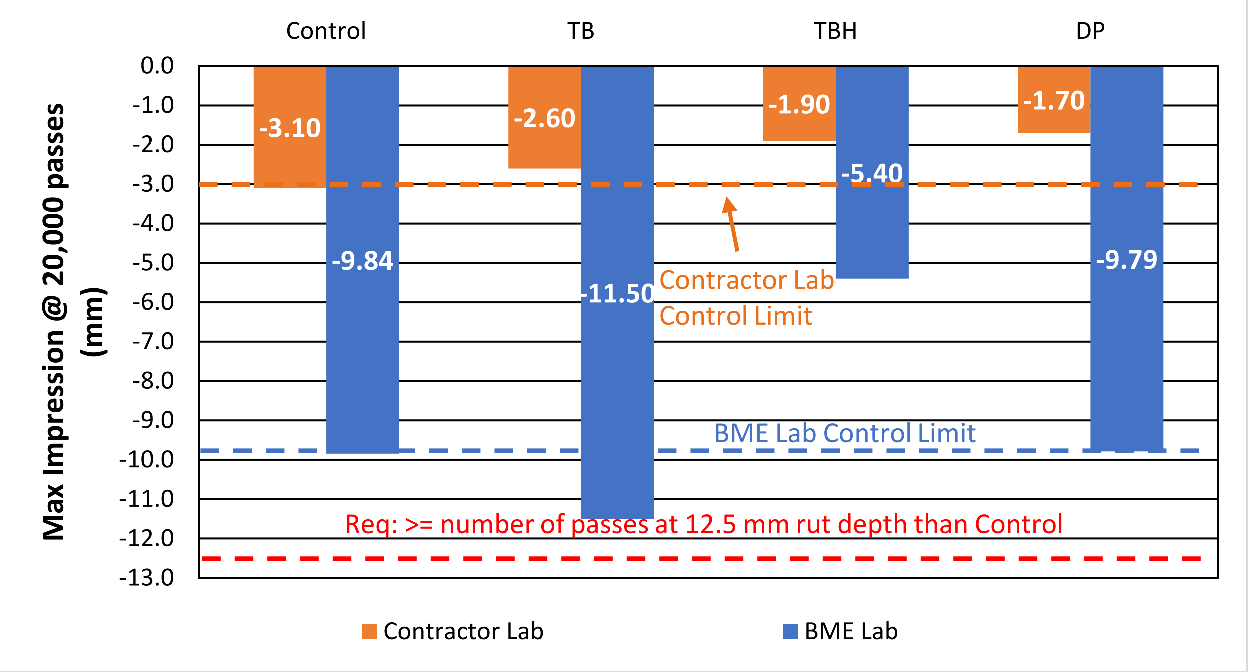


Figure 11: Laboratory Mixed, Pre-Production Hamburg Wheel Tracking Results

As shown in **Figure 11**, the contractor's Hamburg testing results all passed the performance requirements of having less than or equal to the rutting depth of the control mixtures after 20,000 cycles. However, when verified by the BME lab, there were substantial differences in the maximum rutting depth compared to the contractor, and the TB mixture also showed worse rutting performance than the control mixture.

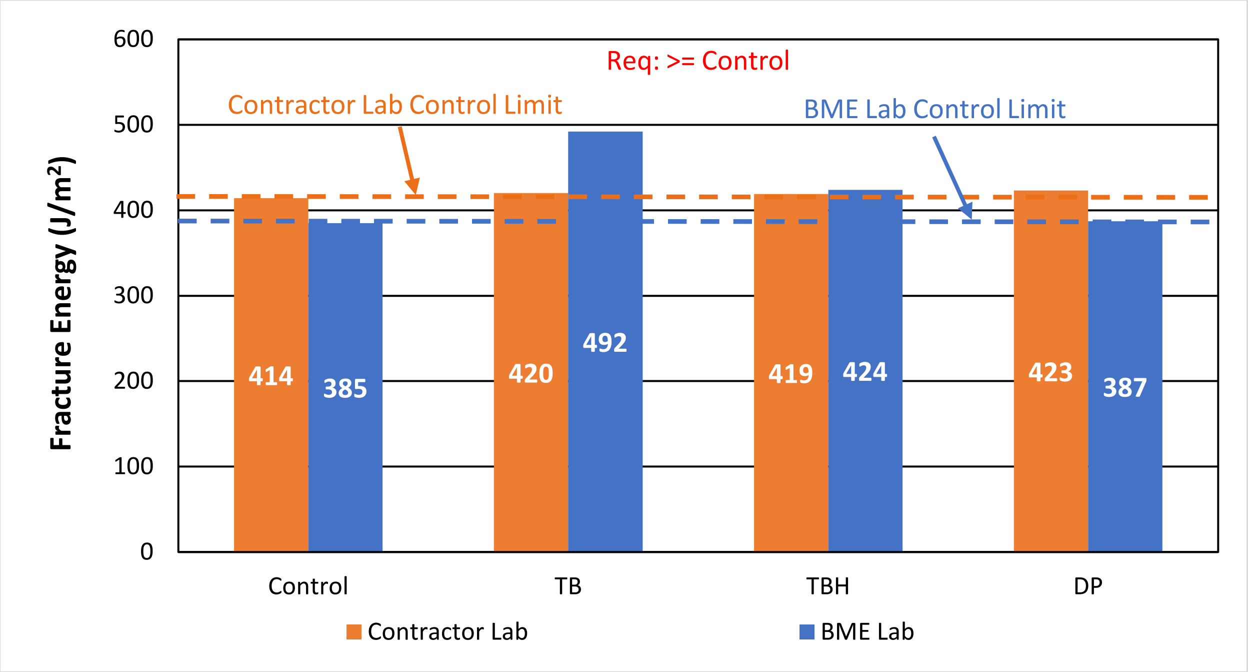


Figure 12: Laboratory Mixed, Pre-Production Disk-Shaped Compact Tension Test Results

Figure 12 shows that both the contractor and BME DCT results met the performance requirements outlined in the SPV where rubber modified blends are to meet or exceed the performance of the control mixtures.

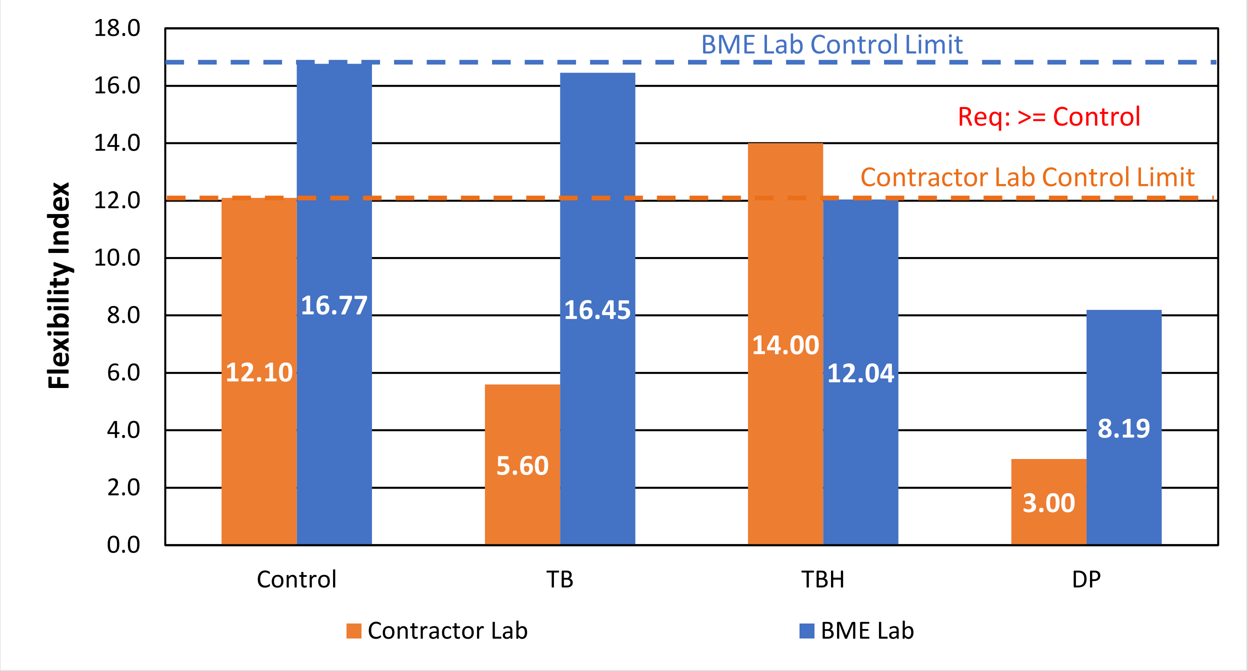


Figure 13: Laboratory Mixed, Pre-Production Illinois Flexibility Index Test Results

Figure 13 shows that contractor testing for both the DP and TB did not meet the I-FIT flexibility index requirement of being greater than or equal to that of the control blend. When tested in the BME lab, however, all mixtures but the TBH had substantial improvement in their flexibility indices, when compared to the contractor, including the control mixture. Neither the contractor nor BME lab were able to obtain flexibility indices that satisfied the performance requirement from the SPV.

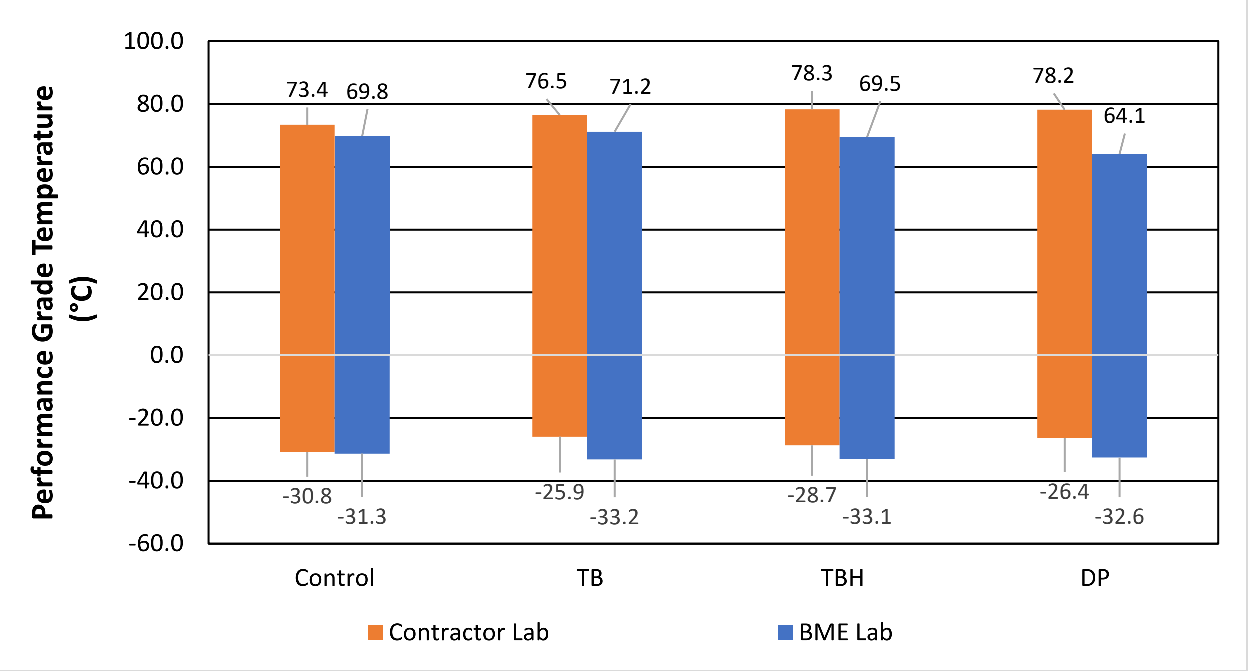


Figure 14: Laboratory Mixed, Pre-Production Recovered PG Grade

Figure 14 shows the extracted, recovered and PG graded asphalt from the Control, TB, TBH and DP mixtures. BME's recovered binder grading results for all of the mixtures are softer for both the high temperature and low temperatures.

4.2.1 Mix Design Verification Meeting

A meeting was held to discuss the results of the preproduction verification tests as they were concerning. The mix design requirements set by the SPV were discussed by both BME and the contractor to ensure both parties were following the correct procedures and that equipment was properly calibrated. While no main culprit was determined, it is worth noting that the aggregates for the BME batch tests were sampled at a different time from the contractor, and therefore may not be representative of the contractor's mixtures since there could be differences in P8 materials. The batch testing was not performed with a split sample. Additionally, the BME softer recovered binder grades cold be attributed to: a softer binder grade of the RAP used during lab mixing, less aging time, or a softer grade of the virgin binder. Lastly, the differences between the contractor and BME I-FIT results could be due to aging of the mixtures, which the I-FIT test is sensitive to.

Unfortunately, the project start date was approaching, and there was not enough time or information to justify new mix designs by the contractor or verifications by BME. Therefore, some considerations were made. It was decided to accept the Hamburg results because they were all under 12.5mm rut depth. The DCT data was accepted because it demonstrated results that were all greater than or equal to the control results as required by the SPV. And, while the I-FIT data showed variable and non-equivalent performance, it was decided to move forward to collect production data and hopefully learn more at the end of this research study.

It was also decided during this meeting that additional material would be collected during production, compacted, and provided to WisDOT so that they could perform the Indirect Tensile Asphalt Cracking Test (IDEAL-CT).

4.3 Preconstruction Pavement Condition Survey

As part of the RFP, a pavement condition survey was required before the old pavement was removed and again approximately one year after the new test sections were constructed. The purpose of this survey was to determine the type, quantity, and severity of the distresses in the pavement. These distresses included longitudinal cracking, transverse cracking, fatigue (alligator) cracking, international roughness index (IRI), and rutting. The distresses were measured following ASTM D6433-16 in a digital survey vehicle and summarized for each 1/10-mile segments for the length of the entire project to make detailed comparisons in performance. The vehicle used to take the measurements is shown in **Figure 15**.

Figure 15: Digital Survey Vehicle Used to Measure Pavement Distresses

The results for longitudinal cracking are shown below in **Figure 16**. These cracks form along the length of the pavement. They can be caused by a poorly constructed joint, shrinkage of the asphalt layer, cracks that reflect up from and underlying layer, and longitudinal segregation due to improper paver operation [13]. These cracks are not load related. The distresses are measured in feet and are normalized to feet/mile of segment length. The survey measures 3 levels of severity which are defined as:

- **Low**: Filled cracks or non-filled cracks with a width less than 10 mm.
- **Medium**: Non-filled cracks with widths between 10 to 75 mm and/or light random cracking.
- **High**: Non-filled cracks with widths greater than 75 mm and/or medium severity random cracking.

In the case of **Figure 16**, lower values and severities for longitudinal cracking are better.

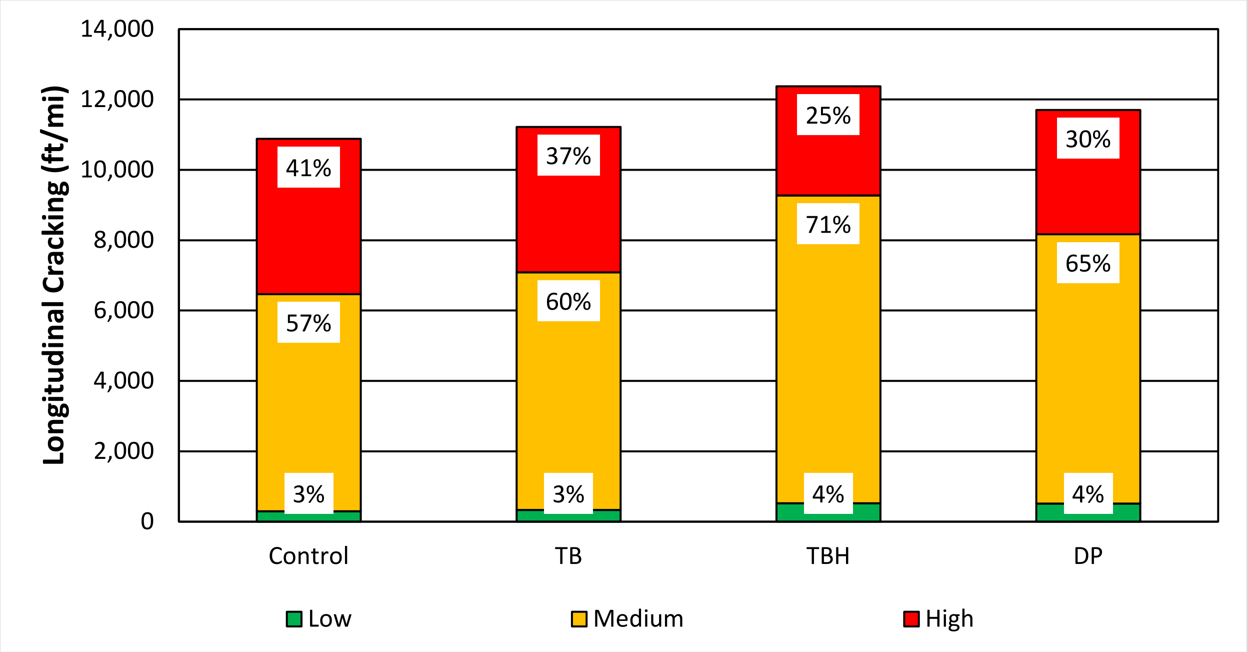


Figure 16: Preconstruction Pavement Condition Survey – Longitudinal Cracking

The results for transverse cracking are shown below in **Figure 17**. These cracks form across the pavement width. They can be caused by cold-weather shrinkage of the asphalt or reflection from an existing crack from the underlying layer [13]. These cracks are not load related. The distresses are again measured in feet and are normalized to feet/mile of segment length. The survey measures 3 levels of severity which are defined in the same manner as longitudinal cracking. Lower values and severities are for transverse cracking are better.

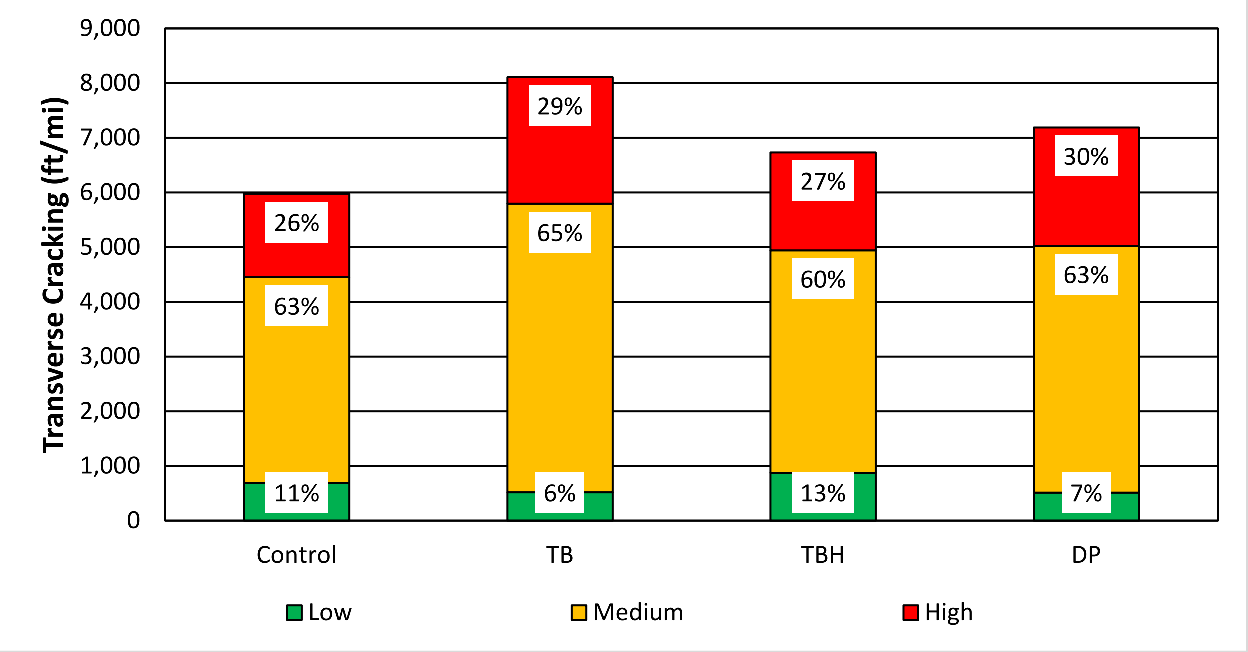


Figure 17: Preconstruction Pavement Condition Survey – Transverse Cracking

The results for fatigue (alligator) cracking are shown below in **Figure 18**. These cracks present as a series of interconnected cracks. They are caused by load-related deterioration resulting from a weakened base course or subgrade, too thin of a pavement layer, poor drainage, overloading, or a combination of these factors [13]. These stresses are measured in feet^2 and are normalized to feet2/mile of segment length. The survey measures 3 levels of severity which are defined as:

- **Low**: Few interconnected hairline cracks with no spalling.
- **Medium**: Light cracks in a pattern with some spalling.
- **High**: Well defined patterns and noticeable spalling at edges.

In the case of **Figure 18**, lower values and severities for fatigue cracking are better.

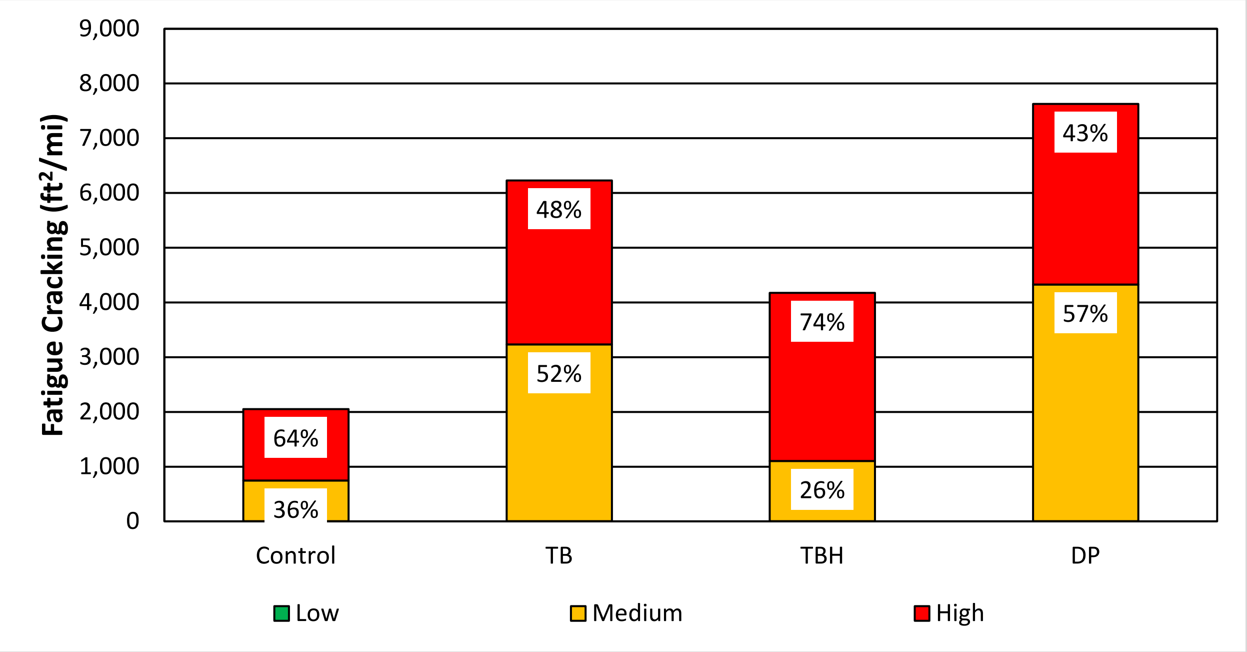


Figure 18: Preconstruction Pavement Condition Survey – Fatigue Cracking

The results for International Roughness Index (IRI) are shown below in **Figure 19**. IRI is used to measure the roughness and irregularities on a pavement surface. It is based on the average rectified slope, which is a filtered ratio of a standard vehicle's accumulated suspension motion divided by the distance traveled by the vehicle during measurement. The IRI is equal to the average rectified slope multiplied by 1,000 [14]. IRI is measured in inches/mile of pavement segment and lower values are better.

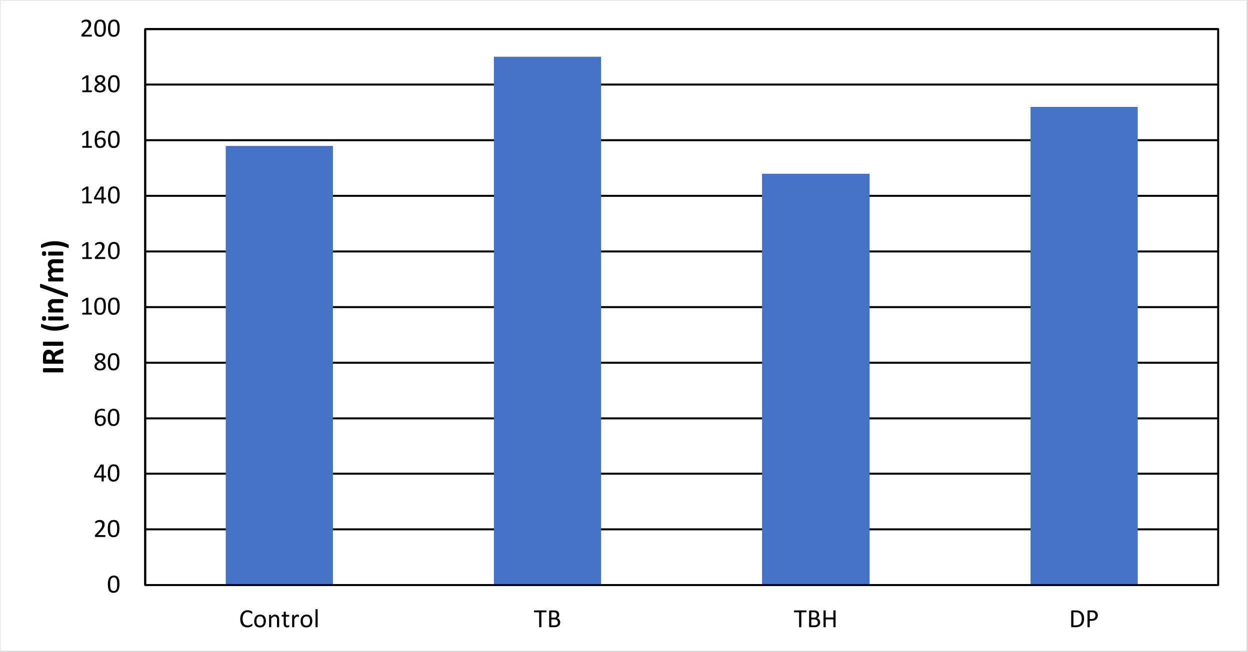


Figure 19: Preconstruction Pavement Condition Survey – International Roughness Index

The results for rutting are shown below in **Figure 20**. Rutting is defined as a surface depression in the pavement. There are two types of rutting, mix rutting and subgrade rutting. Mix rutting occurs when the subgrade does not rut but the pavement surface exhibits rutting as a result of insufficient compaction or mix design issues. Subgrade rutting occurs when the subgrade exhibits rutting due to loading. When this happens, the pavement settles into the subgrade ruts causing rutting to occur in the pavement layer as well. This survey, however, does not discriminate between mix and subgrade rutting. Rutting is measured in inches as an average rut depth and lower values are better.

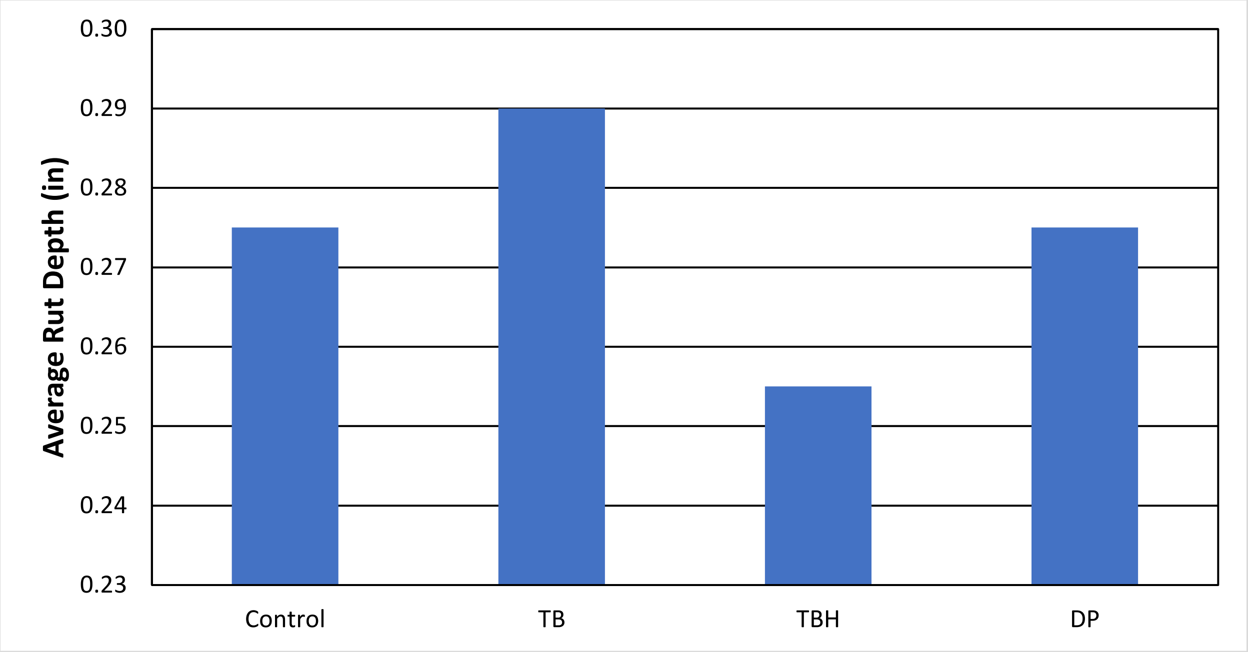


Figure 20: Preconstruction Pavement Condition Survey - Rutting

5. Production of GTR Test Strips

The following are the dates for the GTR test strips and control section productions:

Table 7: Test Strip Construction Schedule

Date	Mix Design	Test Section
6/6/2019	Terminal Blend	Test Section #1
6/7/2019	Terminal Blend Hybrid	Test Section #2
6/20/2019	Control	Test Section #3
6/20/2019	Dry Process	Test Section #4

5.1 Sampling Procedure and Quantities

To complete the required performance and volumetrics testing, enough material had to be sampled from each production mix. The performance testing regime includes Disk-shaped Compact Tension testing at short- and long-term aging, Illinois Flexibility Index Test at short- and long-term aging, Hamburg Wheel Track testing at short-term age only, and IDEAL CT at short-term age only. Each test strip is broken down into four (4) sublots. Based on each test's material requirements to produce adequate replicates and the number of sublots for each test section, it was determined that 2.1 tons of material were needed. That breaks down to 1,067 lbs. (484 kg) per test section (lot) and 267 lbs. (121.1 kg) per sublot.

A breakdown of the testing regime is presented in **Table 8** with the number of sublots tested per test.

Table 8: Testing Regime and Number of Tested Sublots per Mix Type

Lab Tests	Volumetrics	AC & Gradation	DCT	DCT (LTOA)	IFIT	IFIT (LTOA)	Hamburg	IDEAL CT*
Dry-Process	4	4	4	4	4	4	4	4
Terminal Blend	4	4	4	4	4	4	4	4
Terminal Hybrid	4	4	4	4	4	4	4	4
Control	4	4	4	4	4	4	4	4
Total	16	16	16	16	16	16	16	16

*IDEAL-CT will be collected and compacted as part of a separate contract.

Material for each mixture was sampled on the day the test strips were paved. A crew of technicians was present at the plant during production. Samples were collected from the truck box by dumping a portion of the material onto the grade corresponding to each sublot. Material was then shoveled into buckets, re-blended, and quartered back into pans weighing approximately 5,500 grams (12.13 lbs) each to satisfy AASHTO R 30 depth requirements. Proper aging of the mixture according to AASHTO R 30, required pans measuring 16" x 11" x 2.5" (406.4 mm x 279.4 mm x 63.5 mm) in size which were filled with not greater than 50 mm (~1.97 in.) of material (shown in **Figure 21**). Using this procedure, 22 pans per sublot of material was required for a total of 88 pans per lot and 352 pans of material collected for the entire project. Pans were then covered with foil to limit further aging and prevent contamination, and labeled accordingly with the test section number, the rubber product name, and the sublot number. After all the material was collected it was immediately returned to the BME lab for testing.

Figure 21: Pans used and Filled with Asphalt Mixture for Uniform Aging

5.2 Field Nuclear Density and Coring

Density was tested during production using the random location format typically used for Wisconsin's Quality Management Program. Test durations were 1-minute, rotating the gauge 180° for each subsequent measurement at a testing location. A third test was taken in the original gauge orientation (in the direction of paving) if the two initial tests were not within 1.0 lb. (0.45 g) of each other. Density results are available in the Appendix in sections 13.7-13.10.

Each test strip had twenty (20) density locations. Of those twenty locations, two (2) of them were used to create compaction growth curves. The two locations were then averaged for percent max density and temperature and plotted in **Figure 22**, **Figure 23**, and **Figure 24**. The compaction growth curves were made by taking density immediately after the paver and before the roller, and after each successive pass of the roller. The roller types were noted whether they were hot, intermediate, cold, or static rollers. Temperatures were also measured and recorded using heat guns after each roller pass while density was being measured. Due to the frequency at which the rollers would pass a testing location, test times had to be reduced on the gauge or in some cases stopped early. Test durations ranged from 10-30 seconds for the growth curves. The reduced testing durations did not seem to significantly impact the results. Final densities were still taken at these locations using properly specified times and gauge orientations.

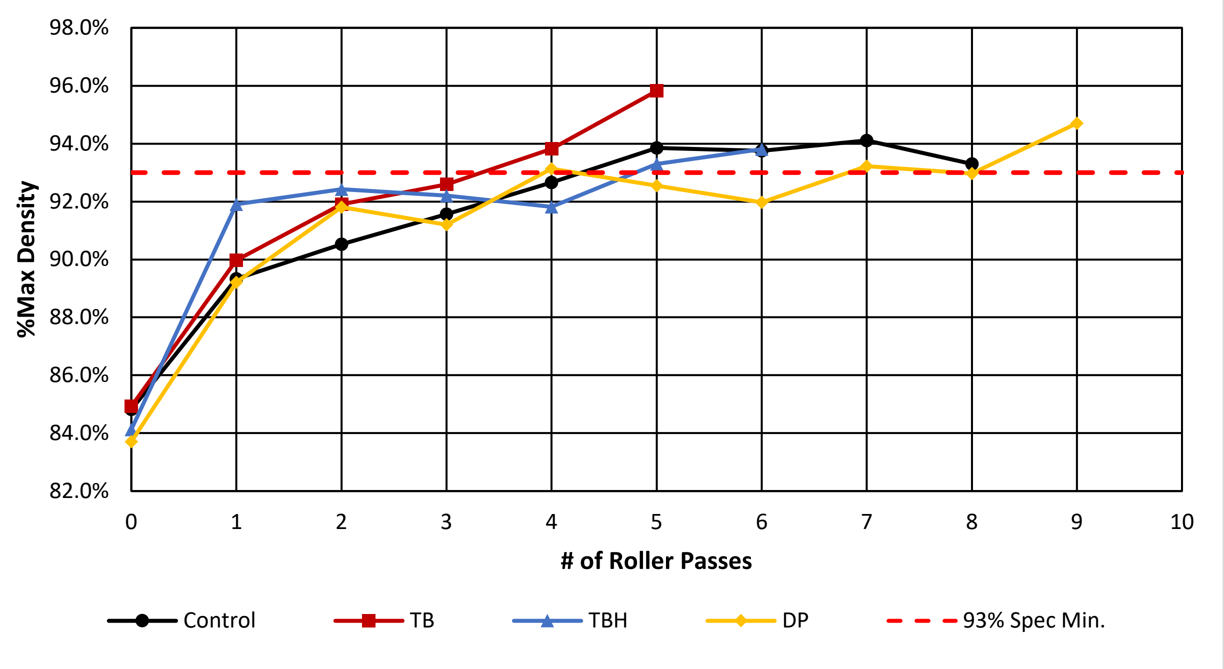


Figure 22: Nuclear Density Compaction Growth Curves – Roller Passes vs. % Max Density

Figure 22 shows that all but the DP mixture achieved the minimum required density of 93% after 5 roller passes. The DP mixture achieved minimum required compaction after 4 roller passes and then oscillated around 93% maximum density until the 9th pass which then surpassed 94%. Compaction after the 5th pass did not generally improve the density and in some cases even reduced it as can be seen with the control mixture and the DP mixture.

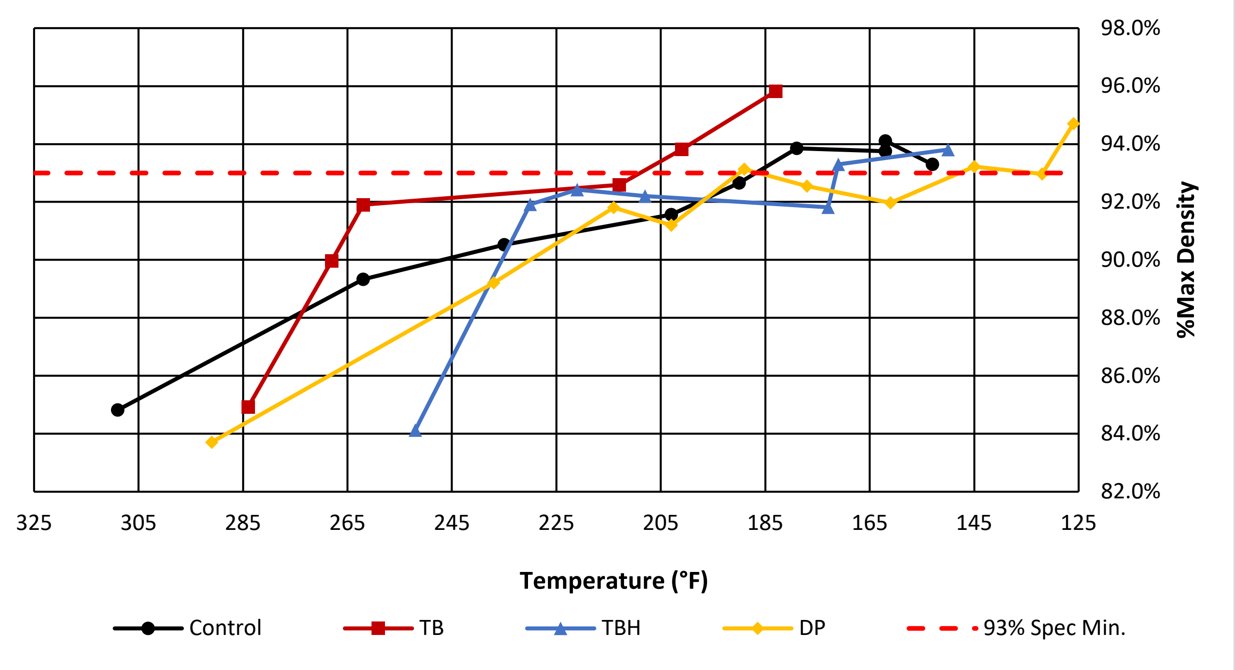


Figure 23: Nuclear Density Compaction Growth Curve – Temperature vs. % Max Density

Figure 23 shows compaction as a function of the temperature when the roller passed the testing location. Each individual point still represents one successive pass of a roller. The purpose of this graph is to show what temperatures appear to be the most effective for density gain by analyzing the slopes between two consecutive points. The TB shows that between about 126.7°C (260°F) and 98.9°C (210°F) that there was a plateau with very little gain in density with each roller pass. After the mixture had cooled below 98.9°C (210°F) each successive roll had a greater impact on densification. A similar trend can be seen with the TBH with the exception that the plateau has shifted towards lower temperatures (between 110°C [230°F] and 79.4°C [175°F]). While not as apparent, the DP rubber also exhibited a similar behavior, but again at a lower temperature range than the TB and TBH (between 87.8°C [190°F] and 54.4°C [130°F]). This plateauing could be caused by the increased elasticity provided by the rubber and polymer as the mixtures cool with a dependence on both the additives and blending process used to produce the GTR modified mixture (terminal vs. dry process). The control mixture showed relatively uniform densification with each successive pass of the roller throughout the cooling process up until about 94% max density was achieved.

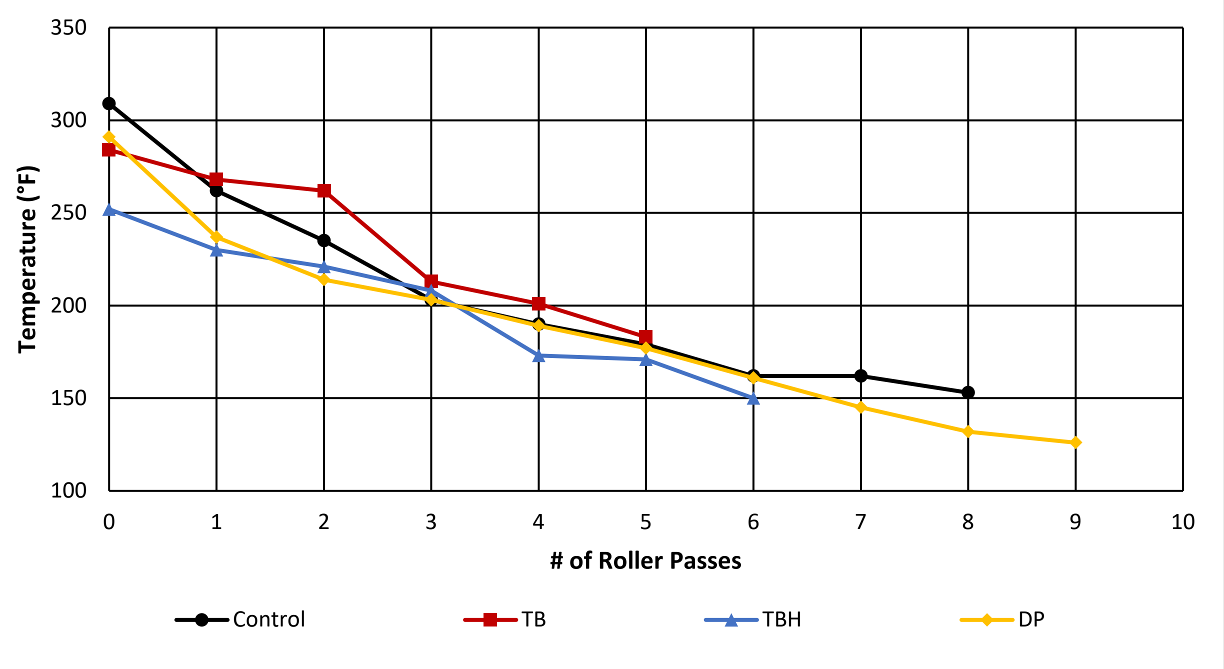


Figure 24: Nuclear Density Compaction Growth Curves – Roller Passes vs. Temperature

Figure 24 shows temperature loss as a function of the number of roller passes. Both the control and DP mixes show an approximately equal initial rate for loss in temperature after the first roller pass. This rate in temperature loss is greater than when compared to the terminal and terminal hybrid blends which also exhibited an approximately equal rate for loss in temperature. After the third roller pass, all mixtures exhibited approximately the same rate of decrease in temperature with successive rolls. It is worth noting that while the temperature decreased at approximately the same rate for all mixtures after the third roller pass this did not always correspond to a substantial increase in density as was seen with the terminal and terminal hybrid blends in **Figure 23**. Additionally, since the time between rolls was not measured, in terms of time, it cannot be said that the temperature decreased uniformly, just that when a roller passed the temperatures dropped about the same amount, regardless of the mixture type.

Ultimately, it appears the biggest factor for achieving densification for GTR asphalt mixtures is temperature. As **Figure 22** suggests, minimum density can be achieved in as a little as 4-5 roller passes as long as those passes occur within temperature ranges that do not plateau as demonstrated in **Figure 23**. It is conceivable to achieve density with less than 4-5 roller passes if those passes are made in temperature ranges where density is most likely to be impacted, depending on the mixture type.

5.3 Production Volumetric Lab Testing

This section summarizes the production testing results of the various GTR asphalt products used to construct the test strips by both the Contractor and the BME lab. Volumetric analysis was performed to determine how production mixtures compared to the JMF. Test results include Air Voids (Va), VMA, Gradation and AC.

5.3.1 Volumetric Testing Results

Samples collected during production were tested by the contractor and BME. Please note that the BME samples were reheated samples, where reheating followed the procedures provided in the SPV. Contractor samples were tested onsite while the sample was still hot. Also, BME tested four samples per test section, while the contractor tested three. All graphs below show the test data in chronological order from left to right, however actual tonnages were not provided.

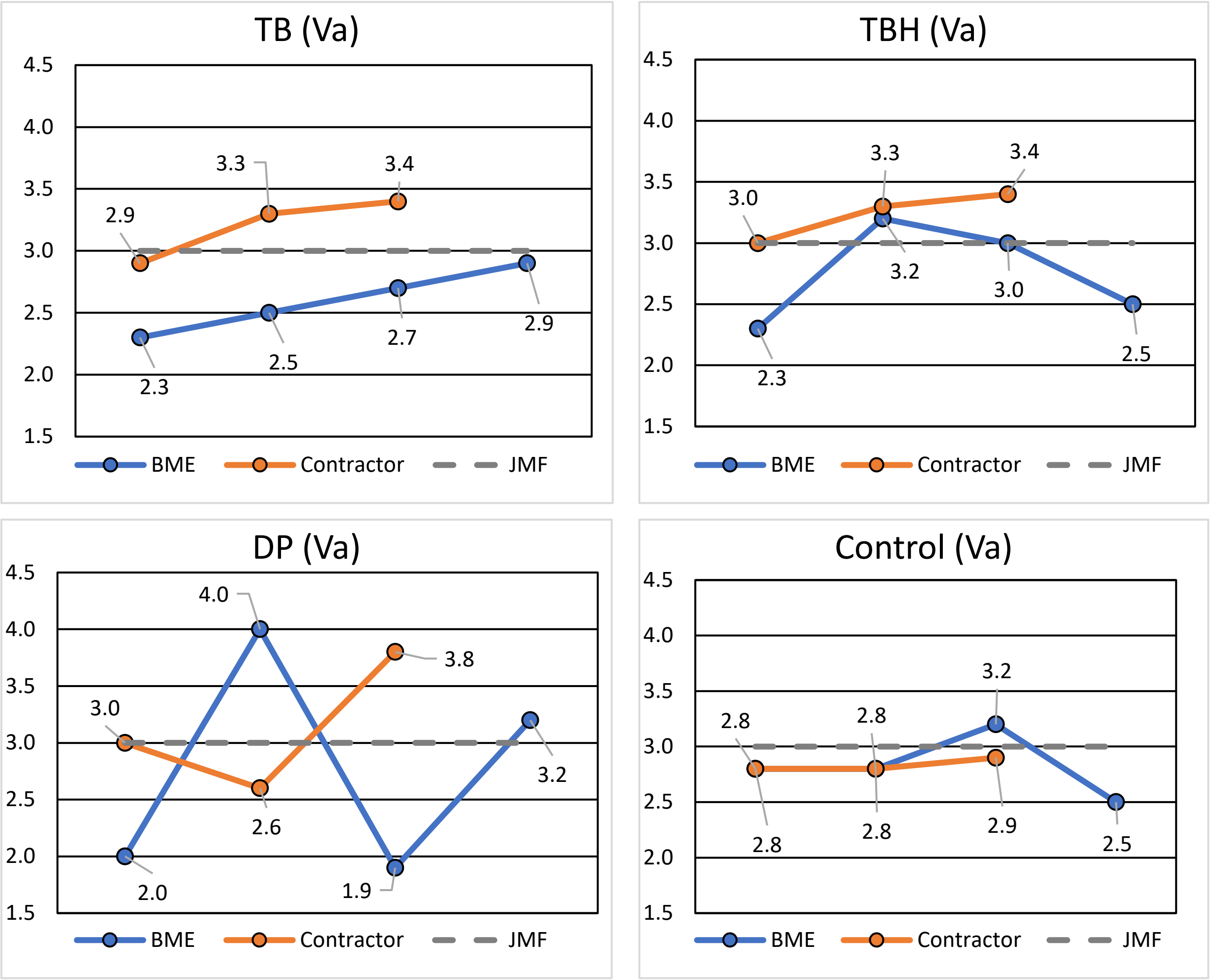


Figure 25: Production Air Voids (Va)

The control, TB, and TBH mix had air voids and VMAs that were within approximately 1 standard deviation for of the JMF for the BME samples, while the DP mix had a higher and more variable VMA than the JMF during production. It is interesting to note that both terminal blends air voids and VMA from the BME lab were consistently lower than the contractor's air voids, which may indicate an impact of reheating.

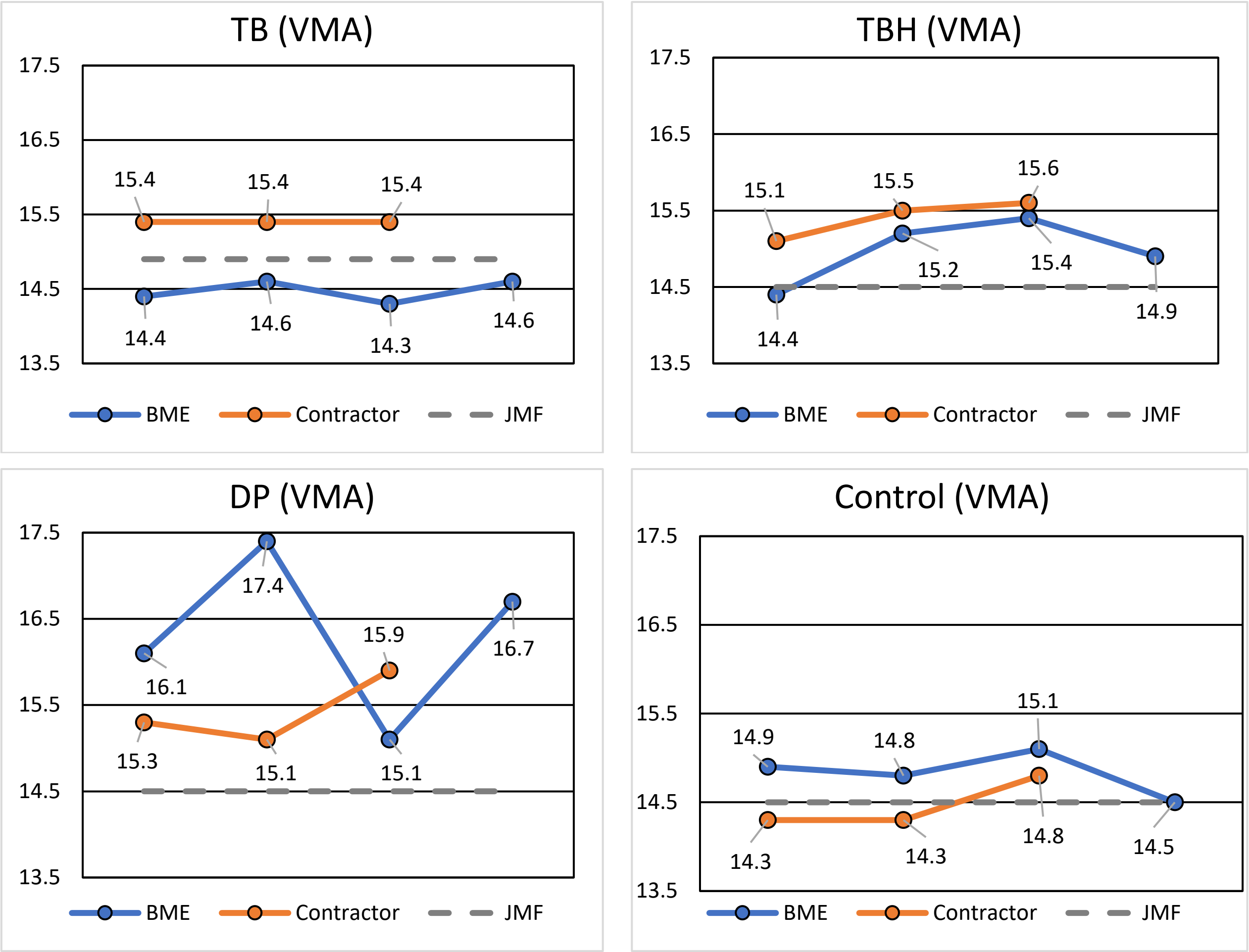


Figure 26: Production Voids in the Mineral Aggregate (VMA)

It is worth mentioning that producing pucks using reheated production DP mix was significantly more difficult. Technicians frequently had issues extruding the specimens from the Superpave Gyratory Compactor (SGC). Additionally, the air voids were much more variable, even for mixtures produced using similar batch weights and gyrations in the SGC. In order to resolve this, the compaction temperature was increased from 135°C to 160°C (275°F to 320°F). This temperature increase made it much easier to extrude the samples, as well as improved the ability to achieve air voids. This issue is further explored in section 6.0 Unique Challenges Working with GTR Mixtures.

5.3.2 Asphalt Content

Production ACs for both the contractor and BME are presented below in **Figure 27**.

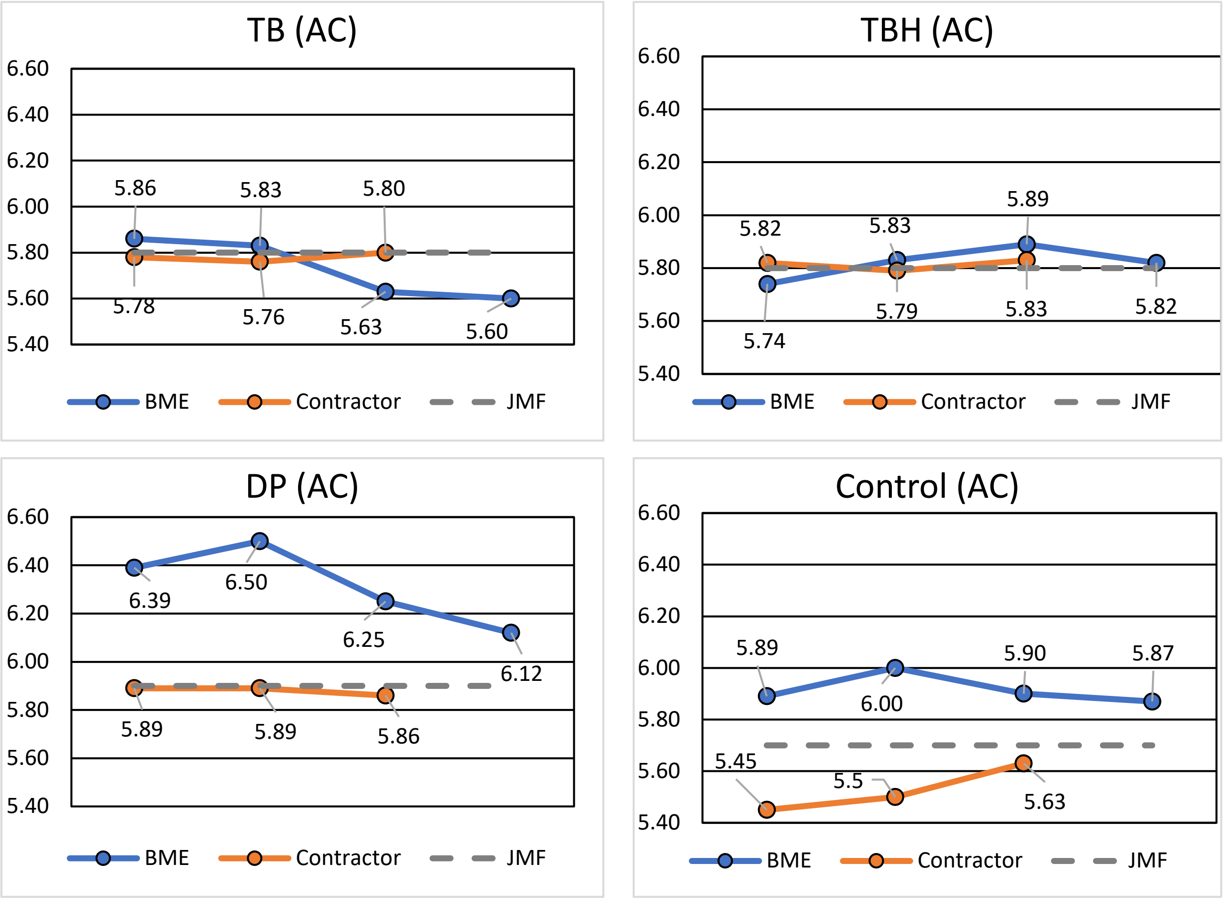


Figure 27: Production Asphalt Content (AC)

Figure 27 compares the asphalt contents, however the methods used to determine the asphalt content were different, as shown below in **Table 9**.

Table 9: AC Test Methods

Mix Design	AC Test Method	
	Contractor Lab	**BME Lab**
TB	Plant print-out	Automatic Extraction
TBH	Plant print-out	Automatic Extraction
DP	Plant print-out	Automatic Extraction
Control	Ignition Oven	Automatic Extraction

Addressing the control mix first, the difference in reported ACs can be attributed to the different methods of extraction. It is important to note that the BME gradation also resulted in 1% higher P200. This difference could be attributed to a correction factor, or additional wash cycles during the automatic extraction.

The plant printout is a method where the plant will measure and report weights (across the belts or through the asphalt pump) for an arbitrary amount of time. This data will result in a calculated percent AC. From the submitted data for the contractor’s second DP sample (plant printouts are available for all mixes in the Appendix in sections 13.11-13.14), the plant printout reported the following:

Given from the plant printout:

Aggregate Wt. = 60 lbs.
RAP Wt. = 32.6 lbs.
Binder Wt. = 4.2 lbs.

Given from the mix design:

RAP AC = 4.5%

$$\%AC = \left(100 * \left(\frac{Binder\ Wt}{(\ Binder\ Wt + \ Agg\ Wt + \ RAP\ Wt)}\right)\right) + \left(\left(\frac{RAP\ Wt}{(Binder\ Wt + \ Agg\ Wt + \ RAP\ Wt}\right) * RAP\ AC\right)$$

$$\%AC = \left(100 * \left(\frac{4.2}{(4.2 + \ 60 + \ 32.6)}\right)\right) + \left(\left(\frac{32.6}{(4.2 + 60 + 32.6}\right) * 4.5\right)$$

$$\%\ AC = 5.85$$

The contractor reported 5.89% AC from their plant printout for their second DP sample, the difference of which is most likely rounding. On this same second sample, the contractor also conducted an automatic extraction per ASTM D8159 (same as BME). The result of that extraction was reported at 6.55% AC which matches more closely with BME’s automatic extraction data. All plant printout calculations compared to BME automatic extractions can be found in appendix, section 13.15.

With two automatic extractions reporting 0.6% higher AC than the JMF, a deeper analysis was needed. The AC reported from the plant printouts for the TB and TBH match up to BME’s automatic extractions. The main difference between the TB, TBH and the DP, is how the GTR binder is introduced at the plant. The percentages of TB and TBH binders are regulated by the plant’s asphalt pump or meter, where the GTR is included in the rubber modified binder material. On the other hand, the percentage of DP GTR is regulated by two separate operations where the DP GTR is augured into the mixing chamber and the virgin asphalt binder is regulated by the plant’s asphalt pump.

Going back to the mix design process, the DP GTR was premixed with the PG 58-28H and blended with the aggregates at the design JMF (5.9% AC). This process was part of the supplier’s recommendations and used in both the contractor and BME labs. So, while the mix design considers DP GTR modified asphalt as one product (like the TB and TBH), the plant is weighing the virgin binder and DP GTR separately. And, if the plant were to replicate the mix design, the plant should have accounted for the DP GTR weight and pumped less than 5.9% virgin AC into the plant.

In other words, the dry process is supposed to be 10% of the virgin binder. The plant computer (plant printout) for the contractor’s DP samples are close to 5.9% virgin AC, therefore it is clear the plant did not subtract off the 10% by weight of GTR. It should be noted that the contractor set the plant computer based on the supplier’s instructions.

If the weight of the GTR is added to the virgin asphalt weight (reported), the contractor’s second DP sample would have looked like this:

DP Binder Wt. = Binder Wt. + 10% GTR Wt.

DP Binder Wt. = 4.2 + 0.42 = 4.62

$$\%AC = \left(100 * \left(\frac{DP\ Binder\ Wt}{(DP\ Binder\ Wt +\ Agg\ Wt +\ RAP\ Wt)}\right)\right) + \left(\left(\frac{RAP\ Wt}{(DP\ Binder\ Wt +\ Agg\ Wt +\ RAP\ Wt}\right) * RAP\ AC\right)$$

$$\%AC = \left(100 * \left(\frac{4.62}{(4.62 +\ 60 +\ 32.6)}\right)\right) + \left(\left(\frac{32.6}{(4.62 +\ 60 +\ 32.6}\right) * 4.5\right)$$

$$\%AC\ (including\ DP\ GTR) = 6.26\%$$

This %AC (6.26%) matches closely with the BME reported (6.32% average) samples, as well as the contractor reported (6.55%) automatic extraction sample.

With this discovery, more questions were raised. BME spoke with S.T.A.T.E. Testing to discuss the procedures used in Illinois and on the Illinois Tollway. It was discussed that contractors do not adjust the added virgin AC to account for the DP GTR, but rather set the plant at the design JMF (most likely similarly instructed by the supplier). It is unknown if the contractors are seeing this same discrepancy with extractions. However, it is entirely possible that this discrepancy could be masked if the contractors are reducing virgin AC as a field JMF change in response to field testing results.

For this research, the contractor set the plant and did not adjust any parameters for the whole test strip. Therefore, the automatic extractions are correct, highlighting roughly 0.3% - 0.5% additional virgin AC than when compared to the mix design.

Volumetric results for each mix are also presented in tabular form in appendix section 13.6 Volumetric Summary of Production Tested Mix.

5.4 Production Performance Testing Results

All performance testing was conducted in the BME laboratory. The BME lab is AASHTO Re:Source accredited, and performs proficiency samples for Hamburg (AASHTO T 324). As was outlined in the SPV, the performance testing regime included short-term oven aged Hamburg Wheel Track testing, short- and long-term oven aged Disk-Shaped Compact Tension testing, and short- and long-term aged Illinois Flexibility Index testing.

5.4.1 Hamburg Wheel Tracking Test

The samples that were prepared as described in section 3.3.4.2 were tested using the Hamburg Wheel Tracking Test. Parameters of interest are the maximum impression, stripping inflection point, and the creep and stripping slopes. The maximum impression is the maximum amount of rutting observed after 20,000 passes (or less, if the maximum impression is reached before 20,000 passes) of the wheel. Mixtures must have maximum impressions less than 12.5 mm to pass the test after 20,000-wheel passes. The stripping inflection point (SIP) is the number of passes at which point the rutting begins to happen at a greater rate. This increased rate of rutting is thought to be attributed to the asphalt binder stripping from the aggregates weakening the overall asphalt aggregate matrix. The SIP occurs at the intersection of the creep and stripping slope tangents. The creep slope is the regular rate of rutting per wheel pass after the initial deflection (a higher rate of rutting observed shortly after the test begins for the first 1,000 or so passes). The stripping slope is the rate of rutting after there is a relatively substantial increase in the rate of deflection of the specimen.

The maximum impressions of the GTR mixtures are presented in **Figure 28**. The control and TB mixtures exhibited the most consistency between sublots whereas the TBH and DP mixtures had greater variability between sublots. The TB on average rutted less than the control by 1.29 mm and the TBH rutted 0.22 mm less than the control. The DP mixture had the highest susceptibility to rutting and on average rutted 3.92 mm more than the control mixture and in some sublots almost failing the test (≥12.5 mm rutting) while also exhibiting the highest variability of all the mixtures. This larger than expected rutting of the DP mixture is very likely due to the high %AC in the mixture as reported in section 5.3. High %AC is widely known to increase the film thickness and therefore the "lubricity" between the aggregates causing the mixture to be significantly more malleable.

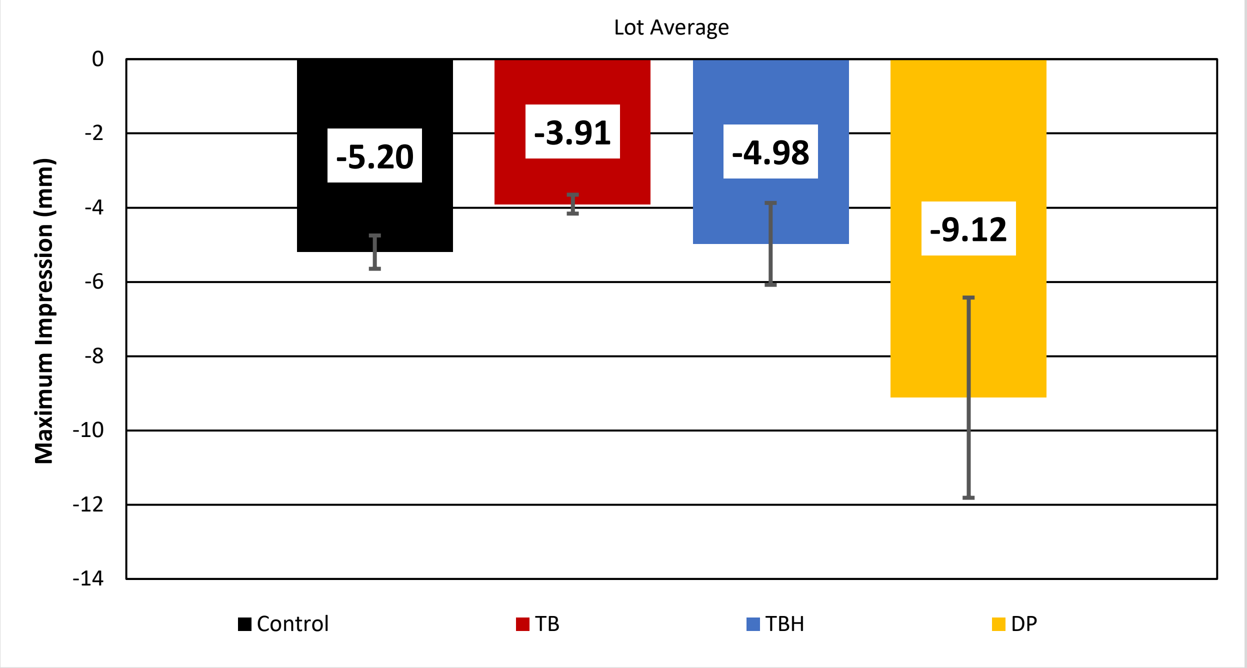


Figure 28: Hamburg Wheel Tracking – Average Maximum Impression for all Mixtures

The average creep slope results are shown in **Figure 29** and the average stripping slope in **Figure 30**.

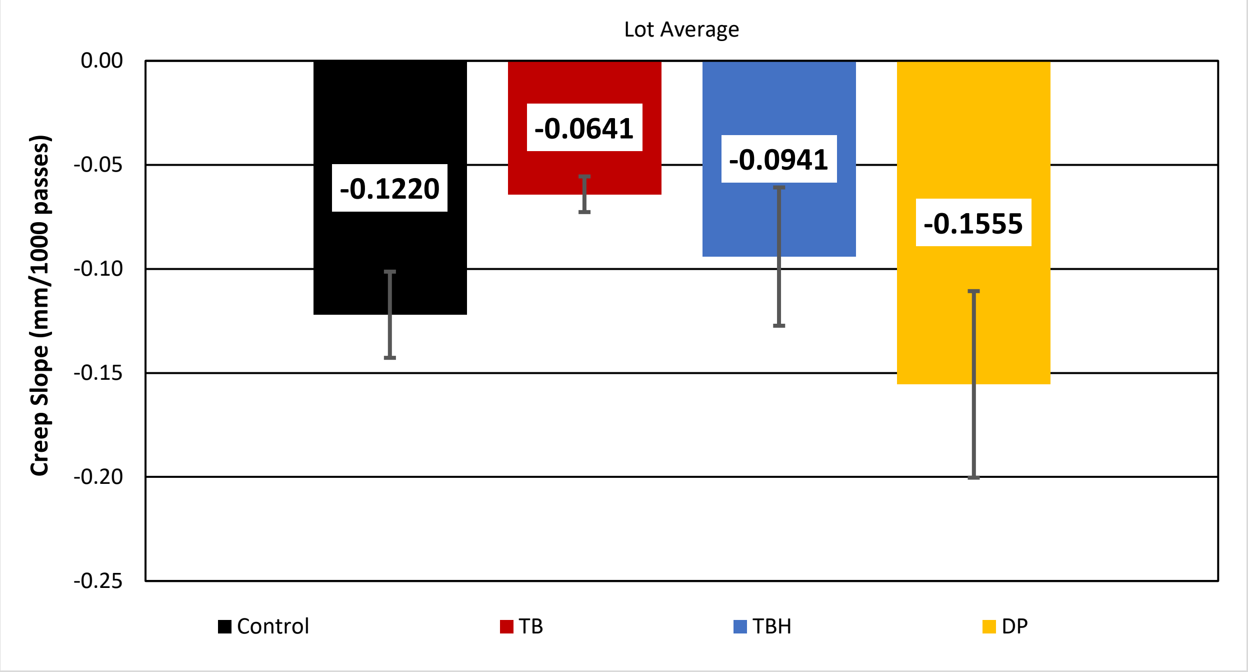


Figure 29: Hamburg Wheel Tracking – Average Creep Slope

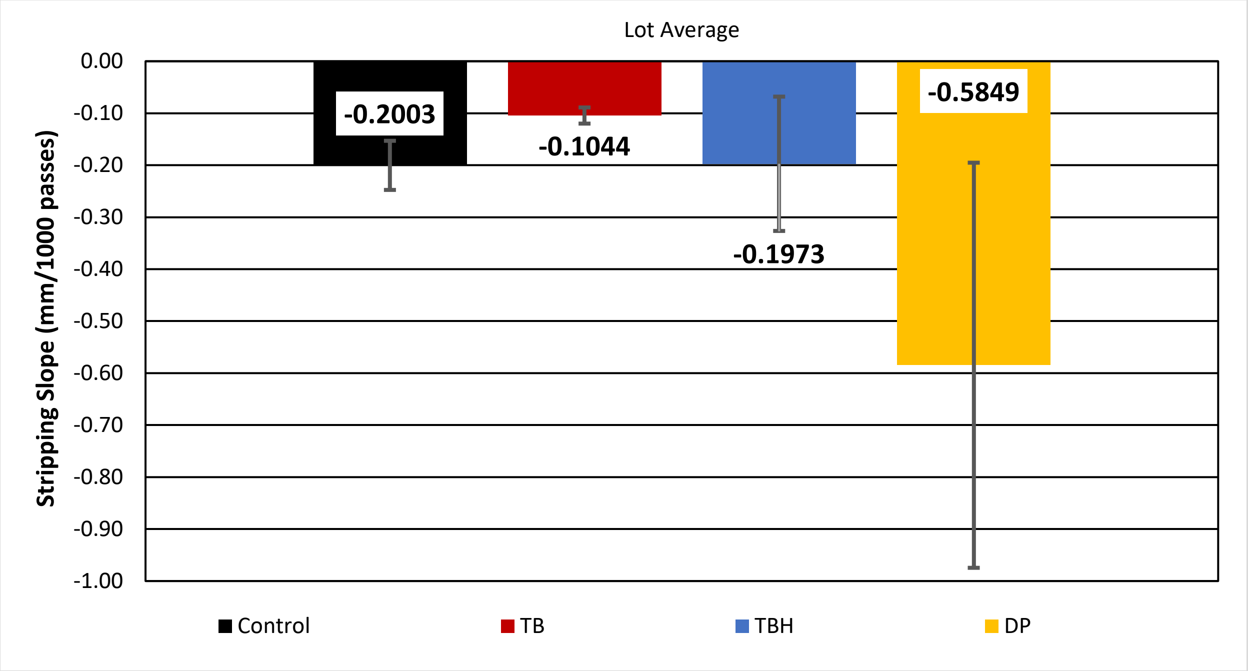


Figure 30: Hamburg Wheel Tracking – Average Stripping Slope

Both the creep slopes and stripping slopes agree in terms of ranking of performance based on rut depth compared to the control mix. The DP mixture shows the steepest slopes for both creep and stripping compared to the control, again with the most variability. This means that even before the mixture begins to strip and deteriorate more rapidly, it is structurally less performing than the control mix. If the DP mix had a more gradual creep slope, its stripping slope may not be as concerning. However, since this study is limited to only one mix design for each modification type, it is not possible to say this behavior would be expected for all DP mix designs, and again is likely caused by the high production %AC.

Due to all mixtures having slope inflection points (shown in **Figure 31**) occurring at a very high number of wheel passes, there is a strong correlation between the creep slope and final maximum impression. High slope inflection points as measured here indicate that these mixtures are not expected to exhibit stripping issues in the field. Please note the control mixture was a polymer-modified blend.

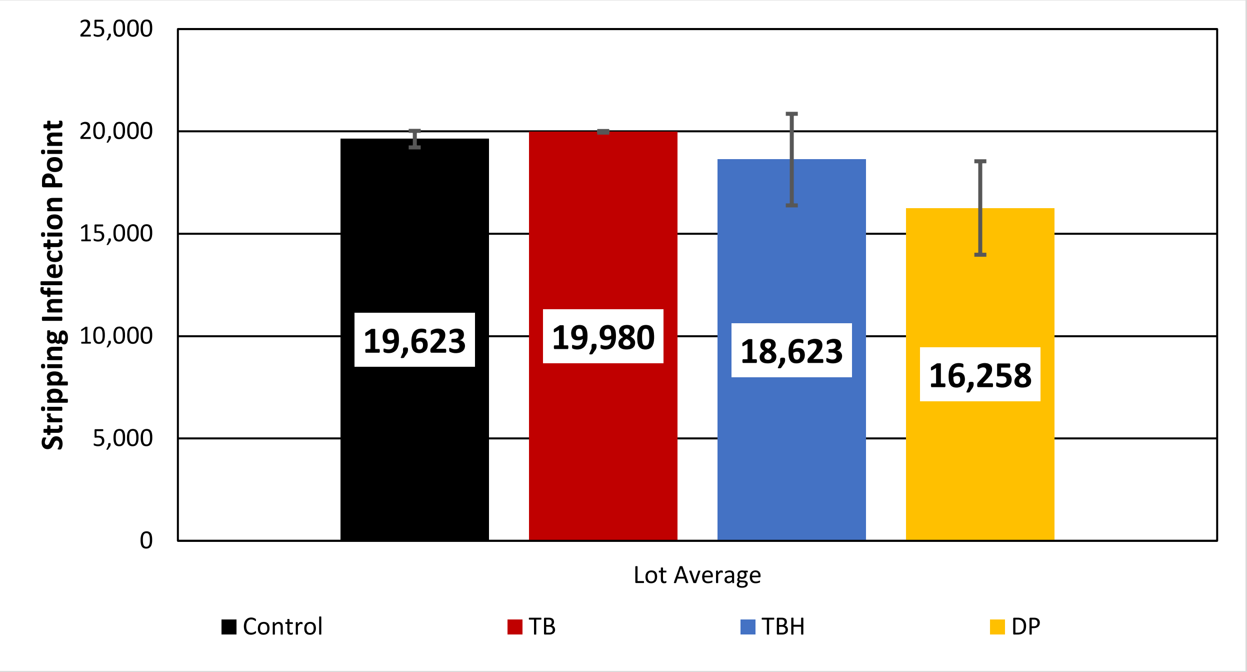


Figure 31: Hamburg Wheel Tracking – Average Stripping Inflection Point for all Mixtures

5.4.2 Disk-Shaped Compact Tension Test

The samples that were prepared as described in section 3.3.4.3 were tested using the Disk Compact Tension (DCT) test. The parameter of interest is the average fracture energy. Since this is a low temperature test, tested at -18°C (-0.4°F), the higher the fracture energy the better. A high fracture energy means that the specimen has a large ultimate tensile strength and/or a greater ability to relax accumulating internal stresses. In a typical pavement, low temperature cracks occur because of thermal contraction. As the pavement contracts, it is met with resistance due to friction from the underlying layers. Because the pavement is not allowed to shrink, it builds internal thermal stresses. Once that stress exceeds the pavements ultimate tensile strength, a crack forms which dissipates the accumulated stresses. These cracks are known as thermal cracks and form transversely to the length of the roadway.

In this study results were collected on samples that were both short- and long-term oven aged. This gives an indication of the mixture's performance after a few years in the field as well as after many years in service. The narrower the gap between short- and long-term oven aged performance the better because it means the mixture will remain durable throughout its service life. A wider gap between short- and long-term oven aging performance indicates a more rapidly deteriorating low temperature cracking resistance.

Average fracture energies for short-term oven aging of the specimens are presented in **Figure 32**, while long-term aged results are shown in **Figure 33**, and a comparison between short- and long-term aged specimens are shown in **Figure 34**.

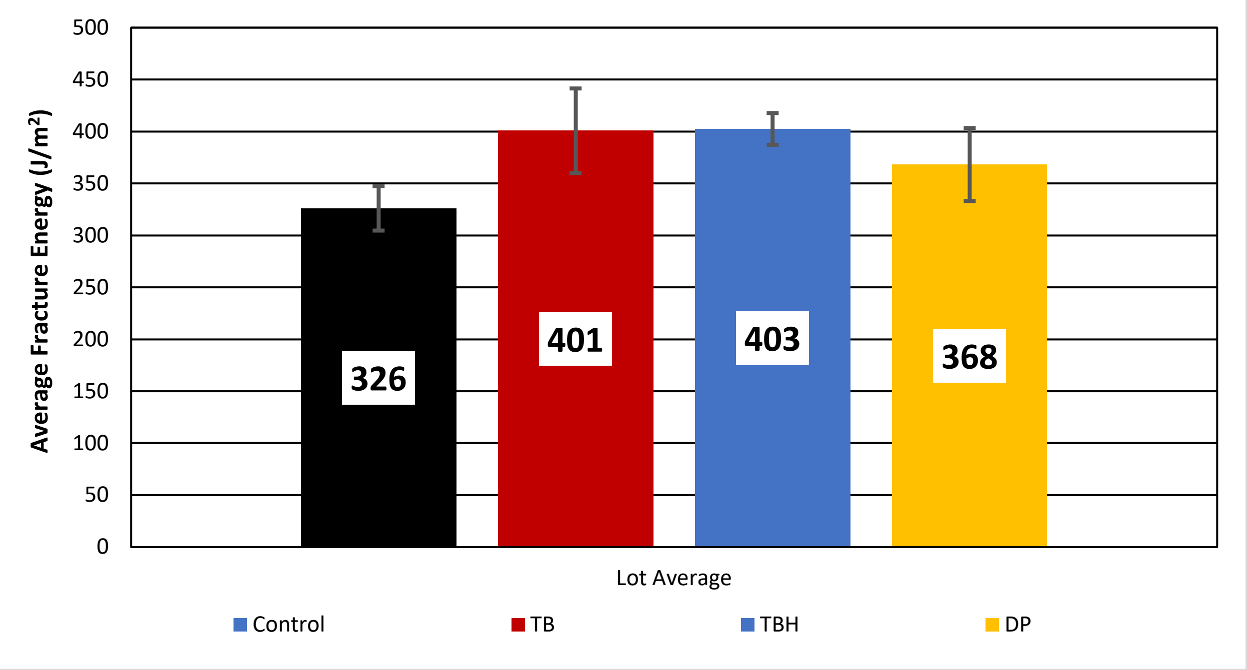


Figure 32: Disk-Shaped Compact Tension – Short-Term Oven Aged Fracture Energy

Figure 32 shows that all the rubber modified mixtures show improvement in the energy required to fracture the specimens over the baseline control mixture. All the mixtures, including the control, exhibit similar standard deviations, with the TB exhibiting the most and the TBH exhibiting the least. These results show that rubber modification can improve low temperature performance, even though performance gains are typically thought to primarily affect high and intermediate temperature performance such as rutting.

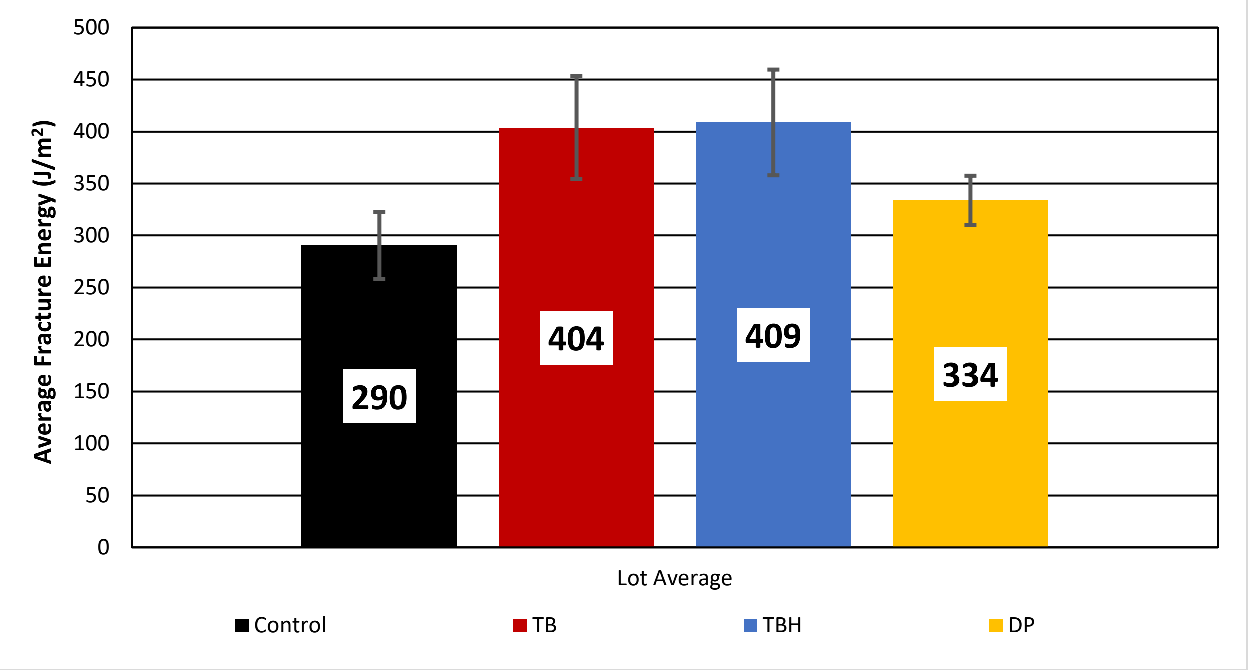


Figure 33: Disk-Shaped Compact Tension – Long-Term Oven Aged Fracture Energy

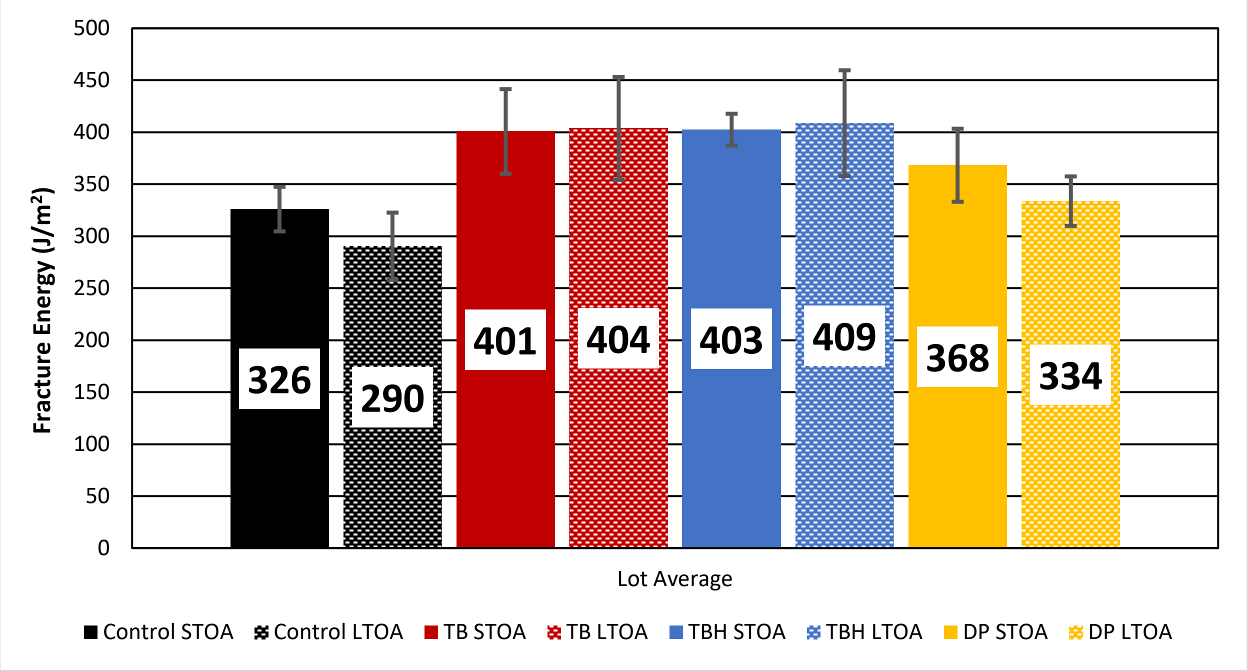


Figure 34: Disk-Shaped Compact Tension – Fracture Energy Comparison between Short- and Long-Term Aged Specimens

Figure 33 and **Figure 34** show the performance of the mixtures after long-term aging and compare the performance of the specimens between short- and long-term aging. Interestingly both the TB and TBH show a small improvement in fracture energy with age, while both the control and DP mixtures exhibited marginal losses in performance. These results, however, are within variability, so the overall conclusion is that there is likely very little impact on the low temperature cracking performance at least for the long-term aging protocol specified. Variability also marginally increased after aging for all mixtures except the DP, which saw a minor decrease in variability. Additionally, the increased %AC in the DP does not appear to have had any significant impact on the DCT results.

5.4.3 Illinois Flexibility Index Test

The samples that were prepared as described in section 3.3.4.4 were tested using the Illinois Flexibility Index test. The parameter of interest is the average flexibility index which is performed at intermediate temperatures. The flexibility index is calculated from the fracture energy and post-peak slope of the load-displacement curve. The flexibility index is used to identify brittle mixtures that are prone to premature cracking. Higher flexibility indices indicate mixtures that have better cracking resistance. However, the range for acceptable flexibility indices varies according to local environmental conditions, application of the mixture, nominal maximum aggregate size, the asphalt's performance grade, air void content, and the expected service life of the pavement.

The fracture energy indicates an asphalt mixture's overall capacity to resist cracking related damage. In general, a mixture with a higher fracture energy can withstand greater stresses with higher damage resistance. The fracture energy is dependent on the size of the specimen, loading time, and temperature. The fracture energy in this test includes the amount of energy dissipated by crack propagation, viscoelastic mechanisms away from the crack formation, and other inelastic, irreversible processes such as friction and damage at the loading and support points. Fracture mechanisms for viscoelastic materials are influenced by crack front viscoelasticity and non-localized to the crack bulk material viscoelasticity.

Fracture energies for short- and long-term aging for each sample are presented below in **Figure 35**.

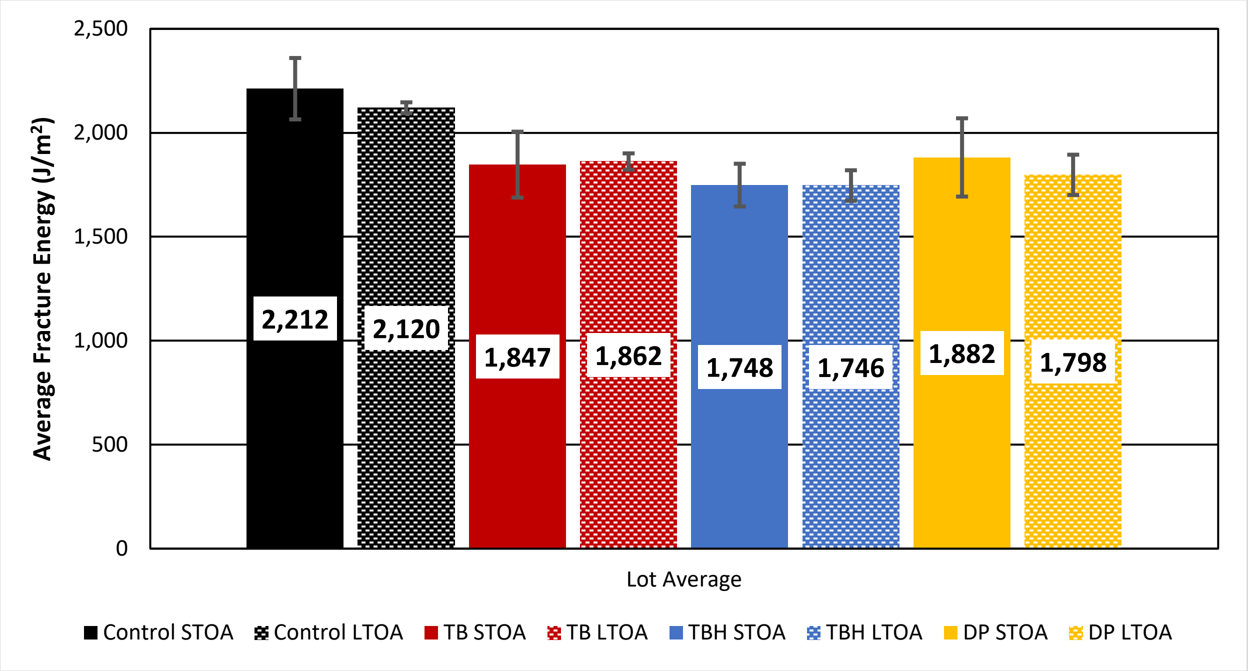


Figure 35: Illinois Flexibility Index – Fracture Energy Comparison between Short- and Long-Term Aged Specimens

Figure 35 shows that the fracture energies for the GTR mixtures were all lower than the control mixture. It is also apparent that the fracture energies are essentially unchanged from short-term to long-term aging for all the mixtures, indicating that fracture energy is not susceptible to aging, at least within the timeframes used in the aging protocol in this study. Since the flexibility index is calculated using the fracture energy and post-peak slope, this means that if any changes are occurring due to aging, they are occurring in the post peak slope. **Figure 36**, shown below, in fact shows this to be the case.

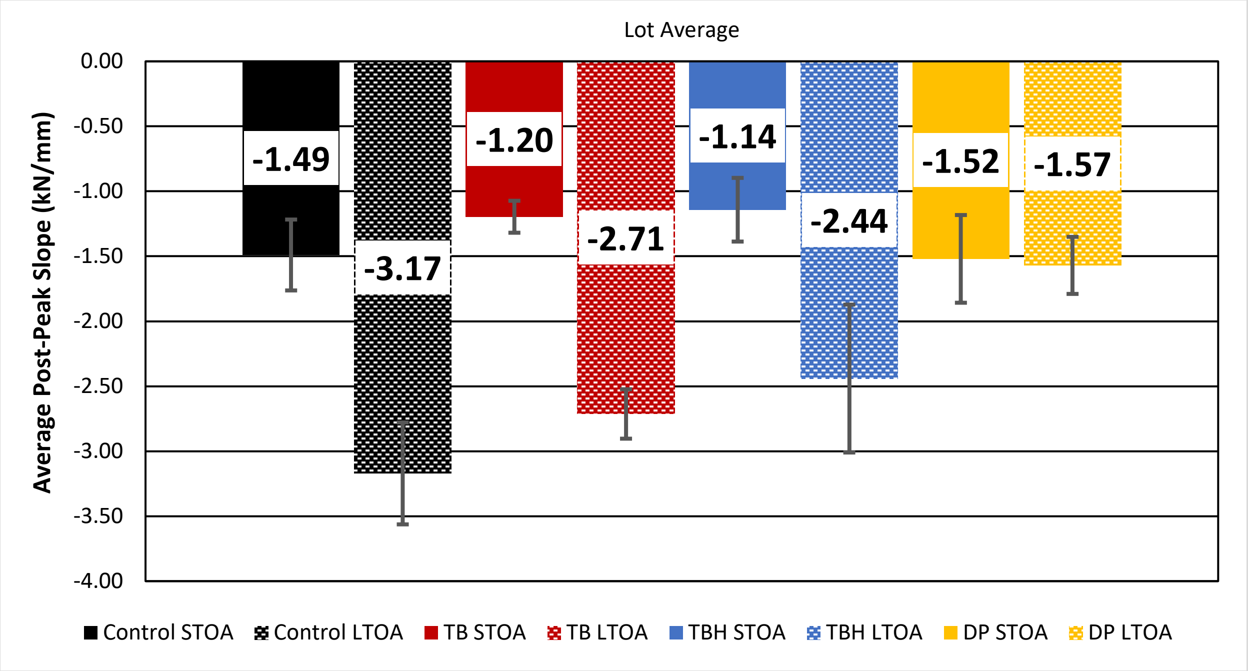


Figure 36: Illinois Flexibility Index – Post-Peak Slope Comparison between Short- and Long-Term Aged Specimens

Most of the post-peak slopes became much steeper going from short-term aging to long-term aging. This increase in slope indicates an increase in brittleness of the mixtures. Interestingly, the DP mixture exhibited very little change in both its fracture energy and post-peak slope meaning that this mixture has very little susceptibility to aging in terms of cracking. This decreased susceptibility is again likely caused by the increased film thickness due to the higher than specified %AC during production. The impacts of aging on the specimens can then be seen normalized as the flexibility index in **Figure 37**.

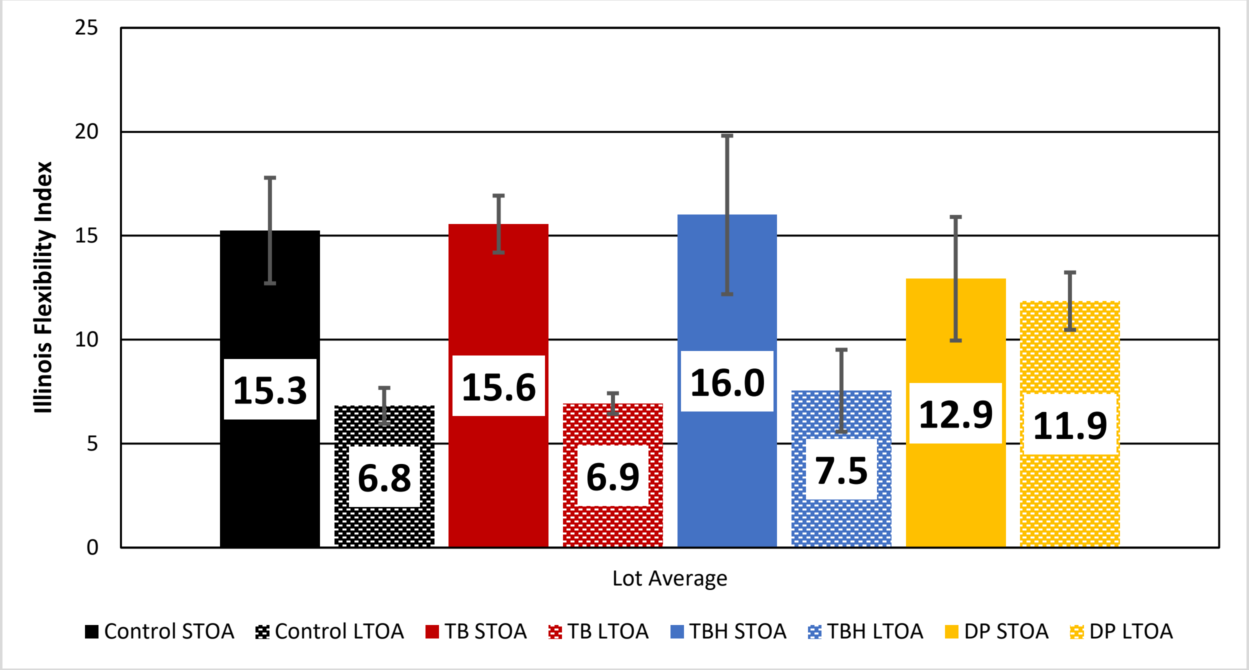


Figure 37: Illinois Flexibility Index – Flexibility Index Comparison between Short- and Long-Term Aged Specimens

Figure 37 shows that with the exception of the DP mixture, all the mixtures' resistance to cracking was reduced by just over 50%. It is important to note that – again with the exception of the DP mixture – that the terminal blends performed about equally as well as the control mixture. While the DP exhibited slightly lower performance in the short-term aged condition compared to the other mixtures, it's redeeming quality appears to be its ability to be resilient to aging in the long term, outperforming the other mixtures by nearly double the flexibility index. As mentioned previously, this reduction in aging susceptibility is most likely due to the higher than specified %AC during production. For the majority of the mixtures tested in this study, it can be said that the rubber modification provided very little benefit in terms of improvement to the flexibility index. It is likely that if the DP mixture had the correct %AC, it would have performed similarly to the other rubber modified mixtures.

5.4.4 Recovered Binder – PG and Presence of GTR Materials

Asphalt binder was extracted using an automated extraction according to ASTM D8159 and recovered according to ASTM D5404. The results of the continuous PG are shown below in **Figure 38** compared to those measured during mix design.

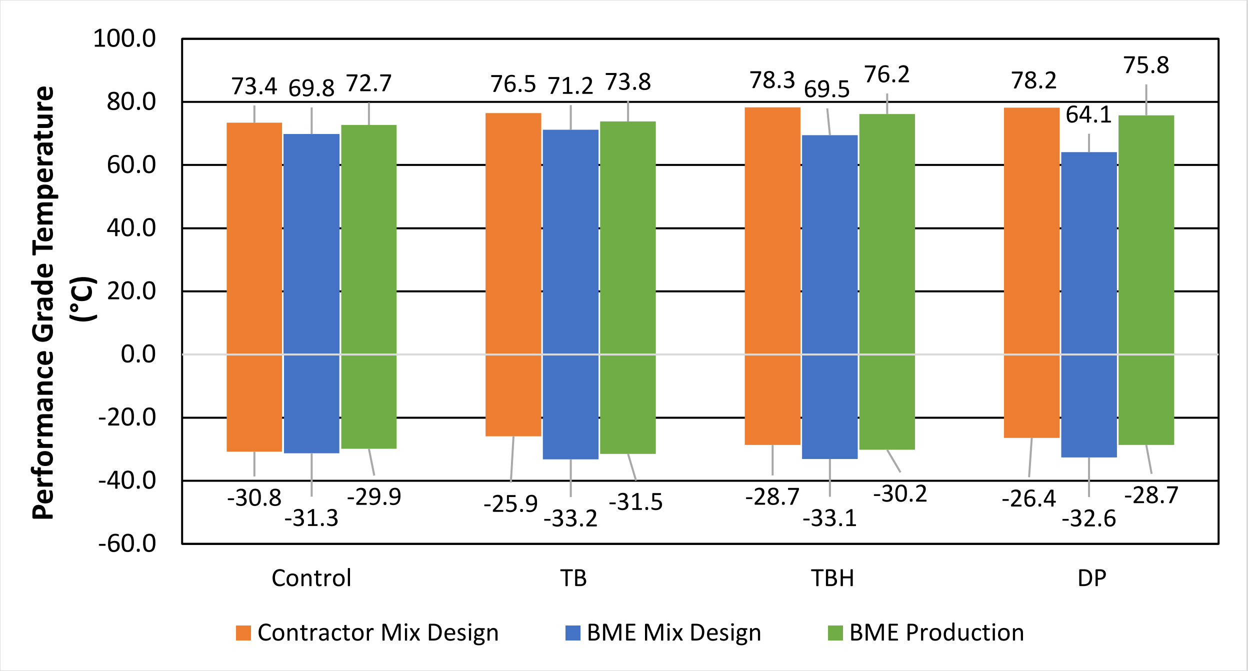


Figure 38: Recovered Binder PG for Lab Batched and Production Mix.

The production results were very consistent with the contractor's results during the mix design process. BME's mix design results were consistently, marginally lower than the contractor's. This difference could be due to a softer binder grade of the RAP used during lab mixing, less aging time, or a softer grade of the virgin binder. However, all resultant binders all met the same PG classification.

A question arose during the analysis of these resultant binders, "Does all of the GTR get captured in the binder when extracted?" **Figure 39** below shows the extracted aggregate materials.

Figure 39: DP Aggregate (Coarse and P200) Material After the Automated Extraction

It does not appear that any GTR remains in the extracted aggregate material. An additional check was performed by looking at the phase angles of the recovered binders. The results are shown below in **Table 10**.

Table 10: Recovered Binder Phase Angles for Production Mix

Temperature	Phase Angle (°)			
	Control	TB	TBH	DP
64	-	-	-	73.6
70	74.8	74.7	71.3	76.5
76	77.3	77.4	73.7	79.2
82	-	-	76.3	-

The phase angle is the time lagged strain response to an applied stress in the binder, a phenomenon associated with viscoelastic materials. A phase angle of 90° indicates a material that is perfectly viscous or inelastic, while a phase angle of 0° indicates the material is perfectly elastic. A phase angle anywhere in between is considered a viscoelastic response. When combining a more elastic component, such as GTR (lower phase angle), into the more viscous component, such as the asphalt binder (higher phase angle), it will produce a resultant material that has a phase angle somewhere in between the two constituents. Temperature also affects the phase angle of many viscoelastic materials to varying degrees.

In this check it was assumed that the TB binder's phase angle would be lower than the DP's if more rubber made it through the extraction process and remained in the TB extracted binder. Indeed, **Table 10** shows that this was the case for both common temperatures tested between the TB and DP binders (70° and 76°C) (158° and 168.8°F). In both cases, the phase angle was approximately 2° greater in the DP binder than in the TB binder. Two conclusions can be drawn from this. If it is assumed that the rubber products were the same (same phase angles before blending with binder) between the TB binder and the DP binder and that there is similar dosages of rubber to achieve similar performance, then it can be concluded that less rubber was fully incorporated into the DP binder, likely due to the incomplete blending in the dry process procedure. If they are assumed not to be the same rubber products and that the rubber is fully incorporated in the dry process, then it is possible that the DP rubber had a higher phase angle than the rubber used in the TB binder. Since there are stringent controls on the quality of rubber, it is more likely that the rubber products are similar between the TB and DP binders and that the dry process is less efficient at fully incorporating the rubber into the binder.

The extraction process qualitatively seems to indicate that most of the GTR is captured in the extracted binder material. The phase angle data indicates a presence of GTR. Therefore, from the standpoint of verification of mixtures, WisDOT should be able to verify the AC content (without a correction factor).

6. Unique Challenges Working with GTR Mixtures

This section discusses the unique challenges posed when working with GTR asphalt mixtures. These issues primarily arise due to the swelling nature of the GTR mixes, particularly the dry process mixtures.

6.1 Challenges when Producing Lab Compacted Specimens with Plant Produced Mix

The biggest challenge while working with the GTR mixtures was swelling, particularly after the production mixtures were reheated. This primarily created issues with the DP mixture. After compacting the reheated, plant produced, DP mixture, it became very difficult to extrude the compacted puck from the mold after the prescribed wait time of 30 minutes. In addition to being difficult to extrude, the DP pucks also exhibited large variability in their air voids. These issues were only encountered after reheating the mixtures as these difficulties were not experienced during the mix design phase earlier in the project.

When creating a puck for performance testing, BME would keep the height constant and change the mass of material in each mold. For most mixes, small changes in mass would dial in the mixture to ensure proper air voids (6.5% - 7.5%). Due to continual nonconforming air voids, samples were discarded and specimens had to be remade multiple times. Graphs illustrating this variability are shown below in **Figure 40** and **Figure 41**.

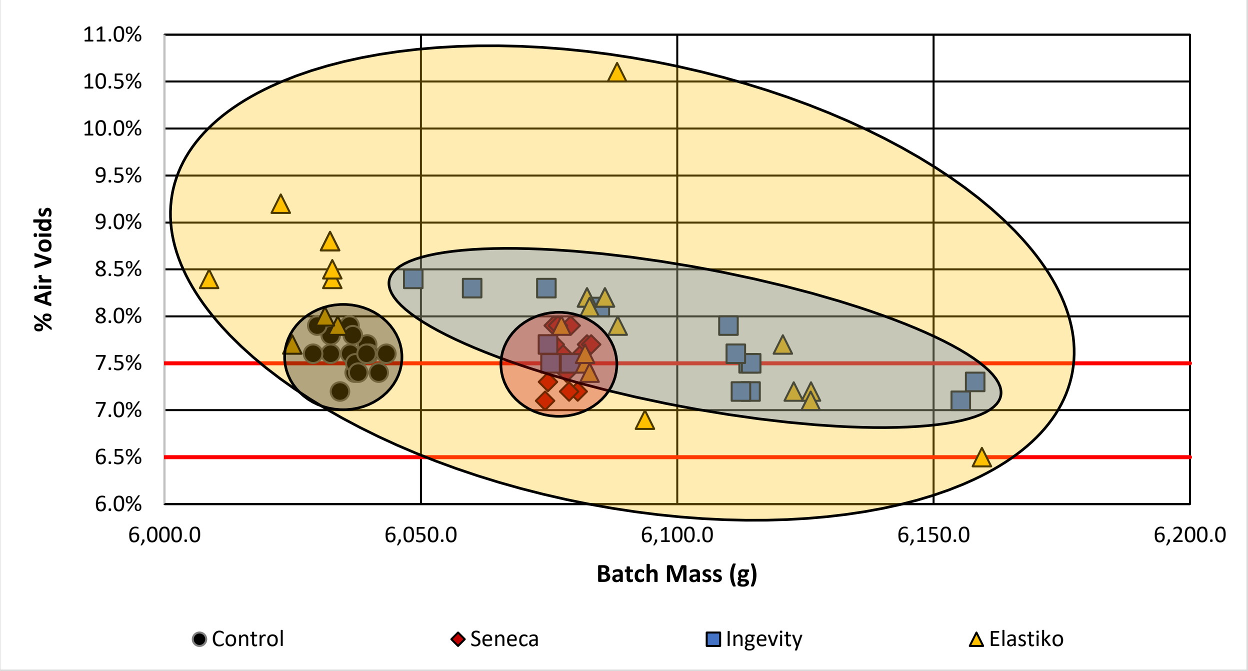


Figure 40: Air Void Production Reheat Variability – 150 mm Pucks

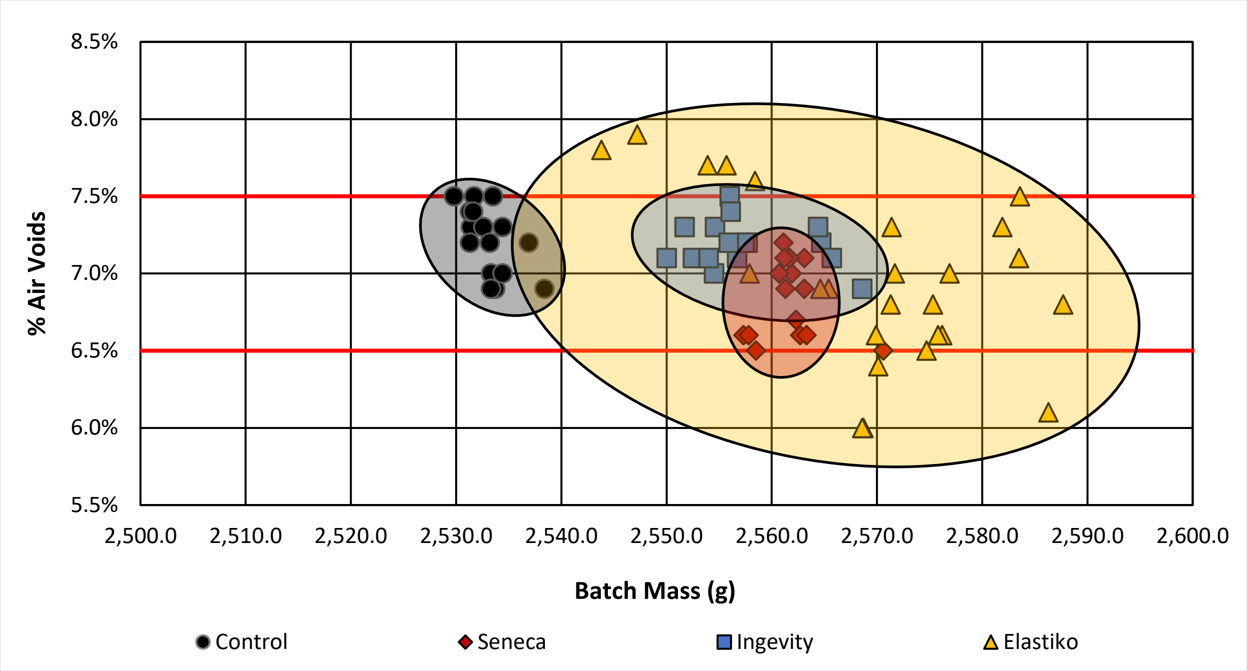


Figure 41: Air Void Production Reheat Variability – 63 mm Pucks

Both **Figure 40** and **Figure 41** plot percent air voids for individually cast pucks versus the batch masses used to produce them. Typically, when batching around the same masses for the same compaction heights, there is good repeatability of achieving the desired air voids. However, this was not the case for at least two of the mixtures, the TBH, and the DP mixture. Both 150 mm pucks (from which the 50 mm pucks were cut) and 63 mm pucks showed variability in the measured air voids for the two mixtures. Please note, air voids were tested on the cut specimen.

The variability is illustrated by the translucent circles encompassing the individual points which each represent one puck. The wider and larger the circle, the larger the variability. It can also be seen when choosing a particular batch mass because there may be a wide range of outputs (% air voids) for the given input (batch mass). The variability between the DP and TBH is in stark contrast with the variability shown for the control and TB which have very little variability in air voids around the batch masses. It is thought this variability could be due to additional swelling occurring during the reheating procedures of the plant produced mix.

6.2 Challenges when Measuring Field Density and Comparing to Cores

Another challenge when working with GTR mixtures is achieving accurate density. As was described in section 5.2 Nuclear Density and Coring, densification of the asphalt mat was generally nonlinear especially after 1-2 passes of the roller. In addition to this, measured density with the nuclear gauge in some cases was not representative of the location. In order to verify the nuclear gauge density readings, cores were taken at 5 of the random locations where density was measured with the nuclear gauge for direct comparison between the gauge and core. The comparison between the nuclear density gauge (solid bars) and of the cores (hashed bars) is shown below in **Figure 42**.

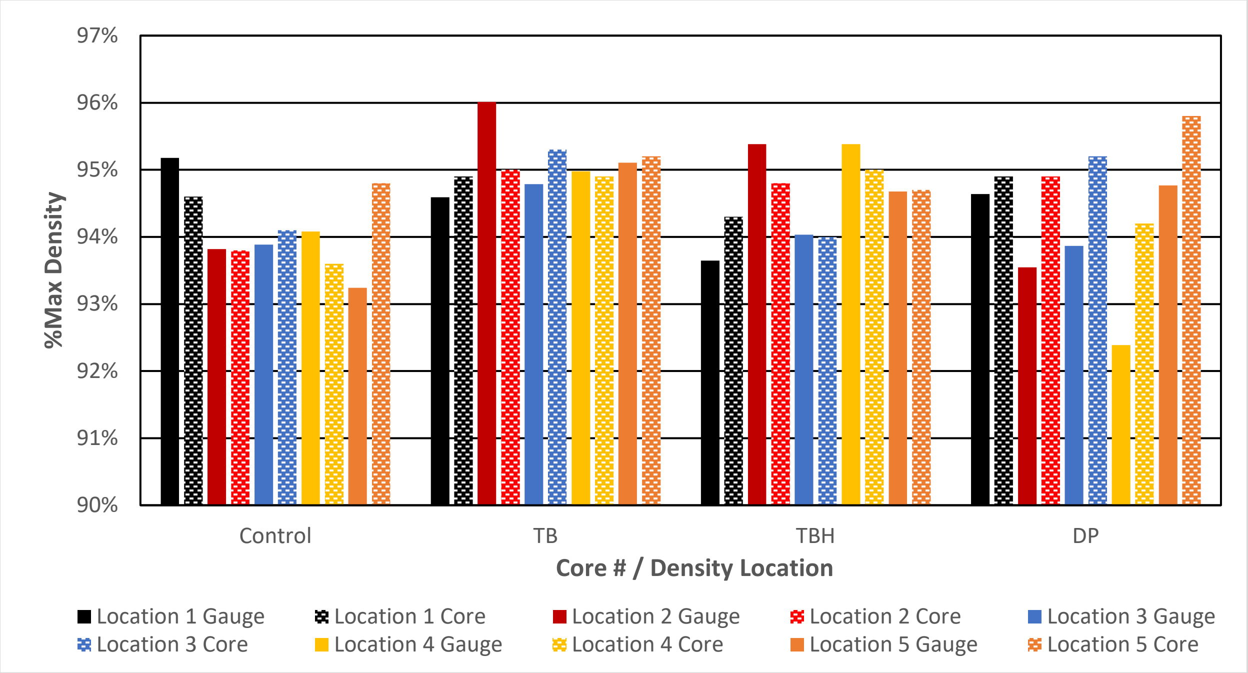


Figure 42: Field Density Comparison between Nuclear Gauge and Cores

In general, there was good correlation between nuclear gauge density results and core density results for the control, TB, and TBH. However, there are isolated instances of differences between the gauge and the core density, usually about 1% or less above or below that of the core. Conversely, the DP mix resulted in nuclear gauge density test results consistently lower, with some substantially lower, than the determined core density. In one case, the gauge reading determined a density that did not meet the minimum required 93% (location 4), while the core was actually over 94% max density. The average differences between the core and nuclear density gauge (core density - nuclear density) are as follows:

- Control: 0.14%
- Terminal Blend: -0.03%
- Terminal Blend Hybrid: -0.07%
- Dry Process: 1.2%

If dry process GTR is going to be used, it is recommended that a correlation be performed if nuclear density gauges are to be used to determine field density. Terminal blends do not appear to have this issue, so a correlation is less necessary.

6.3 Dry Process Mixture AC Content – Mix Design vs. Plant Production

As described in section 5.3.2, there is a discrepancy between the mix design procedures and the plant set up. During the mix design, both the contractor and BME labs premixed the dry process GTR with the virgin binder and added the JMF percentage (supplier's recommendations). During plant production, the contractor added virgin AC to the total JMF percentage (supplier's instructions). Please note, contractors in Illinois use this same plant set up. However, for this test section the contractor did not make any field adjustments, so the %AC remained elevated.

Furthermore, when WisDOT verifies a future dry process mixture, it is important for the mix design JMF AC (i.e. 5.9% AC) to be the same target value for the extraction. Therefore, with this new information a modification in either the design procedure or plant setup is needed.

7. 1-Year Post Construction Condition Survey

Section 4.3, Preconstruction Pavement Condition Survey, established the need for an additional condition survey to be completed approximately one year after construction of the GTR and control test sections of the roadway. The purpose of the survey remains the same, to identify the type, quantity, and severity of the various pavement distresses. While very few distresses should be present after only one year in service, a condition survey is beneficial in identifying early signs of pavement failures such as reflective cracking or rutting due to base issues. Again, the distresses that were measured include longitudinal cracking, transverse cracking, fatigue (alligator) cracking, international roughness index (IRI), and rutting. Distresses were measured following ASTM D6433-16 in a digital survey vehicle and summarized for each 1/10-mile segments for the length of the entire project to make detailed comparisons in performance. A picture of the vehicle used can be seen in section 4.3 in **Figure 15**. To avoid redundancy descriptions of each type of crack will be omitted in this section, however, detailed descriptions are available in section 4.3.

As a reminder for longitudinal and transverse cracking the levels of severity are defined as the following:

- **Low**: Filled cracks or non-filled cracks with a width less than 10mm.
- **Medium**: Non-filled cracks with widths between 10 to 75mm and/or light random cracking.
- **High**: Non-filled cracks with widths greater than 75mm and/or medium severity random cracking.

The results for longitudinal and transverse cracking are shown below in **Figure 43**.

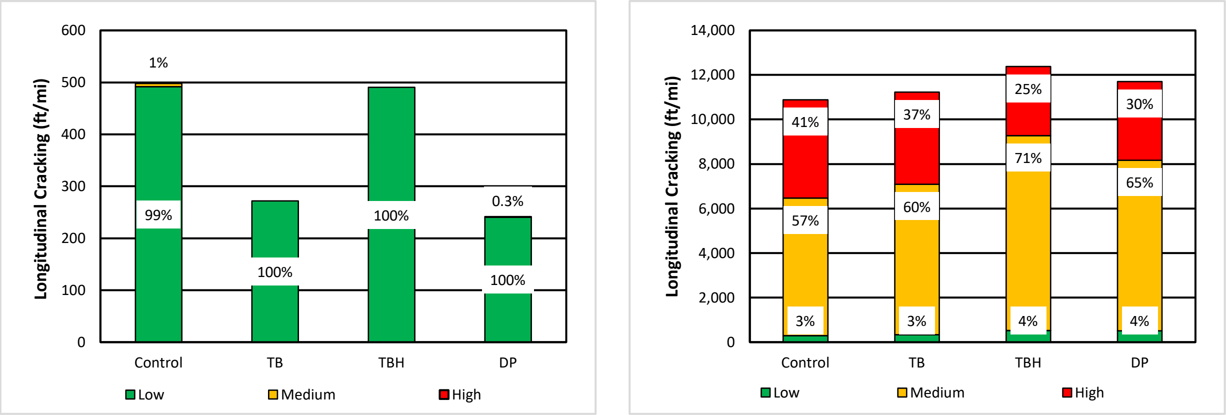


Figure 43: 1-Year Post Construction Pavement Condition Survey (Left) Compared to Preconstruction Pavement Condition Survey (Right) – Longitudinal Cracking

As expected after only about one year in service, there are very few and low severity longitudinal cracks formed. Compared to the preconstruction survey Test Strip 1 (TB) about 10,500 ft/mi less of cracking, Test Strip 2 (TBH) had 10,700 ft/mi less cracking, Test Strip 3 (Control) about 11,500 ft/mi less cracking, and Test strip 4 (DP) about 11,750 ft/mi less cracking. Since all the preconstruction cracks were about the same density and severity, there do not appear to be any concerning trends yet in the service life. It is worth noting, however, that both the control and terminal blend hybrid test strips have roughly double the density of longitudinal cracks than the

TB and DP test strips, with the control test strip already beginning to exhibit some medium severity cracking.

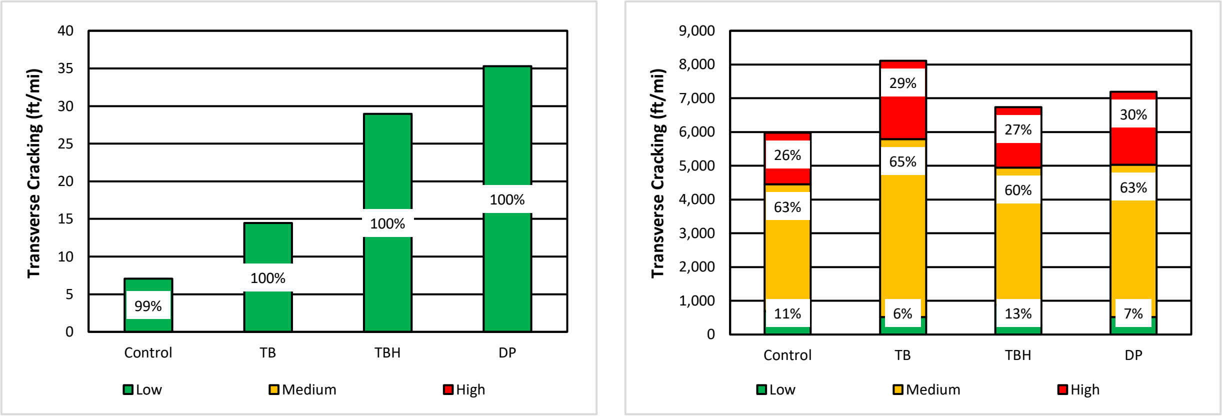


Figure 44: 1-Year Post Construction Pavement Condition Survey (Left) Compared to Preconstruction Pavement Condition Survey (Right) – Transverse Cracking

Compared to the preconstruction condition survey, the transverse cracking is negligible and of low severity. Transverse cracks are inevitable with pavements, especially as they age. As the pavement becomes more brittle with age, the ability to relax accumulating internal stresses also diminishes. Even with new pavements, transverse cracks can form. Depending on localized viscoelastic minutiae, a crack can form if the temperature drops lower than the low temperature PG grade. In this case the PG grade of the binder was specified as a 58-28. There will be some variability on the continuous grade, but if the temperature dropped rapidly or reached a very low temperature there is a chance for the formation of a transverse crack. It is also a possibility the crack is reflective from the underlying milled surface. Ultimately, the transverse cracking that has occurred over the last year is not of concern and shows no distinguishable pattern when compared to the preconstruction survey at this time.

After one year in service, there has been no formation of alligator (fatigue) cracks, therefore no data is available to present as all values are 0 ft/mi. Fatigue related damage should not be noticed for the first several years of service after pavement is placed. The lack of fatigue cracks indicates the pavement is performing as it should be.

IRI and rutting are shown below in **Figure 45** and **Figure 46** compared back to their preconstruction values (preconstruction in blue, post-construction in orange).

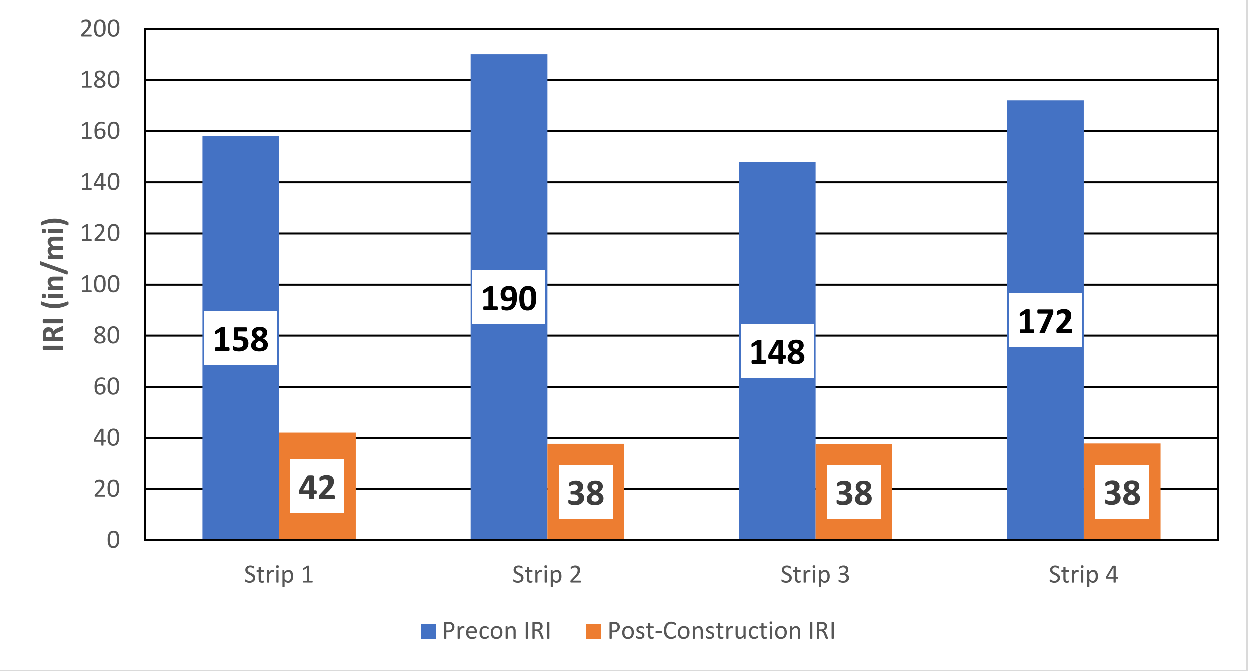


Figure 45: 1-Year Post Construction Pavement Condition Survey - IRI

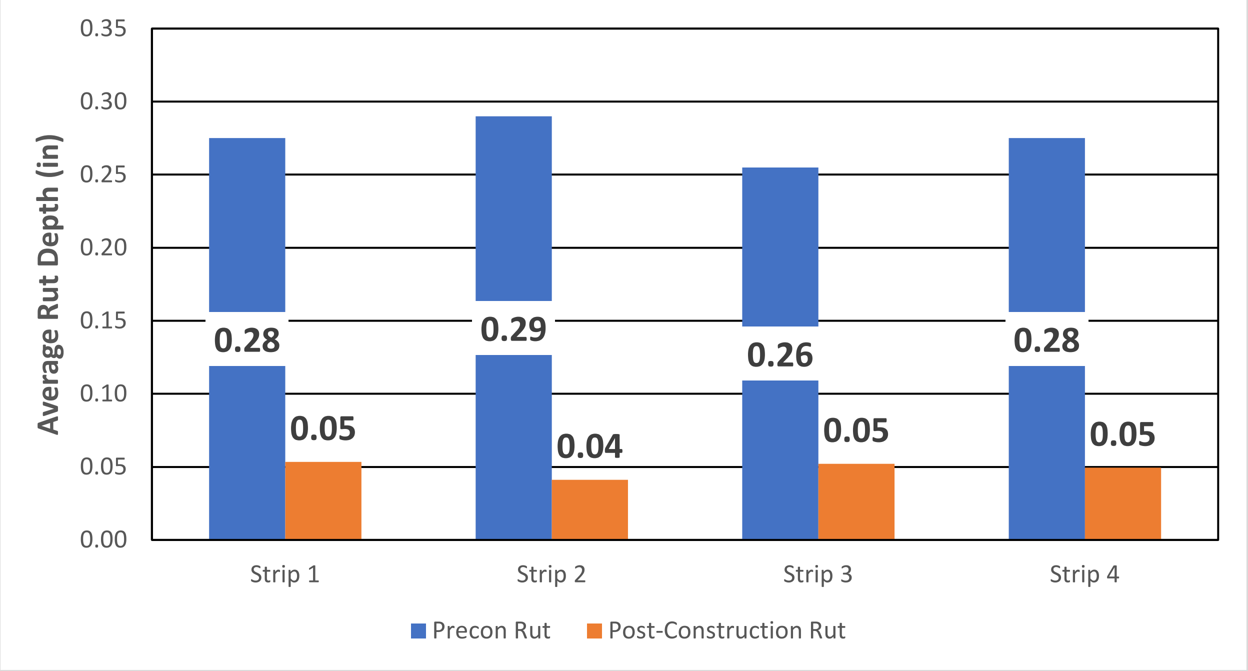


Figure 46: 1-Year Post Construction Pavement Condition Survey – Rutting

As was the case for the longitudinal and transverse cracking, it is still too early to tell if there are any unusual trends in the expected pavement performance with the IRI and rutting. The IRI values are very consistent across all four test strips with very little deviation between the values. The same is also true for the average rut depth. These values may begin to deviate as the pavement ages and becomes more travelled on due to differences in materials for each test strip. It is recommended this survey be repeated after 5 years in service and then 10 years in service in order to make proper long-term evaluations on the durability of these various rubber-modification methods.

8. Cost Analysis

Another way to view the performance is in terms of unit performance gained per dollar spent. Depending on what criteria is considered critical during design, the choice rubber product and processes for incorporation will vary. Therefore, **Table 11** offers some guidance on how much performance was gained per dollar versus the control mixture. Cells marked in green indicate which mixture performed the best given the criteria. Notes are also provided at the bottom of the table as to how the value should be considered.

Table 11: Unit of Performance per Dollar Spent

Mix	Price/Ton	Hamburg	DCT		IFIT	
		Mm Rut/$	Short Term J/m^2/$	Long Term J/m^2/$	Short Term FI/$	Long Term FI/$
Control	$65.98	0.08	4.9	4.4	0.23	0.10
TB	$78.07	0.05	5.1	5.2	0.20	0.09
TBH	$69.57	0.07	5.8	5.9	0.23	0.11
DP	$65.38	0.14	5.6	5.1	0.20	0.18
	Notes:	Lower is Better	Higher is Better	Higher is Better	Higher is Better	Higher is Better

One major consideration for this analysis is that the DP mixture was produced with roughly 0.3%-0.5% more AC than designed. Therefore, it is impossible to say whether the increased AC or the presence of GTR was the impetus for the higher rutting or increased resistance to aging. Even with higher than designed AC the DP mixture outperformed the control mixture in three of the five performance parameters while also being a more cost-effective mixture. It is unknown, however, whether the contractor accounted for the additional AC in this reported bid price.

Based on the table above, increased rutting performance can be seen with both the TB and TBH mixtures since they offer less rutting per dollar spent when compared to the control mix. The DP mixture's rutting performance per dollar spent was not less than the control's, but it still exhibited passing rutting performance (a maximum impression less than 12.5mm).

When considering the low-temperature cracking performance, the TBH mixture offers the greatest performance per dollar spent. It is worth noting that all the GTR mixtures offer values greater than that of the control, just to varying degrees. Since all the short-term and long-term values are greater than the control, they are all more economical than the control mixture for low temperature cracking performance. This criterion can be flexible when deciding which type of mixture to produce since they all perform better than the control mixture. This gives the contractor the choice of selecting a mixture that performs better for other criteria to achieve, in essence, a balanced mix design. For example, while the TB is not the top performer for low-temperature cracking susceptibility, it was a top performer for rutting per dollar spent. This means at the cost of some low-temperature cracking performance (compared to the TBH, additional rutting performance can be gained.

Flexibility indices were all roughly similar in terms of economic value since GTR mixtures offered very little improvement over the control baseline. In the best-case scenario in the short term, the TBH tied with the control blend in terms of performance per dollar spent. Long-term, however, the clear winner is the DP mixture since it showed a very low degree of aging susceptibility. Again, this may be due to the additional AC during production.

Overall, in terms of performance per dollar spent, the TB and TBH mixtures are the optimal choice. They offer an economical option and provide earnest improvements in every metric over the control mixture. The TBH, however, may be the most economical since it offers an improved rutting resistance, substantially better low-temperature cracking performance, and a similar flexibility index in the short- and long-term for $3.59 more per ton than the control.

9. Conclusions

GTR asphalt mixtures have been widely adopted and used for many years throughout the country. They are known for their ability to enhance durability properties of asphalt mixtures, primarily at the high to intermediate temperature range, but also to a lesser extent at lower temperatures. GTR mixtures can also improve cracking performance, binder elasticity and recovery, rutting and skid resistance, ride quality, noise levels, and decrease moisture susceptibility.

While it is still too early to tell from the post-construction condition survey, it is expected that after a similar number of years in service the performance will be superior to that of the pre-constructed roadway. To best track this long-term performance, as was suggested in section 7.0 1-Year Post Construction Condition Survey, additional condition surveys should be taken after 5 and 10 years in service. Any long-term pavement performance issues will likely start to show after those time periods and will offer a better perspective as to which process of the rubber-modification performs best.

Until that time comes, the test data produced from the plant produced mixtures will give the best indications as to the expected long-term performance. A brief summary of this data is presented in **Table 12** with generalized conclusions following.

Table 12: Performance Testing Summary

Mix	HWT				DCT				IFIT			
	Average Maximum Impression	**Max Impression Std. Dev.**	**Average SIP**	**SIP Std. Dev**	**STOA Fracture Energy**	**STOA Fracture Energy Std. Dev**	**LTOA Fracture Energy**	**LTOA Fracture Energy Std. Dev**	**STOA Flexibility Index**	**STOA FI Std. Dev**	**LTOA Flexibility Index**	**STOA FI Std. Dev**
Control	-5.20	0.45	19623	404	326	21	290	32	15.25	2.54	6.82	0.86
Terminal Blend	-3.91	0.25	19980	40	401	41	404	50	15.56	1.37	6.93	0.49
Terminal Blend Hybrid	-4.98	1.10	18623	2237	403	15	409	51	16.00	3.81	7.55	1.97
Dry Process	-9.12	2.70	16258	2283	368	35	334	24	12.93	2.97	11.86	1.38

From this data the following conclusions can be made:

Hamburg Wheel Tracking Test

- Except for the DP mixture, GTR mixtures decreased the maximum amount of rutting exhibited in the Hamburg Wheel Tracking Test. This suggests an improvement in rutting susceptibility as well as moisture susceptibility.
- The DP mixture exhibited an increase in rutting susceptibility when compared to the control mixture, stripped sooner than the control mixture, as well as exhibited increased variability in results. This is most likely caused by the higher than specified %AC during production.

Disk Compact Tension Test

- In the short-term aged condition low-temperature DCT, all the GTR mixtures showed marked improvement over the control mixture, with the TBH and TB showing about 23% improvement and the DP 13% improvement.
- After long-term aging the DCT specimens, performance deteriorated for the control and DP mixture about equally (loss of about 35 J/m2), interestingly though, the TBH and TB mixtures exhibited very mild improvement (increase of 3-6 J/m2). These results were all within the variability between the short- and long-term aged specimens, and therefore indicates there is very little impact on the low temperature cracking performance as measured by the DCT, at least for the long-term aging protocol specified.

Illinois Flexibility Index Test

- GTR mixtures showed very little, if any, improvement in the Illinois Flexibility Index Test at short-term aging. While both the TB (FI: 15.56) and TBH (FI: 16.00) showed slightly better performance compared to the control (15.25), it was not enough of a difference to conclude there was improvement. In fact, the DP mixture (FI: 12.93) performed worse than the control mixture.
- After aging, the control, TBH and TB mixtures both lost about 53-56% of their flexibility indices. The DP mixture, on the other hand, lost about 8% of its flexibility index, even after accounting for the variability in the test. This is in stark contrast the other mixtures and suggests that the DP mixture remains much more flexible after long-term aging. This was likely caused by increased film thickness due to a higher than specified %AC during production for the DP mixture.

Overall

- TBH and TB mixtures meet or exceed the performance of the control in both cold and intermediate temperature cracking resistance, and rutting resistance.
    - Additionally, the TBH mixture is the most economical in terms of performance per dollar spent when compared to the control.
- The DP mixture was cheaper per ton than the control mixture. Additionally, some performance (low-temperature cracking, and flexibility index) can be gained for a more economical price overall. These benefits would need to be carefully evaluated since the DP mixture was produced with additional AC.
    - However, DP mixtures can be more difficult to work with, especially after reheating, without adjusting mix design procedures such as compaction temperature. They also exhibit far more variability during testing for nearly all tests performed., which could complicate the WisDOT percent within limits (PWL) specification analysis.
- Field densification using rollers can be non-linear. Densification can be optimized depending on the mixture using density growth curves and observing the temperatures where plateauing may occur.

- Nuclear core correlations are recommended for DP mixtures due to the difference between cores and gauge readings.

While this study highlighted some issues with the DP GTR, it is this researcher's opinion that DP is a good product, just like its counterparts TB and TBH. However, DP is most likely better suited in an SMA mixture as opposed to the dense graded mixture evaluated in this research. Other states have had success using dry process GTR in open graded and SMA mixtures, most likely because the swelling occurs within the existing aggregate structure (see section 10).

Lastly, it is very important for WisDOT to continue the survey analysis of Hwy 51 after 5 and 10 years. This is the only way to quantify the actual performance of each product compared to the control. The results of the survey will calibrate the performance tests to real world performance, and a new cost benefit analysis can be evaluated.

10. Surrounding States

Applied Research Associates was part of research in 2014 where they interviewed multiple states on their rubber experience. This information is helpful when considering specification updates for WisDOT. **Table 13** below is a summary of ARA's findings as it relates to this research.

Table 13: Surrounding States Survey Responses

Agency	Mixes using Rubber	Rubber Guidelines?	Rubber directed in Spec?	Other
Mass DOT	Gap Graded Open Graded	None	Yes	
Missouri DOT	SMA Dense Graded	None	Contractor Choice	Uses 2mm gap in DSR to test Rubber, considering percent recovery
Ohio DOT	70-22 modified binder mixtures, allows GTR	Yes	Do not differentiate between rubber and nonrubber	
Texas DOT	Not comfortable using in Dense Graded, uses in Gap Graded and Open Graded	Yes, separate spec for SMA with rubber	Specification does not specify modifiers	Uses rubber in Chip Seals
Arizona DOT	Terminal Blend in Dense Graded. Wet Process in gap graded and OPFC		DOT specifies	
Florida DOT	Low Volume Dense Graded and Open Graded "dry process was eliminated in the 90s"		Yes. Rubber is not interchangeable with polymers – no "competitive bidding" between rubber and polymer.	Using an asphalt rubber membrane interlayer with some success on overlays

An important similarity is that other states specify GTR in SMA and/or Open Graded mixtures. This research only looked at one dense graded mixture. Since swelling is a concern, SMA mixtures may provide a solution in that the swelling can occur within the aggregate structure, without creating additional VMA.

11. WisDOT Specification Recommendations

WisDOT specifications consider “modifiers” separate from “additives.” A modifier is defined as a product that will change the binder performance grade (PG), whereas an additive is a product that is added to the mixture that does/should not change the PG grade. Examples of WisDOT defined additives (according to Standard Section 460.2.4) are: hydrated lime or liquid antistripping agent, SMA stabilizer, warm mix asphalt additive or process. While the terminal blend GTR process could be considered a modifier or an additive, the dry process GTR can most likely be considered an additive. Either way, there are ways to incorporate both types of GTR processes into WisDOT specifications. It all depends on whether WisDOT uses PG grade or Performance Testing as the equivalency standard.

11.1 Option 1: Specify by PG

If WisDOT chooses to use PG grade as the specification equivalency standard, terminal blend processes are recommended substitutes for any type of mixture. The dry process is recommended for SMA mixtures only. This report has shown that a similar asphalt mixture, where the only change is the incorporation of GTR at the terminal can perform the same or better than a standard PG 58-28H mixture. Since this report did not research wet process GTR mixtures, it is not recommended to consider wet process equivalent to terminal blend. Suggested specification language is shown in **Table 14**.

Table 14: Suggested Specification Language for GTR Mixes

Existing WisDOT PG Grades	Proposed additional WisDOT GTR Language (provided as an option to the contractors)	Proposed additional WisDOT Dry Process GTR Language (provided as an option to the contractors for SMA Mixtures)
PG 58-28 S	-	-
PG 58-34 S	-	-
PG 58-28 H	or Terminal GTR PG 70-28	PG 58-28H + 10% Dry Process GTR
PG 58-34 H	or Terminal GTR PG 70-34	Additional binder testing is needed to establish equivalents.
PG 58-28 V	or Terminal GTR PG 76-28	
PG 58-34 V	or Terminal GTR PG 76-34	

The benefit to specifying by PG grade is that there is little change to the specification language or testing. A benefit to using the terminal blend is that WisDOT is able to verify the PG grade, and the amount of GTR present in the mix, by testing an in-line sample at the plant.

11.2 Option 2: Specify by Performance Testing

To specify by a performance testing equivalency, WisDOT would be able to allow the contractor the option of either the terminal blend or the dry process, as long as they meet the required performance parameters. This type of specification allows for the most options for contractors, and in turn could provide more competitive bid prices.

WHRP is in the final stages of a BMD research study that should provide suggested performance tests and parameters. The findings of this research should be applied to rubber mixes, as they have proven to be equivalent to standard mixtures.

11.3 Additional Specifications Needed

There are other areas of the specification that need to be updated regardless of how WisDOT incorporates GTR into their mixes. Most of these specifications are found in the SPV created for this research. A copy of the SPV can be found in the Appendix of this document. These updates are the following:

1. GTR material quality
2. Plant Modifications
3. Mix design procedures
4. Verification mix testing
5. Performance test methods

GTR material quality should follow the guidelines provided in the SPV Section B.1 GTR Materials. It is important to require quality GTR, however if WisDOT does not want to include the additional verbiage in the standard specification, an approved products list will be a viable option. That way, WisDOT can ask suppliers to provide literature on their processes and provide a sample of their raw product to ensure conformance with the gradation specification.

Plant modifications may be required for both the terminal and dry process. If WisDOT were to allow rubber, they would need to add the items listed in the SPV Section C.1 Plant Modifications to the Standard Specification – most likely Section 450.3.1.1 Asphalt Plants. For dry process GTR SMA mixtures, more guidance is needed to ensure the plant is set up where the %AC of the virgin asphalt matches the mix design.

There are mix design considerations for both the terminal and dry process. It is recommended to start with the requirements of the SPV Section B.2.1 Modifications to the GTR Mix Design Process. The dry process mix design modifications should be checked to ensure additional weight (20 lbs. or 9071.85 g) is accurate for an SMA mixture.

If WisDOT plans to take verification samples of production mix for performance testing, additional sampling methods should be considered. The SPV Section B.3.1 Plant Mix Testing, requires samples to be taken in pans to reduce aging while reheating.

The performance test methods in the SPV are applicable for incorporation into WisDOT spec. However, if the WHRP BMD tolerances are used to establish performance parameters, it would be prudent to ensure that the BMD research did not have any significant testing deviations from this research (test temperature, conditioning, analyzation etc.).

12. References

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13. Appendix

13.1 Special Provision

1. Construction of WHRP Ground Tire Rubber (GTR) Study Test Sections for HMA Pavement.

A. Description

Follow Section 460 Hot Mix Asphalt Pavement, of the 2018 Standard Specifications, except where modified herein.

This work will involve the construction of four test sections for the Ground Tire Rubber Study demonstration project offered through the Wisconsin Highway Research Program (WHRP). The test section tonnage and locations are provided in the plans. For efficient material production, the test sections can be constructed in any order, but each test section must be continuous.

There will be one control section, constructed using the standard HMA Pavement 4 MT 58-28 H, and 3 additional test sections as listed below:

Test Section	Mix Design	GTR Method	GTR Type
Control	4 MT 58-28 H	None	None
1	4 MT Modified	Terminal Blend GTR 1	GTR PG 70-28
2	4 MT Modified	Terminal Blend GTR 2	GTR PG 70-28
3	4 MT Modified	Dry Process GTR	PG 58-28 S 10% Dry

Test sections 1 and 2 must use different suppliers of Terminal Blend GTR, and one supplier may provide a polymer and GTR blend.

The Terminal Blend GTR PG binders are required to meet the PG 70-28 AASHTO M320 specification. Additionally, the GTR PG binders will use a 2.00 mm gap (0.079 in.) for 25 mm (0.984 in.) plates for the AASHTO M320 Dynamic Shear Rheometer tests.

The Dry Process GTR must use a base binder meeting the WisDOT PG 58-28 S specification, with the addition of 10% Dry GTR product.

B. Materials

The WHRP Principle Investigators (PI) may inspect at their discretion and shall have access to the plant and materials.

B.1 GTR Materials

B.1.1 Terminal Blend GTR

The Terminal GTR shall be produced from processing automobile and/or truck tires by the ambient grinding method. Heavy equipment tires, uncured or de-vulcanized rubber will not be permitted. The GTR shall not exceed 1/16 inch (1.59 mm) in length and shall contain no free metal particles. Detection of free metal particles shall be determined by thoroughly passing a magnet through a 2 oz. (56.7 g) sample. Metal embedded in rubber particles will be permitted.

The GTR shall be stored in a dry location protected from the rain. When the GTR is combined with the asphalt cement, the moisture content of the GTR shall not cause foaming of the blend.

When tested in accordance with AASHTO T-27, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates, a 2 oz. (56.7 g) sample of the GTR shall conform to the following gradation requirements:

Sieve Size	Percent Passing
No. 8 (2.36 mm)	100
No. 16 (1.18 mm)	98 ± 2
No. 30 (600 µm)	95 ± 5
No. 50 (300 µm)	50 ± 10
No. 100 (150 µm)	10 ± 5
No. 200 (75 µm)	2 ± 2

A mineral powder (such as talc) meeting AASHTO M17, Standard Specification for Mineral Filler for Bituminous Paving Mixtures, requirements may be added, up to a maximum of 4% by weight of GTR particles, to reduce sticking and caking of the GTR particles.

GTR shall have a specific gravity of 1.15 ± 0.05 when tested in accordance with ASTM D1817, Standard Test Method for Rubber Chemicals-Density.

B.1.2 Dry Process GTR

The dry process GTR shall be produced from processing automobile and/or truck tires by ambient or cryogenic grinding methods. Heavy equipment tires, uncured or de-vulcanized rubber will not be permitted. The GTR shall not exceed 1/20 inch (1.27 mm) in diameter and shall contain no free metal particles. Detection of free metal particles shall be determined by thoroughly passing a magnet through a 2 oz. (56.7 g) sample. Metal embedded in rubber particles will be permitted.

The dry process GTR shall be packaged and shipped in closed-top, water resistant bulk bags. The dry process GTR bags shall be stored in a dry location protected from the rain before use in the field. When the GTR is combined with the asphalt cement and aggregate, the moisture content of the GTR shall not cause foaming of the blend.

When tested in accordance with AASHTO T-27 Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates, a 2 oz. (56.7 g) sample of the dry process GTR shall conform to the following gradation requirements:

Sieve Size	Percent Passing
No. 20 (841 µm)	100
No. 30 (600 µm)	99 ± 1
No. 40 (300 µm)	60 ± 10
No. 100 (150 µm)	10 ± 5

A mineral powder (such as talc) meeting AASHTO M17, Standard Specification for Mineral Filler for Bituminous Paving Mixtures, requirements may be added, up to a maximum of 4% by weight of GTR particles in order to reduce sticking and caking of the GTR particles.

The dry process GTR shall have a specific gravity of 1.15 ± 0.05 when tested in accordance with ASTM D1817, Standard Test Method for Rubber Chemicals-Density.

No extender oils or polymeric additions (elastomers, plastomers) shall be included in the dry process GTR.

B.2. Control and GTR Test Section Mix Designs

The Control and GTR test section mix design(s) shall follow Section 460 of the 2018 Standard Specifications and the Construction Materials Manual (CMM) Section 8-66, except where modified herein.

Each GTR test section mix design shall use the Control mix design as the base line, using the same material sources. Small blend changes, up to ±5% per product, are acceptable to maintain volumetrics when substituting the GTR binder for the virgin PG 58-28 H, however the recycled product percentages cannot increase. Optimum percent AC for each GTR mix design must be within -0.1% or greater than the Control mix design JMF AC content.

WisDOT will assign an individual 250 verification number for each control and trial section mix design.

The intent is for the Control and each GTR test section design to be of equivalent performance. To quantify this, the following performance tests are required. The GTR test section mix designs must be of equal or better performance than the Control mix design, as identified in the table below.

Performance Test	Equivalent Performance Requirements	
	Control Mix Design	GTR Test Sections
DCT ASTM D7313-13[1]	Minimum Baseline Performance	Equal to or greater Fracture Energy than Control
I-FIT Illinois Test Procedure 405[1]		Equal to or greater Flexibility Index than Control
Hamburg AASHTO T 324-17[1]		Equal to or greater number of passes at 12.5mm rut depth than Control (not to exceed 20,000 passes) Equal to or greater # of passes at SIP than Control
Recovered Binder[1]		Within 5^{o} of higher temperature Within 5^{0} of lower temperature

[1] All test procedures will follow 2. Performance Testing of WHRP Ground Tire Rubber (GTR) Study Test Sections for HMA Pavement

Any issues with this requirement, must be brought to the WHRP PI and WisDOT's attention prior to mix design approval and production.

The mix designs will be reviewed for approval by the WHRP PI and WisDOT prior to production. The contractor is required to provide individual aggregate products, asphalt binder and GTR for the control and each test section within 30 days of production. Any concerns with the data will be conveyed to the WHRP Project Oversight Committee (POC) and contractor, to discuss a collaborative solution prior to production.

B.2.1 Modifications to the GTR mix design procedures

B.2.1.1 Terminal Blend Mix Design Procedures

Prior to mixing the aggregate with the terminally blended GTR, re-mix the GTR binder using a low-shear mixer for 10 ± 2 minutes at 300 - 325°F (148.9°C - 162.8°C) to re-suspend the rubber particles within the asphalt binder.

B.2.1.2 Dry Process Mix Design Procedures

When mixing the aggregate, asphalt and dry rubber; the dry rubber will be added to the aggregate batch and not pre-blended with the asphalt. The dry rubber may be pre-heated in the oven with the aggregates for no more than 45 minutes.

To allow time for the final binder/rubber interactions, all SGC Specimen (both during design and production) must remain the mold after compaction for 30 ± 1 minutes with a fan and a total of 9000 +/- 100 gram weight (19.84 lb. +/- 0.22 lb.) (including the top plate. Test the Gmb within 2 hours of compaction.

B.3 Production Testing

B.3.1 Plant Mix Testing

The Control and GTR test section mix design(s) shall follow Section 460 of the 2018 Standard Specifications and the Construction Materials Manual (CMM) Section 8-36, except where modified herein.

The Dry Process production samples must remain the mold after compaction for 30 ± 1 minutes with a fan and a total of a 9000 +/- 100 gram (19.84 lb. +/- 0.22 lb.) weight (including the top plate). Test the Gmb within 2 hours of compaction.

HMA and PG Binder samples will be collected at the plant by the WHRP PI and/or WisDOT team. These samples will be tested for performance and binder grading by the WHRP PI. Performance samples collected at the plant during production will not be aged, only reheated.

B.3.2 Density Testing and Coring

Density values for each test section will be measured as per current specifications. Any incentives/disincentives for density will be calculated per the current contract specifications.

The contractor shall provide up to 10 cores per section at locations determined by the Department.

C. Construction

C.1 Plant Modifications

This work may require plant modifications to the contractor’s asphalt plant. The asphalt plant shall follow Section 450.3.1.1 except where modified herein.

C.1.1 Terminal Blend GTR

Terminal blended GTR may require a vertical asphalt storage tank pending manufacturer’s recommendations. Asphalt storage tanks for terminal blended GTR are required to have an agitator if the contractor does not pump directly from a tanker truck. The requirement for an agitator in a storage may be waived if ASTM D7173 is conducted and a difference of less than 2°C (3.6°F) (is shown in the Softening Points (conducted per AASHTO T53) between the top and bottom portions.

In-line sampling must be available for GTR material.

C.1.2 Dry Process GTR

The dry process GTR must be controlled with a feeder system using a proportioning device that is accurate to within ± 3 percent of the amount required. The system shall automatically adjust the feed rate to maintain the material within this tolerance at all times and shall have a convenient and accurate means of calibration. The system shall provide in-process monitoring, consisting of either a digital display of output or a printout of feed rate, in pounds per minute, to verify feed rate. The supply system shall report the feed in 1 lb. (0.45 kg) increments using load cells that will enable the user to monitor the depletion of the dry process GTR. Monitoring the system volumetrically will not be allowed.

The feeder shall interlock with the aggregate weigh system and asphalt binder pump to maintain the correct proportions at all production rates. Flow indicators or sensing devices for the system shall be interlocked with the plant controls to interrupt the mixture production if the GTR introduction output rate is not within the ± 3 percent tolerance. This interlock will immediately notify the operator if the targeted rate exceeds introduction tolerances.

All plant production will cease if the introduction rate is not brought back within tolerance after 30 seconds. When the interlock system interrupts production and the plant needs to be restarted, upon restarting operations; the modifier system shall run until a uniform feed can be observed on the output display. All mix produced prior to obtaining a uniform feed shall be rejected.

The dry process GTR shall be introduced prior to the injection of asphalt cement. Ensure the dry process GTR will not become entrained in the exhaust system of the drier or plant and will not be exposed to the drier flame at any point after induction. During operations, the asphalt plant shall record feed records daily from the feeder unit for the purposes of verifying dry process GTR inputs into the process.

D. (Vacant)

E. Payment

The department will pay for measured quantities at the contract unit price under the following bid items:

ITEM NUMBER	DESCRIPTION	UNIT
460.6424	HMA Pavement 4 MT 58-28 H – Control	TON
SPV.0195.01	4 MT Modified – Terminal Blend GTR 1	TON
SPV.0195.02	4 MT Modified – Terminal Blend GTR 2	TON
SPV.0195.03	4 MT Modified – Dry Process GTR	TON
460.2000	Incentive Density HMA Pavement	DOL

Payment for each test section is full compensation for providing each mixture design; for Volumetric, performance, density testing, coring and filling core holes; for preparing foundation; for aggregate source testing; for asphalt binder from recycled sources, for asphalt binder modification or processes, addition of GTR, and any needed plant modifications.

2. Performance Testing of WHRP Ground Tire Rubber (GTR) Study Test Sections for HMA Pavement (460.6424, SPV.0195.01, SPV.0195.02, SPV.0195.03)

A. Description

Each WHRP GTR Study test section, constructed under 1. Construction of WHRP Ground Tire Rubber (GTR) Study Test Sections for HMA Pavement, including the control mix design, will additionally include the following tests, to be performed by the contractor for mix design and the researcher for mix design confirmation and test sections.

B. Materials

B.1 Disk-Shaped Compact Tension (DCT)

Follow ASTM D7313-13 *Standard Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry*, except where modified herein.

Replace the third sentence of Section 4.1 with the following:
The test method is valid for specimens that are tested at -18ºC (-0.4ºF)

Add the following three sentences to the end of Section 4.1:
The gyratory specimens shall be a minimum of 150 mm (5.91 in.) in height. Two slices shall be cut from two gyratory specimen, producing 4 test replicates. Air voids shall be 7.0 ± 0.5%., calculated on each specimen slice, prior to cutting the notch or holes.

Replace the second sentence of Section 7.1 with the following:
The temperature for the last 2 hours of conditioning shall be within ±0.2ºC (±0.36ºF).

Add the following to Section 9. Report:
Average all four test specimens. Discard the specimen that produces the furthest fracture energy result from the average. Average the remaining three specimens to produce the final fracture energy result.

The table below is a summary of the test procedure modifications:

Gyratory height	Minimum of 150 mm (5.91 in.)
Number of specimens	4
Short Term Oven Aging according to AASHTO R30	Mix Design – 2 hours for Dry Process GTR only Production – none
Air Voids (tested on slice)	7.0 ± 0.5%
Conditioning	8-16 hours in freezer 2 hours in DCT Chamber
Test Temperature	-18ºC (-0.4ºF)

B.2 Illinois Fracture Index Test (I-FIT) – Method B

Follow the Illinois Test Procedure (ITP) 405, Modified Date: December 1, 2017, *Determining the Fracture Potential of Asphalt Mixtures Using the Illinois Flexibility Index Test (I-FIT) –* Method B, except where modified herein.

Remove Section 6.1.2.1 – Method A.

Replace the first and second sentences of the third paragraph of Section 9.1 with the following:
Prepare a minimum of one laboratory SGC specimen according to T 312 in the SGC with a compaction height a minimum of 150 mm (5.91 in.). From the middle of each 150 mm (5.91 in.) – tall specimen, obtain two cylindrical 50 mm (1.97 in.) ± 1 mm (0.04 in.) thick discs (see Figure 4).

In Note 5, replace all references of air voids to read: 7.0 ± 0.5%.

In Note 5 and Figure 4, replace all references of SGC height to read: a minimum of 150 mm (5.91 in.).

Add the following to Section 13. Report:
Average all four test specimens. Discard the specimen that produces the furthest flexibility index result from the average. Average the remaining three specimens to produce the final flexibility index result.

The table below is a summary of the test procedure modifications:

Short Term Oven Aging according to AASHTO R30	Mix Design – 2 hours for Dry Process GTR only Production – none
Gyratory height	Minimum 150 mm (5.91 in.)
Number of specimens	4
Air Voids (tested on specimen)	7.0 ± 0.5%
Conditioning	Water bath or environmental chamber for 2±0.5 hours
Test Temperature	25ºC (77°F)

B.3 Hamburg Wheel

Follow the AASHTO T 324-17, *Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures*, except where modified herein.

Replace Section 6.1. with the following:
Number of Test Specimens – Prepare four specimens, two for each wheel path.

Replace the first two sentences of Section 6.2.6.2 with the following:
Compacting SGC Cylindrical Specimens – Compact four 150-mm (5.91 in.) diameter specimen in accordance with T 312. Specimen thickness must be 62 mm (2.44 in.) ± 2 mm (0.079 in.).

Replace Section 8.6.1., 8.6.2 and 8.6.3 with the following:
Select 46°C (114.8°F) as the testing temperature.
Select 12.5 mm (0.49 in.) as the maximum rut depth.
Select 20,000 as the maximum number of passes.

The table below is a summary of the test procedure modifications:

Short Term Oven Aging according to AASHTO R30	Mix Design – 2 hours for all designs Production – none
Gyratory height	62 mm (2.44 in.) ± 2 mm (0.079 in.)
Number of specimens	4
Air Voids	7.0 ± 0.5%
Conditioning	45-minute soak time in temperature-controlled water bath at testing temperature prior to test starting.
Test Temperature	46ºC (114.8°F)

B.4 Recovered Binder Grading

Follow ASTM D8159-18 *Standard Test Method for Automated Extraction of Asphalt Binder from Asphalt Mixtures*, for sample extraction.

Follow ASTM D5404-12 *Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator*, except modified herein.

Replace Section 8.1 with the following:
The sample shall be extracted in accordance with Test Method D8159-18. Recovery shall be conducted immediately after the extraction process is completed. Total time from beginning of extraction to end of recovery shall not exceed 8 hours.

Add the following sentence in between the first and second sentence of Section 9.4:

Increase oil bath temperature to 155ºC (311°F) and hold for 10 ± 1 minute to allow for temperature to increase.

Replace the third sentence of Section 9.5 with the following:
Invert the flask and place in an oven at 165 ± 5ºC (329 ± 9°F) for 10 to 15 min to cause the asphalt to flow into the container.

Follow AASHTO M320-10 *Performance-Graded Asphalt Binder*, except modified herein.

Add the following sentences to Section 7 – Test Methods:

Test at both pass and fail temperatures to allow for continuous grading.

Recovered asphalt material shall be treated as RTFO-conditioned asphalt binder at the end of the recovery process. Do not run RTFO on material.

Exclude all testing on Original Binder.

Exclude Mass Change (T 240).

Exclude Direct Tension (T 314).

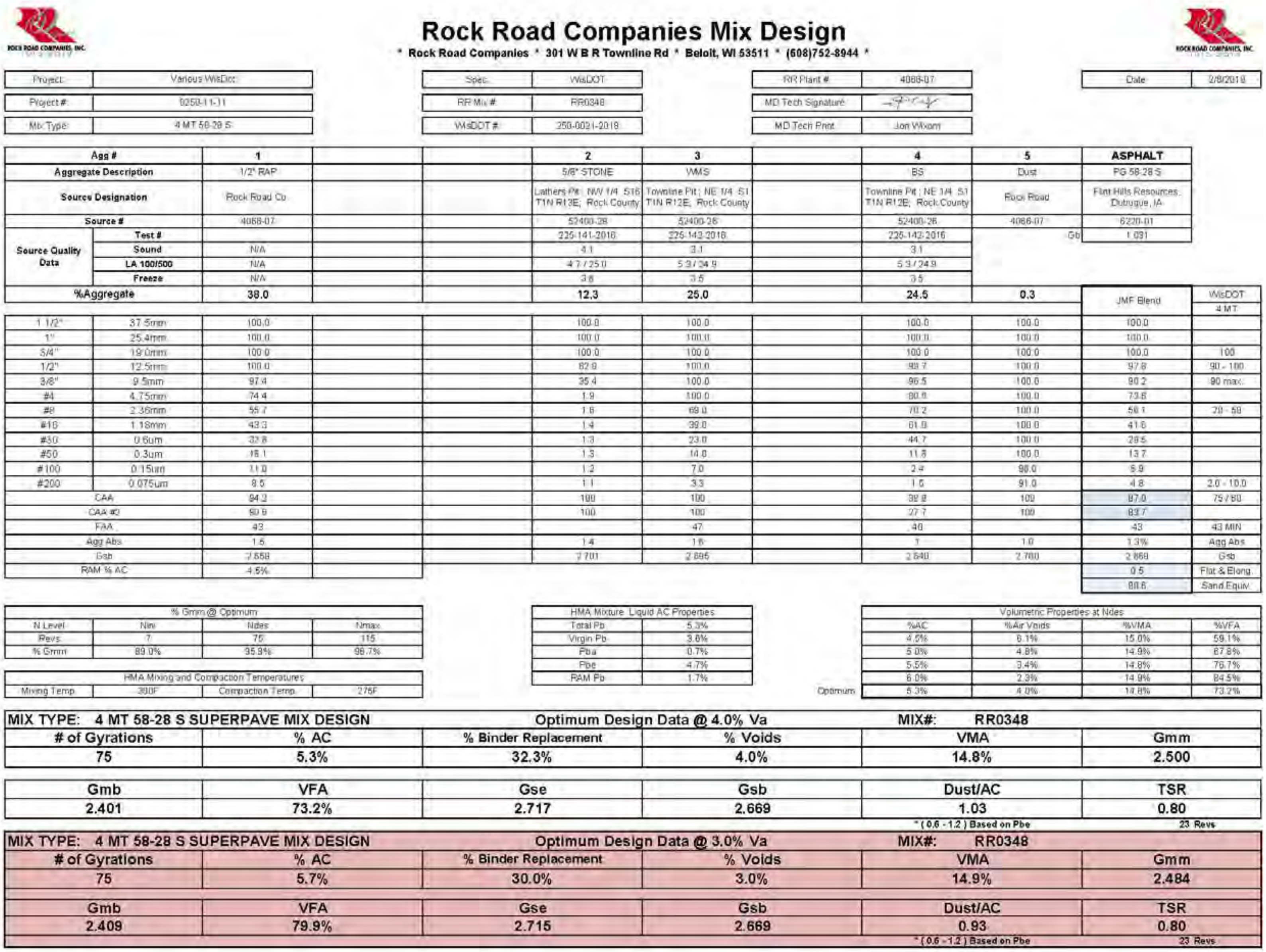
Follow ASTM D7643 *Standard Practice for Determining the Continuous Grading Temperatures and Continuous Grades for PG Graded Asphalt Binders*, to report the binder grade of the recovered binder sample.

C. (VACANT)

D. (VACANT)

E. (VACANT)

13.2 Control Mix Design



Rock Road Companies Mix Design

* Rock Road Companies * 301 W B R Townline Rd * Beloit, WI 53511 * (608)752-8944 *

Project	Various WisDot		Spec	WisDOT		RR Plant #	4088-07	Date	2/8/2018
Project #	9250-11-11		RR Mix #	RR0348		MD Tech Signature			
Mix Type	4 MT 58-28 S		WisDOT #	250-0021-2018		MD Tech Print	Jon Wixom		

Agg #		1			2	3		4	5	ASPHALT	
Aggregate Description		1/2" RAP			5/8" STONE	WMS		BS	Dust	PG 58-28 S	
Source Designation		Rock Road Co			Lathers Pit: NW 1/4 S16 T1N R13E; Rock County	Townline Pit; NE 1/4 S1 T1N R12E; Rock County		Townline Pit; NE 1/4 S1 T1N R12E; Rock County	Rock Road	Flint Hills Resources; Dubuque, IA	
Source #		4068-07			52400-28	52400-26		52400-26	4066-07	6220-01	
Source Quality Data	Test #				225-141-2016	225-142-2016		225-142-2016	Gb	1.031	
	Sound	N/A			4.1	3.1		3.1			
	LA 100/500	N/A			4.7 / 25.0	5.3 / 24.9		5.3 / 24.9			
	Freeze	N/A			3.8	3.5		3.5			
%Aggregate		38.0			12.3	25.0		24.5	0.3	JMF Blend	WisDOT 4 MT
1 1/2"	37.5mm	100.0			100.0	100.0		100.0	100.0	100.0	
1"	25.4mm	100.0			100.0	100.0		100.0	100.0	100.0	
3/4"	19.0mm	100.0			100.0	100.0		100.0	100.0	100.0	100
1/2"	12.5mm	100.0			82.9	100.0		98.7	100.0	97.8	90 - 100
3/8"	9.5mm	97.4			35.4	100.0		96.5	100.0	90.2	90 max.
#4	4.75mm	74.4			1.9	100.0		80.8	100.0	73.6	
#8	2.36mm	55.7			1.6	69.0		70.2	100.0	56.1	20 - 58
#16	1.18mm	43.3			1.4	39.0		61.0	100.0	41.6	
#30	0.6um	32.8			1.3	23.0		44.7	100.0	28.5	
#50	0.3um	18.1			1.3	14.0		11.8	100.0	13.7	
#100	0.15um	11.0			1.2	7.0		2.4	98.0	5.9	
#200	0.075um	8.5			1.1	3.3		1.6	91.0	4.8	2.0 - 10.0
CAA		94.2			100	100		32.8	100	87.0	75 / 60
CAA #2		90.9			100	100		27.7	100	83.7	
FAA		43				47		40		43	43 MIN
Agg Abs		1.5			1.4	1.6		1	1.0	1.3%	Agg Abs
Gsb		2.658			2.701	2.695		2.640	2.700	2.668	Gsb
RAM % AC		4.5%								0.5	Flat & Elong.
										88.6	Sand Equiv.

% Gmm @ Optimum			
N Level	Nini	Ndes	Nmax
Revs	7	75	115
% Gmm	89.0%	95.9%	96.7%

HMA Mixing and Compaction Temperatures			
Mixing Temp	300F	Compaction Temp	275F

HMA Mixture Liquid AC Properties	
Total Pb	5.3%
Virgin Pb	3.6%
Pba	0.7%
Pbe	4.7%
RAM Pb	1.7%

	Volumetric Properties at Ndes			
	%AC	%Air Voids	%VMA	%VFA
	4.5%	6.1%	15.0%	59.1%
	5.0%	4.8%	14.9%	67.8%
	5.5%	3.4%	14.8%	76.7%
	6.0%	2.3%	14.9%	84.5%
Optimum	5.3%	4.0%	14.8%	73.2%

MIX TYPE: 4 MT 58-28 S SUPERPAVE MIX DESIGN		Optimum Design Data @ 4.0% Va		MIX#: RR0348	
# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.3%	32.3%	4.0%	14.8%	2.500
Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.401	73.2%	2.717	2.669	1.03	0.80
				* (0.6 - 1.2) Based on Pbe	23 Revs

MIX TYPE: 4 MT 58-28 S SUPERPAVE MIX DESIGN		Optimum Design Data @ 3.0% Va		MIX#: RR0348	
# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.7%	30.0%	3.0%	14.9%	2.484
Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.409	79.9%	2.715	2.669	0.93	0.80
				* (0.6 - 1.2) Based on Pbe	23 Revs

ROCK ROAD COMPANIES, INC.

Mix Type: 4 MT 58-28 S SUPERPAVE MIX DESIGN   Mix #: RR0348

ROCK ROAD COMPANIES, INC.

Measured Specific Gravity Analysis

Gmm(meas)

Sp. Gravity of AC	1.031

Mix	AC1	AC2	AC3	AC4	
%AC	4.5	5.0	5.5	6.0	
	Gmm	Gmm	Gmm	Gmm	
Mix Wt. in Air	1622.3	1566.9	1571.0	1657.0	
Wt. Pyc + H2O	1337.0	1337.0	1337.0	1337.0	
Mix + Pyc + H2O	2317.8	2280.6	2277.5	2323.5	
Volume	641.5	623.3	630.5	670.5	
Max Sp. Gravity, Gmm	2.529	2.514	2.492	2.471	Ave of 4
Gse	2.715	2.720	2.716	2.713	2.716

Gmb(meas)

Gyration Level : **Nini =** 7 **Ndes =** 75 **Nmax =** 115

Mixing Temp. °F	300	Compaction Temp. °F	275

Mix	AC1		AC2		AC3		AC4	
%AC	4.5		5.0		5.5		6.0	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6	Spec. 7	Spec. 8
Spec. Wt. in Air	4842.2	4846.6	4844.8	4845.7	4843.8	4852	4842.2	4847.4
Spec. Wt. In H2O	2811.2	2815.2	2822.6	2823.9	2835.3	2839	2842.2	2840.7
SSD	4851.1	4854.4	4849.3	4850.1	4847.5	4855.5	4843.1	4848.6
Bulk Volume	2039.9	2039.2	2026.7	2026.2	2012.2	2016.5	2000.9	2007.9
Bulk Sp. Gravity, Gmb	2.374	2.377	2.390	2.392	2.407	2.406	2.420	2.414
Av. Bulk Sp. Gravity	2.375		2.391		2.407		2.417	

T-283 TSR Data

Specimen # ----->	1	2	6	3	4	5
Orig. Wt. ----->	3866.9	3870.0	3872.2	3871.0	3869.9	3871.1
SSD WT ----->	3873.7	3877.3	3878.5	3877.5	3875.6	3876.9
SUB WT. ----->	2210.1	2215.2	2214.2	2213.3	2213.2	2215.1
Volume ----->	1663.6	1662.1	1664.3	1664.2	1662.4	1661.8
SPGR. "d" ----->	2.324	2.328	2.327	2.326	2.328	2.329
%VOIDS ----->	7.0	6.9	6.9	7.0	6.9	6.8
VOIDS (CC) ----->	117.1	114.4	115.2	115.8	114.4	113.7
BIG "D"	2.500	AV SPGR	2.327		AVG. % VOIDS	6.9

SPECIMEN NO. (S) UNCONDITIONED	1	2	6
SPECIMEN NO. (S) CONDITIONED	3	4	5
WEIGHT FOR 70% SATURATION	3952.1	3950.0	3950.7
WEIGHT FOR 80% SATURATION	3963.7	3961.4	3962.0
FINAL STAURATED WEIGHT	3961.6	3952.7	3958.1
FINAL % SATURATION	78.2	72.4	76.5

AVE % SAT 75.7

	CONDITIONED				UNCONDITIONED		
SPEC. NO (S)	3	4	5		1	2	6
LOAD (kN)	16.6	18.4	16.4		22	22.2	20
TENS STR. k Pa (psi)	748.1	830.1	740.2		991.8	1001.7	901.3

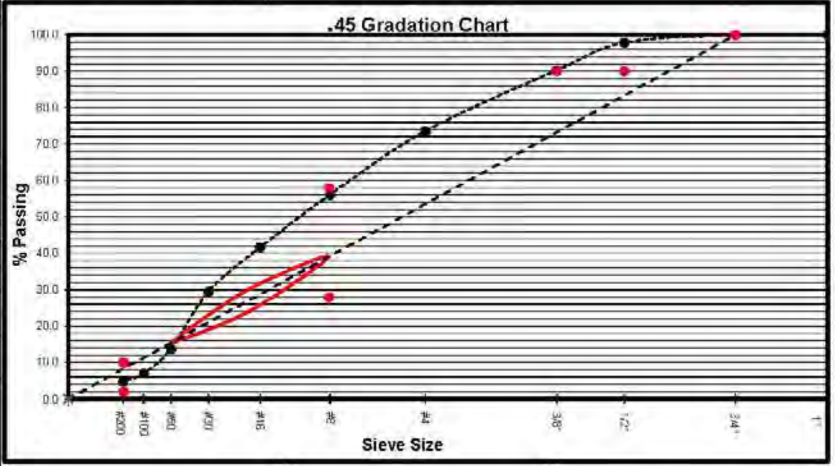
CONDITIONED		UNCONDITIONED	
AV TENS STR.	772.8	AVE TEN STR.	964.9
TENSILE STRENGTH RATIO	0.80	REVS.	23

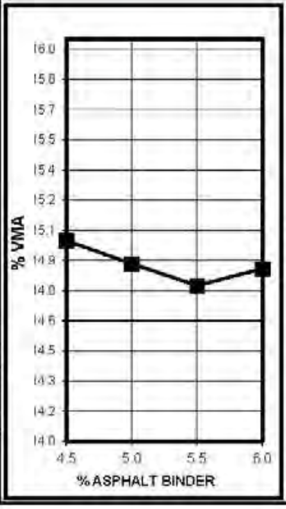
Summary of Compaction Properties at Different Asphalt Contents

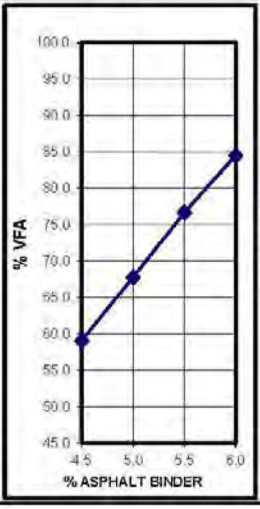
Volumetric Properties at Ndes

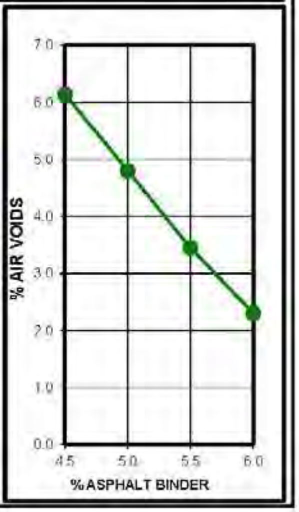
%AC	%Air Voids	%VMA	%VFA
4.5	6.1	15.0	59.1
5.0	4.8	14.9	67.8
5.5	3.4	14.8	76.7
6.0	2.3	14.9	84.5
5.3%	4.0%	14.8%	73.2%

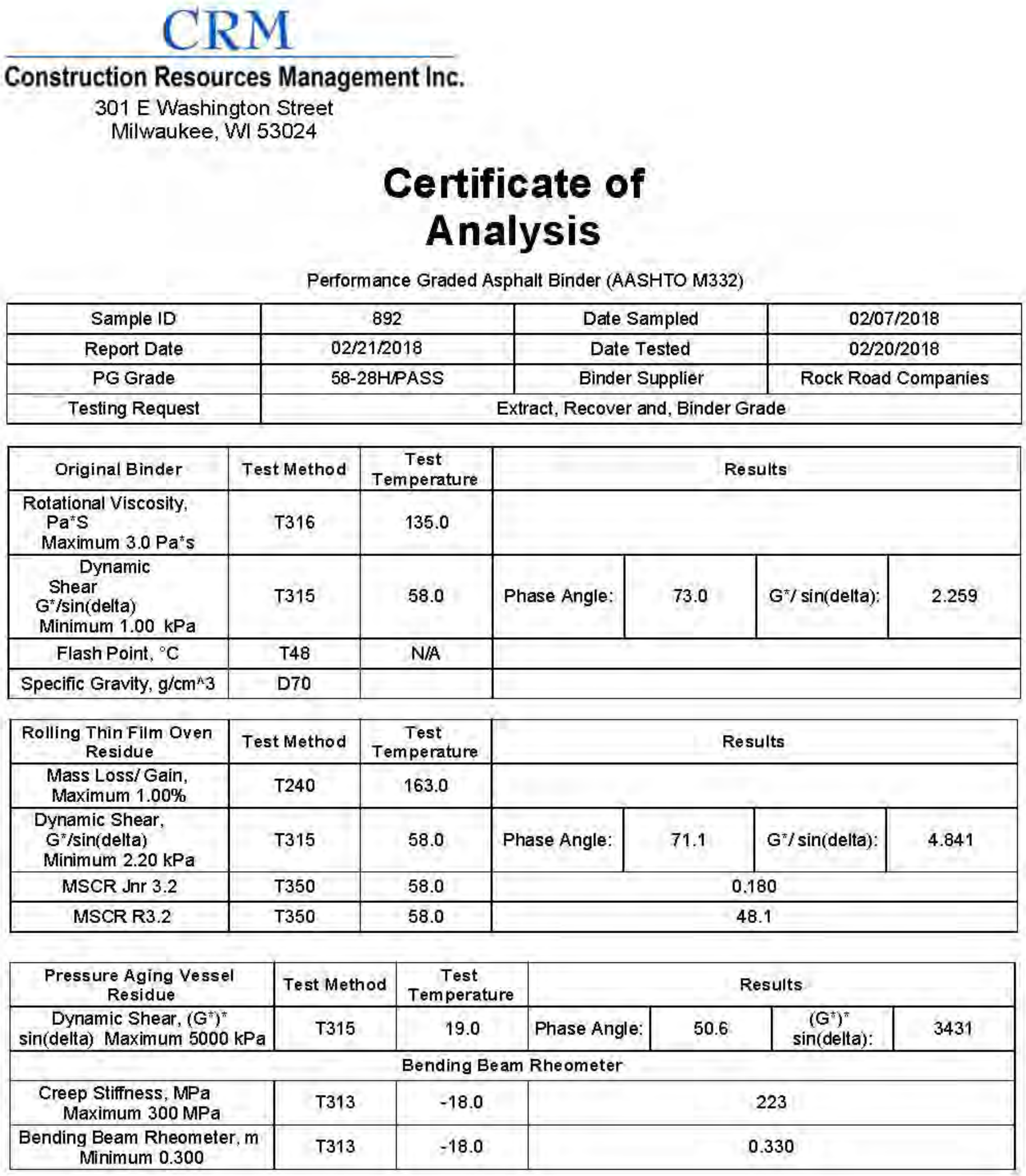
Project	Various WisDot
Project #	0250-11-11
Mix Type	4 MT 58-28 S











CRM

Construction Resources Management Inc.

301 E Washington Street
Milwaukee, WI 53024

Certificate of Analysis

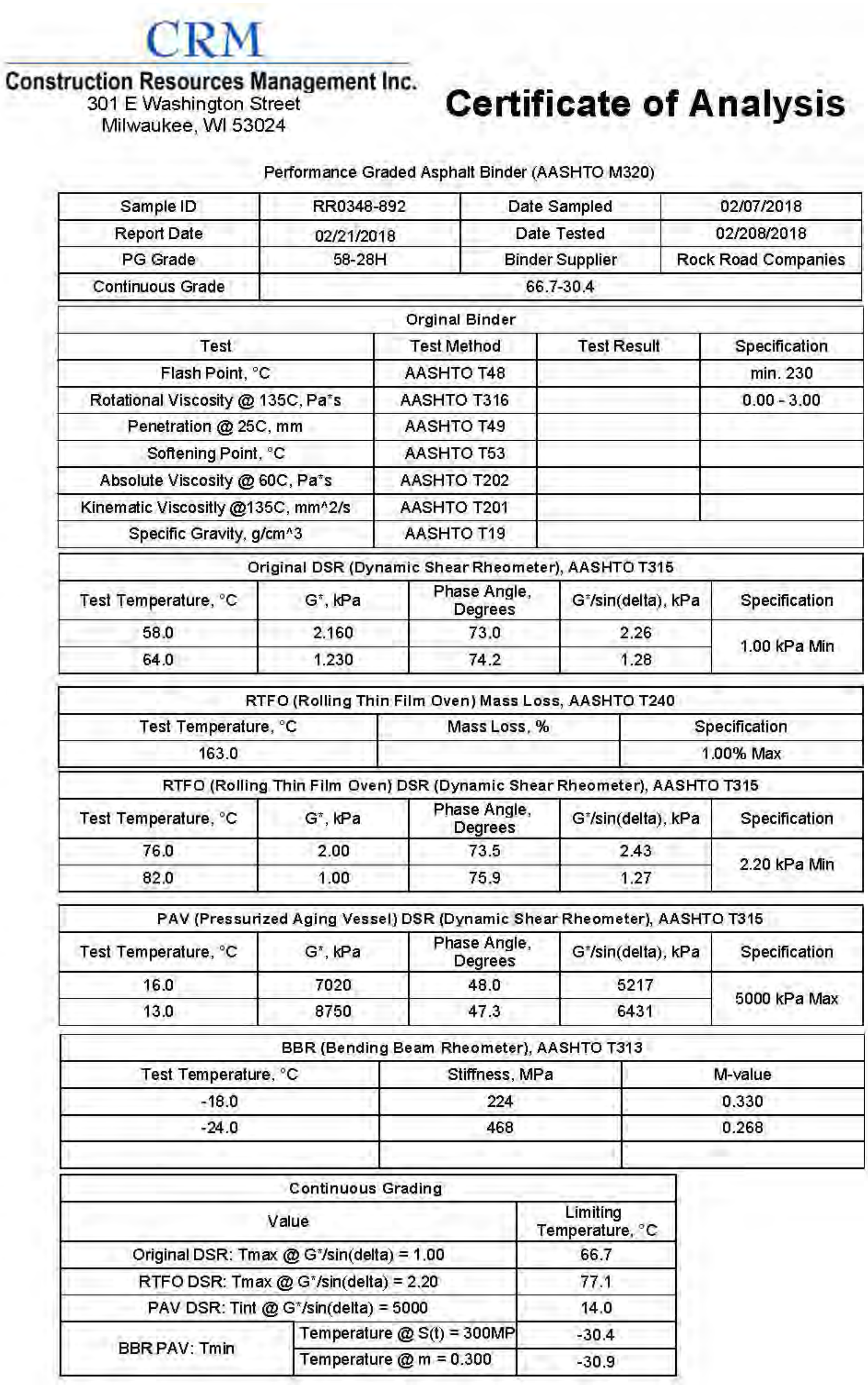
Performance Graded Asphalt Binder (AASHTO M332)

Sample ID	892	Date Sampled	02/07/2018
Report Date	02/21/2018	Date Tested	02/20/2018
PG Grade	58-28H/PASS	Binder Supplier	Rock Road Companies
Testing Request	Extract, Recover and, Binder Grade		

Original Binder	Test Method	Test Temperature	Results			
Rotational Viscosity, Pa*S Maximum 3.0 Pa*s	T316	135.0				
Dynamic Shear G*/sin(delta) Minimum 1.00 kPa	T315	58.0	Phase Angle:	73.0	G*/ sin(delta):	2.259
Flash Point, °C	T48	N/A				
Specific Gravity, g/cm^3	D70					

Rolling Thin Film Oven Residue	Test Method	Test Temperature	Results			
Mass Loss/ Gain, Maximum 1.00%	T240	163.0				
Dynamic Shear, G*/sin(delta) Minimum 2.20 kPa	T315	58.0	Phase Angle:	71.1	G*/ sin(delta):	4.841
MSCR Jnr 3.2	T350	58.0	0.180			
MSCR R3.2	T350	58.0	48.1			

Pressure Aging Vessel Residue	Test Method	Test Temperature	Results			
Dynamic Shear, (G*)* sin(delta) Maximum 5000 kPa	T315	19.0	Phase Angle:	50.6	(G*)* sin(delta):	3431
Bending Beam Rheometer						
Creep Stiffness, MPa Maximum 300 MPa	T313	-18.0	223			
Bending Beam Rheometer, m Minimum 0.300	T313	-18.0	0.330			



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Construction Resources Management Inc.
301 E Washington Street
Milwaukee, WI 53024

Certificate of Analysis

Performance Graded Asphalt Binder (AASHTO M320)

Sample ID	RR0348-892	Date Sampled	02/07/2018
Report Date	02/21/2018	Date Tested	02/208/2018
PG Grade	58-28H	Binder Supplier	Rock Road Companies
Continuous Grade	66.7-30.4		

Orginal Binder			
Test	Test Method	Test Result	Specification
Flash Point, °C	AASHTO T48		min. 230
Rotational Viscosity @ 135C, Pa*s	AASHTO T316		0.00 - 3.00
Penetration @ 25C, mm	AASHTO T49		
Softening Point, °C	AASHTO T53		
Absolute Viscosity @ 60C, Pa*s	AASHTO T202		
Kinematic Viscosity @135C, mm^2/s	AASHTO T201		
Specific Gravity, g/cm^3	AASHTO T19		

Original DSR (Dynamic Shear Rheometer), AASHTO T315				
Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
58.0	2.160	73.0	2.26	1.00 kPa Min
64.0	1.230	74.2	1.28	

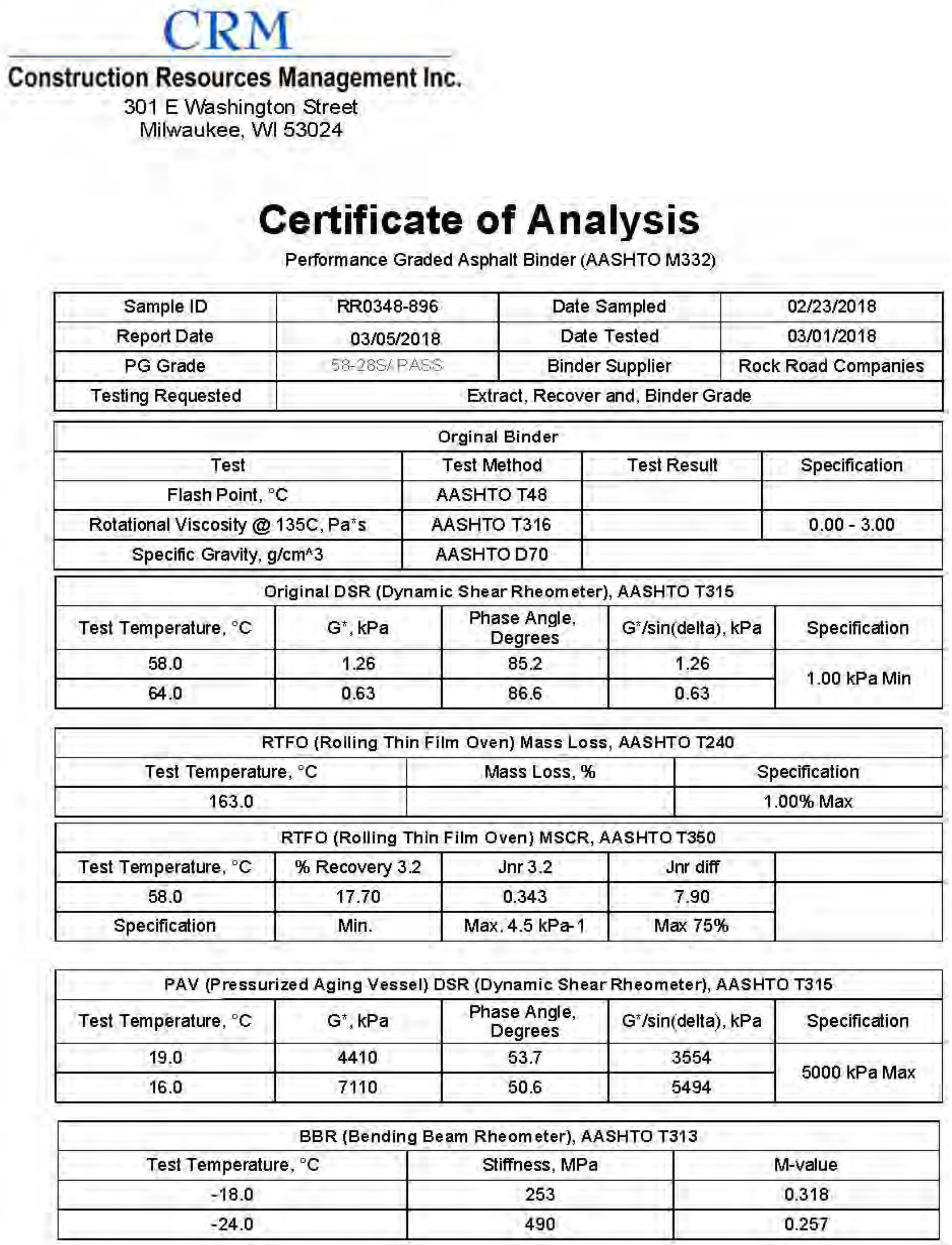
RTFO (Rolling Thin Film Oven) Mass Loss, AASHTO T240		
Test Temperature, °C	Mass Loss, %	Specification
163.0		1.00% Max

RTFO (Rolling Thin Film Oven) DSR (Dynamic Shear Rheometer), AASHTO T315				
Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
76.0	2.00	73.5	2.43	2.20 kPa Min
82.0	1.00	75.9	1.27	

PAV (Pressurized Aging Vessel) DSR (Dynamic Shear Rheometer), AASHTO T315				
Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
16.0	7020	48.0	5217	5000 kPa Max
13.0	8750	47.3	6431	

BBR (Bending Beam Rheometer), AASHTO T313		
Test Temperature, °C	Stiffness, MPa	M-value
-18.0	224	0.330
-24.0	468	0.268

Continuous Grading		
Value		Limiting Temperature, °C
Original DSR: Tmax @ G*/sin(delta) = 1.00		66.7
RTFO DSR: Tmax @ G*/sin(delta) = 2.20		77.1
PAV DSR: Tint @ G*/sin(delta) = 5000		14.0
BBR PAV: Tmin	Temperature @ S(t) = 300MP	-30.4
	Temperature @ m = 0.300	-30.9



CRM

Construction Resources Management Inc.

301 E Washington Street
Milwaukee, WI 53024

Certificate of Analysis

Performance Graded Asphalt Binder (AASHTO M332)

Sample ID	RR0348-896	Date Sampled	02/23/2018
Report Date	03/05/2018	Date Tested	03/01/2018
PG Grade	58-28S/ PASS	Binder Supplier	Rock Road Companies
Testing Requested	Extract, Recover and, Binder Grade		

Orginal Binder

Test	Test Method	Test Result	Specification
Flash Point, °C	AASHTO T48		
Rotational Viscosity @ 135C, Pa*s	AASHTO T316		0.00 - 3.00
Specific Gravity, g/cm^3	AASHTO D70		

Original DSR (Dynamic Shear Rheometer), AASHTO T315

Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
58.0	1.26	85.2	1.26	1.00 kPa Min
64.0	0.63	86.6	0.63	

RTFO (Rolling Thin Film Oven) Mass Loss, AASHTO T240

Test Temperature, °C	Mass Loss, %	Specification
163.0		1.00% Max

RTFO (Rolling Thin Film Oven) MSCR, AASHTO T350

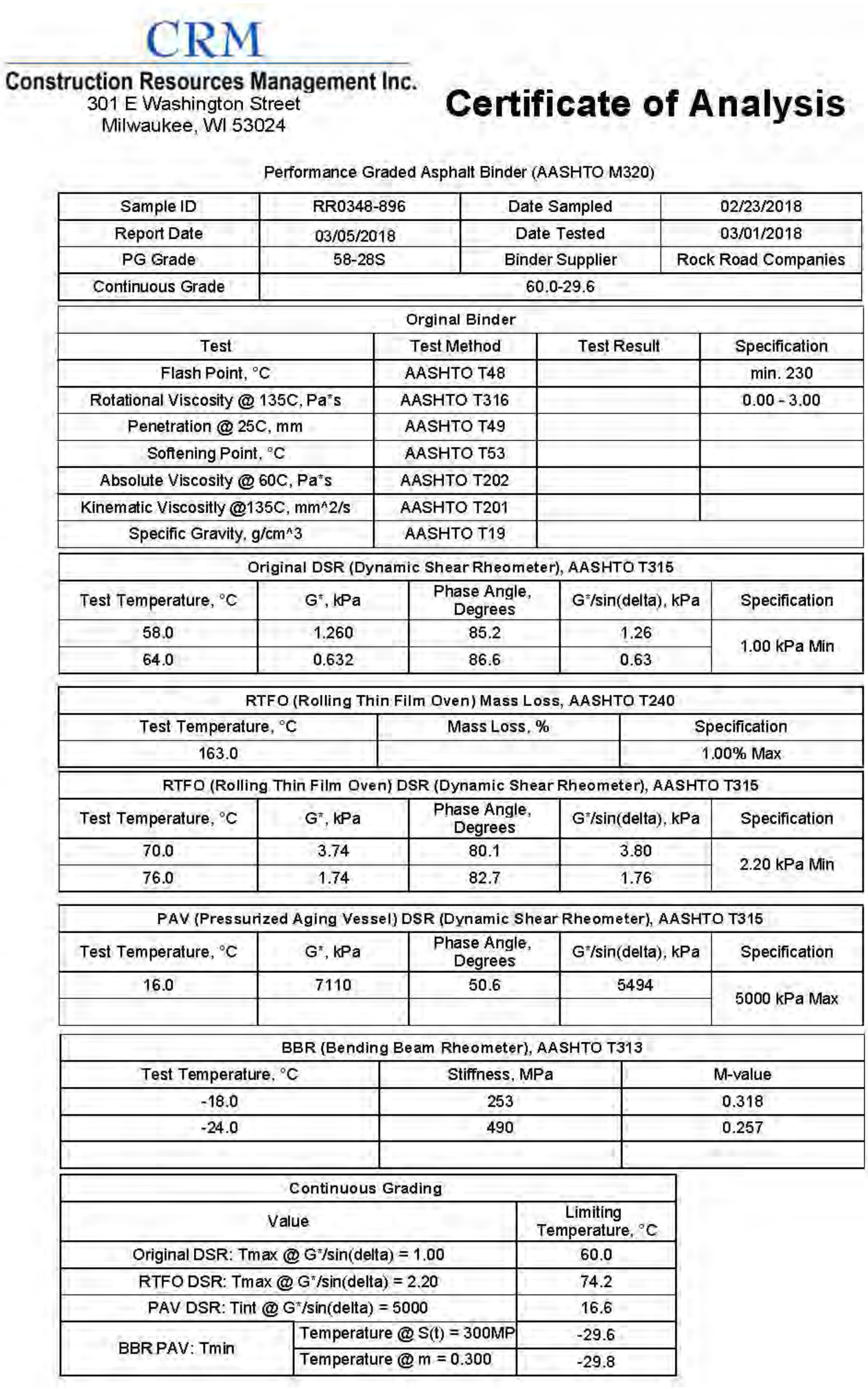
Test Temperature, °C	% Recovery 3.2	Jnr 3.2	Jnr diff	
58.0	17.70	0.343	7.90	
Specification	Min.	Max. 4.5 kPa-1	Max 75%	

PAV (Pressurized Aging Vessel) DSR (Dynamic Shear Rheometer), AASHTO T315

Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
19.0	4410	53.7	3554	5000 kPa Max
16.0	7110	50.6	5494	

BBR (Bending Beam Rheometer), AASHTO T313

Test Temperature, °C	Stiffness, MPa	M-value
-18.0	253	0.318
-24.0	490	0.257



CRM

Construction Resources Management Inc.
301 E Washington Street
Milwaukee, WI 53024

Certificate of Analysis

Performance Graded Asphalt Binder (AASHTO M320)

Sample ID	RR0348-896	Date Sampled	02/23/2018
Report Date	03/05/2018	Date Tested	03/01/2018
PG Grade	58-28S	Binder Supplier	Rock Road Companies
Continuous Grade	60.0-29.6		

Orginal Binder

Test	Test Method	Test Result	Specification
Flash Point, °C	AASHTO T48		min. 230
Rotational Viscosity @ 135C, Pa*s	AASHTO T316		0.00 - 3.00
Penetration @ 25C, mm	AASHTO T49		
Softening Point, °C	AASHTO T53		
Absolute Viscosity @ 60C, Pa*s	AASHTO T202		
Kinematic Viscosity @135C, mm^2/s	AASHTO T201		
Specific Gravity, g/cm^3	AASHTO T19		

Original DSR (Dynamic Shear Rheometer), AASHTO T315

Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
58.0	1.260	85.2	1.26	1.00 kPa Min
64.0	0.632	86.6	0.63	

RTFO (Rolling Thin Film Oven) Mass Loss, AASHTO T240

Test Temperature, °C	Mass Loss, %	Specification
163.0		1.00% Max

RTFO (Rolling Thin Film Oven) DSR (Dynamic Shear Rheometer), AASHTO T315

Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
70.0	3.74	80.1	3.80	2.20 kPa Min
76.0	1.74	82.7	1.76	

PAV (Pressurized Aging Vessel) DSR (Dynamic Shear Rheometer), AASHTO T315

Test Temperature, °C	G*, kPa	Phase Angle, Degrees	G*/sin(delta), kPa	Specification
16.0	7110	50.6	5494	5000 kPa Max

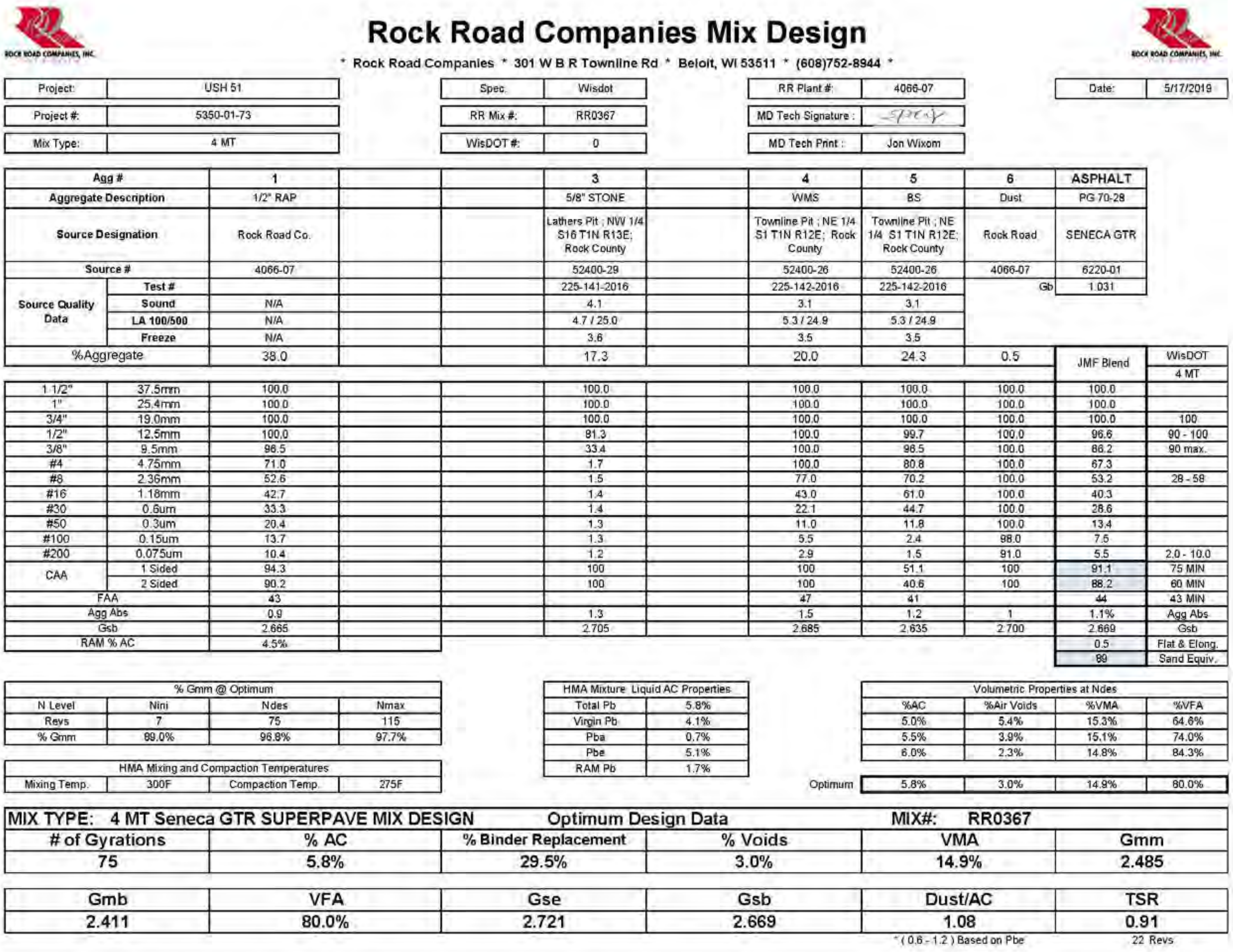
BBR (Bending Beam Rheometer), AASHTO T313

Test Temperature, °C	Stiffness, MPa	M-value
-18.0	253	0.318
-24.0	490	0.257

Continuous Grading

Value		Limiting Temperature, °C
Original DSR: Tmax @ G*/sin(delta) = 1.00		60.0
RTFO DSR: Tmax @ G*/sin(delta) = 2.20		74.2
PAV DSR: Tint @ G*/sin(delta) = 5000		16.6
BBR PAV: Tmin	Temperature @ S(t) = 300MP	-29.6
	Temperature @ m = 0.300	-29.8

13.3 Seneca (Terminal Blend) Mix Design



Rock Road Companies Mix Design

* Rock Road Companies * 301 W B R Townline Rd * Beloit, WI 53511 * (608)752-8944 *

Project:	USH 51	Spec.	Wisdot	RR Plant #:	4066-07	Date:	5/17/2019
Project #:	5350-01-73	RR Mix #:	RR0367	MD Tech Signature :			
Mix Type:	4 MT	WisDOT #:	0	MD Tech Print :	Jon Wixom		

Agg #		**1**			**3**		**4**	**5**	**6**	**ASPHALT**	
Aggregate Description		1/2" RAP			5/8" STONE		WMS	BS	Dust	PG 70-28	
Source Designation		Rock Road Co.			Lathers Pit ; NW 1/4 S16 T1N R13E; Rock County		Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Rock Road	SENECA GTR	
Source #		4066-07			52400-29		52400-26	52400-26	4066-07	6220-01	
Source Quality Data	**Test #**				225-141-2016		225-142-2016	225-142-2016	Gb	1.031	
	Sound	N/A			4.1		3.1	3.1			
	LA 100/500	N/A			4.7 / 25.0		5.3 / 24.9	5.3 / 24.9			
	Freeze	N/A			3.6		3.5	3.5			
%Aggregate		38.0			17.3		20.0	24.3	0.5	JMF Blend	WisDOT 4 MT
1 1/2"	37.5mm	100.0			100.0		100.0	100.0	100.0	100.0	
1"	25.4mm	100.0			100.0		100.0	100.0	100.0	100.0	
3/4"	19.0mm	100.0			100.0		100.0	100.0	100.0	100.0	100
1/2"	12.5mm	100.0			81.3		100.0	99.7	100.0	96.6	90 - 100
3/8"	9.5mm	96.5			33.4		100.0	96.5	100.0	86.2	90 max.
#4	4.75mm	71.0			1.7		100.0	80.8	100.0	67.3	
#8	2.36mm	52.6			1.5		77.0	70.2	100.0	53.2	28 - 58
#16	1.18mm	42.7			1.4		43.0	61.0	100.0	40.3	
#30	0.6um	33.3			1.4		22.1	44.7	100.0	28.6	
#50	0.3um	20.4			1.3		11.0	11.8	100.0	13.4	
#100	0.15um	13.7			1.3		5.5	2.4	98.0	7.5	
#200	0.075um	10.4			1.2		2.9	1.5	91.0	5.5	2.0 - 10.0
CAA	1 Sided	94.3			100		100	51.1	100	91.1	75 MIN
	2 Sided	90.2			100		100	40.6	100	88.2	60 MIN
FAA		43					47	41		44	43 MIN
Agg Abs		0.9			1.3		1.5	1.2	1	1.1%	Agg Abs
Gsb		2.665			2.705		2.685	2.635	2.700	2.669	Gsb
RAM % AC		4.5%								0.5	Flat & Elong.
										89	Sand Equiv.

% Gmm @ Optimum			
N Level	Nini	Ndes	Nmax
Revs	7	75	115
% Gmm	89.0%	96.8%	97.7%

HMA Mixing and Compaction Temperatures			
Mixing Temp.	300F	Compaction Temp.	275F

HMA Mixture Liquid AC Properties	
Total Pb	5.8%
Virgin Pb	4.1%
Pba	0.7%
Pbe	5.1%
RAM Pb	1.7%

	Volumetric Properties at Ndes			
	%AC	%Air Voids	%VMA	%VFA
	5.0%	5.4%	15.3%	64.6%
	5.5%	3.9%	15.1%	74.0%
	6.0%	2.3%	14.8%	84.3%
Optimum	5.8%	3.0%	14.9%	80.0%

MIX TYPE: 4 MT Seneca GTR SUPERPAVE MIX DESIGN **Optimum Design Data** **MIX#: RR0367**

# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.8%	29.5%	3.0%	14.9%	2.485

Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.411	80.0%	2.721	2.669	1.08	0.91
				* (0.6 - 1.2) Based on Pbe	22 Revs

ROCK ROAD COMPANIES, INC.

Mix Type: 4 MT Seneca GTR SUPERPAVE MIX DESIGN Mix #: RR0367

ROCK ROAD COMPANIES, INC.

Measured Specific Gravity Analysis

Gmm(meas)

Sp. Gravity of AC: 1.031

Mix	AC1	AC2	AC3	
%AC	5.0	5.5	6.0	
	Gmm	Gmm	Gmm	
Mix Wt. in Air	1501.3	1503.3	1506.4	
Wt. Pyc + H2O	1432.2	1432.2	1432.2	
Mix + Pyc + H2O	2336.0	2334.3	2330.0	
Volume	597.5	601.2	608.6	
Max Sp. Gravity, Gmm	2.513	2.501	2.475	Ave of 3
Gse	2.718	2.727	2.718	2.721

Gmb(meas)

Gyration Level : Nini = 7 Ndes = 75 Nmax = 115

Mixing Temp. °F: 300 Compaction Temp. °F: 275

Mix	AC1		AC2		AC3	
%AC	4.5		5.0		5.5	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6
Spec. Wt. in Air	4853.3	4847.5	4847	4853.4	4841	4845.7
Spec . Wt. in H2O	2814	2815.1	2828.2	2833	2840	2845.5
SSD	4856.3	4851.1	4849.7	4855.6	4841.8	4846.1
Bulk Volume	2042.3	2036	2021.5	2022.6	2001.8	2000.6
Bulk Sp. Gravity, Gmb	2.376	2.381	2.398	2.400	2.418	2.422
Av. Bulk Sp. Gravity	2.379		2.399		2.420	

T-283 TSR Data

Specimen # ------->	1	3	5	2	4	6
Orig. Wt. ------->	3822.4	3826.3	3824.4	3824.6	3827.4	3826.4
SSD WT. ------->	3833.9	3836.2	3833.5	3834.9	3836.9	3835.3
SUB WT. ------->	2170.4	2187.1	2186.6	2186.6	2184.0	2186.3
Volume ------->	1663.5	1649.1	1646.9	1648.3	1652.9	1649
SPGR. "d" ------->	2.298	2.320	2.322	2.320	2.316	2.320
%VOIDS ------->	7.5	6.6	6.6	6.6	6.8	6.6
VOIDS (CC) ------->	125.2	109.5	108.0	109.4	112.4	109.5
BIG "D"-	2.485	AV.SPGR-	2.316		AVG. % VOIDS-	6.8

SPECIMEN NO. (S) UNCONDITIONED	1	3	5	
SPECIMEN NO. (S) CONDITIONED	2	4	6	
WEIGHT FOR 55% SATURATION	3884.8	3889.2	3886.6	
WEIGHT FOR 80% SATURATION	3912.2	3917.3	3914.0	
FINAL STAURATED WEIGHT	3910.2	3915.6	3912.1	
FINAL % SATURATION	78.2	78.5	78.3	AVE.% SAT.
				78.3

	CONDITIONED			UNCONDITIONED		
SPEC. NO.(S)	2	4	6	1	3	5
LOAD (kN)	15.2	16	15.8	14.8	18.2	18.8
TENS.STR. k Pa (psi)	691.6	726.0	718.6	667.3	827.7	856.2

CONDITIONED
AV.TENS.STR. 712.1

UNCONDITIONED
AVE.TEN.STR. 783.7

TENSILE STRENGTH RATIO- 0.91

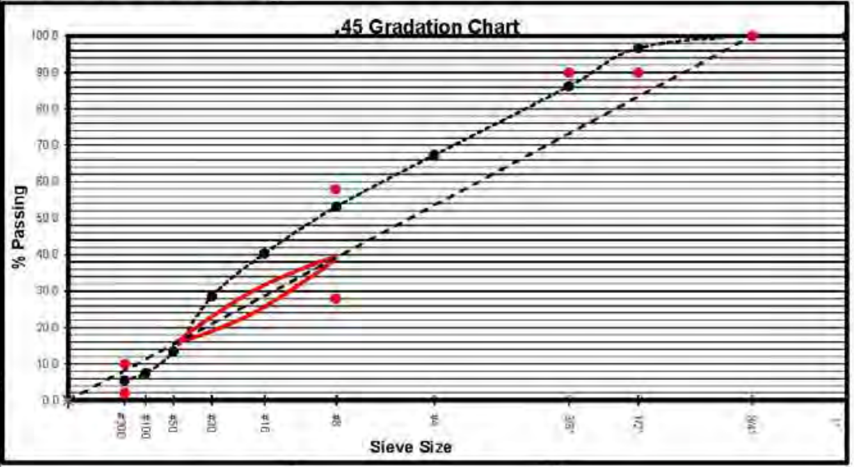
REVS - 22

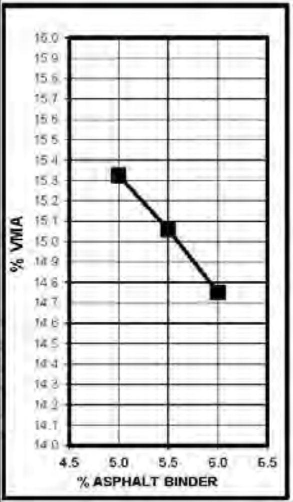
Summary of Compaction Properties at Different Asphalt Contents

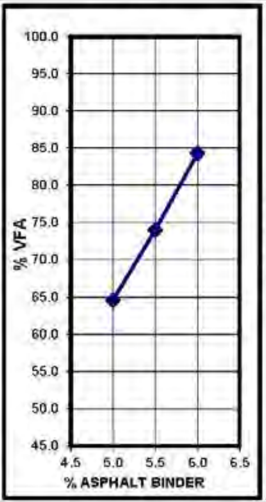
Volumetric Properties at Ndes

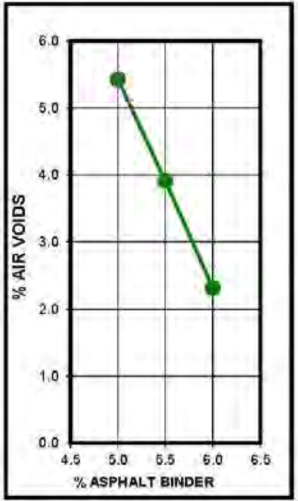
%AC	%Air Voids	%VMA	%VFA
5.0	5.4	15.3	64.6
5.5	3.9	15.1	74.0
6.0	2.3	14.8	84.3
5.8%	4.0%	14.9%	80.0%

Project:	USH 51
Project #	5350-01-73
Mix Type:	4 MT

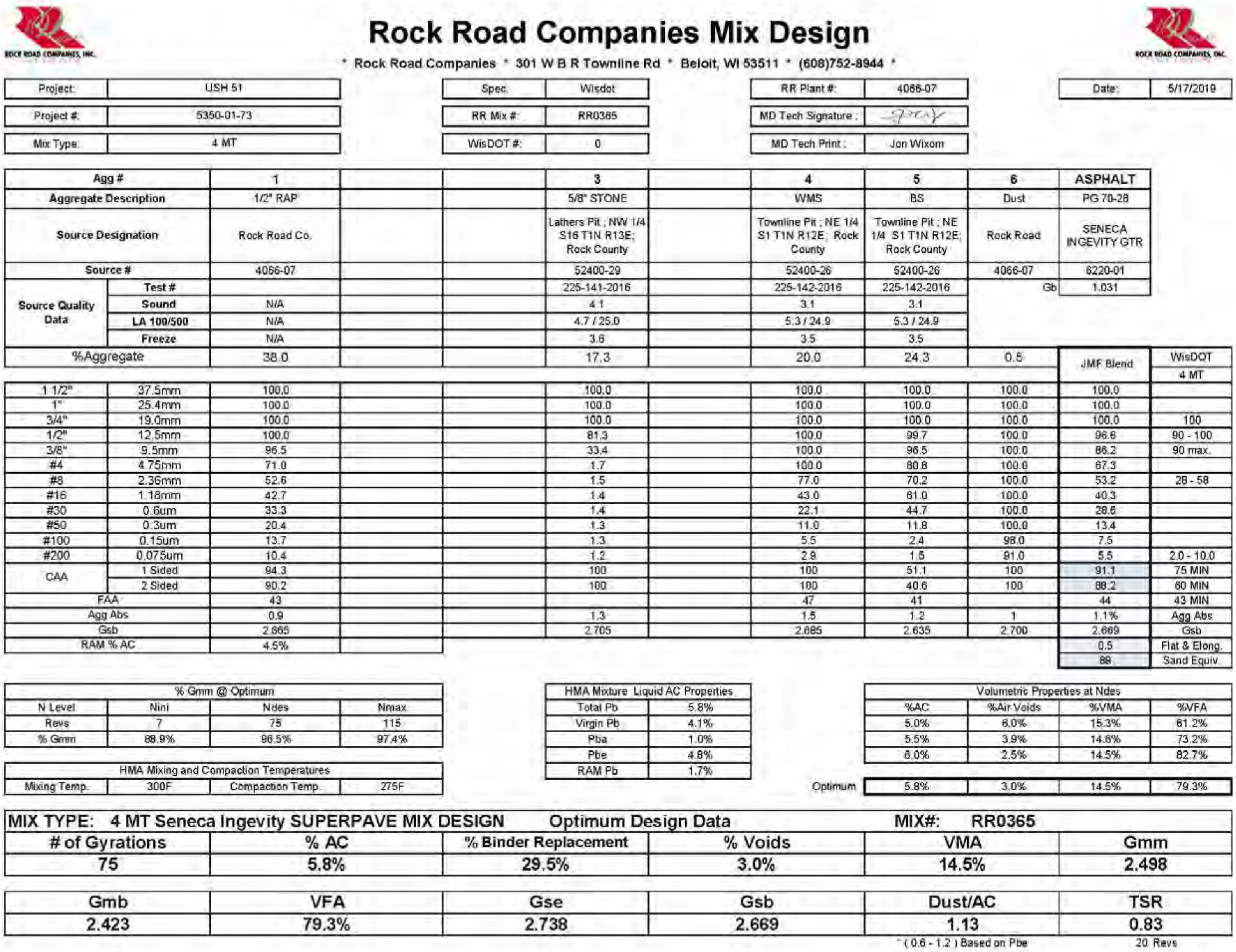








13.4 Seneca/Ingevity (Terminal Hybrid Blend) Mix Design



Rock Road Companies Mix Design

* Rock Road Companies * 301 W B R Townline Rd * Beloit, WI 53511 * (608)752-8944 *

Project:	USH 51	Spec.	Wisdot	RR Plant #:	4066-07	Date:	5/17/2019
Project #:	5350-01-73	RR Mix #:	RR0365	MD Tech Signature :			
Mix Type:	4 MT	WisDOT #:	0	MD Tech Print :	Jon Wixom		

Agg #		1			3		4	5	6	ASPHALT	
Aggregate Description		1/2" RAP			5/8" STONE		WMS	BS	Dust	PG 70-28	
Source Designation		Rock Road Co.			Lathers Pit ; NW 1/4 S16 T1N R13E; Rock County		Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Rock Road	SENECA INGEVITY GTR	
Source #		4066-07			52400-29		52400-26	52400-26	4066-07	6220-01	
Source Quality Data	Test #				225-141-2016		225-142-2016	225-142-2016	Gb	1.031	
	Sound	N/A			4.1		3.1	3.1			
	LA 100/500	N/A			4.7 / 25.0		5.3 / 24.9	5.3 / 24.9			
	Freeze	N/A			3.6		3.5	3.5			
%Aggregate		38.0			17.3		20.0	24.3	0.5	JMF Blend	WisDOT 4 MT
1 1/2"	37.5mm	100.0			100.0		100.0	100.0	100.0	100.0	
1"	25.4mm	100.0			100.0		100.0	100.0	100.0	100.0	
3/4"	19.0mm	100.0			100.0		100.0	100.0	100.0	100.0	100
1/2"	12.5mm	100.0			81.3		100.0	99.7	100.0	96.6	90 - 100
3/8"	9.5mm	96.5			33.4		100.0	96.5	100.0	86.2	90 max.
#4	4.75mm	71.0			1.7		100.0	80.8	100.0	67.3	
#8	2.36mm	52.6			1.5		77.0	70.2	100.0	53.2	28 - 58
#16	1.18mm	42.7			1.4		43.0	61.0	100.0	40.3	
#30	0.6um	33.3			1.4		22.1	44.7	100.0	28.6	
#50	0.3um	20.4			1.3		11.0	11.8	100.0	13.4	
#100	0.15um	13.7			1.3		5.5	2.4	98.0	7.5	
#200	0.075um	10.4			1.2		2.9	1.5	91.0	5.5	2.0 - 10.0
CAA	1 Sided	94.3			100		100	51.1	100	91.1	75 MIN
	2 Sided	90.2			100		100	40.6	100	88.2	60 MIN
FAA		43					47	41		44	43 MIN
Agg Abs		0.9			1.3		1.5	1.2	1	1.1%	Agg Abs
Gsb		2.665			2.705		2.685	2.635	2.700	2.669	Gsb
RAM % AC		4.5%								0.5	Flat & Elong.
										89	Sand Equiv.

% Gmm @ Optimum			
N Level	Nini	Ndes	Nmax
Revs	7	75	115
% Gmm	88.9%	96.5%	97.4%

HMA Mixing and Compaction Temperatures			
Mixing Temp.	300F	Compaction Temp.	275F

HMA Mixture Liquid AC Properties	
Total Pb	5.8%
Virgin Pb	4.1%
Pba	1.0%
Pbe	4.8%
RAM Pb	1.7%

	Volumetric Properties at Ndes			
	%AC	%Air Voids	%VMA	%VFA
	5.0%	6.0%	15.3%	61.2%
	5.5%	3.9%	14.6%	73.2%
	6.0%	2.5%	14.5%	82.7%
Optimum	5.8%	3.0%	14.5%	79.3%

MIX TYPE: 4 MT Seneca Ingevity SUPERPAVE MIX DESIGN Optimum Design Data MIX#: RR0365

# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.8%	29.5%	3.0%	14.5%	2.498

Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.423	79.3%	2.738	2.669	1.13	0.83
				* (0.6 - 1.2) Based on Pbe	20 Revs

ROCK ROAD COMPANIES, INC.

Mix Type: 4 MT Seneca Ingevity SUPERPAVE MIX DESIGN Mix #: RR0365

ROCK ROAD COMPANIES, INC.

Measured Specific Gravity Analysis

Gmm(meas)

Sp. Gravity of AC: 1.031

Mix	AC1	AC2	AC3
%AC	5.0	5.5	6.0
	Gmm	Gmm	Gmm
Mix Wt. in Air	1505.9	1504.1	1517.1
Wt. Pyc + H2O	1432.2	1432.2	1432.2
Mix + Pyc + H2O	2342.5	2338.3	2338.6
Volume	595.6	597.9	610.7
Max Sp. Gravity, Gmm	2.529	2.516	2.484
Gse	2.738	2.746	2.730

Ave of 3: 2.738

Gmb(meas)

Gyration Level : Nini = 7 Ndes = 75 Nmax = 115

Mixing Temp. °F: 300 Compaction Temp. °F: 275

Mix	AC1		AC2		AC3	
%AC	4.5		5.0		5.5	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6
Spec. Wt. in Air	4847	4850	4852.8	4846.8	4843.9	4847.4
Spec . Wt. in H2O	2812.5	2820.2	2838.5	2840	2846.9	2854.8
SSD	4853.6	4856.9	4853.7	4848	4845	4848.4
Bulk Volume	2041.1	2036.7	2015.2	2008	1998.1	1993.6
Bulk Sp. Gravity, Gmb	2.375	2.381	2.408	2.414	2.424	2.431
Av. Bulk Sp. Gravity	2.378		2.411		2.428	

T-283 TSR Data

Specimen # ------->	1	2	3	4	5	6
Orig. Wt. ------->	3884.7	3886.5	3884.9	3886.0	3884.4	3884.9
SSD WT. ------->	3892.6	3895.5	3894.7	3894.2	3895.2	3892.7
SUB WT. ------->	2211.0	2215.5	2217.5	2212.9	2216.8	2211.0
Volume ------->	1681.6	1680	1677.2	1681.3	1678.4	1681.7
SPGR. "d" ------->	2.310	2.313	2.316	2.311	2.314	2.310
%VOIDS ------->	7.5	7.4	7.3	7.5	7.4	7.5
VOIDS (CC) ------->	126.6	124.4	122.2	125.9	123.6	126.6
BIG "D"-	2.498	AV.SPGR-	2.312		AVG. % VOIDS-	7.4

SPECIMEN NO. (S) UNCONDITIONED	1	2	3
SPECIMEN NO. (S) CONDITIONED	4	5	6
WEIGHT FOR 55% SATURATION	3955.2	3952.4	3954.5
WEIGHT FOR 80% SATURATION	3986.7	3983.3	3986.2
FINAL STAURATED WEIGHT	3983.7	3978.9	3975.2
FINAL % SATURATION	77.6	76.4	71.3

AVE.% SAT. 75.1

	CONDITIONED			UNCONDITIONED		
SPEC. NO.(S)	4	5	6	1	2	3
LOAD (kN)	15.6	15.6	15.1	18.4	19.4	18
TENS.STR. k Pa (psi)	695.9	697.1	673.4	820.6	866.1	804.9

CONDITIONED
AV.TENS.STR. 688.8

UNCONDITIONED
AVE.TEN.STR. 830.5

TENSILE STRENGTH RATIO- 0.83

REVS - 20

Summary of Compaction Properties at Different Asphalt Contents

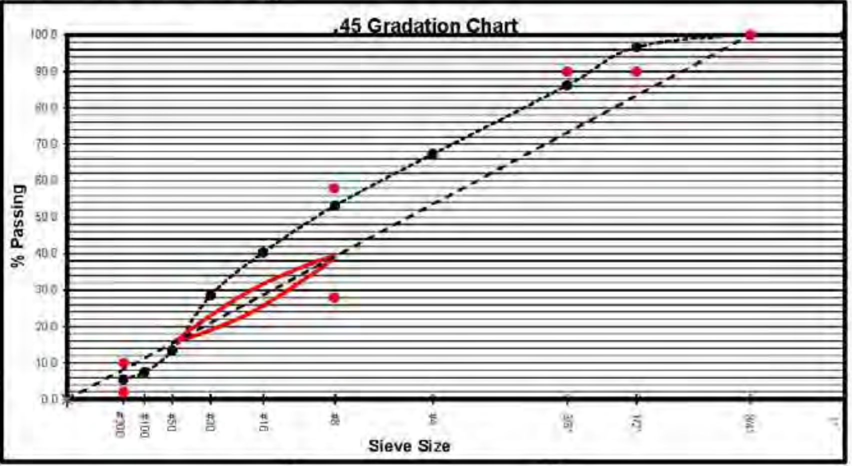
Volumetric Properties at Ndes

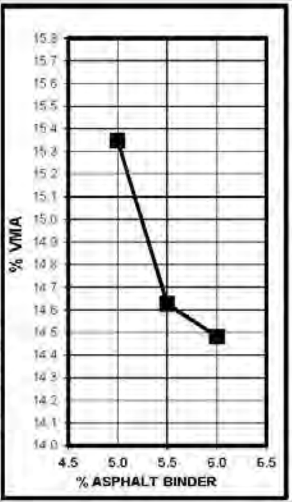
%AC	%Air Voids	%VMA	%VFA
5.0	6.0	15.3	61.2
5.5	3.9	14.6	73.2
6.0	2.5	14.5	82.7
5.8%	4.0%	14.5%	79.3%

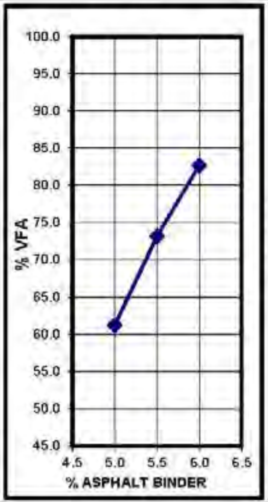
Project: USH 51

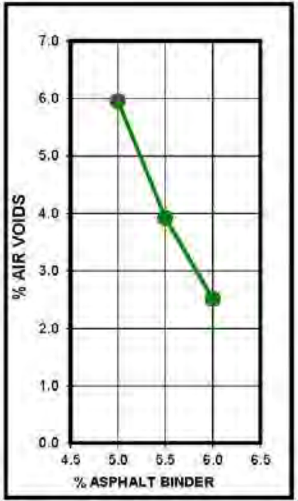
Project # 5350-01-73

Mix Type: 4 MT

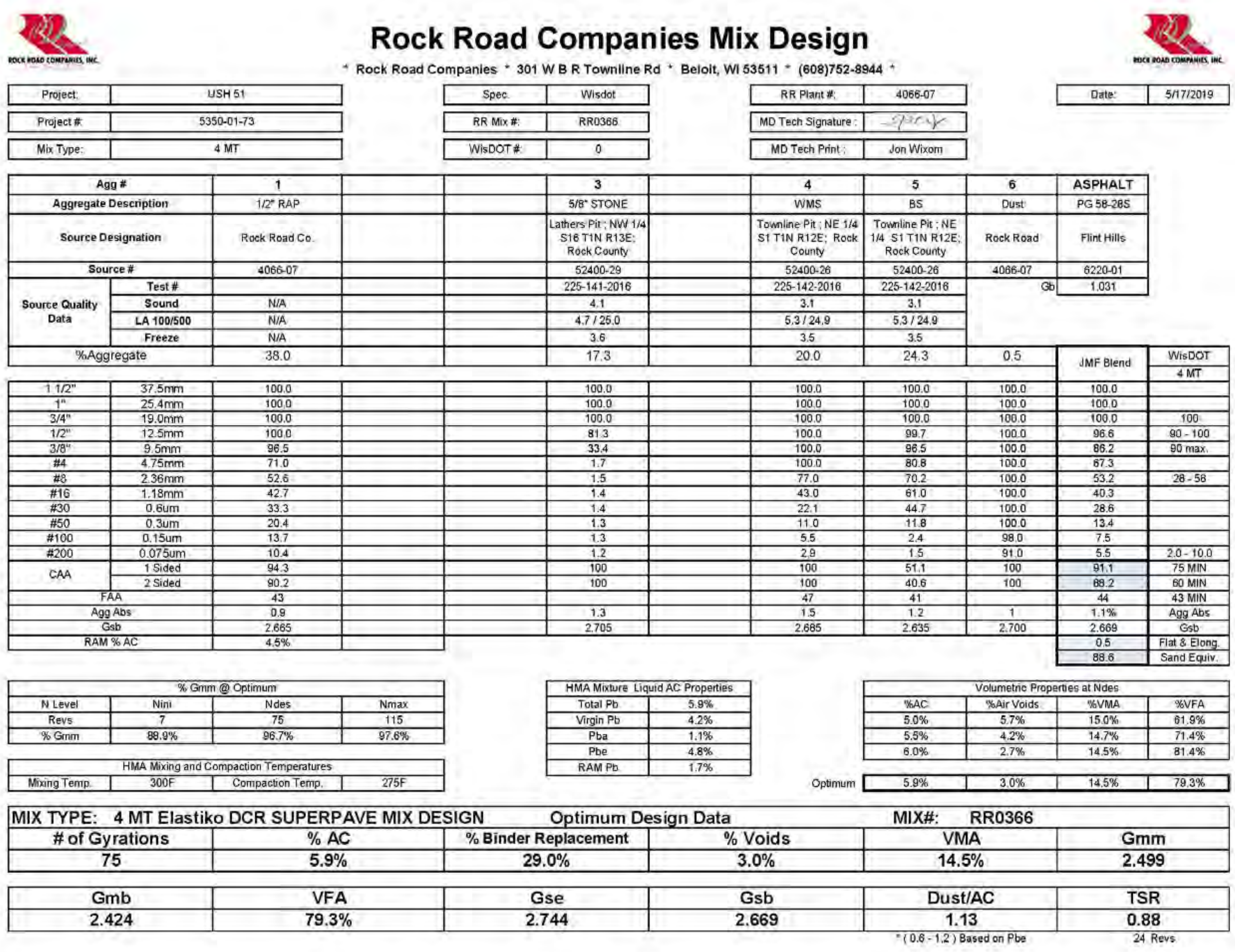








13.5 Elastiko (Dry Process) Mix Design



ROCK ROAD COMPANIES, INC.

Rock Road Companies Mix Design

* Rock Road Companies * 301 W B R Townline Rd * Beloit, WI 53511 * (608)752-8944 *

Project:	USH 51	Spec.	Wisdot	RR Plant #:	4066-07	Date:	5/17/2019
Project #:	5350-01-73	RR Mix #:	RR0366	MD Tech Signature :			
Mix Type:	4 MT	WisDOT #:	0	MD Tech Print :	Jon Wixom		

Agg #		1			3		4	5	6	ASPHALT	
Aggregate Description		1/2" RAP			5/8" STONE		WMS	BS	Dust	PG 58-28S	
Source Designation		Rock Road Co.			Lathers Pit ; NW 1/4 S16 T1N R13E; Rock County		Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Townline Pit ; NE 1/4 S1 T1N R12E; Rock County	Rock Road	Flint Hills	
Source #		4066-07			52400-29		52400-26	52400-26	4066-07	6220-01	
Source Quality Data	Test #				225-141-2016		225-142-2016	225-142-2016	Gb	1.031	
	Sound	N/A			4.1		3.1	3.1			
	LA 100/500	N/A			4.7 / 25.0		5.3 / 24.9	5.3 / 24.9			
	Freeze	N/A			3.6		3.5	3.5			
%Aggregate		38.0			17.3		20.0	24.3	0.5	JMF Blend	WisDOT 4 MT
1 1/2"	37.5mm	100.0			100.0		100.0	100.0	100.0	100.0	
1"	25.4mm	100.0			100.0		100.0	100.0	100.0	100.0	
3/4"	19.0mm	100.0			100.0		100.0	100.0	100.0	100.0	100
1/2"	12.5mm	100.0			81.3		100.0	99.7	100.0	96.6	90 - 100
3/8"	9.5mm	96.5			33.4		100.0	96.5	100.0	86.2	90 max.
#4	4.75mm	71.0			1.7		100.0	80.8	100.0	67.3	
#8	2.36mm	52.6			1.5		77.0	70.2	100.0	53.2	28 - 58
#16	1.18mm	42.7			1.4		43.0	61.0	100.0	40.3	
#30	0.6um	33.3			1.4		22.1	44.7	100.0	28.6	
#50	0.3um	20.4			1.3		11.0	11.8	100.0	13.4	
#100	0.15um	13.7			1.3		5.5	2.4	98.0	7.5	
#200	0.075um	10.4			1.2		2.9	1.5	91.0	5.5	2.0 - 10.0
CAA	1 Sided	94.3			100		100	51.1	100	91.1	75 MIN
	2 Sided	90.2			100		100	40.6	100	88.2	60 MIN
FAA		43					47	41		44	43 MIN
Agg Abs		0.9			1.3		1.5	1.2	1	1.1%	Agg Abs
Gsb		2.665			2.705		2.685	2.635	2.700	2.669	Gsb
RAM % AC		4.5%								0.5	Flat & Elong.
										88.6	Sand Equiv.

% Gmm @ Optimum			
N Level	Nini	Ndes	Nmax
Revs	7	75	115
% Gmm	88.9%	96.7%	97.6%

HMA Mixing and Compaction Temperatures			
Mixing Temp.	300F	Compaction Temp.	275F

HMA Mixture Liquid AC Properties	
Total Pb	5.9%
Virgin Pb	4.2%
Pba	1.1%
Pbe	4.8%
RAM Pb	1.7%

	Volumetric Properties at Ndes			
	%AC	%Air Voids	%VMA	%VFA
	5.0%	5.7%	15.0%	61.9%
	5.5%	4.2%	14.7%	71.4%
	6.0%	2.7%	14.5%	81.4%
Optimum	5.9%	3.0%	14.5%	79.3%

MIX TYPE: 4 MT Elastiko DCR SUPERPAVE MIX DESIGN		Optimum Design Data		MIX#: RR0366	
# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.9%	29.0%	3.0%	14.5%	2.499

Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.424	79.3%	2.744	2.669	1.13	0.88
				* (0.6 - 1.2) Based on Pbe	24 Revs

ROCK ROAD COMPANIES, INC.

Mix Type: 4 MT Elastiko DCR SUPERPAVE MIX DESIGN   Mix #: RR0366

Measured Specific Gravity Analysis

Gmm(meas)

Sp. Gravity of AC: 1.031

Mix	AC1	AC2	AC3
%AC	5.0	5.5	6.0
	Gmm	Gmm	Gmm
Mix Wt. in Air	1504.6	1503.6	1504.0
Wt. Pyc + H2O	1432.2	1432.2	1432.2
Mix + Pyc + H2O	2344.0	2338.8	2331.0
Volume	592.8	596.9	605.2
Max Sp. Gravity, Gmm	2.538	2.519	2.485
Gse	2.750	2.750	2.731

Ave of 3: 2.744

Gmb(meas)

Gyration Level : Nini = 7   Ndes = 75   Nmax = 115

Mixing Temp. °F: 300   Compaction Temp. °F: 275

Mix	AC1		AC2		AC3	
%AC	4.5		5.0		5.5	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6
Spec. Wt. in Air	4858.7	4840.6	4829.1	4836.9	4843.2	4838.8
Spec . Wt. in H2O	2835	2825.2	2824	2829.5	2848.5	2846.2
SSD	4868.1	4851.9	4829.7	4837.5	4843.5	4839
Bulk Volume	2033.1	2026.7	2005.7	2008	1995	1992.8
Bulk Sp. Gravity, Gmb	2.390	2.388	2.408	2.409	2.428	2.428
Av. Bulk Sp. Gravity	2.389		2.408		2.428	

T-283 TSR Data

Specimen # ------->	4	5	6	1	2	3
Orig. Wt. ------->	3878.1	3936.6	3890.4	3909.2	3896.2	3907.6
SSD WT. ------->	3888.2	3944.9	3897.3	3913.5	3904.7	3914.1
SUB WT. ------->	2226.6	2255.0	2230.0	2237.6	2235.6	2240.3
Volume ------->	1661.7	1689.9	1667.3	1675.9	1669.1	1673.8
SPGR. "d" ------->	2.334	2.329	2.333	2.333	2.334	2.335
%VOIDS ------->	6.6	6.8	6.6	6.6	6.6	6.6
VOIDS (CC) ------->	109.7	115.0	110.6	111.3	110.2	109.8
BIG "D"-	2.499	AV.SPGR-	2.333		AVG. % VOIDS-	6.6

SPECIMEN NO. (S) UNCONDITIONED	4	5	6
SPECIMEN NO. (S) CONDITIONED	1	2	3
WEIGHT FOR 55% SATURATION	3970.4	3956.8	3968.0
WEIGHT FOR 80% SATURATION	3998.3	3984.4	3995.5
FINAL STAURATED WEIGHT	3979.1	3970.8	3976.8
FINAL % SATURATION	62.8	67.7	63.0

AVE.% SAT. 64.5

	CONDITIONED			UNCONDITIONED		
SPEC. NO.(S)	1	2	3	4	5	6
LOAD (kN)	31.2	28.6	29	32.4	35.6	32.6
TENS.STR. k Pa (psi)	1396.3	1285.1	1299.4	1462.4	1580.0	1466.4

CONDITIONED AV.TENS.STR. 1326.9

UNCONDITIONED AVE.TEN.STR. 1502.9

TENSILE STRENGTH RATIO- 0.88

REVS - 24

Summary of Compaction Properties at Different Asphalt Contents

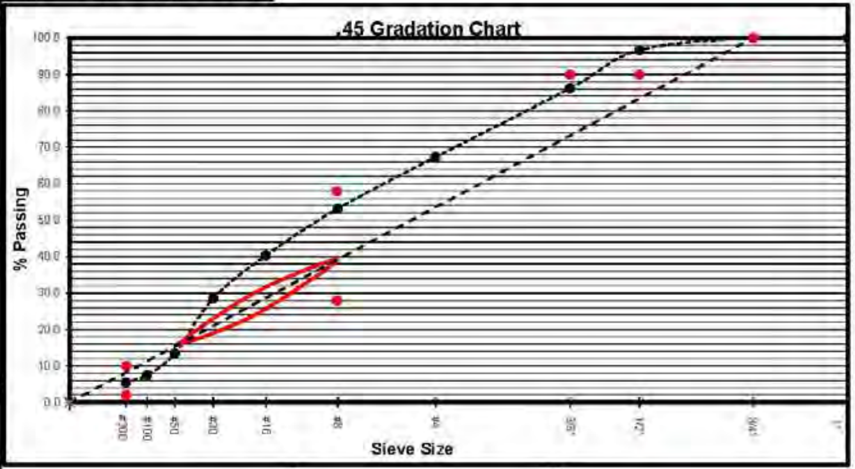
Volumetric Properties at Ndes

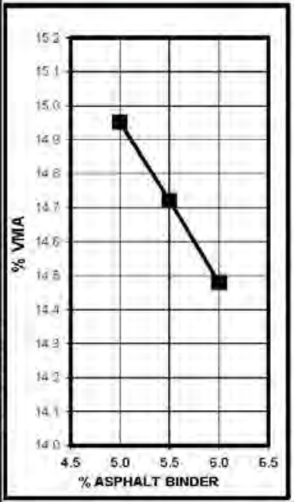
%AC	%Air Voids	%VMA	%VFA
5.0	5.7	15.0	61.9
5.5	4.2	14.7	71.4
6.0	2.7	14.5	81.4
5.9%	4.0%	14.5%	79.3%

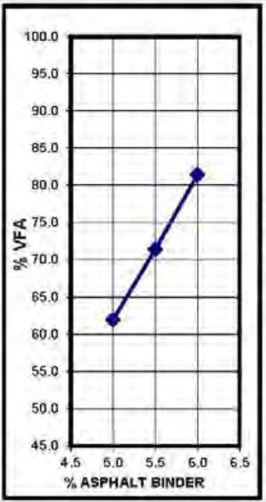
Project: USH 51

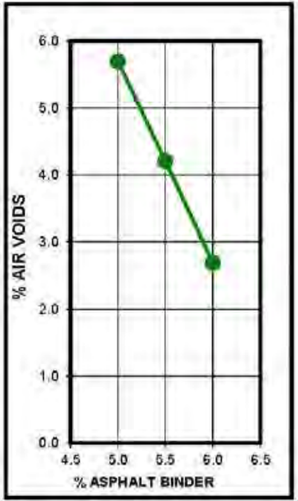
Project # 5350-01-73

Mix Type: 4 MT





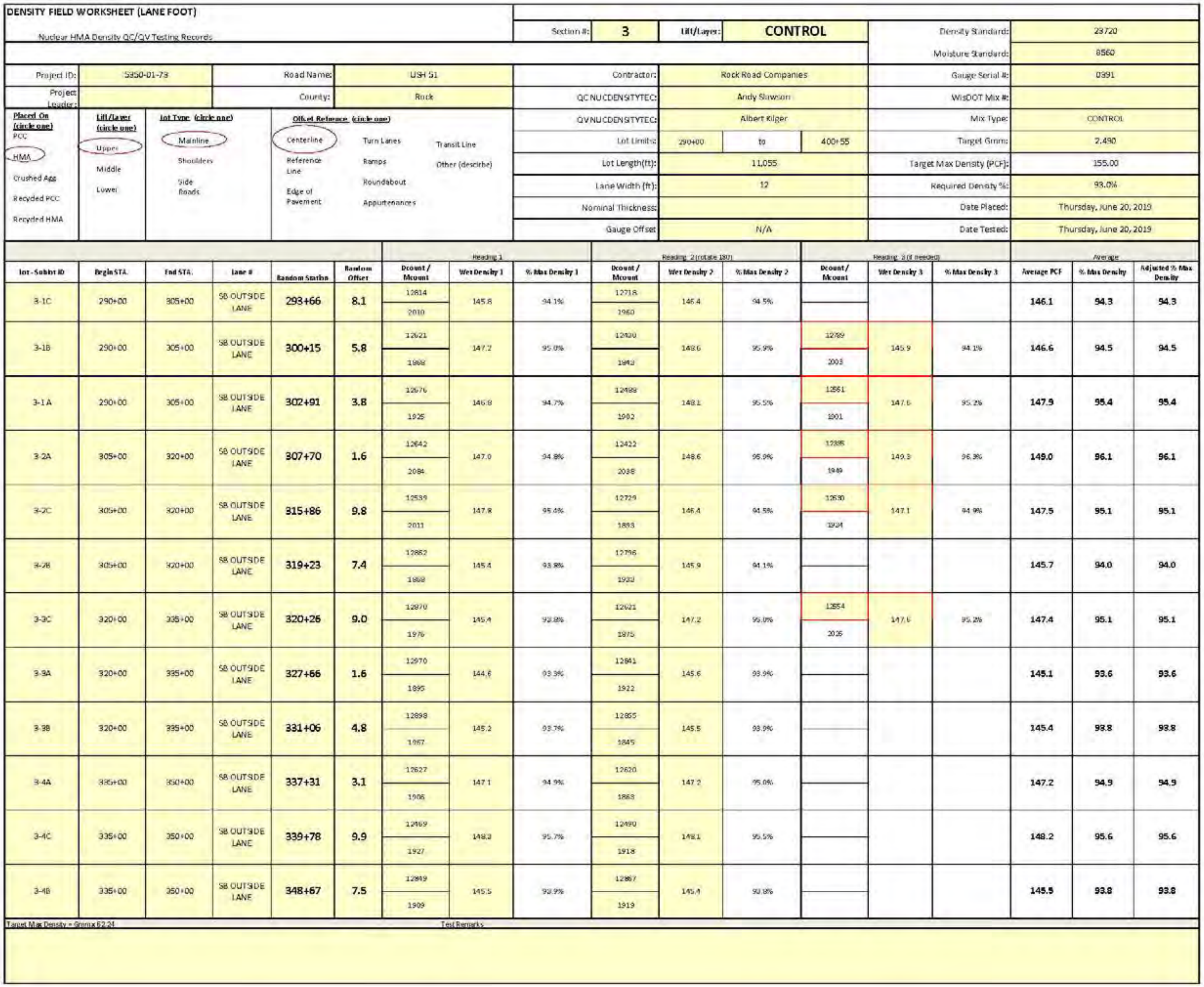




13.6 Volumetric Summary of Production Tested Mix

Mix	Gmm			Gmb			VMA			%AC			%AV		
	JMF	Production Average	Standard Deviation	JMF	Production Average	Standard Deviation	JMF	Production Average	Standard Deviation	JMF	Production Average	Standard Deviation	JMF	Production Average	Standard Deviation
Control	2.484	2.486	0.002	2.409	2.416	0.008	14.9	14.8	0.3	5.70%	5.92%	0.07%	3.0%	2.8%	0.3%
Terminal Blend	2.485	2.487	0.004	2.411	2.421	0.004	14.9	14.5	0.1	5.80%	5.73%	0.13%	3.0%	2.6%	0.3%
Terminal Blend Hybrid	2.498	2.477	0.005	2.423	2.409	0.011	14.5	15.0	0.4	5.80%	5.82%	0.06%	3.0%	2.8%	0.4%
Dry Process	2.499	2.465	0.008	2.424	2.397	0.029	14.5	16.3	1.0	5.90%	6.31%	0.16%	3.0%	2.8%	1.0%

13.7 Control Test Section Density Results



DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	3	Lift/Layer:	CONTROL
Density Standard:	23720	Moisture Standard:	8560
Project ID:	5350-01-73	Road Name:	USH 51
Project Leader:		County:	Rock
Contractor:	Rock Road Companies	Gauge Serial #:	0391
QC NUCDENSITYTEC:	Andy Slawson	WisDOT Mix #:	
QV NUCDENSITYTEC:	Albert Kilger	Mix Type:	CONTROL
Lot Limits:	290+00 to 400+55	Target Gmm:	2.490
Lot Length(ft):	11,055	Target Max Density (PCF):	155.00
Lane Width (ft):	12	Required Density %:	93.0%
Nominal Thickness:		Date Placed:	Thursday, June 20, 2019
Gauge Offset	N/A	Date Tested:	Thursday, June 20, 2019

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

Offset Reference (circle one)
[✓ Centerline]
Reference Line
Edge of Pavement
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate 180)			Reading 3 (if needed)			Average		
Lot-Sublot ID	Begin STA.	End STA.	Lane #	Random Station	Random Offset	Dcount / Mcount	Wet Density 1	% Max Density 1	Dcount / Mcount	Wet Density 2	% Max Density 2	Dcount / Mcount	Wet Density 3	% Max Density 3	Average PCF	% Max Density	Adjusted % Max Density
3-1C	290+00	305+00	SB OUTSIDE LANE	293+66	8.1	12814 2010	145.8	94.1%	12718 1960	146.4	94.5%				146.1	94.3	94.3
3-1B	290+00	305+00	SB OUTSIDE LANE	300+15	5.8	12621 1988	147.2	95.0%	12400 1943	148.6	95.9%	12789 2003	145.9	94.1%	146.6	94.5	94.5
3-1A	290+00	305+00	SB OUTSIDE LANE	302+91	3.8	12676 1925	146.8	94.7%	12488 1902	148.1	95.5%	12561 1901	147.6	95.2%	147.9	95.4	95.4
3-2A	305+00	320+00	SB OUTSIDE LANE	307+70	1.6	12642 2084	147.0	94.8%	12422 2038	148.6	95.9%	12395 1949	149.3	96.3%	149.0	96.1	96.1
3-2C	305+00	320+00	SB OUTSIDE LANE	315+86	9.8	12539 2011	147.8	95.4%	12729 1893	146.4	94.5%	12630 1924	147.1	94.9%	147.5	95.1	95.1
3-2B	305+00	320+00	SB OUTSIDE LANE	319+23	7.4	12852 1868	145.4	93.8%	12796 1932	145.9	94.1%				145.7	94.0	94.0
3-3C	320+00	335+00	SB OUTSIDE LANE	320+26	9.0	12870 1976	145.4	93.8%	12621 1875	147.2	95.0%	12554 2026	147.6	95.2%	147.4	95.1	95.1
3-3A	320+00	335+00	SB OUTSIDE LANE	327+66	1.6	12970 1895	144.6	93.3%	12841 1922	145.6	93.9%				145.1	93.6	93.6
3-3B	320+00	335+00	SB OUTSIDE LANE	331+06	4.8	12898 1967	145.2	93.7%	12855 1845	145.5	93.9%				145.4	93.8	93.8
3-4A	335+00	350+00	SB OUTSIDE LANE	337+31	3.1	12627 1906	147.1	94.9%	12620 1863	147.2	95.0%				147.2	94.9	94.9
3-4C	335+00	350+00	SB OUTSIDE LANE	339+78	9.9	12469 1927	148.3	95.7%	12490 1918	148.1	95.5%				148.2	95.6	95.6
3-4B	335+00	350+00	SB OUTSIDE LANE	348+67	7.5	12849 1909	145.5	93.9%	12867 1919	145.4	93.8%				145.5	93.8	93.8

Target Max Density = Gmm x 62.24

Test Remarks

DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	3	Lift/Layer:	**CONTROL**	Density Standard:	23720
				Moisture Standard:	8560
Project ID:	5350-01-73	Road Name:	USH 51	Contractor:	Rock Road Companies
Project Leader:		County:	Rock	QC NUCDENSITYTEC:	Andy Slawson
Gauge Serial #:	0391	WisDOT Mix #:		QV NUCDENSITYTEC:	Albert Kilger
Mix Type:	CONTROL	Lot Limits:	290+00 to 400+55	Target Gmm:	2.49
Lot Length(ft):	11,055	Target Max Density (PCF):	155.00	Lane Width (ft):	12
Required Density %:	93.0%	Nominal Thickness:		Date Placed:	Thursday, June 20, 2019
Gauge Offset	N/A	Date Tested:	Thursday, June 20, 2019		

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

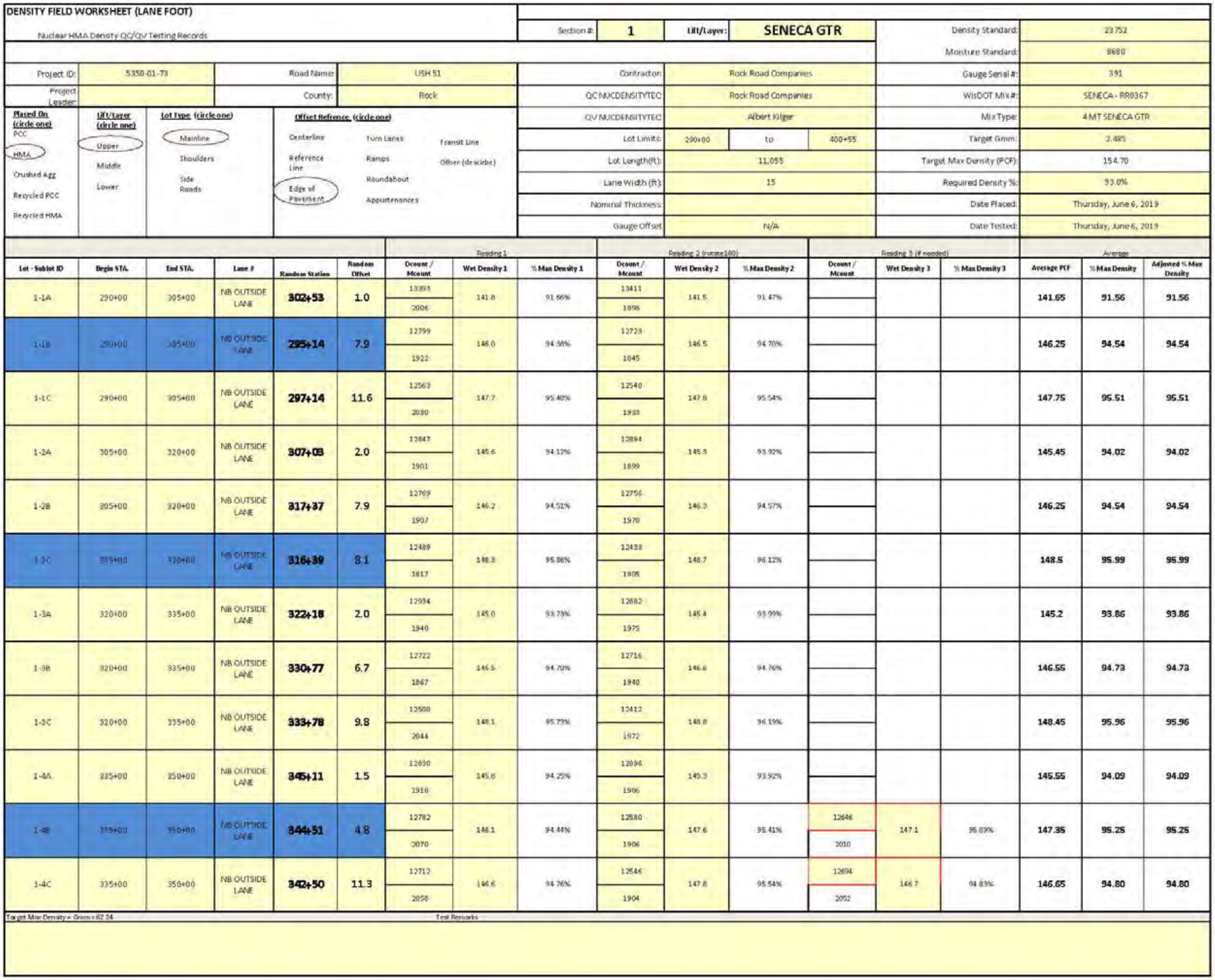
Offset Refrence (circle one)
[✓ Centerline]
Reference Line
Edge of Pavement
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate 180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	**Begin STA.**	**End STA.**	**Lane #**	**Random Station**	**Random Offset**	**Dcount / Mcount**	**Wet Density 1**	**% Max Density 1**	**Dcount / Mcount**	**Wet Density 2**	**% Max Density 2**	**Dcount / Mcount**	**Wet Density 3**	**% Max Density 3**	**Average PCF**	**% Max Density**	**Adjusted % Max Density**
3-5C	350+00	365+00	SB OUTSIDE LANE	**352+72**	**10.3**	12657 1917	146.9	94.8%	12559 1877	147.6	95.2%				**147.3**	**95.0**	**95.0**
3-5A	350+00	365+00	SB OUTSIDE LANE	**354+70**	**3.5**	12356 2022	149.1	96.2%	12472 1879	148.3	95.7%				**148.7**	**95.9**	**95.9**
3-5B	350+00	365+00	SB OUTSIDE LANE	**360+59**	**6.4**	12783 1905	146.0	94.2%	12854 1962	145.5	93.9%				**145.8**	**94.0**	**94.0**
3-6B	365+00	380+00	SB OUTSIDE LANE	**372+85**	**7.6**	12940 1863	144.9	93.5%	12812 1846	145.8	94.1%				**145.4**	**93.8**	**93.8**
3-6C	365+00	380+00	SB OUTSIDE LANE	**374+55**	**9.7**	12707 2034	146.5	94.5%	12515 1945	147.9	95.4%	12467 1926	148.3	95.7%	**148.1**	**95.5**	**95.5**
3-6A	365+00	380+00	SB OUTSIDE LANE	**379+77**	**1.7**	12985 1904	144.5	93.2%	12991 1881	144.5	93.2%				**144.5**	**93.2**	**93.2**
3-7A	380+00	400+55	SB OUTSIDE LANE	**385+40**	**0.6**	13144 1854	143.4	92.5%	12606 1984	147.3	95.0%	12630 2015	147.1	94.9%	**147.2**	**95.0**	**95.0**
3-7B	380+00	400+55	SB OUTSIDE LANE	**387+89**	**6.8**	12917 1852	145.0	93.5%	12878 1900	145.3	93.7%				**145.2**	**93.6**	**93.6**
3-7C	380+00	400+55	SB OUTSIDE LANE	**397+29**	**8.0**	12679 2066	146.7	94.6%	12580 2028	147.5	95.2%				**147.1**	**94.9**	**94.9**

Target Max Density = Gmm x 62.24

Test Remarks

13.8 TB Test Section Density Results



DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	1	Lift/Layer:	SENECA GTR
Project ID:	5350-01-73	Road Name:	USH 51
Project Leader:		County:	Rock
Contractor:	Rock Road Companies	Density Standard:	23752
QC NUCDENSITYTEC	Rock Road Companies	Moisture Standard:	8680
QV NUCDENSITYTEC	Albert Kilger	Gauge Serial #:	391
Lot Limits:	290+00 to 400+55	WisDOT Mix #:	SENECA - RR0367
Lot Length(ft):	11,055	Mix Type:	4 MT SENECA GTR
Lane Width (ft):	15	Target Gmm:	2.485
Nominal Thickness:		Target Max Density (PCF):	154.70
Gauge Offset	N/A	Required Density %:	93.0%
		Date Placed:	Thursday, June 6, 2019
		Date Tested:	Thursday, June 6, 2019

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

Offset Refrence (circle one)
Centerline
Reference Line
[✓ Edge of Pavement]
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	Begin STA.	End STA.	Lane #	Random Station	Random Offset	Dcount / Mcount	Wet Density 1	% Max Density 1	Dcount / Mcount	Wet Density 2	% Max Density 2	Dcount / Mcount	Wet Density 3	% Max Density 3	Average PCF	% Max Density	Adjusted % Max Density
1-1A	290+00	305+00	NB OUTSIDE LANE	**302+53**	1.0	13393 2006	141.8	91.66%	13411 1898	141.5	91.47%				**141.65**	**91.56**	**91.56**
1-1B	290+00	305+00	NB OUTSIDE LANE	**295+14**	7.9	12799 1922	146.0	94.38%	12723 1845	146.5	94.70%				**146.25**	**94.54**	**94.54**
1-1C	290+00	305+00	NB OUTSIDE LANE	**297+14**	11.6	12563 2030	147.7	95.48%	12540 1933	147.8	95.54%				**147.75**	**95.51**	**95.51**
1-2A	305+00	320+00	NB OUTSIDE LANE	**307+03**	2.0	12847 1901	145.6	94.12%	12894 1899	145.3	93.92%				**145.45**	**94.02**	**94.02**
1-2B	305+00	320+00	NB OUTSIDE LANE	**317+37**	7.9	12769 1907	146.2	94.51%	12756 1978	146.3	94.57%				**146.25**	**94.54**	**94.54**
1-2C	305+00	320+00	NB OUTSIDE LANE	**316+39**	8.1	12489 1817	148.3	95.86%	12438 1905	148.7	96.12%				**148.5**	**95.99**	**95.99**
1-3A	320+00	335+00	NB OUTSIDE LANE	**322+18**	2.0	12934 1940	145.0	93.73%	12882 1975	145.4	93.99%				**145.2**	**93.86**	**93.86**
1-3B	320+00	335+00	NB OUTSIDE LANE	**330+77**	6.7	12722 1867	146.5	94.70%	12716 1940	146.6	94.76%				**146.55**	**94.73**	**94.73**
1-3C	320+00	335+00	NB OUTSIDE LANE	**333+78**	9.8	12500 2044	148.1	95.73%	12412 1972	148.8	96.19%				**148.45**	**95.96**	**95.96**
1-4A	335+00	350+00	NB OUTSIDE LANE	**345+11**	1.5	12830 1918	145.8	94.25%	12896 1986	145.3	93.92%				**145.55**	**94.09**	**94.09**
1-4B	335+00	350+00	NB OUTSIDE LANE	**344+51**	4.8	12782 2070	146.1	94.44%	12580 1906	147.6	95.41%	12646 2010	147.1	95.09%	**147.35**	**95.25**	**95.25**
1-4C	335+00	350+00	NB OUTSIDE LANE	**342+50**	11.3	12712 2058	146.6	94.76%	12546 1904	147.8	95.54%	12694 2052	146.7	94.83%	**146.65**	**94.80**	**94.80**

Target Max Density = Gmm x 62.24

Test Remarks

DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	**1**	**Lift/Layer:**	**SENECA GTR**	Density Standard:	23752
				Moisture Standard:	8680
Project ID:	5350-01-73	Road Name:	USH 51	Contractor:	Rock Road Companies
Project Leader:		County:	Rock	QC NUCDENSITYTEC	Rock Road Companies
Gauge Serial #:	391	WisDOT Mix #:	SENECA - RR0367	QV NUCDENSITYTEC	Albert Kilger
Mix Type:	4 MT SENECA GTR	Lot Limits:	290+00 to 400+55	Target Gmm:	2.485
Lot Length(ft):	11,055	Target Max Density (PCF):	154.70	Lane Width (ft):	15
Required Density %:	93.0%	Nominal Thickness:		Date Placed:	Thursday, June 6, 2019
Gauge Offset	N/A	Date Tested:	Thursday, June 6, 2019		

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

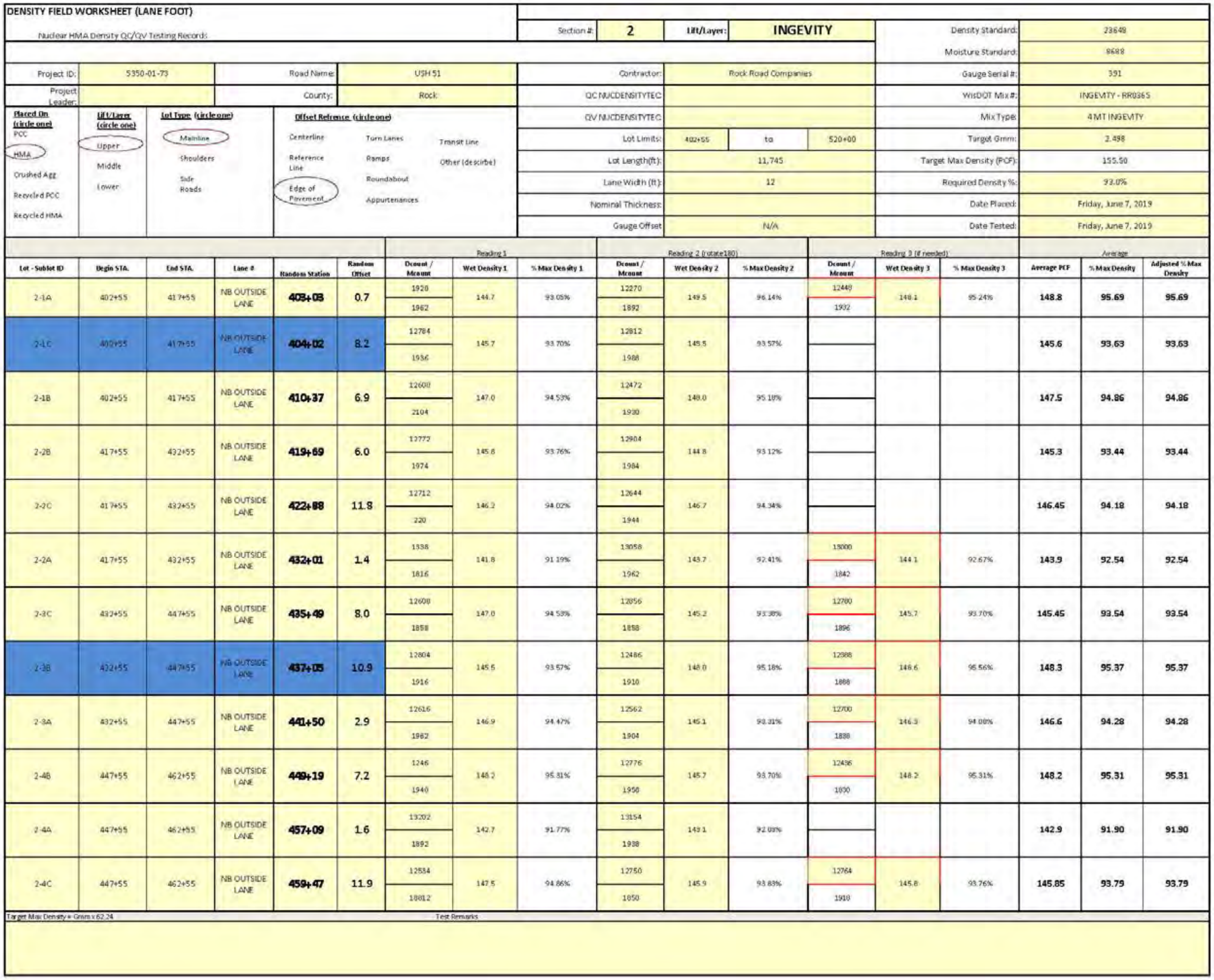
Offset Refrence (circle one)
Centerline
Reference Line
[✓ Edge of Pavement]
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (descirbe)

						Reading 1			Reading 2 (rotate180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	**Begin STA.**	**End STA.**	**Lane #**	**Random Station**	**Random Offset**	**Dcount / Mcount**	**Wet Density 1**	**% Max Density 1**	**Dcount / Mcount**	**Wet Density 2**	**% Max Density 2**	**Dcount / Mcount**	**Wet Density 3**	**% Max Density 3**	**Average PCF**	**% Max Density**	**Adjusted % Max Density**
1-5A	350+00	365+00	NB OUTSIDE LANE	**353+10**	2.0	12421 1906	148.2	95.80%	12642 1866	145.7	94.18%	12688 1964	147.1	95.09%	**147.65**	**95.44**	**95.44**
1-5B	350+00	365+00	NB OUTSIDE LANE	**352+88**	5.7	12716 1904	146.6	94.76%	12816 1928	145.9	94.31%				**146.25**	**94.54**	**94.54**
1-5C	350+00	365+00	NB OUTSIDE LANE	**351+61**	11.7	12184 1898	150.5	97.29%	12184 1874	150.5	97.29%				**150.5**	**97.29**	**97.29**
1-6A	365+00	380+00	NB OUTSIDE LANE	**377+70**	1.3	12462 1976	148.5	95.99%	12430 2028	148.7	96.12%				**148.6**	**96.06**	**96.06**
1-6B	365+00	380+00	NB OUTSIDE LANE	**367+18**	6.0	12708 1898	146.6	94.76%	12438 1900	148.6	96.06%	12628 1914	147.2	95.15%	**146.9**	**94.96**	**94.96**
1-6C	365+00	380+00	NB OUTSIDE LANE	**379+47**	9.9	12438 2006	148.6	96.06%	12286 1958	149.8	96.83%	12494 2110	148.2	95.80%	**148.4**	**95.93**	**95.93**
1-7A	380+00	400+55	NB OUTSIDE LANE	**399+82**	2.5	12476 2098	148.3	95.86%	12616 2024	147.3	95.22%				**147.8**	**95.54**	**95.54**
1-7B	380+00	400+55	NB OUTSIDE LANE	**392+34**	4.9	12672 1938	146.9	94.96%	12624 1978	147.3	95.22%				**147.1**	**95.09**	**95.09**
1-7C	380+00	400+55	NB OUTSIDE LANE	**389+11**	11.9	12566 1960	147.7	95.48%	12708 1948	146.6	94.76%	12984 1894	144.7	93.54%	**147.15**	**95.12**	**95.12**

Target Max Density = Gmm x 62.24

Test Remarks

13.9 TBH Test Section Density Results



DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	2	Lift/Layer:	INGEVITY	Density Standard:	23648
				Moisture Standard:	8688
Project ID:	5350-01-73	Road Name:	USH 51	Contractor:	Rock Road Companies
Gauge Serial #:	391				
Project Leader:		County:	Rock	QC NUCDENSITYTEC	
WisDOT Mix #:	INGEVITY - RR0365				
QV NUCDENSITYTEC		Mix Type:	4 MT INGEVITY		
Lot Limits:	402+55 to 520+00	Target Gmm:	2.498		
Lot Length(ft):	11,745	Target Max Density (PCF):	155.50		
Lane Width (ft):	12	Required Density %:	93.0%		
Nominal Thickness:		Date Placed:	Friday, June 7, 2019		
Gauge Offset	N/A	Date Tested:	Friday, June 7, 2019		

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

Offset Refrence (circle one)
Centerline
Reference Line
[✓ Edge of Pavement]
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	Begin STA.	End STA.	Lane #	Random Station	Random Offset	Dcount / Mcount	Wet Density 1	% Max Density 1	Dcount / Mcount	Wet Density 2	% Max Density 2	Dcount / Mcount	Wet Density 3	% Max Density 3	Average PCF	% Max Density	Adjusted % Max Density
2-1A	402+55	417+55	NB OUTSIDE LANE	403+08	0.7	1920 1962	144.7	93.05%	12270 1892	149.5	96.14%	12449 1932	148.1	95.24%	148.8	95.69	95.69
2-1C	402+55	417+55	NB OUTSIDE LANE	404+02	8.2	12784 1936	145.7	93.70%	12812 1988	145.5	93.57%				145.6	93.63	93.63
2-1B	402+55	417+55	NB OUTSIDE LANE	410+37	6.9	12600 2104	147.0	94.53%	12472 1930	148.0	95.18%				147.5	94.86	94.86
2-2B	417+55	432+55	NB OUTSIDE LANE	419+69	6.0	12772 1974	145.8	93.76%	12904 1984	144.8	93.12%				145.3	93.44	93.44
2-2C	417+55	432+55	NB OUTSIDE LANE	422+88	11.8	12712 220	146.2	94.02%	12644 1944	146.7	94.34%				146.45	94.18	94.18
2-2A	417+55	432+55	NB OUTSIDE LANE	432+01	1.4	1338 1816	141.8	91.19%	13058 1962	143.7	92.41%	13000 1842	144.1	92.67%	143.9	92.54	92.54
2-3C	432+55	447+55	NB OUTSIDE LANE	435+49	8.0	12608 1858	147.0	94.53%	12856 1858	145.2	93.38%	12700 1896	145.7	93.70%	145.45	93.54	93.54
2-3B	432+55	447+55	NB OUTSIDE LANE	437+05	10.9	12804 1916	145.5	93.57%	12486 1910	148.0	95.18%	12988 1888	148.6	95.56%	148.3	95.37	95.37
2-3A	432+55	447+55	NB OUTSIDE LANE	441+50	2.9	12616 1982	146.9	94.47%	12562 1904	145.1	93.31%	12700 1888	146.3	94.08%	146.6	94.28	94.28
2-4B	447+55	462+55	NB OUTSIDE LANE	449+19	7.2	1246 1940	148.2	95.31%	12776 1958	145.7	93.70%	12436 1830	148.2	95.31%	148.2	95.31	95.31
2-4A	447+55	462+55	NB OUTSIDE LANE	457+09	1.6	13202 1892	142.7	91.77%	13154 1938	143.1	92.03%				142.9	91.90	91.90
2-4C	447+55	462+55	NB OUTSIDE LANE	459+47	11.9	12534 18812	147.5	94.86%	12750 1850	145.9	93.83%	12764 1918	145.8	93.76%	145.85	93.79	93.79

Target Max Density = Gmm x 62.24

Test Remarks

DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	2	Lift/Layer:	**INGEVITY**
Project ID:	5350-01-73	Road Name:	USH 51
Project Leader:		County:	Rock
Contractor:	Rock Road Companies	Density Standard:	23648
QC NUCDENSITYTEC:	Rock Road Companies	Moisture Standard:	8688
QV NUCDENSITYTEC:	Kayla Schuler	Gauge Serial #:	3931
Lot Limits:	402+55 to 520+00	WisDOT Mix #:	INGEVITY - RR0365
Lot Length(ft):	11,745	Mix Type:	4 MT INGEVITY
Lane Width (ft):	12	Target Gmm:	2.498
Nominal Thickness:		Target Max Density (PCF):	155.50
Gauge Offset	N/A	Required Density %:	93.0%
		Date Placed:	Friday, June 7, 2019
		Date Tested:	Friday, June 7, 2019

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/Layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

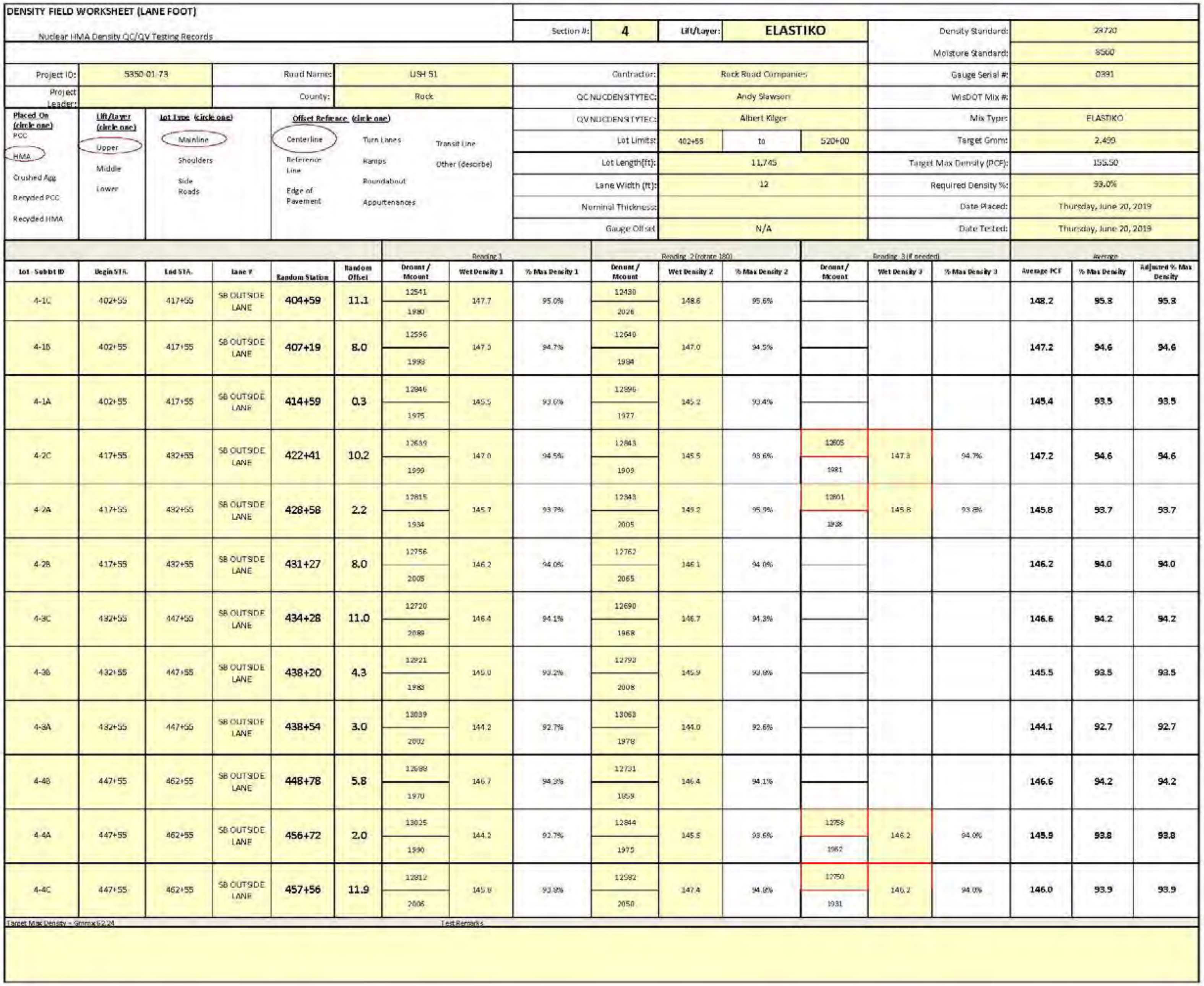
Offset Refrence (circle one)
Centerline
Reference Line
[✓ Edge of Pavement]
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate 180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	Begin STA.	End STA.	Lane #	Random Station	Random Offset	Dcount / Mcount	Wet Density 1	% Max Density 1	Dcount / Mcount	Wet Density 2	% Max Density 2	Dcount / Mcount	Wet Density 3	% Max Density 3	Average PCF	% Max Density	Adjusted % Max Density
2-5B	462+55	477+55	NB OUTSIDE LANE	464+26	7.7	13058 202556	143.7	92.41%	12464 1858	148.0	95.18%	12828 1952	145.4	93.50%	144.55	92.96	92.96
2-5A	462+55	477+55	NB OUTSIDE LANE	470+30	0.1	12630 1844	146.8	94.41%	13062 1946	143.7	92.41%	12828 1936	145.5	93.57%	146.15	93.99	93.99
2-5C	462+55	477+55	NB OUTSIDE LANE	473+08	8.0	12978 2012	144.3	92.80%	12550 1910	147.4	94.79%	12690 1828	146.4	94.15%	146.9	94.47	94.47
2-6C	477+55	492+55	NB OUTSIDE LANE	479+99	11.7	12494 2010	147.8	95.05%	12904 1998	144.8	93.12%	12518 1960	147.6	94.92%	147.7	94.98	94.98
2-6A	477+55	492+55	NB OUTSIDE LANE	484+04	3.3	12892 2016	144.9	93.18%	12620 1896	145.9	93.83%				145.4	93.50	93.50
2-6B	477+55	492+55	NB OUTSIDE LANE	484+21	6.9	12370 1946	148.7	95.63%	12550 1968	147.9	95.11%				148.3	95.37	95.37
2-7C	492+55	507+55	NB OUTSIDE LANE	497+10	8.0	12608 1896	147.0	94.53%	12684 1938	146.4	94.15%				146.7	94.34	94.34
2-7B	492+55	507+55	NB OUTSIDE LANE	501+36	4.9	12546 1870	147.4	94.79%	12620 1932	146.9	94.47%				147.15	94.63	94.63
2-7A	492+55	507+55	NB OUTSIDE LANE	506+76	3.6	12588 1976	147.1	94.60%	12572 1868	147.2	94.66%				147.15	94.63	94.63
2-8B	507+55	520+00	NB OUTSIDE LANE	507+68	4.6	12568 1856	147.3	94.73%	12440 1834	148.2	95.31%				147.75	95.02	95.02
2-8C	507+55	520+00	NB OUTSIDE LANE	508+52	9.6	12720 1898	146.2	94.02%	13225 1842	142.5	91.64%	12610 1796	147.0	94.53%	146.6	94.28	94.28
2-8A	507+55	520+00	NB OUTSIDE LANE	514+54	0.2	12690 1902	146.4	94.15%	12686 1938	146.4	94.15%				146.4	94.15	94.15

Target Max Density = Gmm x 62.24

Test Remarks

13.10 DP Test Section Density Results



DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	4	Lift/Layer:	ELASTIKO	Density Standard:	28720
				Moisture Standard:	8500
Project ID:	5350-01-73	Road Name:	USH 51	Contractor:	Rock Road Companies
Gauge Serial #:	0391				
Project Leader:		County:	Rock	QC NUCDENSITYTEC:	Andy Slawson
WisDOT Mix #:					
QV NUCDENSITYTEC:	Albert Kilger	Mix Type:	ELASTIKO		
Lot Limits:	402+55 to 520+00	Target Gmm:	2.499		
Lot Length(ft):	11,745	Target Max Density (PCF):	155.50		
Lane Width (ft):	12	Required Density %:	93.0%		
Nominal Thickness:		Date Placed:	Thursday, June 20, 2019		
Gauge Offset	N/A	Date Tested:	Thursday, June 20, 2019		

Placed On (circle one): PCC, [✓ HMA], Crushed Agg, Recycled PCC, Recycled HMA

Lift/layer (circle one): [✓ Upper], Middle, Lower

Lot Type (circle one): [✓ Mainline], Shoulders, Side Roads

Offset Refrence (circle one): [✓ Centerline], Reference Line, Edge of Pavement, Turn Lanes, Ramps, Roundabout, Appurtenances, Transit Line, Other (describe)

						Reading 1			Reading 2 (rotate 180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	Begin STA.	End STA.	Lane #	Random Station	Random Offset	Dcount / Mcount	Wet Density 1	% Max Density 1	Dcount / Mcount	Wet Density 2	% Max Density 2	Dcount / Mcount	Wet Density 3	% Max Density 3	Average PCF	% Max Density	Adjusted % Max Density
4-1C	402+55	417+55	SB OUTSIDE LANE	404+59	11.1	12541 1980	147.7	95.0%	12430 2026	148.6	95.6%				148.2	95.3	95.3
4-1B	402+55	417+55	SB OUTSIDE LANE	407+19	8.0	12596 1998	147.3	94.7%	12640 1984	147.0	94.5%				147.2	94.6	94.6
4-1A	402+55	417+55	SB OUTSIDE LANE	414+59	0.3	12846 1975	145.5	93.6%	12896 1977	145.2	93.4%				145.4	93.5	93.5
4-2C	417+55	432+55	SB OUTSIDE LANE	422+41	10.2	12639 1999	147.0	94.5%	12843 1909	145.5	93.6%	12605 1981	147.3	94.7%	147.2	94.6	94.6
4-2A	417+55	432+55	SB OUTSIDE LANE	428+58	2.2	12815 1934	145.7	93.7%	12343 2005	149.2	95.9%	12801 1938	145.8	93.8%	145.8	93.7	93.7
4-2B	417+55	432+55	SB OUTSIDE LANE	431+27	8.0	12756 2005	146.2	94.0%	12762 2065	146.1	94.0%				146.2	94.0	94.0
4-3C	432+55	447+55	SB OUTSIDE LANE	434+28	11.0	12720 2089	146.4	94.1%	12690 1968	146.7	94.3%				146.6	94.2	94.2
4-3B	432+55	447+55	SB OUTSIDE LANE	438+20	4.3	12921 1983	145.0	93.2%	12793 2008	145.9	93.8%				145.5	93.5	93.5
4-3A	432+55	447+55	SB OUTSIDE LANE	438+54	3.0	13039 2002	144.2	92.7%	13063 1978	144.0	92.6%				144.1	92.7	92.7
4-4B	447+55	462+55	SB OUTSIDE LANE	448+78	5.8	12689 1970	146.7	94.3%	12731 1959	146.4	94.1%				146.6	94.2	94.2
4-4A	447+55	462+55	SB OUTSIDE LANE	456+72	2.0	13025 1990	144.2	92.7%	12844 1975	145.5	93.6%	12758 1962	146.2	94.0%	145.9	93.8	93.8
4-4C	447+55	462+55	SB OUTSIDE LANE	457+56	11.9	12812 2006	145.8	93.8%	12592 2050	147.4	94.8%	12750 1931	146.2	94.0%	146.0	93.9	93.9

Target Max Density = Gmm x 62.24

Test Remarks

DENSITY FIELD WORKSHEET (LANE FOOT)

Nuclear HMA Density QC/QV Testing Records

Section #:	**4**	Lift/Layer:	**ELASTIKO**	Density Standard:	23720
				Moisture Standard:	8560
Project ID:	5350-01-73	Road Name:	USH 51	Contractor:	Rock Road Companies
Project Leader:		County:	Rock	QC NUCDENSITYTEC:	Andy Slawson
Gauge Serial #:	0391	WisDOT Mix #:		QV NUCDENSITYTEC:	Albert Kilger
Mix Type:	ELASTIKO	Lot Limits:	402+55 to 520+00	Target Gmm:	2.499
Lot Length(ft):	11,745	Target Max Density (PCF):	155.50	Lane Width (ft):	12
Required Density %:	93.0%	Nominal Thickness:		Date Placed:	Thursday, June 20, 2019
Gauge Offset	N/A	Date Tested:	Thursday, June 20, 2019		

Placed On (circle one)
PCC
[✓ HMA]
Crushed Agg
Recycled PCC
Recycled HMA

Lift/layer (circle one)
[✓ Upper]
Middle
Lower

Lot Type (circle one)
[✓ Mainline]
Shoulders
Side Roads

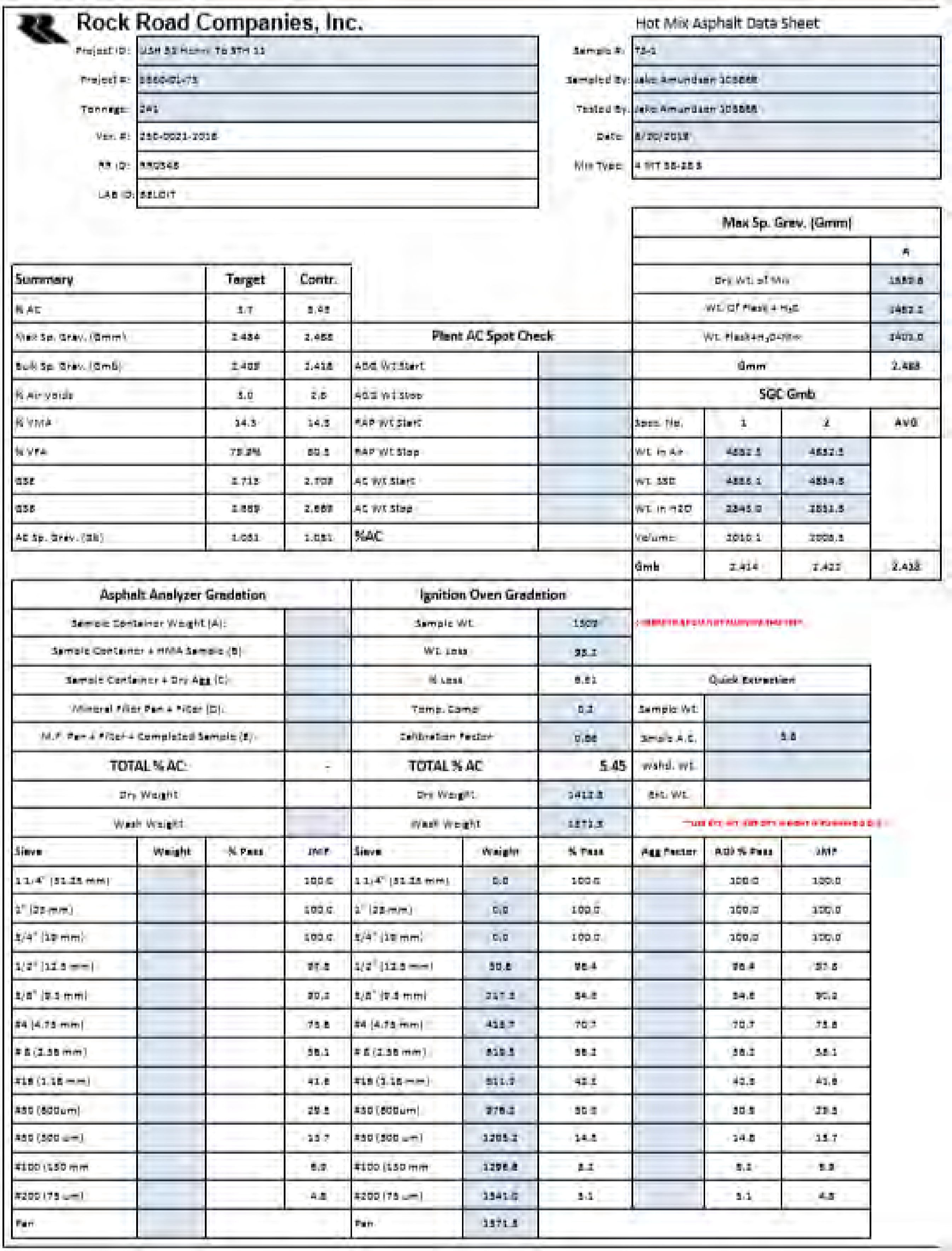
Offset Refrence (circle one)
[✓ Centerline]
Reference Line
Edge of Pavement
Turn Lanes
Ramps
Roundabout
Appurtenances
Transit Line
Other (describe)

						Reading 1			Reading 2 (rotate 180)			Reading 3 (if needed)			Average		
Lot - Sublot ID	**Begin STA.**	**End STA.**	**Lane #**	**Random Station**	**Random Offset**	**Dcount / Mcount**	**Wet Density 1**	**% Max Density 1**	**Dcount / Mcount**	**Wet Density 2**	**% Max Density 2**	**Dcount / Mcount**	**Wet Density 3**	**% Max Density 3**	**Average PCF**	**% Max Density**	**Adjusted % Max Density**
4-5B	462+55	477+55	SB OUTSIDE LANE	**463+22**	**7.6**	12869 1938	145.4	93.5%	12638 1943	147.0	94.5%	12934 1962	144.9	93.18%	**145.2**	**93.3**	**93.3**
4-5A	462+55	477+55	SB OUTSIDE LANE	**465+60**	**0.3**	13335 2012	142.1	91.4%	13071 2016	143.9	92.5%	12976 1974	144.6	92.99%	**144.3**	**92.8**	**92.8**
4-5C	462+55	477+55	SB OUTSIDE LANE	**465+75**	**8.3**	13075 1896	143.9	92.5%	13139 1909	143.4	92.2%				**143.7**	**92.4**	**92.4**
4-6A	477+55	492+55	SB OUTSIDE LANE	**480+39**	**3.5**	12933 2015	144.9	93.2%	12927 1929	144.9	93.2%				**144.9**	**93.2**	**93.2**
4-6C	477+55	492+55	SB OUTSIDE LANE	**481+35**	**10.3**	12897 1963	145.2	93.4%	12858 1918	145.4	93.5%				**145.3**	**93.4**	**93.4**
4-6B	477+55	492+55	SB OUTSIDE LANE	**486+89**	**6.6**	12886 2082	145.2	93.4%	12860 2003	145.4	93.5%				**145.3**	**93.4**	**93.4**
4-7A	492+55	507+55	SB OUTSIDE LANE	**497+01**	**2.1**	13519 2018	140.8	90.5%	12995 2054	144.5	92.9%	12973 2000	144.6	92.99%	**144.6**	**93.0**	**93.0**
4-7C	492+55	507+55	SB OUTSIDE LANE	**502+76**	**8.8**	12640 1974	147.0	94.5%	12545 2083	147.7	95.0%				**147.4**	**94.8**	**94.8**
4-7B	492+55	507+55	SB OUTSIDE LANE	**505+28**	**6.6**	12631 1985	147.1	94.6%	12544 2050	147.7	95.0%				**147.4**	**94.8**	**94.8**
4-8A	507+55	520+00	SB OUTSIDE LANE	**516+00**	**0.9**	13202 1991	143.0	92.0%	12936 1971	144.9	93.2%	12975 2036	144.6	92.99%	**144.8**	**93.1**	**93.1**
4-8C	507+55	520+00	SB OUTSIDE LANE	**516+71**	**9.0**	13106 1992	143.7	92.4%	12950 1989	144.8	93.1%	13088 1948	143.8	92.48%	**143.8**	**92.4**	**92.4**
4-8B	507+55	520+00	SB OUTSIDE LANE	**517+52**	**4.7**	12855 2033	145.5	93.6%	12651 1883	146.9	94.5%	12816 2027	145.7	93.70%	**145.6**	**93.6**	**93.6**

Target Max Density = Gmm x 62.24

Test Remarks

13.11 Control Production Plant Printouts



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 53 [illegible] To STH 11	Sample #:	T3-1
Project #:	3860-01-73	Sampled By:	Jake Amundson 103688
Tonnage:	241	Tested By:	Jake Amundson 103688
Ver. #:	250-0021-2018	Date:	8/20/2018
RR ID:	RR0348	Mix Type:	4 MT 58-28 S
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.7	5.45
Max Sp. Grav. (Gmm)	2.484	2.488
Bulk Sp. Grav. (Gmb)	2.409	2.418
% Air Voids	3.0	2.8
% VMA	14.3	14.5
% VFA	79.2%	80.5
Gse	2.713	2.708
Gsb	2.669	2.669
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	
AGG Wt Stop	
RAP Wt Start	
RAP Wt Stop	
AC Wt Start	
AC Wt Stop	
%AC	

Max Sp. Grav. (Gmm)	A
Dry Wt. of Mix	1589.8
Wt. Of Flask + H_2O	7452.2
Wt. Flask+H_2O+Mix	8403.0
Gmm	2.488

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4852.5	4852.3	
Wt. SSD	4855.1	4854.8	
Wt. in H2O	2845.0	2851.5	
Volume	2010.1	2003.3	
Gmb	2.414	2.422	2.418

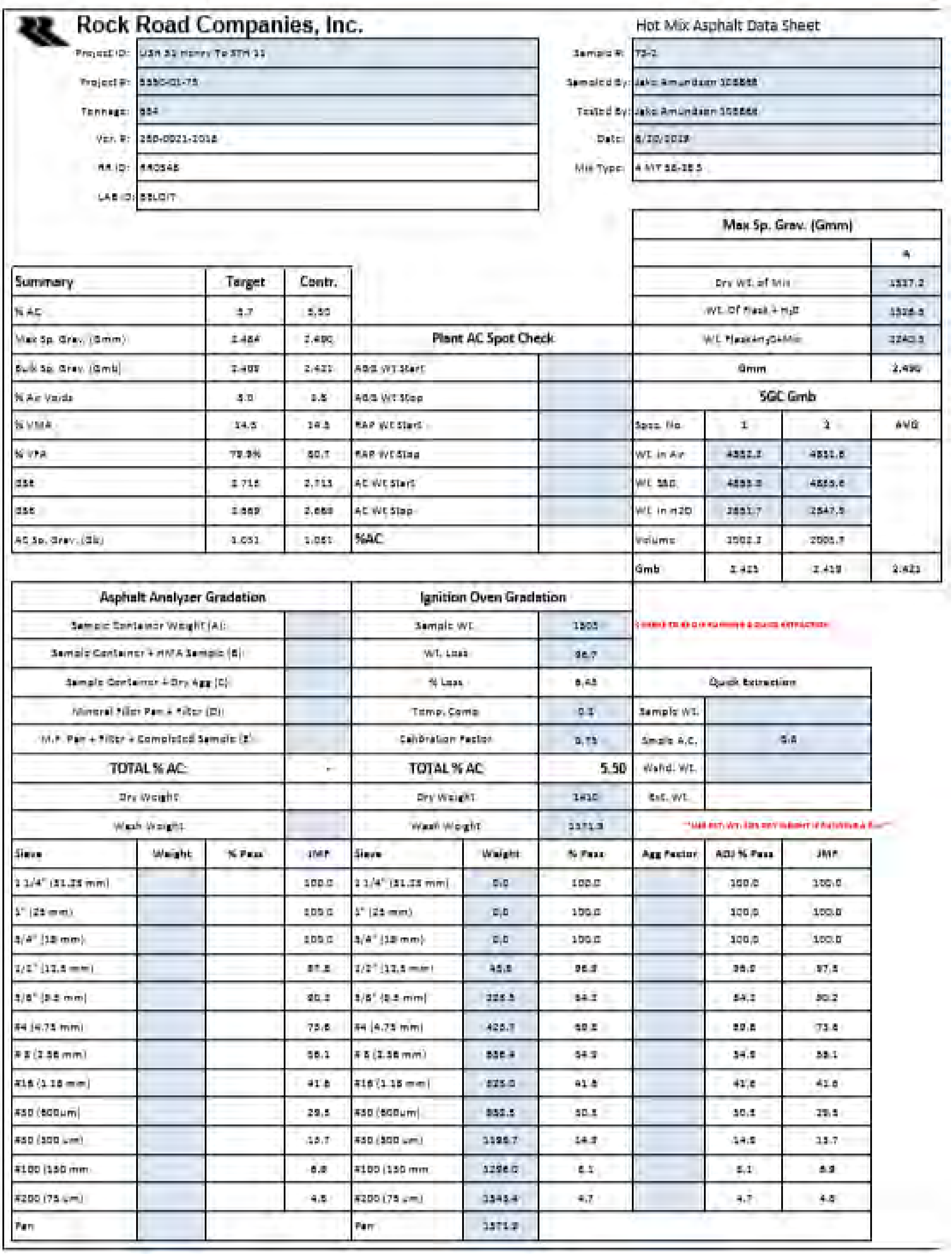
Asphalt Analyzer Gradation		Ignition Oven Gradation	
Sample Container Weight (A):		Sample Wt.	1509
Sample Container + HMA Sample (B)		Wt. Loss	95.2
Sample Container + Dry Agg (C)		% Loss	6.31
Mineral Filler Pan + Filter (D):		Temp. Comp	0.2
M.F. Pan + Filter + Completed Sample (E):		Calibration Factor	0.66
TOTAL % AC:	-	**TOTAL % AC**	5.45
Dry Weight		Dry Weight	1413.8
Wash Weight		Wash Weight	1371.5

[illegible]

Quick Extraction	
Sample Wt.	
Sample A.C.	5.8
Wshd. Wt.	
Ext. Wt.	

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	Adj % Pass	JMF
1 1/4" (31.25 mm)			100.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	100.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			97.8	1/2" (12.5 mm)	50.8	96.4		96.4	97.8
3/8" (9.5 mm)			90.2	3/8" (9.5 mm)	217.3	84.6		84.6	90.2
#4 (4.75 mm)			73.8	#4 (4.75 mm)	413.7	70.7		70.7	73.8
# 8 (2.36 mm)			58.1	# 8 (2.36 mm)	591.5	58.2		58.2	58.1
#16 (1.18 mm)			41.8	#16 (1.18 mm)	817.2	42.2		42.2	41.8
#30 (600um)			29.5	#30 (600um)	978.2	30.8		30.8	29.5
#50 (300 um)			13.7	#50 (300 um)	1205.2	14.8		14.8	13.7
#100 (150 mm			8.8	#100 (150 mm	1298.8	8.1		8.1	8.8
#200 (75 um)			4.8	#200 (75 um)	1341.0	5.1		5.1	4.8
Pan				Pan	1371.5				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hanry To STH 11	Sample #:	TS-2
Project #:	5590-01-75	Sampled By:	Jake Amundson 305868
Tonnage:	854	Tested By:	Jake Amundson 305868
Ver. #:	250-0021-2018	Date:	8/20/2019
RR ID:	440548	Mix Type:	4 MT 58-28 S
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.7	5.50
Max Sp. Grav. (Gmm)	2.484	2.490
Bulk Sp. Grav. (Gmb)	2.409	2.421
% Air Voids	3.0	2.8
% VMA	14.5	14.5
% VFA	79.9%	80.7
Gsb	2.715	2.713
Gse	2.669	2.668
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG WT Start	
AGG WT Stop	
RAP Wt Start	
RAP Wt Stop	
AC Wt Start	
AC Wt Stop	
%AC	

Max Sp. Grav. (Gmm)	
	4
Dry Wt. of Mix	1537.2
Wt. Of Flask + H_2O	1528.5
Wt. Flask+H_2O+Mix	2240.5
Gmm	2.490

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4852.2	4851.8	
Wt. SSD	4855.9	4855.6	
Wt. in H2O	2853.7	2847.5	
Volume	2002.2	2008.1	
Gmb	2.423	2.419	2.421

Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

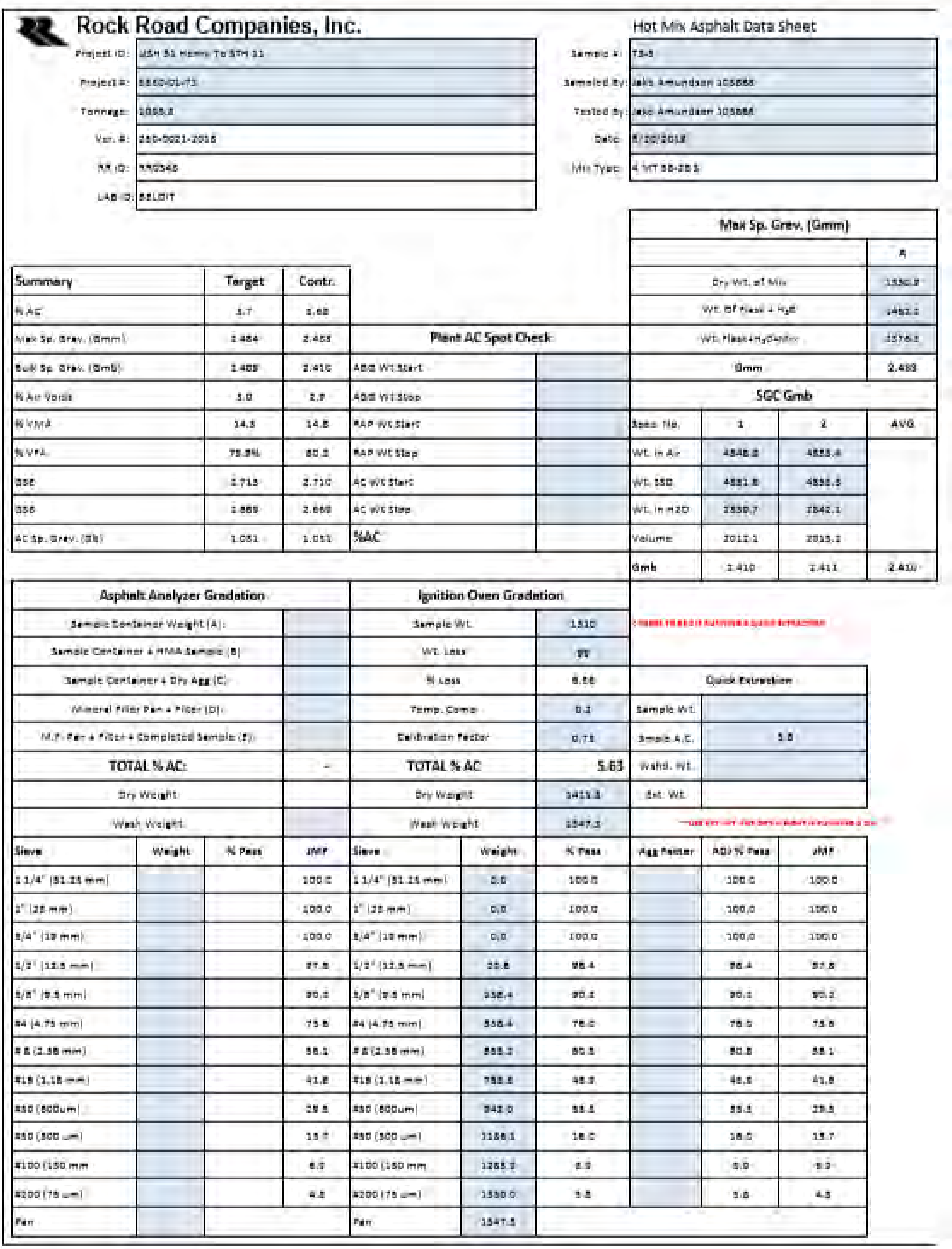
Ignition Oven Gradation	
Sample Wt.	1505
Wt. Loss	96.7
% Loss	6.43
Temp. Comp	0.2
Calibration Factor	0.75
TOTAL % AC	**5.50**
Dry Weight	1410
Wash Weight	1371.9

[illegible]

Quick Extraction	
Sample Wt.	
Sample A.C.	5.6
Wshd. Wt.	
Ext. Wt.	

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			100.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	100.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			97.8	1/2" (12.5 mm)	45.8	96.8		96.8	97.8
3/8" (9.5 mm)			90.2	3/8" (9.5 mm)	226.5	84.2		84.2	90.2
#4 (4.75 mm)			73.6	#4 (4.75 mm)	426.7	69.8		69.8	73.6
# 8 (2.36 mm)			58.1	# 8 (2.36 mm)	636.4	54.9		54.9	58.1
#16 (1.18 mm)			41.6	#16 (1.18 mm)	825.0	41.6		41.6	41.6
#30 (600um)			29.5	#30 (600um)	982.5	30.5		30.5	29.5
#50 (300 um)			13.7	#50 (300 um)	1196.7	14.9		14.9	13.7
#100 (150 mm			6.8	#100 (150 mm	1296.0	8.1		8.1	6.8
#200 (75 um)			4.8	#200 (75 um)	1343.4	4.7		4.7	4.8
Pan				Pan	1371.9				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hanna To STH 11
Project #:	5860-01-73
Tonnage:	1055.8
Ver. #:	250-0021-2018
RR ID:	990548
LAB ID:	BELOIT

Sample #:	T3-3
Sampled By:	Jake Amundson 105888
Tested By:	Jake Amundson 105888
Date:	8/20/2018
Mix Type:	4 MT 58-28 S

Summary	Target	Contr.
% AC	5.7	5.68
Max Sp. Grav. (Gmm)	2.484	2.483
Bulk Sp. Grav. (Gmb)	2.408	2.410
% Air Voids	3.0	2.9
% VMA	14.3	14.6
% VFA	79.0%	80.2
Gse	2.715	2.710
Gsb	2.689	2.668
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	
AGG Wt Stop	
RAP Wt Start	
RAP Wt Stop	
AC Wt Start	
AC Wt Stop	
%AC	

Max Sp. Grav. (Gmm)	
	A
Dry Wt. of Mix	1530.9
Wt. Of Flask + H_2O	1452.1
Wt. Flask+H_2O+Mix	2376.1
Gmm	2.483

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4846.0	4855.4	
Wt. SSD	4851.8	4858.5	
Wt. in H2O	2839.7	2842.1	
Volume	2012.1	2016.2	
Gmb	2.410	2.411	2.410

Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B)	
Sample Container + Dry Agg (C)	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E)	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation	
Sample Wt.	1510
Wt. Loss	85
% Loss	5.66
Temp. Comp	0.1
Calibration Factor	0.71
TOTAL % AC	5.63
Dry Weight	1411.3
Wash Weight	1347.3

[illegible]

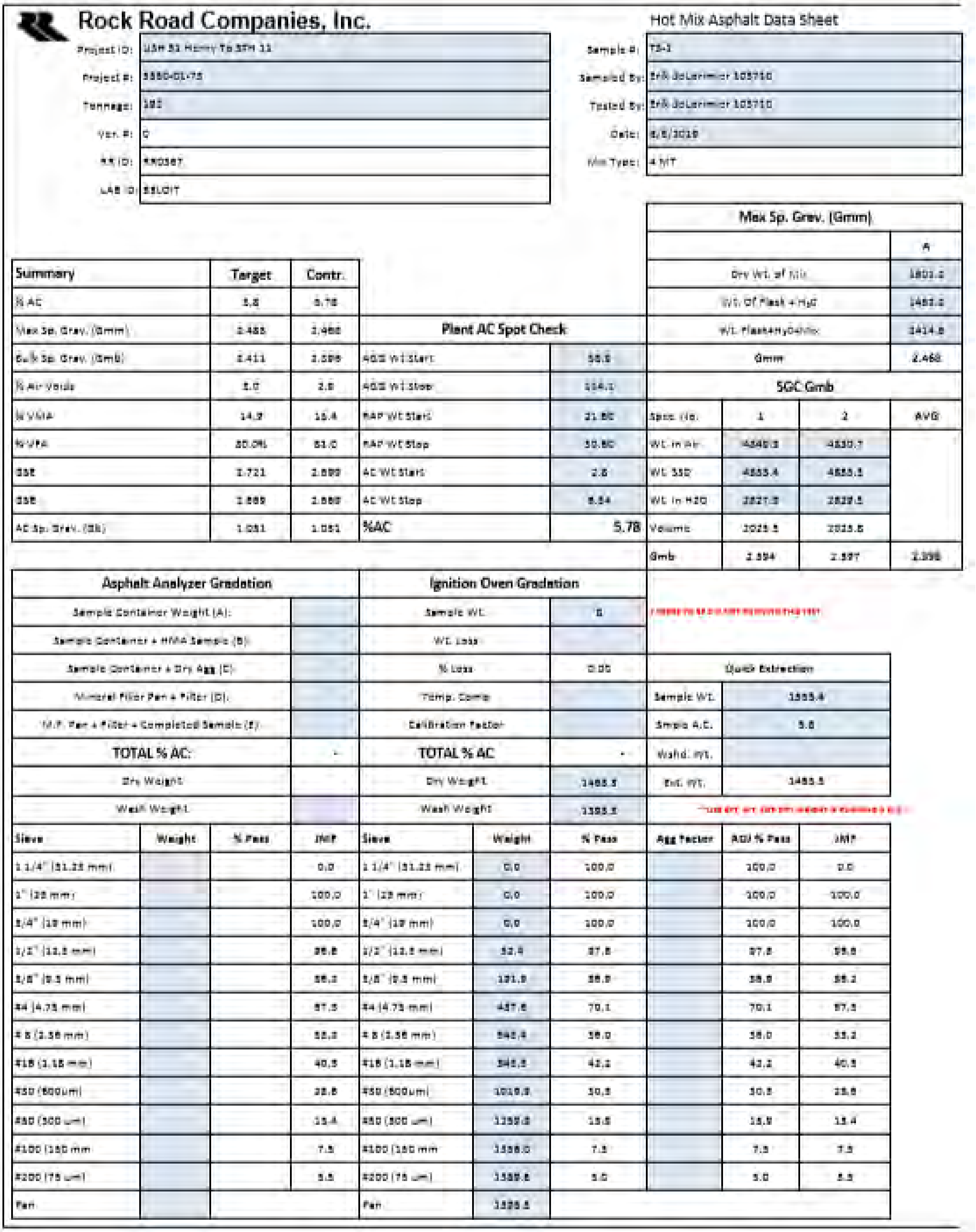
Quick Extraction	
Sample Wt.	
Small A.C.	5.8
Wshd. Wt.	
Ext. Wt.	

[illegible]

Sieve	Weight	% Pass	JMF
1 1/4" (31.25 mm)			100.0
1" (25 mm)			100.0
3/4" (19 mm)			100.0
1/2" (12.5 mm)			97.8
3/8" (9.5 mm)			90.2
#4 (4.75 mm)			75.8
# 8 (2.36 mm)			58.1
#16 (1.18 mm)			41.8
#30 (600um)			29.5
#50 (300 um)			15.7
#100 (150 mm			8.2
#200 (75 um)			4.8
Pan			

Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)	0.0	100.0		100.0	100.0
1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)	22.6	98.4		98.4	97.8
3/8" (9.5 mm)	138.4	90.2		90.1	90.2
#4 (4.75 mm)	338.4	76.0		76.0	75.8
# 8 (2.36 mm)	555.2	60.5		60.8	58.1
#16 (1.18 mm)	755.6	46.3		46.5	41.8
#30 (600um)	942.0	33.3		33.3	29.5
#50 (300 um)	1156.1	18.0		18.0	15.7
#100 (150 mm	1265.7	8.9		9.0	8.2
#200 (75 um)	1330.0	5.5		5.6	4.8
Pan	1347.5				

13.12 TB Production Plant Printouts



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID: USH 51 [illegible] To STH 11
Project #: 3550-01-75
Tonnage: 182
Ver. #: 0
RR ID: RR0387
LAB ID: BELOIT

Sample #: TB-1
Sampled By: [illegible] 103710
Tested By: [illegible] 103710
Date: 8/8/2018
Mix Type: 4 MT

Summary	Target	Contr.
% AC	5.8	5.78
Max Sp. Grav. (Gmm)	2.485	2.468
Bulk Sp. Grav. (Gmb)	2.411	2.398
% Air Voids	3.0	2.8
% VMA	14.9	15.4
% VFA	80.0%	81.0
Gse	2.721	2.699
Gsb	2.669	2.669
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	55.5
AGG Wt Stop	154.1
RAP Wt Start	21.80
RAP Wt Stop	30.80
AC Wt Start	2.8
AC Wt Stop	8.54
%AC	5.78

Max Sp. Grav. (Gmm)	
	A
Dry Wt. of Mix	1801.0
Wt. Of Flask + H_2O	1482.0
Wt. Flask+H_2O+Mix	1414.8
Gmm	2.468

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4840.3	4830.7	
Wt. SSD	4855.4	4855.3	
Wt. in H2O	2821.9	2829.5	
Volume	2023.5	2025.8	
Gmb	2.394	2.397	2.396

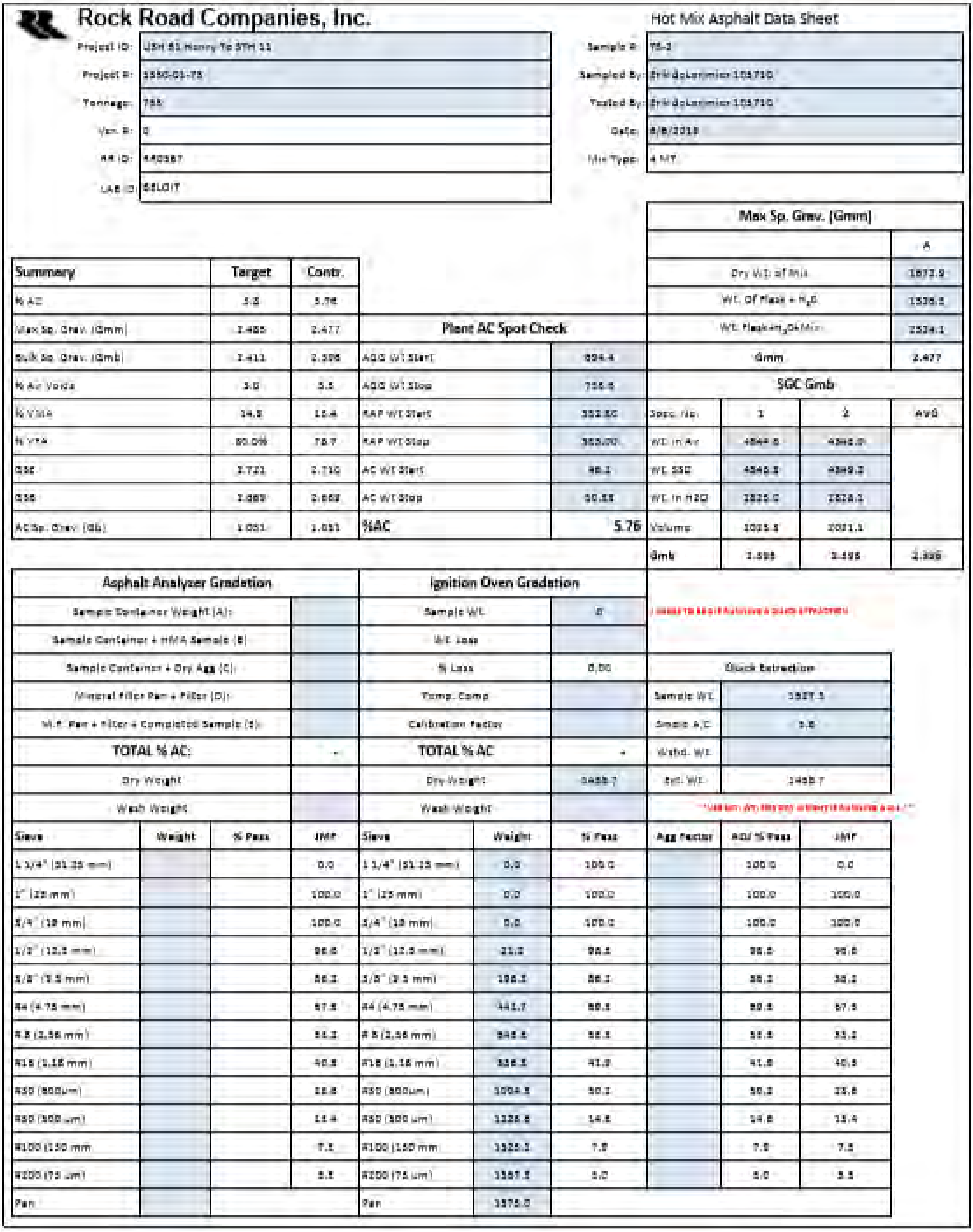
Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation	
Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	1485.5
Wash Weight	1393.5

Quick Extraction	
Sample Wt.	1555.4
Smple A.C.	5.8
Wshd. Wt.	
Ext. Wt.	1485.5

Sieve	Weight	% Pass	JMF
1 1/4" (31.25 mm)			0.0
1" (25 mm)			100.0
3/4" (19 mm)			100.0
1/2" (12.5 mm)			99.8
3/8" (9.5 mm)			86.2
#4 (4.75 mm)			67.5
# 8 (2.36 mm)			53.2
#16 (1.18 mm)			40.5
#30 (600um)			25.8
#50 (300 um)			13.4
#100 (150 mm			7.5
#200 (75 um)			5.5
Pan			

Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)	32.4	97.8		97.8	99.8
3/8" (9.5 mm)	161.9	88.9		88.9	86.2
#4 (4.75 mm)	437.6	70.1		70.1	67.5
# 8 (2.36 mm)	642.4	58.0		58.0	53.2
#16 (1.18 mm)	845.5	42.2		42.2	40.5
#30 (600um)	1019.3	30.5		30.5	25.8
#50 (300 um)	1255.0	15.6		15.9	13.4
#100 (150 mm	1358.0	7.3		7.3	7.5
#200 (75 um)	1385.6	5.0		5.0	5.5
Pan	1395.5				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hanny To STH 11	Sample #:	TS-2
Project #:	3550-01-75	Sampled By:	Erik deLorimier 105710
Tonnage:	785	Tested By:	Erik deLorimier 105710
Ver. #:	0	Date:	8/8/2018
RR ID:	440387	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.2	5.76
Max Sp. Grav. (Gmm)	2.485	2.477
Bulk Sp. Grav. (Gmb)	2.411	2.398
% Air Voids	3.0	3.2
% VMA	14.5	15.4
% VFA	80.0%	78.7
Gse	2.721	2.730
Gsb	2.669	2.662
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	894.4
AGG Wt Stop	756.6
RAP Wt Start	352.50
RAP Wt Stop	363.00
AC Wt Start	46.2
AC Wt Stop	50.88
%AC	5.76

Max Sp. Grav. (Gmm)	A
Dry Wt. of Mix	1872.9
Wt. Of Flask + H_2O	1536.2
Wt. Flask+H_2O+Mix	2534.1
Gmm	2.477

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4849.8	4848.0	
Wt. SSD	4849.3	4849.2	
Wt. in H2O	2826.0	2828.1	
Volume	2023.3	2021.1	
Gmb	2.398	2.398	2.398

Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

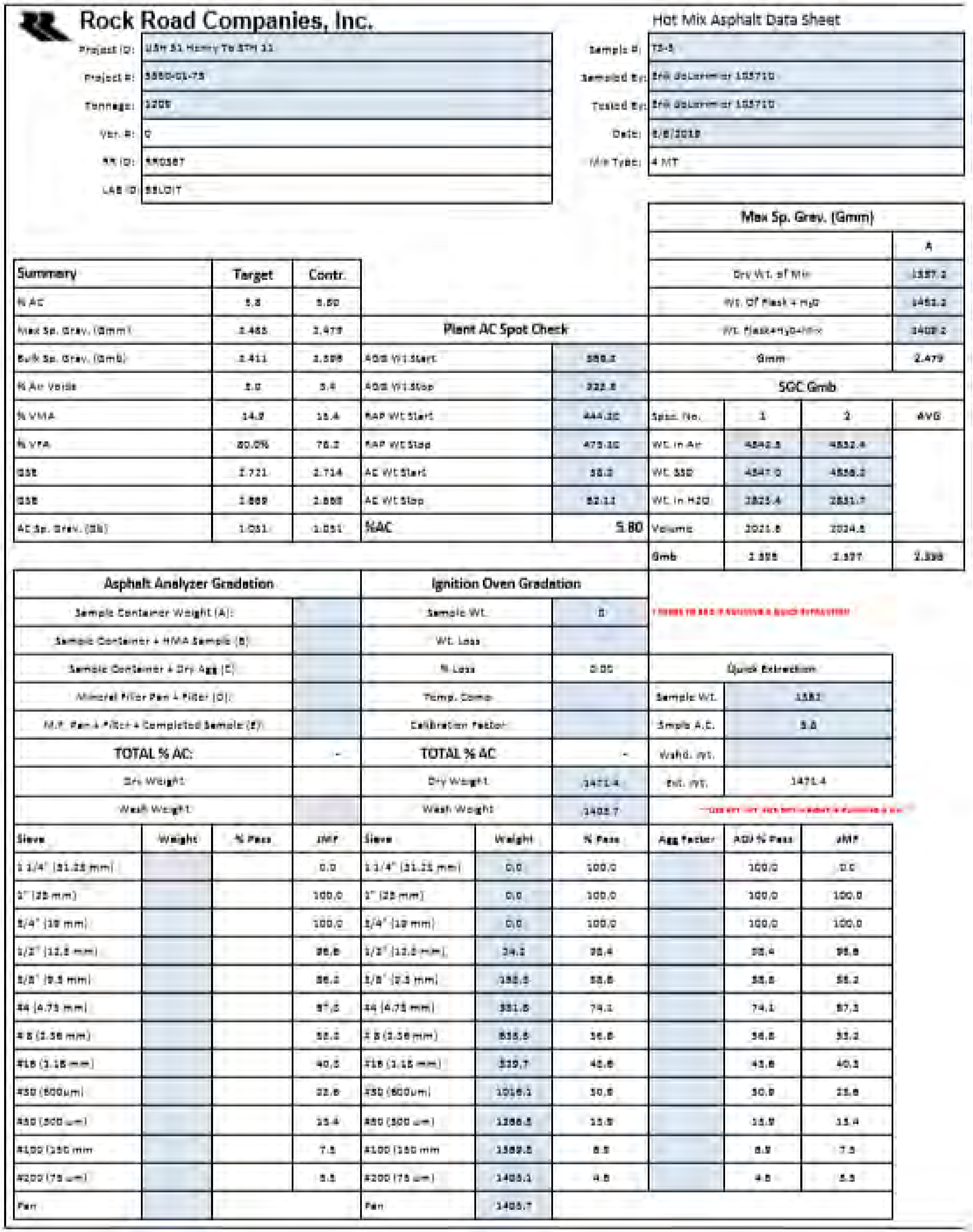
Ignition Oven Gradation	
Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	3488.7
Wash Weight	

[illegible]

Quick Extraction	
Sample Wt.	3327.3
Smple A.C	5.8
Wshd. Wt.	
Ext. Wt.	3488.7

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			98.8	1/2" (12.5 mm)	21.2	99.4		98.8	98.8
3/8" (9.5 mm)			86.2	3/8" (9.5 mm)	196.3	86.1		88.2	88.2
#4 (4.75 mm)			67.5	#4 (4.75 mm)	441.7	80.5		80.5	67.5
# 8 (2.36 mm)			53.2	# 8 (2.36 mm)	945.6	55.3		55.4	53.2
#16 (1.18 mm)			40.5	#16 (1.18 mm)	826.5	41.0		41.8	40.5
#30 (600μm)			25.8	#30 (600μm)	1004.3	30.2		30.2	25.8
#50 (300 μm)			13.4	#50 (300 μm)	1326.6	14.8		14.8	13.4
#100 (150 mm			7.5	#100 (150 mm	1325.1	7.8		7.8	7.5
#200 (75 μm)			5.5	#200 (75 μm)	1367.3	5.0		5.0	5.5
Pan				Pan	1375.0				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hurley To STH 11	Sample #:	T3-3
Project #:	3550-01-73	Sampled By:	Erik [illegible] 105710
Tonnage:	1205	Tested By:	Erik [illegible] 105710
Ver. #:	0	Date:	6/8/2018
RR ID:	RR0387	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.8	5.80
Max Sp. Grav. (Gmm)	2.485	2.479
Bulk Sp. Grav. (Gmb)	2.411	2.396
% Air Voids	3.0	3.4
% VMA	14.8	15.4
% VFA	80.0%	78.2
GSE	2.721	2.714
GSB	2.689	2.688
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	559.2
AGG Wt Stop	932.8
RAP Wt Start	444.30
RAP Wt Stop	475.30
AC Wt Start	58.2
AC Wt Stop	62.11
%AC	5.80

Max Sp. Grav. (Gmm)	A
Dry Wt. of Mix	1587.2
Wt. Of Flask + H_2O	1461.2
Wt. Flask+H_2O+Mix	2408.2
Gmm	2.479

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4842.3	4852.4	
Wt. SSD	4847.0	4856.2	
Wt. in H2O	2825.4	2831.7	
Volume	2021.6	2024.5	
Gmb	2.395	2.397	2.396

Asphalt Analyzer Gradation		Ignition Oven Gradation	
Sample Container Weight (A):		Sample Wt.	0
Sample Container + HMA Sample (B)		Wt. Loss	
Sample Container + Dry Agg (C)		% Loss	0.00
Mineral Filler Pan + Filter (D):		Temp. Comp.	
M.F. Pan + Filter + Completed Sample (E)		Calibration Factor	
TOTAL % AC:	-	TOTAL % AC	-
Dry Weight		Dry Weight	1471.4
Wash Weight		Wash Weight	1405.7

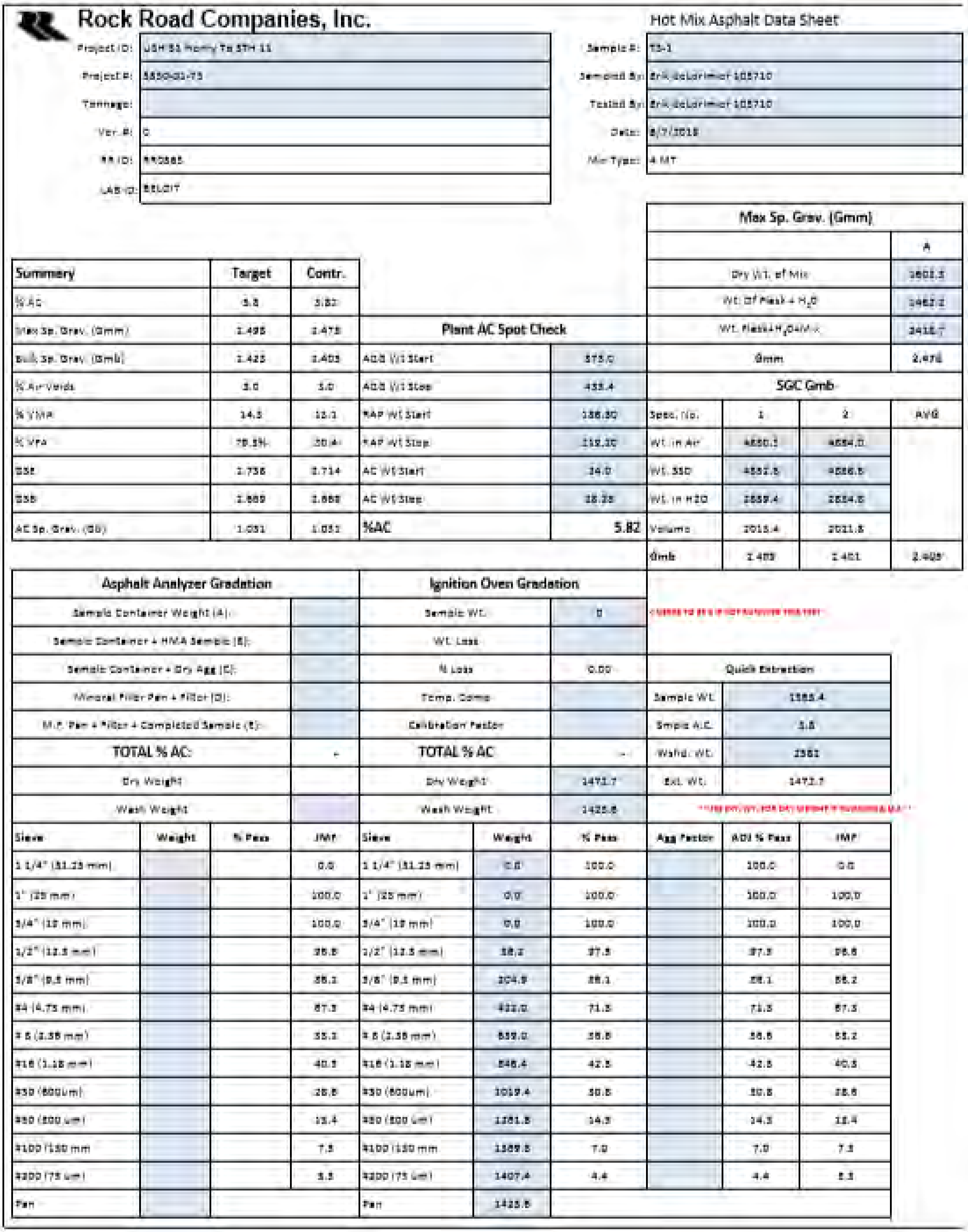
[illegible]

Quick Extraction	
Sample Wt.	1562
Smple A.C.	5.8
Wshd. Wt.	
Ext. Wt.	1471.4

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			98.8	1/2" (12.5 mm)	24.2	98.4		98.4	98.8
3/8" (9.5 mm)			88.2	3/8" (9.5 mm)	165.5	88.8		88.8	88.2
#4 (4.75 mm)			67.0	#4 (4.75 mm)	381.8	74.1		74.1	67.3
# 8 (2.36 mm)			53.2	# 8 (2.36 mm)	635.5	56.8		56.8	53.2
#16 (1.18 mm)			40.3	#16 (1.18 mm)	839.7	42.8		42.8	40.3
#30 (600um)			25.8	#30 (600um)	1018.1	30.8		30.8	25.8
#50 (300 um)			15.4	#50 (300 um)	1238.5	15.8		15.8	15.4
#100 (150 mm			7.5	#100 (150 mm	1339.8	8.9		8.9	7.5
#200 (75 um)			5.5	#200 (75 um)	1400.1	4.8		4.8	5.5
Pan				Pan	1405.7				

13.13 TBH Production Plant Printouts



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Romy To STH 11	Sample #:	TS-1
Project #:	5850-01-73	Sampled By:	Erik DeLorimier 105710
Tonnage:		Tested By:	Erik DeLorimier 105710
Ver. #:	0	Date:	8/7/2018
RR ID:	RR0585	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.8	5.82
Max Sp. Grav. (Gmm)	2.498	2.478
Bulk Sp. Grav. (Gmb)	2.423	2.403
% Air Voids	3.0	3.0
% VMA	14.5	15.1
% VFA	79.3%	80.4
GSE	2.738	2.714
GSB	2.669	2.668
AC Sp. Grav. (GB)	1.031	1.031

Plant AC Spot Check

AGG Wt Start	375.0
AGG Wt Stop	433.4
RAP Wt Start	188.30
RAP Wt Stop	212.30
AC Wt Start	24.0
AC Wt Stop	28.28
%AC	5.82

Max Sp. Grav. (Gmm)

	A
Dry Wt. of Mix	1602.3
Wt. Of Flask + H_2O	1462.2
Wt. Flask+H_2O+Mix	2416.7
Gmm	2.476

SGC Gmb

Spec. No.	1	2	AVG
Wt. in Air	4850.3	4854.0	
Wt. SSD	4852.8	4856.5	
Wt. in H2O	2839.4	2834.8	
Volume	2013.4	2021.8	
Gmb	2.409	2.401	2.405

Asphalt Analyzer Gradation

Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation

Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp.	
Calibration Factor	
TOTAL % AC	--
Dry Weight	1471.7
Wash Weight	1425.8

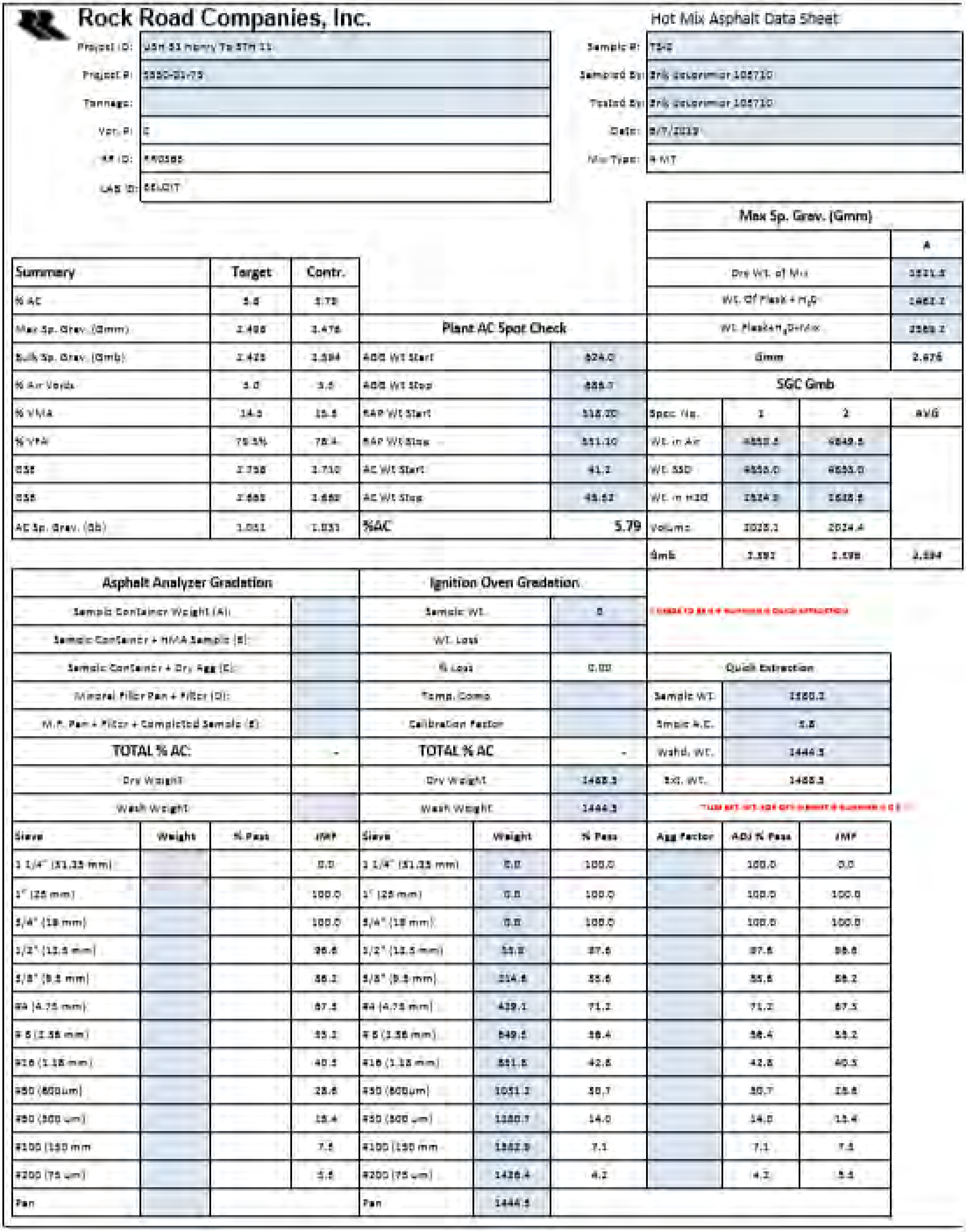
[illegible]

Quick Extraction

Sample Wt.	1583.4
Smpl A.C.	5.8
Wshd. Wt.	2382
Ext. Wt.	1472.7

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			96.8	1/2" (12.5 mm)	38.2	97.3		97.3	96.8
3/8" (9.5 mm)			88.1	3/8" (9.5 mm)	204.9	86.1		86.1	88.2
#4 (4.75 mm)			67.3	#4 (4.75 mm)	422.0	71.3		71.3	67.3
# 8 (2.36 mm)			55.2	# 8 (2.36 mm)	659.0	55.8		55.8	55.2
#16 (1.18 mm)			40.3	#16 (1.18 mm)	848.4	42.3		42.3	40.3
#30 (600um)			28.8	#30 (600um)	1019.4	30.8		30.8	28.8
#50 (300 um)			13.4	#50 (300 um)	1261.8	14.3		14.3	12.4
#100 (150 mm			7.3	#100 (150 mm	1369.8	7.0		7.0	7.3
#200 (75 um)			5.3	#200 (75 um)	1407.4	4.4		4.4	5.3
Pan				Pan	1425.8				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Henry To STH 11
Project #:	5550-01-73
Tonnage:	
Ver. #:	0
RAP ID:	RR0385
LAB ID:	BELOIT

Sample #:	TS-2
Sampled By:	Eric DeLorimier 105710
Tested By:	Eric DeLorimier 105710
Date:	8/7/2019
Mix Type:	4 MT

Summary	Target	Contr.
% AC	5.8	5.79
Max Sp. Grav. (Gmm)	2.498	2.476
Bulk Sp. Grav. (Gmb)	2.425	2.394
% Air Voids	3.0	3.3
% VMA	14.5	15.3
% VFA	79.3%	78.4
Gse	2.758	2.710
Gsb	2.685	2.680
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	824.0
AGG Wt Stop	886.7
RAP Wt Start	518.20
RAP Wt Stop	551.10
AC Wt Start	41.2
AC Wt Stop	45.62
%AC	5.79

Max Sp. Grav. (Gmm)	
	A
Dry Wt. of Mix	1521.5
Wt. Of Flask + H_2O	1462.2
Wt. Flask+H_2O+Mix	2368.2
Gmm	2.476

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4852.4	4849.5	
Wt. SSD	4853.0	4853.0	
Wt. in H2O	2824.9	2828.5	
Volume	2028.1	2024.4	
Gmb	2.392	2.396	2.394

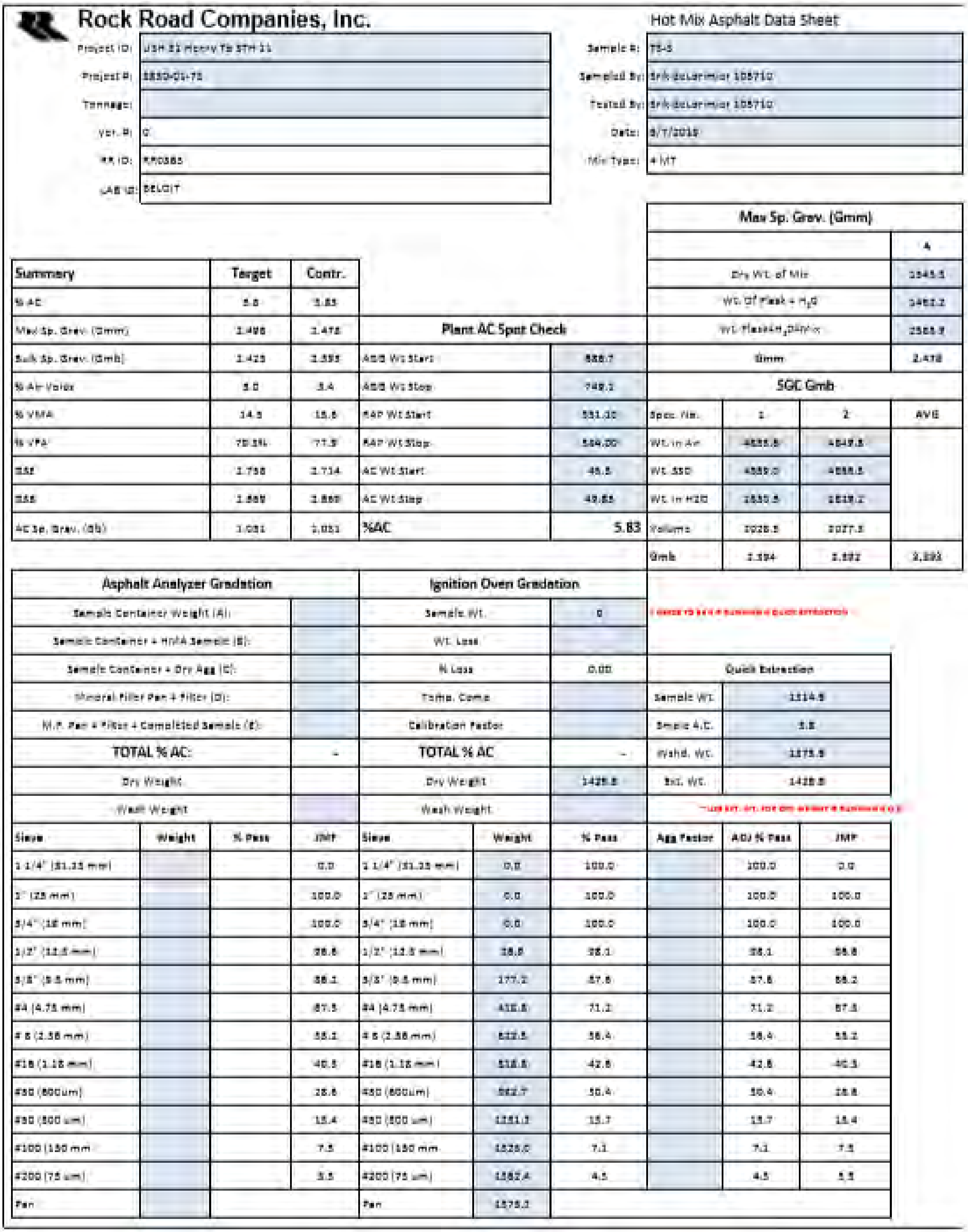
Asphalt Analyzer Gradation		Ignition Oven Gradation	
Sample Container Weight (A):		Sample Wt.	0
Sample Container + HMA Sample (B):		Wt. Loss	
Sample Container + Dry Agg (C):		% Loss	0.00
Mineral Filler Pan + Filter (D):		Temp. Comp.	
M.F. Pan + Filter + Completed Sample (E):		Calibration Factor	
TOTAL % AC:	-	TOTAL % AC	-
Dry Weight		Dry Weight	1488.5
Wash Weight		Wash Weight	1444.3

[illegible]

Quick Extraction	
Sample Wt.	1580.2
Smple A.C.	5.8
Wshd. Wt.	1444.3
Ext. Wt.	1488.5

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			98.6	1/2" (12.5 mm)	35.8	97.6		97.6	98.6
3/8" (9.5 mm)			88.2	3/8" (9.5 mm)	214.6	85.6		85.6	88.2
#4 (4.75 mm)			67.5	#4 (4.75 mm)	429.1	71.2		71.2	67.5
# 8 (2.36 mm)			53.2	# 8 (2.36 mm)	619.5	58.4		58.4	53.2
#16 (1.18 mm)			40.5	#16 (1.18 mm)	851.8	42.8		42.8	40.5
#30 (600um)			28.6	#30 (600um)	1031.2	30.7		30.7	25.6
#50 (300 um)			15.4	#50 (300 um)	1280.7	14.0		14.0	15.4
#100 (150 mm			7.5	#100 (150 mm	1382.9	7.1		7.1	7.5
#200 (75 um)			5.5	#200 (75 um)	1426.4	4.2		4.2	5.5
Pan				Pan	1444.3				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Henry To STH 11	Sample #:	TS-3
Project #:	5830-01-70	Sampled By:	Erik DeLarimier 105710
Tonnage:		Tested By:	Erik DeLarimier 105710
Ver. #:	0	Date:	8/7/2019
RR ID:	RR0385	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.8	5.83
Max Sp. Grav. (Gmm)	2.498	2.478
Bulk Sp. Grav. (Gmb)	2.423	2.393
% Air Voids	3.0	3.4
% VMA	14.5	15.6
% VFA	70-75%	77.9
Gse	2.758	2.714
Gsb	2.689	2.689
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	888.7
AGG Wt Stop	748.1
RAP Wt Start	531.10
RAP Wt Stop	504.00
AC Wt Start	45.5
AC Wt Stop	42.65
%AC	5.83

Max Sp. Grav. (Gmm)	
	4
Dry Wt. of Mix	1545.5
Wt. Of Flask + H_2O	1482.2
Wt. Flask+H_2O+Mix	2565.9
Gmm	2.478

SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4855.8	4849.8	
Wt. SSD	4859.0	4856.5	
Wt. in H2O	2830.5	2819.2	
Volume	2028.5	2037.3	
Gmb	2.394	2.392	2.393

[illegible]

Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation	
Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	1428.8
Wash Weight	

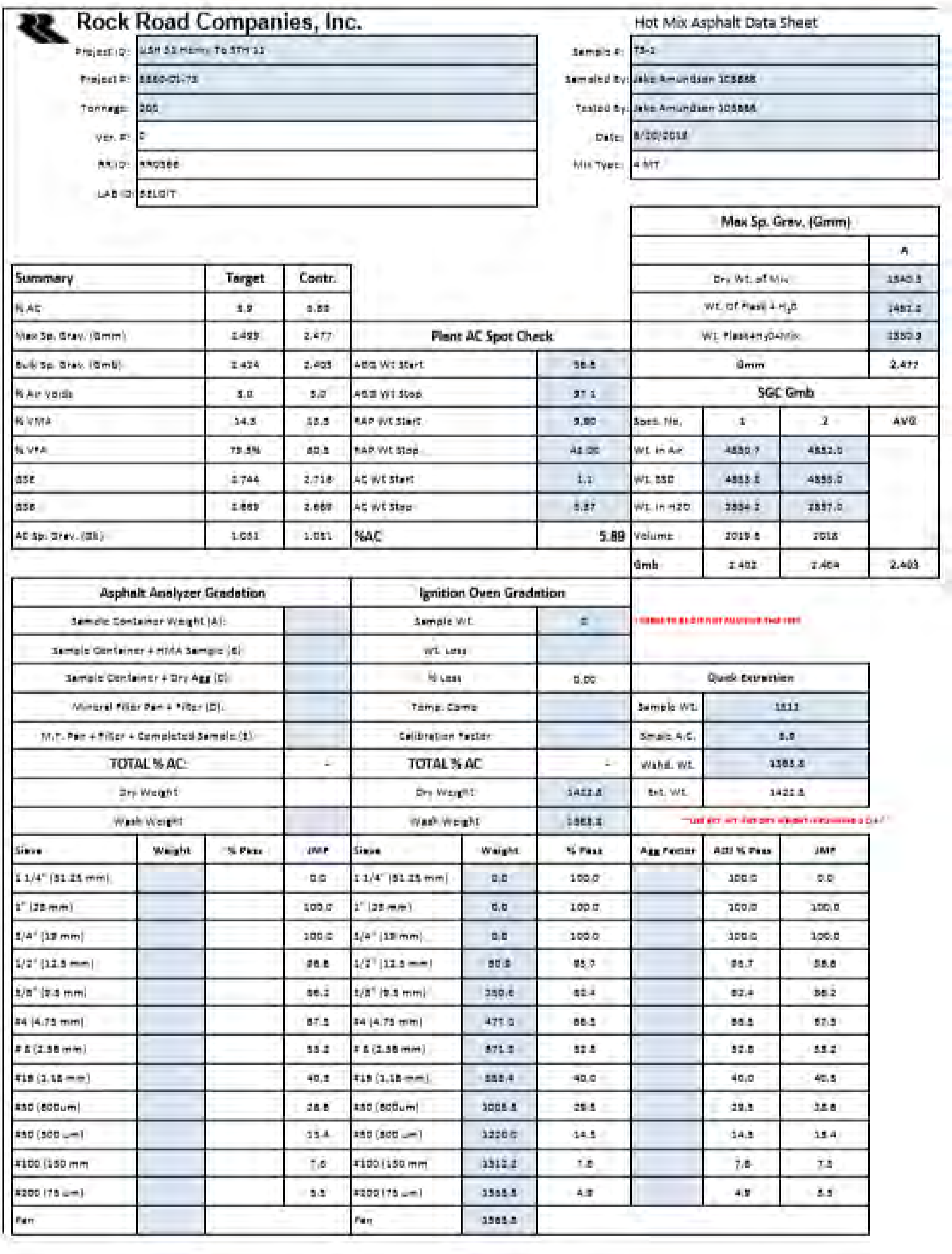
Quick Extraction	
Sample Wt.	1514.9
Smple A.C.	5.8
Wshd. Wt.	1373.9
Ext. Wt.	1428.8

[illegible]

Sieve	Weight	% Pass	JMF
1 1/4" (31.25 mm)			0.0
1" (25 mm)			100.0
3/4" (18 mm)			100.0
1/2" (12.5 mm)			98.8
3/8" (9.5 mm)			88.1
#4 (4.75 mm)			67.5
# 8 (2.36 mm)			55.2
#16 (1.18 mm)			40.3
#30 (600um)			28.8
#50 (300 um)			15.4
#100 (150 mm			7.5
#200 (75 um)			5.5
Pan			

Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (18 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)	28.8	98.1		98.1	98.8
3/8" (9.5 mm)	177.2	87.6		87.6	88.2
#4 (4.75 mm)	410.8	71.2		71.2	67.5
# 8 (2.36 mm)	612.5	58.4		58.4	55.2
#16 (1.18 mm)	818.8	42.8		42.8	40.3
#30 (600um)	992.7	30.4		30.4	28.8
#50 (300 um)	1231.3	15.7		15.7	15.4
#100 (150 mm	1326.0	7.1		7.1	7.5
#200 (75 um)	1362.4	4.5		4.5	5.5
Pan	1373.3				

13.14 DP Production Plant Printouts



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID: USH 51 Hwy To STH 11
Project #: 5860-01-73
Tonnage: 200
Ver. #: 0
RR ID: RR0366
LAB ID: BELOIT

Sample #: TS-1
Sampled By: Jake Amundsen 105888
Tested By: Jake Amundsen 105888
Date: 8/20/2018
Mix Type: 4 MT

Summary	Target	Contr.
% AC	5.9	5.89
Max Sp. Grav. (Gmm)	2.499	2.477
Bulk Sp. Grav. (Gmb)	2.424	2.403
% Air Voids	3.0	3.0
% VMA	14.3	15.5
% VFA	79.3%	80.5
GSE	2.744	2.718
GSB	2.669	2.669
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
AGG Wt Start	56.8
AGG Wt Stop	97.1
RAP Wt Start	9.80
RAP Wt Stop	42.00
AC Wt Start	1.1
AC Wt Stop	5.87
%AC	5.89

Max Sp. Grav. (Gmm)	A
Dry Wt. of Mix	1540.5
Wt. of Flask + H_2O	1482.2
Wt. Flask+H_2O+Mix	2380.9
Gmm	2.477

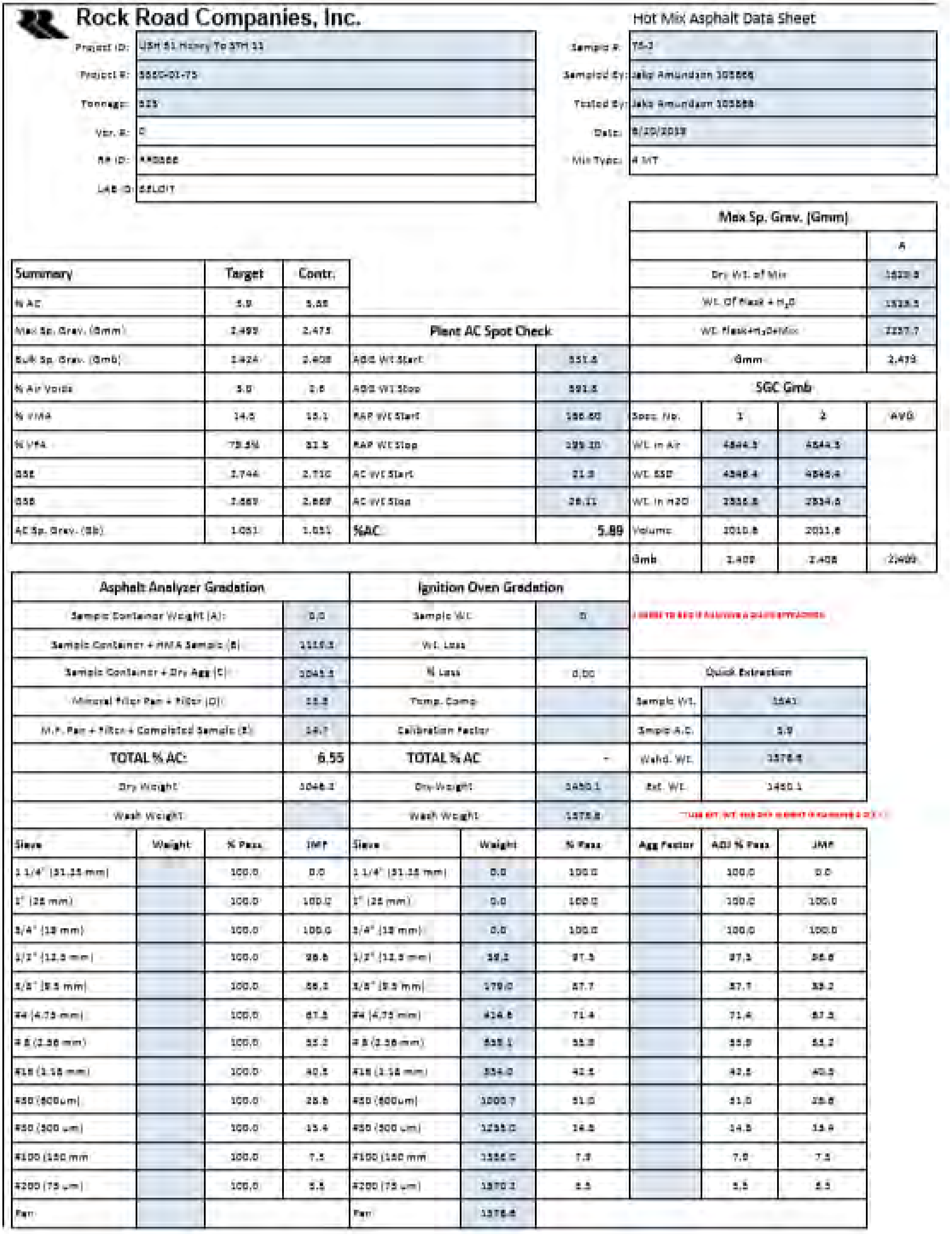
SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4850.7	4852.0	
Wt. SSD	4853.1	4855.0	
Wt. in H2O	2834.1	2837.0	
Volume	2019.0	2018	
Gmb	2.402	2.404	2.403

Asphalt Analyzer Gradation	
Sample Container Weight (A):	
Sample Container + HMA Sample (B)	
Sample Container + Dry Agg (C)	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E)	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation	
Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	1422.8
Wash Weight	1365.5

Quick Extraction	
Sample Wt.	1512
Sample A.C.	5.9
Wshd. Wt.	1365.5
Ext. Wt.	1422.8

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	Agg % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			88.8	1/2" (12.5 mm)	80.8	85.7		95.7	88.8
3/8" (9.5 mm)			86.2	3/8" (9.5 mm)	250.6	82.4		82.4	86.2
#4 (4.75 mm)			57.5	#4 (4.75 mm)	471.0	66.5		66.5	57.5
# 8 (2.36 mm)			53.2	# 8 (2.36 mm)	671.3	52.8		52.8	53.2
#16 (1.18 mm)			40.5	#16 (1.18 mm)	853.4	40.0		40.0	40.5
#30 (600um)			28.8	#30 (600um)	1005.5	29.5		29.5	28.8
#50 (300 um)			15.4	#50 (300 um)	1220.0	14.5		14.5	15.4
#100 (150 mm			7.6	#100 (150 mm	1312.2	7.8		7.8	7.5
#200 (75 um)			5.5	#200 (75 um)	1365.5	4.8		4.9	5.5
Pan				Pan	1365.5				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hanny To STH 11	Sample #:	TS-2
Project #:	5560-01-75	Sampled By:	Jake Amundson 305888
Tonnage:	525	Tested By:	Jake Amundson 305888
Ver. #:	0	Date:	8/20/2019
RR ID:	RR0588	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.9	5.88
Max Sp. Grav. (Gmm)	2.499	2.473
Bulk Sp. Grav. (Gmb)	2.424	2.408
% Air Voids	3.0	2.6
% VMA	14.5	15.1
% VFA	79.3%	82.5
GSE	2.744	2.730
GSB	2.689	2.669
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check	
ADG Wt Start	531.4
ADG Wt Stop	591.4
RAP Wt Start	186.60
RAP Wt Stop	185.10
AC Wt Start	21.9
AC Wt Stop	26.11
%AC	5.89

Max Sp. Grav. (Gmm)	A
Dry Wt. of Mix	1820.9
Wt. Of Flask + H_2O	1528.5
Wt. Flask+H_2O+Mix	2237.7
Gmm	2.473

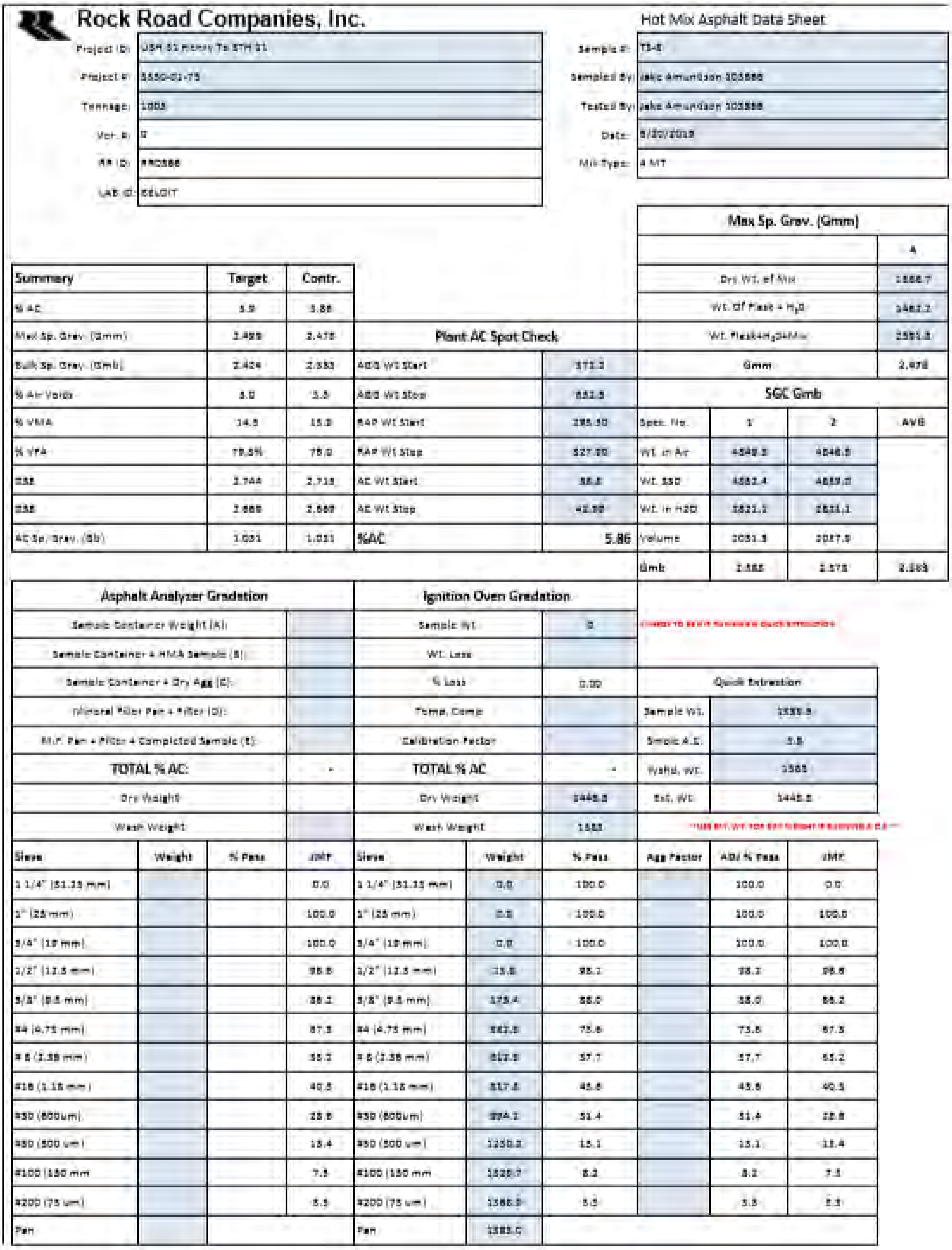
SGC Gmb			
Spec. No.	1	2	AVG
Wt. in Air	4844.5	4844.5	
Wt. SSD	4848.4	4846.4	
Wt. in H2O	2836.8	2834.8	
Volume	2010.6	2011.6	
Gmb	2.408	2.408	2.408

Asphalt Analyzer Gradation	
Sample Container Weight (A):	0.0
Sample Container + HMA Sample (B)	1116.3
Sample Container + Dry Agg (C)	1043.3
Mineral Filler Pan + Filter (D)	33.3
M.F. Pan + Filter + Completed Sample (E)	34.7
TOTAL % AC:	6.55
Dry Weight	1046.2
Wash Weight	

Ignition Oven Gradation	
Sample Wt.	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	1450.1
Wash Weight	1378.8

Quick Extraction	
Sample Wt.	1541
Smple A.C.	5.9
Wshd. Wt.	1378.8
Ext. Wt.	1450.1

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)		100.0	0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)		100.0	100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)		100.0	100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)		100.0	98.6	1/2" (12.5 mm)	38.2	97.3		97.3	98.6
3/8" (9.5 mm)		100.0	88.2	3/8" (9.5 mm)	179.0	87.7		87.7	88.2
#4 (4.75 mm)		100.0	67.5	#4 (4.75 mm)	414.6	71.4		71.4	67.5
# 8 (2.36 mm)		100.0	53.2	# 8 (2.36 mm)	639.1	55.9		55.9	53.2
#16 (1.18 mm)		100.0	40.5	#16 (1.18 mm)	834.0	42.5		42.5	40.5
#30 (600um)		100.0	28.8	#30 (600um)	1000.7	31.0		31.0	28.8
#50 (300 um)		100.0	15.4	#50 (300 um)	1255.0	14.5		14.5	15.4
#100 (150 mm		100.0	7.5	#100 (150 mm	1356.0	7.0		7.0	7.5
#200 (75 um)		100.0	5.5	#200 (75 um)	1370.2	5.5		5.5	5.5
Pan				Pan	1378.4				



Rock Road Companies, Inc.

Hot Mix Asphalt Data Sheet

Project ID:	USH 51 Hanover To STH 11	Sample #:	TS-8
Project #:	5550-01-75	Sampled By:	Jake Amundson 103888
Tonnage:	1003	Tested By:	Jake Amundson 103888
Ver. #:	0	Date:	8/20/2018
RR ID:	RR0588	Mix Type:	4 MT
LAB ID:	BELOIT		

Summary	Target	Contr.
% AC	5.9	5.86
Max Sp. Grav. (Gmm)	2.499	2.478
Bulk Sp. Grav. (Gmb)	2.424	2.353
% Air Voids	3.0	3.5
% VMA	14.5	15.3
% VFA	79.3%	78.0
Gse	2.744	2.715
Gsb	2.688	2.689
AC Sp. Grav. (Gb)	1.031	1.031

Plant AC Spot Check

AGG Wt Start	573.3
AGG Wt Stop	852.5
RAP Wt Start	285.30
RAP Wt Stop	327.00
AC Wt Start	38.8
AC Wt Stop	42.90
%AC	5.86

Max Sp. Grav. (Gmm)

	A
Dry Wt. of Mix	1556.7
Wt. Of Flask + H_2O	1482.2
Wt. Flask+H_2O+Mix	2391.8
Gmm	2.478

SGC Gmb

Spec. No.	1	2	AVG
Wt. in Air	4849.3	4846.8	
Wt. SSD	4882.4	4889.0	
Wt. in H2O	2821.2	2831.1	
Volume	2061.3	2057.9	
Gmb	2.352	2.375	2.363

Asphalt Analyzer Gradation

Sample Container Weight (A):	
Sample Container + HMA Sample (B):	
Sample Container + Dry Agg (C):	
Mineral Filler Pan + Filter (D):	
M.F. Pan + Filter + Completed Sample (E):	
TOTAL % AC:	-
Dry Weight	
Wash Weight	

Ignition Oven Gradation

Sample Wt	0
Wt. Loss	
% Loss	0.00
Temp. Comp	
Calibration Factor	
TOTAL % AC	-
Dry Weight	1446.5
Wash Weight	1383

[illegible]

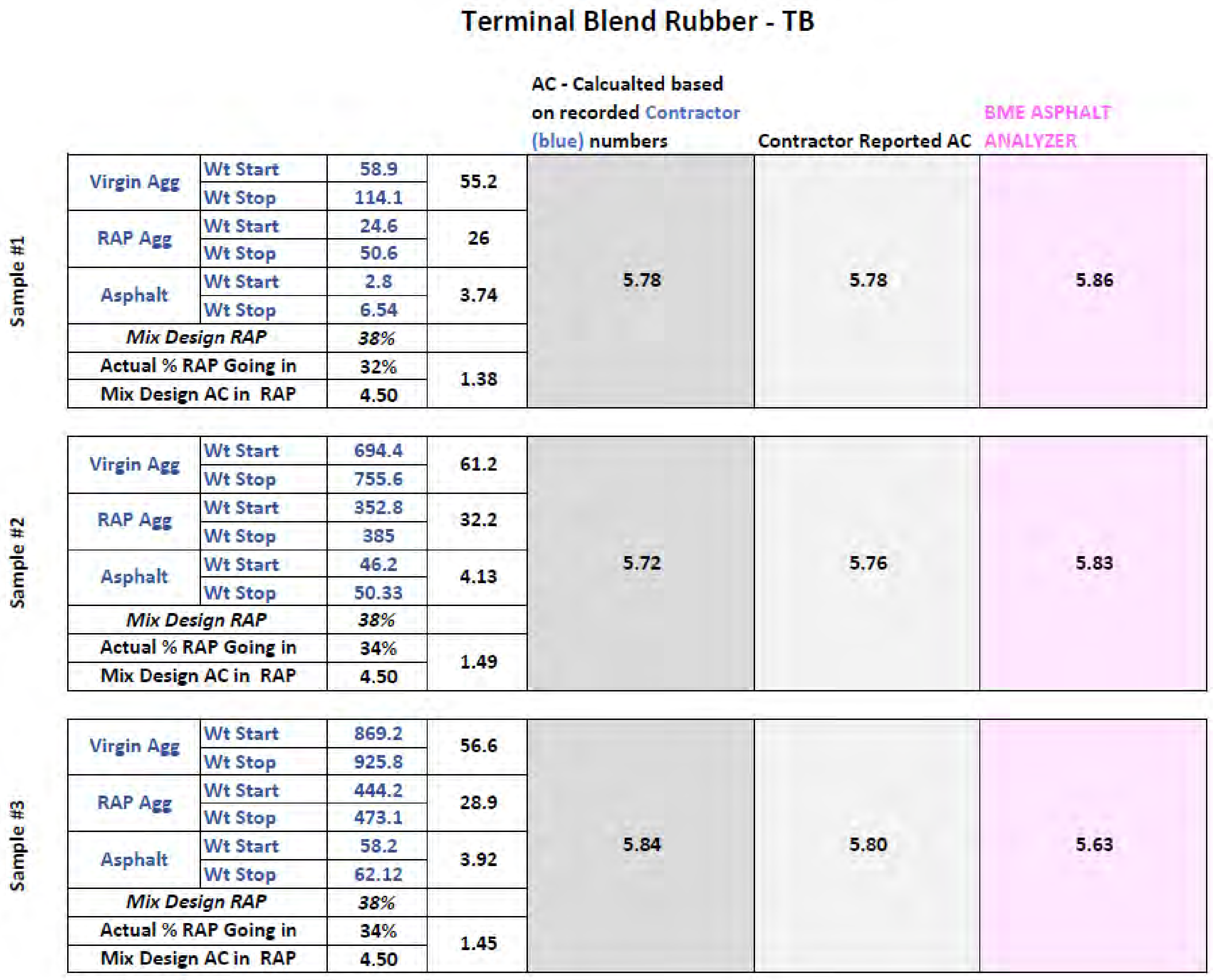
Quick Extraction

Sample Wt.	1535.5
Smple A.C.	5.8
Wshd. Wt.	1383
Ext. Wt.	1446.5

[illegible]

Sieve	Weight	% Pass	JMF	Sieve	Weight	% Pass	Agg Factor	ADJ % Pass	JMF
1 1/4" (31.25 mm)			0.0	1 1/4" (31.25 mm)	0.0	100.0		100.0	0.0
1" (25 mm)			100.0	1" (25 mm)	0.0	100.0		100.0	100.0
3/4" (19 mm)			100.0	3/4" (19 mm)	0.0	100.0		100.0	100.0
1/2" (12.5 mm)			98.8	1/2" (12.5 mm)	23.8	98.2		98.2	98.8
3/8" (9.5 mm)			88.2	3/8" (9.5 mm)	175.4	88.0		88.0	88.2
#4 (4.75 mm)			67.3	#4 (4.75 mm)	382.8	73.6		73.6	67.3
# 8 (2.36 mm)			55.2	# 8 (2.36 mm)	612.5	57.7		57.7	55.2
#16 (1.18 mm)			40.5	#16 (1.18 mm)	817.8	45.8		45.8	40.5
#30 (600um)			28.8	#30 (600um)	994.1	31.4		31.4	28.8
#50 (300 um)			18.4	#50 (300 um)	1230.2	15.1		15.1	18.4
#100 (150 mm			7.5	#100 (150 mm	1320.7	8.2		8.2	7.5
#200 (75 um)			5.5	#200 (75 um)	1386.3	5.3		5.3	5.5
Pan				Pan	1383.0				

13.15 AC Content Calculations Compared to BME Extractions



Terminal Blend Rubber - TB

					AC - Calcualted based on recorded Contractor (blue) numbers	Contractor Reported AC	BME ASPHALT ANALYZER
Sample #1	Virgin Agg	Wt Start	58.9	55.2	5.78	5.78	5.86
		Wt Stop	114.1				
	RAP Agg	Wt Start	24.6	26			
		Wt Stop	50.6				
	Asphalt	Wt Start	2.8	3.74			
		Wt Stop	6.54				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		32%	1.38			
	Mix Design AC in RAP		4.50				
Sample #2	Virgin Agg	Wt Start	694.4	61.2	5.72	5.76	5.83
		Wt Stop	755.6				
	RAP Agg	Wt Start	352.8	32.2			
		Wt Stop	385				
	Asphalt	Wt Start	46.2	4.13			
		Wt Stop	50.33				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		34%	1.49			
	Mix Design AC in RAP		4.50				
Sample #3	Virgin Agg	Wt Start	869.2	56.6	5.84	5.80	5.63
		Wt Stop	925.8				
	RAP Agg	Wt Start	444.2	28.9			
		Wt Stop	473.1				
	Asphalt	Wt Start	58.2	3.92			
		Wt Stop	62.12				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		34%	1.45			
	Mix Design AC in RAP		4.50				

Terminal Blend Hybrid - TBH

					AC - Calcualted based on recorded Contractor (blue) numbers	Contractor Reported AC	BME ASPHALT ANALYZER
Sample #1	Virgin Agg	Wt Start	373	62	5.81	5.82	5.74
		Wt Stop	435				
	RAP Agg	Wt Start	186.3	32.9			
		Wt Stop	219.2				
	Asphalt	Wt Start	24	4.28			
		Wt Stop	28.28				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		35%	1.49			
	Mix Design AC in RAP		4.50				
Sample #2	Virgin Agg	Wt Start	624	62.7	5.81	5.79	5.83
		Wt Stop	686.7				
	RAP Agg	Wt Start	318.2	32.9			
		Wt Stop	351.1				
	Asphalt	Wt Start	41.2	4.32			
		Wt Stop	45.52				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		34%	1.48			
	Mix Design AC in RAP		4.50				
Sample #3	Virgin Agg	Wt Start	686.7	62.4	5.85	5.83	5.89
		Wt Stop	749.1				
	RAP Agg	Wt Start	351.1	32.9			
		Wt Stop	384				
	Asphalt	Wt Start	45.5	4.35			
		Wt Stop	49.85				
	Mix Design RAP		*38%*				
	Actual % RAP Going in		35%	1.49			
	Mix Design AC in RAP		4.50				

Dry Process - DP

					AC - Calcualted based on recorded Rock Road (blue) numbers	Rock Road Reported AC	AC - Calcualted based on Added Dry Process Rubber	BME ASPHALT ANALYZER
Sample #1	Virgin Agg	Wt Start	36.6	60.5	5.90	5.89	6.34	6.39
		Wt Stop	97.1					
	RAP Agg	Wt Start	9.9	32.1				
		Wt Stop	42					
	Asphalt	Wt Start	1.1	4.27				
		Wt Stop	5.37					
	Mix Design RAP		*38%*					
	Actual % RAP Going in		35%	1.49				
	Mix Design AC in RAP		4.50					
	DP Ground Tire Rubber		10%	0.43				
Sample #2	Virgin Agg	Wt Start	331.8	60	5.86	5.89	6.30	6.50
		Wt Stop	391.8					
	RAP Agg	Wt Start	166.6	32.6				
		Wt Stop	199.2					
	Asphalt	Wt Start	21.9	4.21				
		Wt Stop	26.11					
	Mix Design RAP		*38%*					
	Actual % RAP Going in		35%	1.52				
	Mix Design AC in RAP		4.50					
	DP Ground Tire Rubber		10%	0.42				
Sample #3	Virgin Agg	Wt Start	575.2	57.1	6.03	5.86	6.48	6.25
		Wt Stop	632.3					
	RAP Agg	Wt Start	295.5	32.4				
		Wt Stop	327.9					
	Asphalt	Wt Start	38.8	4.19				
		Wt Stop	42.99					
	Mix Design RAP		*38%*					
	Actual % RAP Going in		36%	1.56				
	Mix Design AC in RAP		4.50					
	DP Ground Tire Rubber		10%	0.42				