2020

Procedure for Asphalt Mixture Friction Evaluation for WVDOH

Danielle Marie Hoyer
West Virginia University, dmhoyer@mix.wvu.edu

Procedure for Asphalt Mixture Friction Evaluation for WVDOH

Danielle Hoyer

Thesis submitted
to the Benjamin M. Statler College of Engineering and Mineral Resources
at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Science in

Civil and Environmental Engineering

John. P. Zaniewski, Ph. D., P.E., Chair
Yoojung Yoon, Ph. D.
Fei Dai, Ph. D.

Department of Civil Engineering

Morgantown, West Virginia
2020

Keywords: Asphalt, Polishing, BPT, Friction, Skid Resistance

ABSTRACT

Procedure for Asphalt Mixture Friction Evaluation for WVDOH

Danielle Hoyer

Monitoring asphalt skid resistance in the laboratory could aid in improved friction prediction capabilities and provide insight for developing alternative asphalt mixture designs in the future. The West Virginia Department of Highways (WVDOH) sought the design of a laboratory accelerated asphalt polishing machine to further expand on current skid resistance measurement practices. The design is modeled after the North Carolina State University (NCSU) polishing machine detailed in ASTM E660. The purpose of this research was to develop a testing procedure for the polishing equipment. Friction was monitored with the British Pendulum Tester (BPT) according to ASTM E303.

Specimens were prepared using a Superpave Gyratory Compactor (SGC) at two air void contents (4% and 8%) using four asphalt surface course mixtures (JFA 12.5mm Skid-RAP, WVP W1-RAP, Greer W1, WVP 12.5mm Skid-RAP). Specimens were placed in the polishing machine for a minimum of 48,000 wheel passes and conditioned with silicon carbide abrasive powder for accelerated polishing. Tire toe angles were adjusted between low (4° toed in and 2° toed out) and high (8° toed in and 4° toed out) toe angles. Average BPN values were plotted and used for slope calculations to investigate asymptotic behavior. These trend lines were also used as prediction models to determine the number of wheel passes required to reach minimum BPN limits; a larger number of wheel passes indicates more polish resistance. Variables evaluated: specimen air void content (VTM), tire toe angles, tire type, nominal maximum aggregate size (NMAS), and asphalt production company were considered for analysis. Data were compared using t-tests at 95% confidence to determine statistical differences between average BPN measurements. The most polish resistant mixture was the WVP W1-RAP mix; JFA 12.5mm Skid-RAP was the least. T-tests concluded only statistically different results for toe angles and lab/field comparisons. Lower friction values for higher toe angles suggest increased polishing when using higher toe. These results could provide insight on polishing procedure optimization and skid resistant characteristics of asphalt mixtures.

ACKNOWLEDGEMENTS

I would like to take this opportunity to extend my gratitude to those who have helped me in achieving this goal. First, I would like to thank my advisor, Dr. Zaniewski, for not only presenting me with this opportunity, but also for providing me with the tools and guidance needed to complete this degree. I also want to thank Dr. Yoojung Yoon and Dr. Fei Dai for being a part of my committee and supporting this journey.

Additionally, I want to thank the WVDOH for this project opportunity as well as the resources and equipment necessary to complete it. I would like to thank participating contractors for also providing resources throughout the course of my experiment. I am also extremely grateful to my fellow peers for their time and effort in assisting and supporting me with this project. And lastly, I would like to take a moment to sincerely thank my family and friends. I truly could not have done this without their endless love and support.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AASHTO = American Association of State Highway and Transportation Officials

APM = Aachen Polishing Machine

ASTM = American Society for Testing and Materials

BPN = British Pendulum Number

BPW = British Polishing Wheel

BPT = British Pendulum Tester

CalTrans =California Department of Transportation

CTM = Circular Track/Texture Meter

CTPM = Circular Track Polishing Machine

DFT = Dynamic Friction Tester

FHWA = Federal Highway Administration

G_{mb} = Bulk Specific Gravity

G_{mm} = Specific Gravity of Mix

HMA = Hot Mix Asphalt

I-79 = Interstate 79

JFA = J.F. Allen Company

Micro-Deval Device (MDD)

MIWT = Michigan Indoor Wear Track

MMLS3 = Third-Scale Model Mobile Load Simulator

MDOT = Michigan Department of Transportation

NCAT = National Center for Asphalt Technology

NCHRP = National Cooperative Highway Research Program

NCSU = North Carolina State University

NMAS = Nominal Maximum Aggregate Size

N_p = Predicted Number of Wheel Passes

PSU = The Pennsylvania State University

RAP = Reclaimed Asphalt Pavement

SGC = Superpave Gyratory Compactor

SN = Skid Number

SR = Skid-RAP Asphalt Mixture

SSD = Saturated Surface Dry

TWPD = Three Wheel Polishing Device

VFT = Variable Speed Friction Tester

VTM = Voids in the Total Mixture (Air Void Content)

W1 = Wearing 1 Asphalt Mixture Course

WSPM = Wehner/Schulze Polishing Machine

WV = West Virginia

WVDOH = West Virginia Division of Highways

WVP = West Virginia Paving, Inc.

WVU = West Virginia University

Chapter 1: Introduction

Background

As an integral part of infrastructure, roadways provide a daily avenue for individuals to carry out various activities or trips. Because the roadway infrastructure is so important, it is imperative for engineers to maintain the safety of the public, which includes the maintenance of proper levels of skid resistance. Skid resistance poses issues for a number of crash types including non-departure and departure accidents. According to statistics stated by the Federal Highway Administration (FHWA), more than half of the 35,092 fatalities reported in 2015 were due to roadway departures (FHWA, 2016). Specific to the state of West Virginia, 214 out of a total of 303 fatalities reported in 2017 (71%) were due to at least one vehicle departing the roadway, placing West Virginia in the top five within the United States (including Washington D.C.) for the largest percentage of fatalities associated with roadway departures (National Highway Traffic Safety Administration, 2017). While there are many factors affecting roadway departures, the lack of proper skid resistance on roadway surfaces remains a large contributing factor, especially in wet conditions (FHWA, 2016). Wet conditions contribute to the majority of roadway departure crashes, and approximately 70% could be mitigated with friction improvements (FHWA, 2016).

To combat skid resistance issues, pavement engineers have developed skid resistance surface courses, high friction treatments, as well as various other high friction developments. In order for these treatments to be successful, engineers rely heavily skid resistant aggregates. Unfortunately, the supplies of these aggregates are quickly diminishing in West Virginia, prompting a need for the West Virginia Department of Highways (WVDOH) to develop additional approaches in providing the public with proper skid resistance on asphalt pavements. Eliminating the substantial reliance on skid resistant aggregates requires research in the laboratory to measure the skid potential of hot mix asphalt (HMA) mixtures, rather than aggregate properties specifically. This approach involves the proper polishing of asphalt samples as well as measurements of a skid resistance parameter. This information can provide insight on an alternate approach in providing appropriate skid resistance properties based the asphalt concrete mixture itself.

Problem Statement

Available skid aggregate in West Virginia is quickly depleting. While aggregates can be transported from alternate locations, it is costly and time consuming. Because of this, research is necessary to investigate the behavior of readily available aggregates as well as alternate methods of providing sufficient skid resistance on roadway surfaces. WVDOH MP 402.02.20 describes the procedure for prequalifying aggregates for skid by determining the content of polish susceptible carbonate particles in the aggregates. Field skid resistance measurements are performed using the locked skid trailer, ASTM E274. The WVDOH does not currently employ laboratory methods of measuring skid resistance for asphalt mixtures. Improved testing and research is needed in order to improve friction monitoring and predicting capabilities.

This study was performed in order to evaluate asphalt concrete mixtures with respect to skid resistance by means of a newly developed polishing machine and a British Pendulum Tester (BPT). Gathering data tracking asphalt mixtures' ability to resist polishing can provide the WVDOH and other agencies with necessary information for performing efficient laboratory testing procedures. In addition, this research will aid in developing alternative techniques for providing skid resistant mixtures and better predicting pavement performance in the future.

Objectives

There are two primary objectives for this research study. The WVDOH has not previously incorporated an accelerated polishing machine into laboratory friction testing procedures. As such, an accelerated polishing machine was developed. This lead to the first key objective for this research, which is to develop an optimal protocol for polishing asphalt concrete samples using an accelerated polishing machine. In establishing a proper polishing procedure, the next main objective of the study was to evaluate the skid resistance of some current asphalt mixtures used across the state by analyzing BPT measurements.

In addition to the key goals established for this experiment, it is necessary to complete supplemental tasks. This primarily includes the monitoring of factors having the potential to influence skid resistance and subsequent BPT readings. With continued testing, results could provide insight on current issues in correlating laboratory and field friction measurements. This research could also aid in discovering alternative characteristics that influence pavement surface friction to compensate for the limited supply of skid aggregates available in the state.

Scope and Limitations

Within this experimental study, there were a few constraints regarding asphalt mixture types and polishing machine design. Testing materials were limited to plant produced mixtures as well as field and laboratory cores provided by contractors and the WVDOH. This includes the amount and type of asphalt concrete available from participating plants prior to the experiment. Because of this, sample heights also varied. While all laboratory compacted samples could be prepared or measured at specific air void contents for tracking purposes, field core air void contents could not be controlled.

The WVDOH provided the accelerated laboratory polishing machine and the BPT used for this research. Alternative methods of friction and surface texture measurements were not available. With restrictions in the equipment and variety of testing materials, overall conclusions from the experiment are also limited.

Report Outline

This thesis contains five chapters including an introduction, literature review, methodology, results and discussion, and conclusion and recommendations. Chapter 1 is the introduction, which is then followed by a literature review (Chapter 2). The literature review is comprised of three key topics: pavement surface texture and friction, laboratory polishing methods, and friction and texture evaluation. Chapter 3 corresponds to the methodology of the experiment. Chapter 4 includes general and statistical results from the experiment. Finally, a summary of conclusions and recommendations are presented in Chapter 5. Appendices comprised of additional experimental information and details are located at the end of this thesis.

Chapter 2: Literature Review

Skid resistance is a function of vehicle parameters and the texture of the pavement surface. Other than field testing for skid resistance, e.g. the locked wheel skid trailer, pavement engineers cannot control the vehicle parameters. Hence, laboratory evaluation of asphalt mixtures is forced to focus on polishing methods and a measure of how the polishing affects either the texture or a controlled friction test. According to Panagouli and Kokkalis (1998), pavement surface texture can be categorized into three orders: microtexture, macrotexture, and megatexture. While megatexture is an important parameter to monitor for general roadway safety, skid resistance relies heavily on pavement microtexture and macrotexture (Corley-Lay, 1998). A simplified illustration of pavement microtexture and macrotexture is shown in Figure 1 (Liang, 2013).

In general terms, macrotexture is the texture caused by aggregate arrangement or spacing, while microtexture describes the texture contained on the aggregate itself on a small-scale level ("Skid Resistance," 2019). Texture variations ranging between 0.3-4.0 millimeters and 0.005-0.3 millimeters represent macrotexture and microtexture, respectively (Panagouli and Kokkalis, 1998). Within this distinction, macrotexture describes the texture allowing for excess water storage on a pavement's surface, and microtexture represents the interaction between the tire and the pavement surface (Federal Highway Administration Research and Technology, 2015). "Tire-pavement friction" combines friction elements of hysteresis and adhesion. Hysteresis and adhesion correspond to macrotexture and microtexture, respectively (FHWA, 2015).

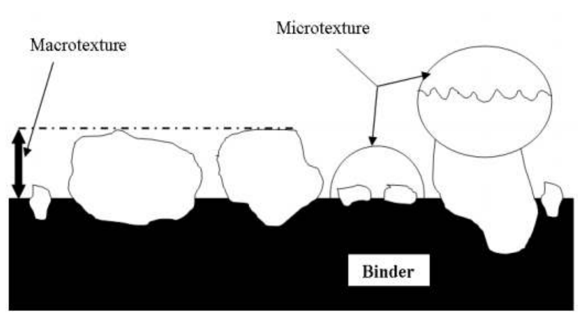


***Figure 1**: Representative Illustration of Pavement Surface Microtexture and Macrotexture (Liang, 2013)*

Erukulla (2011) found that microtexture defines the magnitude of skid resistance at low speeds, while macrotexture controls the slope of skid resistance versus speed relationship. The FHWA issues guidelines for roadway departure safety; the compliance by state agencies requires monitoring and maintaining proper pavement surface friction. While most state agencies employ high speed methods to measure skid resistance, there are techniques in measuring skid resistance in low speed applications, which are important for monitoring pavement surface texture.

Polishing

During the life of a pavement, the surface becomes polished due to the environment, number of wheel passes, and durability of the pavement surface materials. The polishing action occurring in the field can be demonstrated under laboratory conditions with accelerated polishing devices, which is the focus of this research. Polishing devices are categorized in terms of aggregate, HMA, or aggregate and HMA polishing.

Generally speaking, polishing is discussed in terms of the polishing of aggregates. With respect to aggregates, polishing can be described as "the wearing down and smoothing of the small surface irregularities of the aggregate under traffic loading" (Gandhi et al., 1991). Aggregate polishing devices include the British Polishing Wheel (BPW) and the Michigan Indoor Wear Track (MIWT). The ability of aggregates to provide a skid resistant surface can also be evaluated with the Micro-Deval Device (MDD) given in (Greer and Heitzman, 2017) and the Insoluble Residue Test (WVDOH, 2018). While the polishing of aggregates is important to understand the polishing of asphalt mixtures, it is not the focus of this research, and will not be further discussed.

HMA polishing devices include the National Center for Asphalt Technology (NCAT) Three Wheel Polishing Device (TWPD), Ohio Polisher, and Third-Scale Model Mobile Load Simulator (MMLS3). There are also devices to polish either HMA or aggregates, including the Pennsylvania State University (PSU) Reciprocating Polishing Machine, Wehner/Schulze Polishing Machine (WSPM), Aachen Polishing Machine (APM), and North Carolina State University (NCSU) Circular Track Polishing Machine (CTPM).

Hall et al. (2009) recognize the three most relevant polishing devices as the NCSU CTPM, MIWT, and NCAT TWPD. The NCSU CTPM is the only device with a published

ASTM Standard (ASTM E660). The Ohio Polisher (Liang, 2013) is a recent development since the completion of the NCHRP report. For this research, the NCSU, NCAT, and Ohio polishing devices were primarily considered for equipment development due to their relevancy in current standards and usage. Table 1 is Hall et al.'s (2009) summary of polishing devices. Table 2 is a summary of the WS and Ohio polishing devices compiled from Freil et al. (2013) and Liang (2013). Table 3 provides additional information on the strengths and weaknesses of laboratory polishing equipment (Liang, 2013).

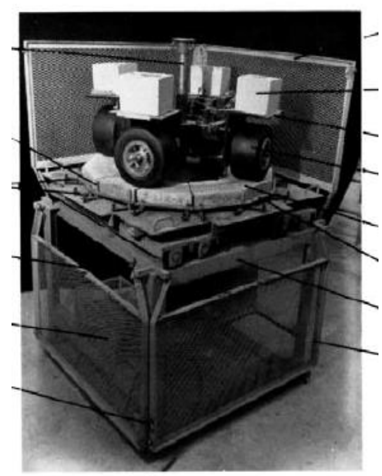
Friction and Texture Evaluation

Friction Measuring Devices

Friction measuring devices provide measurements at either high or low speeds. Hall et al., 2009 recognizes four primary types of high-speed devices: locked-wheel, side-force, variable-slip, and fixed-slip. Descriptions of test methods and corresponding devices are summarized by Hall et al. (2009) in Table 4. The locked-wheel skid trailer (ASTM E274) is identified as the most used method in the U.S. (Hall et al., 2009). This is also the current method used by the WVDOH.

Table 5 (Hall et al., 2009) describes additional lower speed test methods including the BPT and the Dynamic Friction Tester (DFT). The BPT is specified in ASTM E303 and is the friction measuring equipment used for this research. While the BPT was a favored low-speed friction measuring device in the past, the DFT is often used in current methods (Hall et al., 2009). It is typically used by NCAT along with the CTM device (Hall et al., 2009). The CTM is specific to pavement texture evaluation. Generally speaking, texture measuring methods rely on volumetric or laser techniques for evaluating surface friction. Methods for pavement surface texture measurements are described by Hall et al., 2009 and displayed in Table 6. However, texture measuring devices were not available for this research.

Table 1: Summary of Polishing Devices

Polishing Method/Device	Standard	Testing Material	Description	Equipment
Michigan Indoor Wear Track (MIWT)	N/A	Aggregates	The MIWT is a wheel-type accelerated polishing device for coarse aggregates. the wear track design allows for two tires to pass over samples placed in a horizontal circular path. Once polished, aggregates are evaluated for an aggregate wear index by measuring the frictional tire resistance on a wetted sample surface (MDOT, 2019).	 (Erukulla, 2011)
NCSU Circular Track Polishing Machine (CTPM)	ASTM E660	HMA	The CTPM provides polishing action by rotating wheels on twelve samples in a circular track formation. ASTM E660 specifies the use of four smooth, 11 x 6.00 x 5 inch tires rotated over samples at a rate of 30 rpm. Vertical force on the tires is controlled with weights (Mullen et al., 1977). Per E660-90, slab samples are cut into triangular sections to allow the samples to fit together into a circular track. E660-90 indicates an 8-hour sufficient polishing time, or 57,600 cycles. A variable speed friction tester (VFT) and a BPT were used to measure friction (Mullen et al., 1977).	 (ASTM E660-90)

NCAT Three Wheel Polishing Device (TWPD)	N/A	HMA	The NCAT TWPD polishes asphalt concrete slabs by the rotation of three wheels on the asphalt surface. Laboratory samples are prepared using a rolling kneading compactor, resulting in 20-inch square slabs, which are 2 inches in thickness (NCAT, 2016). Supplemental friction measurements are typically performed with a dynamic friction tester (DFT). Texture can be measured with the Circular Texture Meter (CTM).	 (NCAT, 2016)

Table 2: Summary of Additional Polishing Devices

Polishing Method/ Device	Standard	Testing Material	Description	Equipment
Wehner-Schulze Polishing Machine (WPSM)	N/A	Aggregates and HMA	The WPSM uses cone-shaped rubber rollers for polishing (Do et al., 2013). These rollers rotate on the surface of 225mm diameter samples at 500 revolutions per minute (Patrick, 2011). An abrasive water mixture is supplied to accelerate polishing. The device also includes friction measuring equipment, using three rotating rubber pads to measure the coefficient of friction (Friel et al., 2013).	 (Friel et al., 2013)
The Ohio Polisher	N/A	HMA	The Ohio Polisher polishes by rotating a rubber shoe against a sample surface. It has the ability to polish either slab or gyratory compacted samples with dimensions of 18 x 18 x 2 inches and 6 x 4 inches, respectively (Liang, 2013). The rubber pads and vertical forced placed, the rotational speed, and the rate of water applied to the sample can be varied. (Liang, 2013). Samples are measured for surface friction using either the Dynamic Friction Tester (DFT) or the Circular Track/Texture Meter (CTM). The Ohio Polisher is the only commercially available polishing machine in the U.S.	 (Liang, 2013)

Table 3: Strengths and Weaknesses of Laboratory Polishing Devices (Liang, 2013)

Device	Strengths	Weaknesses	Specifications
Polishing Devices for Aggregates			
British Polishing Wheel	Accelerated polishing for lab testing. Bench sized.	Used for aggregates only	ASTM D3319
Michigan Indoor Wear Track	Close to real world.	Specimen preparation is cumbersome and time-consuming. Used for aggregate only.	MDOT
Micro-Deval	Effective for polishing aggregates in a short time.	Used for aggregates only	AASHTO T327-05/Tex-461-A
Polishing Devices for HMA			
NCAT Polishing Machine	Sized to match DFT and CTM. Can be used in the lab or in the field.	42 hours to complete the test. Specimen preparation is cumbersome and labor intensive.	NCAT
Polishing Devices for Both			
NCSU Wear and Polishing Machine	No need for water or grinding compounds.	Polishes a relatively small area.	ASTM E660
Wehner/Schulz Polishing Machine	Can conduct polishing and friction measurements	Unable to handle gyratory-compacted specimens.	ASTM E1393
Penn State Reciprocating Polishing Machine	Portable. Can be used in the lab or in the field.	Polishes a relatively small area. Fallen into disuse.	Do et al., 2006

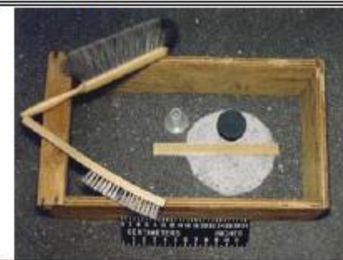
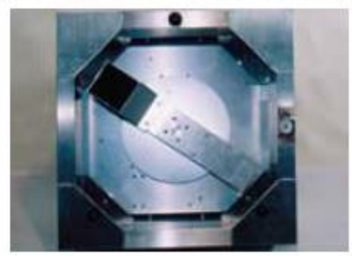
Table 4: Table of Field Friction Test Methods and Devices (Hall et al., 2009)

Test Method	Measurement Index	Applications	Advantages	Disadvantages
Locked-Wheel	The measured resistive drag force and the wheel load applied to the pavement are used to compute the coefficient of friction, μ. Friction is reported as friction number (*FN*) or skid number (*SN*).	Field testing (straight segments). Network-level friction monitoring.	Well developed and very widely used in the U.S. More than 40 states use locked-wheel devices. Systems are user friendly, relatively simple, and not time consuming.	Can only be used on straight segments (no curves, T-sections, or roundabouts). Can miss slippery spots because measurements are intermittent.
Side-Force	The side force perpendicular to the plane of rotation is measured and averaged to compute the Mu Number, *MuN*, or the sideways force coefficient, *SFC*.	Field testing straight sections, curves, steep grades. Data in different applications should be collected separately.	Relatively well controlled skid condition similar to fixed-slip device results. Measurements are continuous throughout a test pavement section. Method is commonly used in Europe.	Very sensitive to road irregularities (potholes, cracks, etc.) which can destroy tires quickly. Mu-Meter is primarily only used for airports in the U.S.
Fixed-Slip	The measured resistive drag force and the wheel load applied to the pavement are used to compute the coefficient of friction, *μ*. Friction is reported as *FN*.	Field testing (straight segments). Network-level friction monitoring. Project-level friction monitoring.	Continuous, high resolution friction data collected.	Fixed-slip devices take readings at a specified slip speed. Their slip speeds do not always coincide with the critical slip speed value, especially over ice- and snow-covered surfaces. Uses large amounts of water in continuous mode. Requires skillful data reduction.
Variable-Slip	When used for variable-slip measurements, the system provides a chart of the relationship between slip friction number and slip speed. The resulting indices are: • Longitudinal slip friction number • Peak slip friction number • Critical slip ratio • Slip ratio • Slip to skid friction number • Estimated friction number • Rado Shape factor When used for locked-wheel measurements, the system provides *FN* values.	Field testing (straight or curved segments). Network-level friction monitoring. Project-level friction monitoring.	Can provide continuously any desired fixed or variable slip friction results. Can provide the Rado shape factor for detailed evaluation.	Large, complex equipment with high maintenance costs and complex data processing and analysis needs. Uses large amounts of water in continuous mode.

Table 5: Table of Lower Speed Friction Test Methods (Hall et al., 2009)

Test Method	Associated Standard	Description	Equipment	
Stopping Distance Measurement	ASTM E 445	The pavement surface is sprayed with water until saturated. A vehicle is driven at a constant speed (40 mi/hr [64 km/hr] specified) over the surface. The wheels are locked, and the distance the vehicle travels while reaching a full stop is measured. Alternatively, different speeds and a fully engaged antilock braking system (ABS) have been used.	A passenger car or light truck (at least 3,200 lb [preferable equipped with a heavy-duty suspension system]) is specified. The braking system should be capable of full and sustained lockup. Tires should be ASTM E 501 ribbed design.	
Deceleration Rate Measurement	ASTM E 2101	Testing is typically done in winter contaminated conditions. While traveling at standard speed (20 to 30 mi/hr [32 to 48 km/hr]), the brakes are applied to lock the wheels, until deceleration rates can be measured. The deceleration rate is recorded for friction computation.	Mechanical or electronic equipment, shown at right, is installed on any vehicle to measure and record deceleration rate during stopping.	
Portable Testers	ASTM E 303 ASTM E 1911	Portable testers can be used to measure the frictional properties of pavement surfaces. These testers use pendulum or slider theory to measure friction in a laboratory or in the field. The British Pendulum Tester (BPT) produces a low-speed sliding contact between a standard rubber slider and the pavement surface. The elevation to which the arm swings after contact provides an indicator of the frictional properties. Data from five readings are typically collected and recorded by hand. The Dynamic Friction Tester measures the torque necessary to rotate three small, spring-loaded, rubber pads in a circular path over the pavement surface at speeds from 3 to 55 mi/hr (5 to 89 km/hr). Water is applied at 0.95 gal/min (3.6 L/min) during testing. Rotational speed, rotational torque, and downward load are measured and recorded electronically.	-The BPT is manually operated and documented, as shown at top right. -The DFT, shown at bottom right, is a modular system that is controlled electronically. Results are typically recorded at 12, 24, 36, and 48 mi/hr (20, 40, 60, and 80 km/hr), and the speed, friction relationship can be plotted. It fits in the trunk of a car and is accompanied by a water tank and portable computer.	 

Table 6: Table of Methods for Pavement Texture Measurements (Hall et al., 2009)

Test Method/ Equipment	Associated Standard	Description	Equipment	
Sand Patch Method (SPM)	ASTM E 965, ISO 10844	This volumetric-based spot test method provides the mean depth of pavement surface macro-texture. The operator spreads a known volume of glass beads in a circle onto a cleaned surface and determines the diameter and subsequently mean texture depth (*MTD*).	Equipment includes: Wind screen, 1.5 in^3 (25,000 mm^3) container, scale, brush, and disk (2.5- to 3-in [60- to 65-mm] diameter). ASTM D 1155 glass beads.	
Outflow Meter (OFM)	ASTM E 2380	This volumetric test method measures the water drainage rate through surface texture and interior voids. It indicates the hydroplaning potential of a surface by relating to the escape time of water beneath a moving tire. Correlations with other texture methods have also been developed.	Equipment is a cylinder with a rubber ring on the bottom and an open top. Sensors measure the time required for a known volume of water to pass under the seal or into the pavement.	
Circular Texture Meter (CTM)	ASTM E 2157	This non-contact laser device measures the surface texture in an 11.25-in (286-mm) diameter circular profile of the pavement surface at intervals of 0.034 in (0.868 mm), matching the measurement path of the DFT. It rotates at 20 ft/min (6 m/min) and provides profile traces and mean profile depth (*MPD*) for the pavement surface.	Equipment includes a water supply, portable computer, and the texture meter device.	 

Friction Criteria

Transportation agencies provide recommendations for minimum skid numbers (SN) using skid trailers in the field. However, the BPT was the only friction measuring device available for this research. There are limited reports providing minimum skid requirements in terms of British Pendulum Numbers (BPN). Asi (2005) provides values for varying roadway applications, listed in Table 7. The California Department of Transportation (CalTrans) display plotted minimum BPT measurements for both Virginia DOT and British standards (Lu and

Steven, 2006), Figure 2. Kowalski et al. (2010) compare minimum SN and BPN measurements for various mean traffic speeds of roadways in Table 8.

Table 7: Recommended Minimum BPN Measurements for Various Roadway Applications (Asi, 2005)

Category	Type of site	Minimum skid resistance value (surface wet)
A	Difficult sites such as: (i) Roundabouts (ii) Bends with radius less than 150 m on unrestricted (iii) Gradients, 1 in 20 or steeper, of lengths greater than 100 m (iv) Approaches to traffic lights on unrestricted roads	65
B	Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day)	55
C	All other sites	45

Note: For category A and B sites where speed of traffic is high (in excess of 95 km/h) an additional requirement is a minimum texture depth of 0.65 mm.

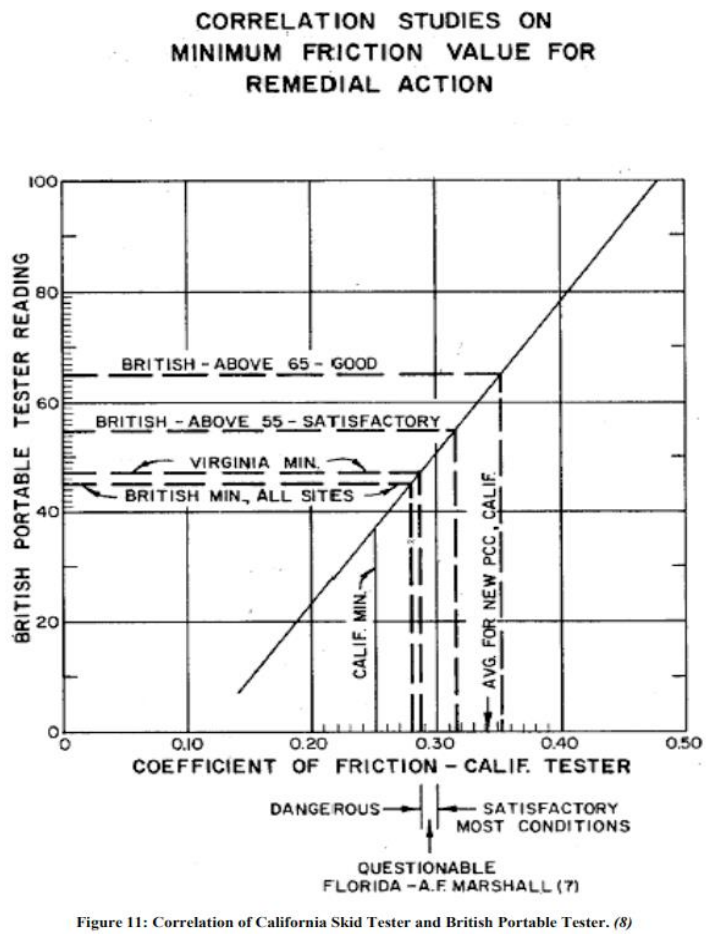


Figure 2*: Minimum Skid Resistance Requirements (Lu and Steven, 2006)*

Table 8: Suggested SN and BPN Minimum Measurements for Various Mean Traffic Speeds (Kowalski et al., 2010)

Mean Traffic Speed, km/h	Skid Number, SN[a]	British Pendulum Number, BPN
48	31	35
64	33	40
81	37	45
97	41	50
113	46	---
129	51	---

[a] ASTM E-274 friction trailer test conducted at 64 km/h using rib tire

Asphalt Mixture Friction Characteristics

There are several asphalt mixture characteristics that influence pavement skid resistance. Characteristics discussed in this thesis include: air void content (VTM), aggregate type, aggregate size, aggregate gradation, binder content, and asphalt mixture type. A general increase in pavement friction with the addition of skid aggregates and textural differences is reported throughout literature. The effects of skid aggregate are indicated by Kowalski et al. (2010), Do et al. (2007), Erukulla (2011) and Asi (2005), especially with slag. Textural differences from VTM, aggregate size, and aggregate gradation are reported to increase skid resistance according to Liang (2013) and Hall et al. (2009). Table 9 summarizes the effects of mixture characteristics on pavement friction measurements from various reports.

Table 9: Friction Results According to Different Asphalt Mixture Characteristics

Mix Characteristic	Testing Details	Friction Observation	Reported By
VTM	Specimens at 0.8%, 2.8%, and 5.4% VTM	Statistical difference between friction values	Liang, 2013
	Increase VTM	Increase friction values	Liang, 2013
Aggregate Type	Presence of carbonate, steel slag, or quartzite	Increase friction values	Kowalski et al., 2010
	Comparison of aggregate specimens and field cores composed of identical aggregates	Pavement friction corresponds to aggregate friction	Do et al., 2007
	Decrease friction aggregate amount	Decrease friction values	Erukulla, 2011
	Comparison of Marshall, Superpave, slag, and SMA specimens	Highest friction values for slag specimens	Asi, 2005
Aggregate Size	Increase aggregate size	Increase friction values	Kowalski et al., 2010
	Decrease aggregate size	Increase friction values	Do et al., 2007
	Increase aggregate size	Increase macrotexture, increasing friction	Hall et al., 2009
Aggregate Gradation	Coarse aggregate gradation (SMA)	Increased field friction values	Asi, 2005
	Larger open, gap, or uniform graded mix	Increase texture depth, increasing friction	Hall et al., 2009
Binder Content	Increased binder content, Marshall specimens	Decrease friction values	Asi, 2005
	SMA specimens at 6.9% binder content	Low friction values	Asi, 2005
Mix Type	Comparison of Marshall, Superpave, and SMA specimens	Increased friction values for Superpave	Asi, 2005
	SMA specimens	Increased field friction values	Asi, 2005

Chapter 3: Research Methodology

The two main objectives of this research were to develop a polishing procedure for asphalt samples with a newly developed laboratory accelerated polishing machine and subsequently evaluate some current surface mixtures approved by the WVDOH.

Materials

Because the primary focus of this research was the development of laboratory polishing protocol, only a total of four asphalt mixtures were obtained for testing. Asphalt mixtures used for this research include J.F. Allen 12.5mm Skid-RAP (JFA 12.5mm SR), West Virginia Paving 12.5mm Skid-RAP (WVP 12.5mm SR), West Virginia Paving W1-RAP (WVP W1-RAP), and Greer W1 Heavy (Greer W1H). Additional specimens prepared at the WVDOH laboratory for preliminary testing were also used, but the mixture type is unknown. Table 10 provides a summary of the four primary mixtures used for this research. Mixture T400 sheets are provided in Appendix A.

Table 10: Asphalt Mixture Material Information

Plant Name	Plant Location	Mix NMAS	Mix Type	T400 Number
J. F. Allen Company (JFA)	Lorentz, WV	12.5mm (1/2")	Skid-RAP (SR)	1462122
West Virginia Paving, Inc. (WVP)	Dunbar, WV	12.5mm (1/2")	Skid-RAP (SR)	1462115
West Virginia Paving, Inc. (WVP)	Huntington, WV	9.5mm (3/8")	Wearing 1-RAP (W1-RAP)	1436773
Greer Asphalt (Greer)	Greer, WV	9.5mm (3/8")	Wearing 1 Heavy (W1H)	1360465

There were also several tire substitutions made throughout the experiment due to either poor performance results or availability. Table 11 lists the tires used in this experiment. Tire hardness was monitored throughout the experiment to ensure that polishing was consistent throughout. The procedure used for measuring tire hardness is in Appendix B. Measurements remained consistent throughout and are provided in Appendix C.

Table 11: Tire Information

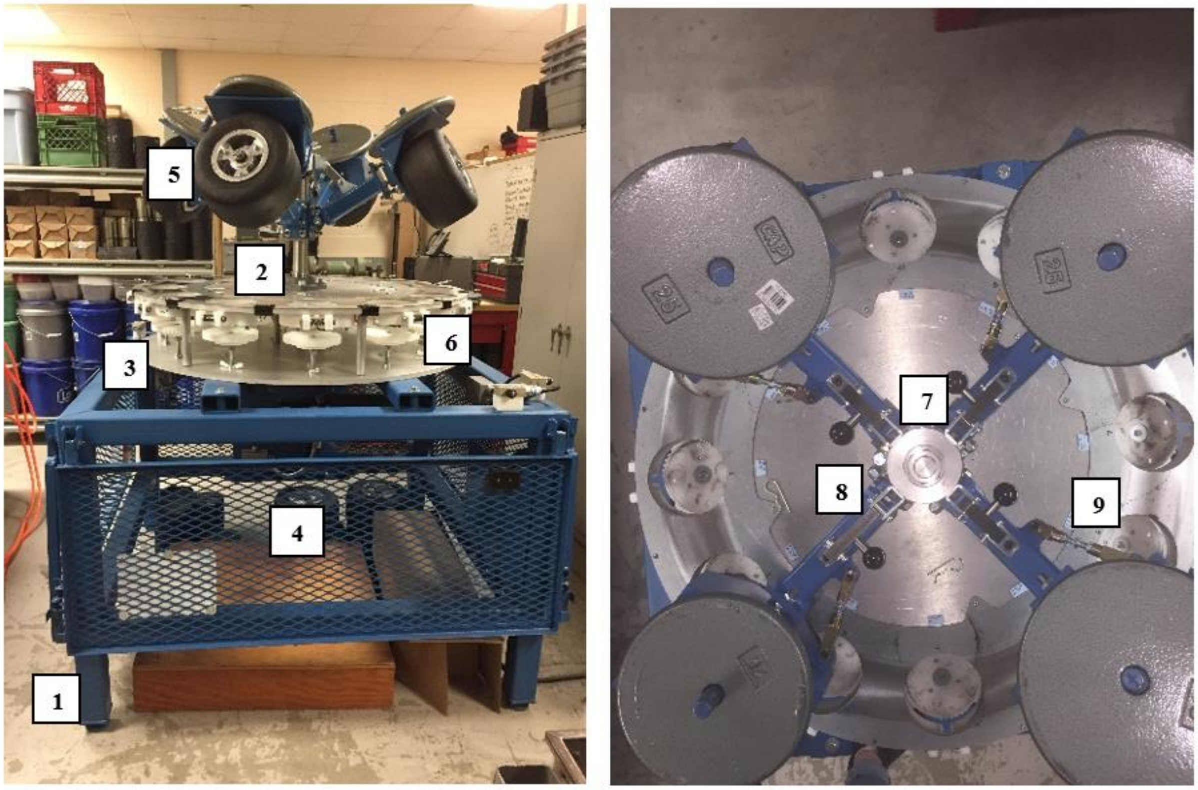
Manufacturer	Type	Size	Shore A Hardness
Burris	B44A	11 x 6-5.00"	75
Burris	B55A	11 x 6-5.00"	84
Hoosier	R80	11 x 6-5.00"	79

Equipment

The WVDOH hired a machinist to fabricate the polishing machine based on ASTM E660-90. The primary features include:

- Polishes 12 samples at once
- Four tires for polishing
- Variable rotation speed
- Accommodates variable sample heights and gyratory compacted or field core samples
- Maintains sample height settings for extraction

The polishing machine components are displayed in Figures 3 through 6.



(a) Side View (b) Top View

Figure 3: *WVDOH Polishing Machine Overview*

1. Equipment frame
2. Upper surface plate, Figure 4
3. Lower base plate
4. Safety guards, Figure 6
5. Rotating wheel assembly, Figure 5
6. Specimen housing components
7. Central shaft for rotation
8. Support pin for wheel assembly in upright position
9. Tie rod connection for toe angle adjustments

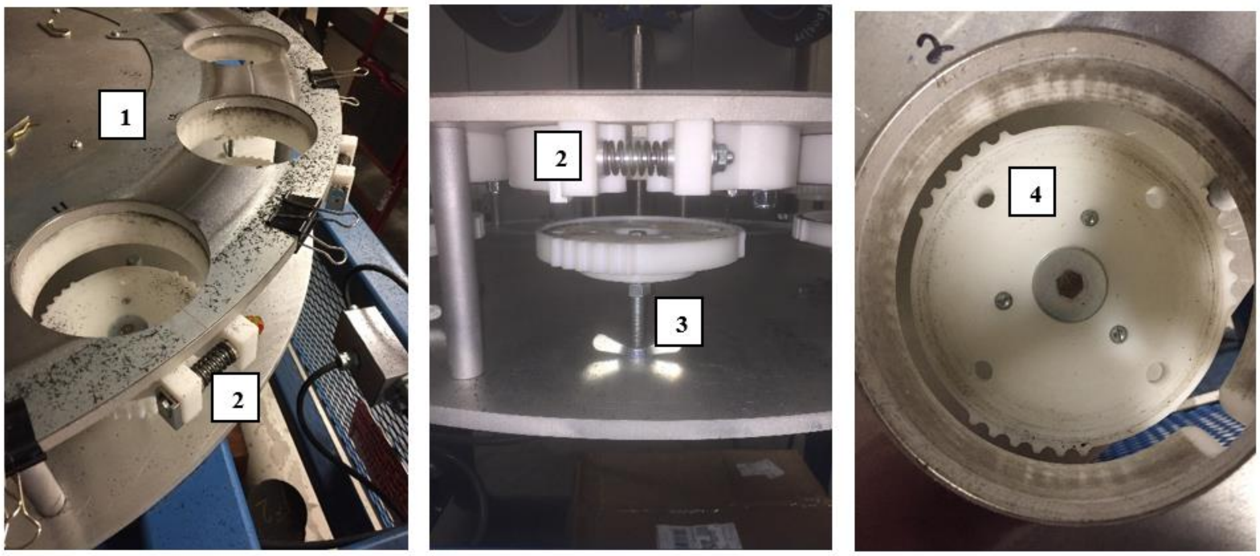


Figure 4*: Specimen Housing and Clamping Assembly*

1. Upper surface plate
2. Clamping assembly
3. Specimen height adjustment
4. Specimen extraction openings

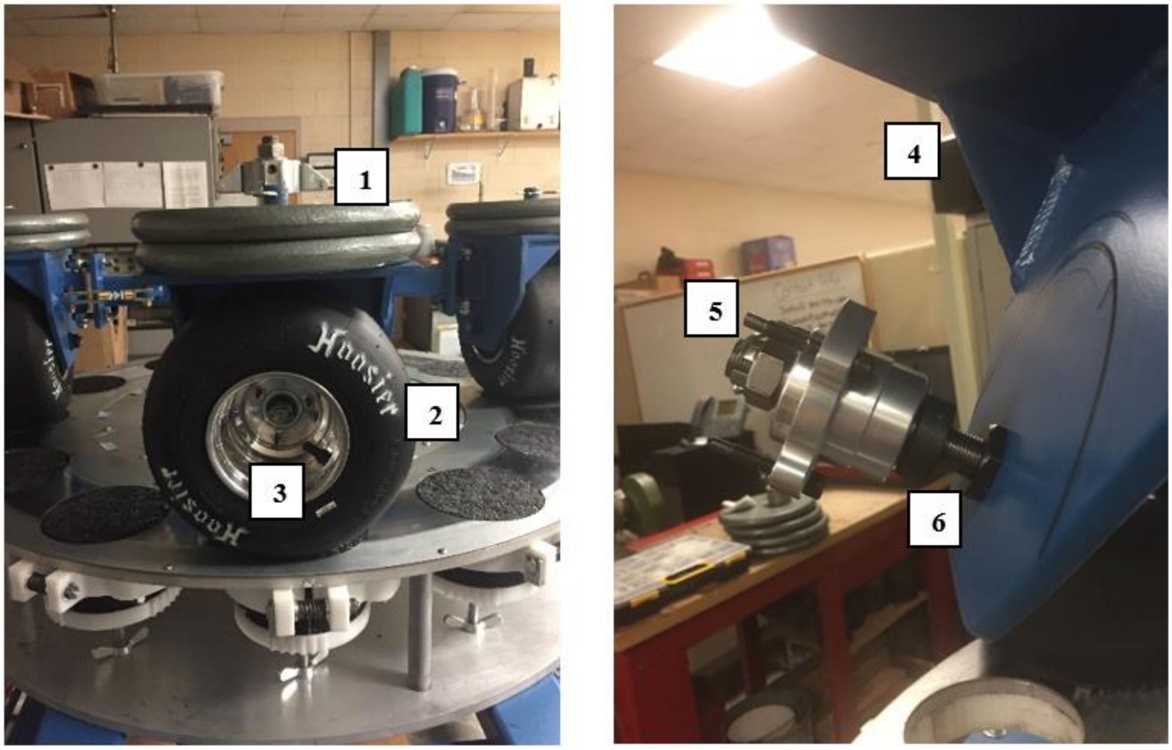


Figure 5*: Equipment Wheel Assembly*

1. Weights for wheel loading (50 pounds total)
2. Tires (size 11x6-5.00 inches)
3. Wheel hub and bolt pattern
4. Wheel fender
5. Castellated nut for wheel bearing preload
6. Wheel axle

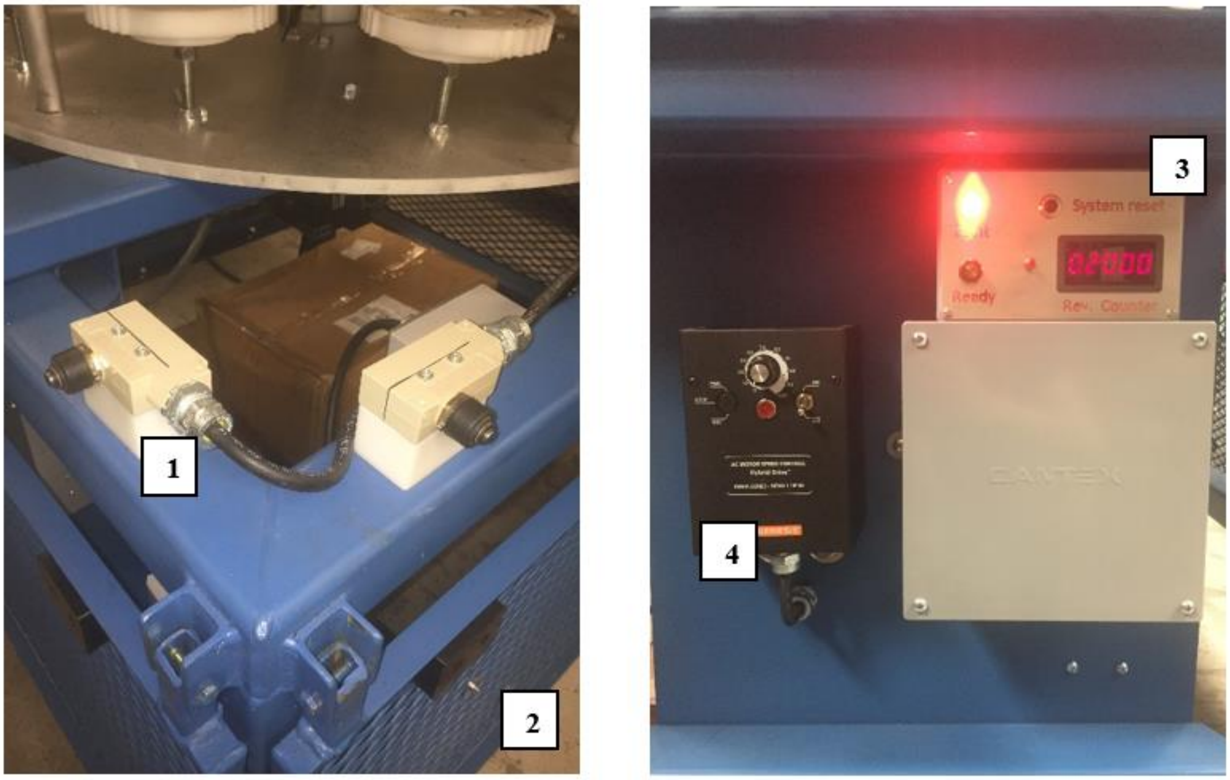


***Figure 6**: Equipment Operating System*

1. Interlock switch mechanism
2. Safety guards
3. Polishing cycle counter
4. Variable frequency drive for 3-phase gear motor control

Sample Preparation

Three primary steps for the sample preparation process included inventory, compaction, and volumetric verifications. Mixtures were first inventoried and randomized to reduce bias. Specimens were compacted to a height of 90mm using a Superpave Gyratory Compactor (SGC) according to AASHTO T-312. Target air void contents of 4% ±0.5 and 8% ±0.5 were verified using the saturated surface dry (SSD) method, AASHTO T-166. Three replicates of two mixtures and two VTMs were prepared, totaling 12 specimens for each polishing session.

Development of Accelerated Polishing Procedure

The polishing procedure was developed through a sequence of trials as summarized in Table 12. Various parameters that could affect the polishing process were evaluated with the different trials. The first trial evaluated the operation of the polisher; no friction data were recorded. The second and third trials used tires that were harder than the original set. Both sets of tires used for trials one through three were provided by the WVDOH. An attempt to purchase another set of the Burris tires found they were no longer produced. Hoosier R80 tires were selected as the replacement based on their properties and availability. These tires were used for trials 4 to 9. ASTM specifies toe angles of 2° and 4° on alternating tires. For trials 3, 4, and 7, the toe angles were increased to 4° and 8° to check if the greater toe angle increases the rate of polishing. Table 13 shows differences between the equipment and procedures described in ASTM E660-90 and this research.

Table 12: Table of Testing Parameters for Trial Experiments

Trial	Number of Maximum Wheel Passes	Mixtures Tested	Test Surface	VTM	Toe-In/Toe-Out*	Tire Type
1	160000	WVDOH (Unknown Mix Type)	N/A	N/A	Low Toe	Burris B44A
2	48000	JFA 12.5mm SR and WVP W1-RAP	Top	4% and 8%	Low Toe	Burris B55A
3	80000	JFA 12.5mm SR and WVP W1-RAP	Bottom	4% and 8%	High Toe	Burris B55A
4	48000	WVP 12.5mm SR and Greer W1H	Top	4% and 8%	High Toe	Hoosier R80
5	64000	WVP 12.5mm SR and Greer W1H	Bottom	4% and 8%	Low Toe	Hoosier R80
6	48000	JFA 12.5mm SR and WVP W1-RAP	Bottom	4% and 8%	Low Toe	Hoosier R80
7	48000	JFA 12.5mm SR and WVP W1-RAP	Top	4% and 8%	High Toe	Hoosier R80
8	48000	JFA 12.5mm SR Lab and Field Cores	N/A	4% and 8%	High Toe	Hoosier R80
9	48000	JFA 12.5mm SR Field Cores	N/A	N/A	High Toe	Hoosier R80

Note:
*Low Toe = 4° toed in and 2° toed out, alternating; High Toe = 8° toed in and 4° toed out, alternating.

Table 13: Differences Between ASTM E660 and WVDOH Polishing Equipment and Procedure

		ASTM E660-90	WVDOH
Equipment	Tires	Pressure = 20psi	Pressure = 30psi
		Nylon smooth no-pattern; 2-ply rating	Hoosier R80
	Wheels	Option for studded wheels	No studded wheels
Procedure	Specimens	Laboratory = 6" diameter, no height specified; field core = 6" diameter, 38mm height (bituminous)	Laboratory = 6" diameter, 90mm height; 6" diameter field core specimens ≈90mm height if possible (bituminous)
		Option for concrete specimens	No concrete specimens
	Abrasive	No abrasive	Silicon Carbide Powder
	Toe Angles	4° toe in 2° toe out only	4° toe in 2° toe out; 8° toe in 4° toe out
	Tire Hardness	No monitoring	Monitored with durometer every 4,000/6,000 revolutions (16,000/24,000 wheel passes)
	Friction Evaluation	NCSU Variable Speed Friction Tester recommended	British Pendulum Tester (BPT)
		Measurements recorded at 0, 7200, 14400, 28000, 43200, and 57,600 wheel passes	Measurements recorded at 0, 8000, 16000, 32000, and 48000 wheel passes
	Sufficient Polishing	57,600 wheel passes (7,200 wheel passes per hour for 8hr)	48,000 wheel passes

Friction Evaluation

The procedures for calibrating and testing surface friction using the BPT were followed as described in ASTM E303-93. Arm length and center of gravity were verified; sliders were conditioned by swinging the arm ten times over dry sand paper. Each sample required five swings of the pendulum, and the first swing was not recorded. Sample surfaces were wetted prior to all swings. Sliders were replaced according to ASTM E303-93 failure criteria. There are supplementary notes significant to laboratory and field procedures in this experiment.

BPT Laboratory Procedure Notes

Supplementary information includes BPT slider preparation, general procedure specifics, and optional documentation performed throughout the experiment. These details include:

- ASTM E303-93 recommended slider spring clip, Figure 7, to reduce rotation of slider during impact by the addition of a spring clip.

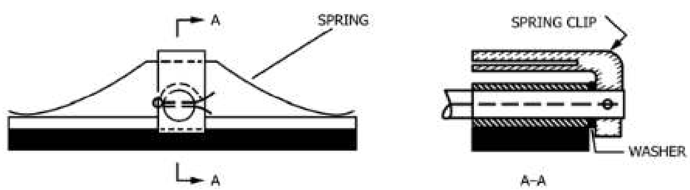


Figure 7: *Recommended Spring Clip Design for BPT Slider Foot (ASTM E303-93)*

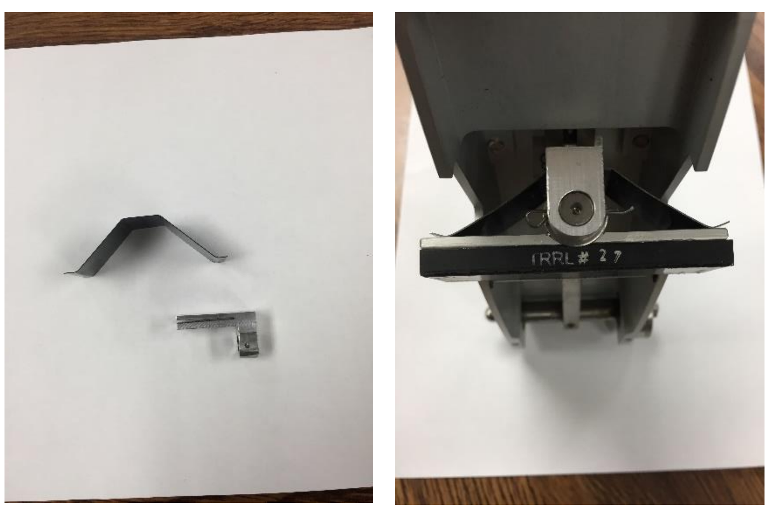
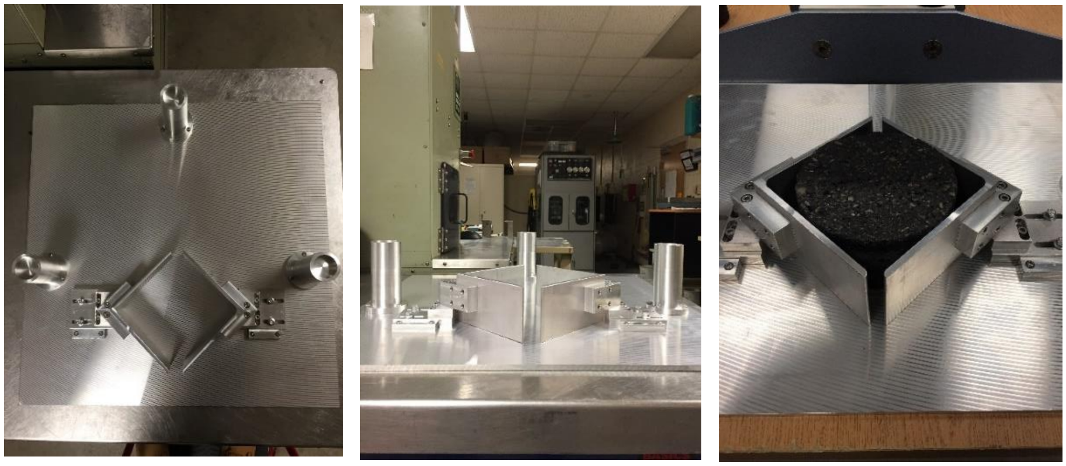


Figure 8: *WVU Fabricated Spring Clip on BPT Slider Foot*

• BPT fixing jig for SGC laboratory prepared specimens, Figure 9.



(a) Top View (b) Front View (c) Jig with sample

***Figure 9**: BPT Fixing Jig*

• BPT slider conditioning apparatus, Figure 10.

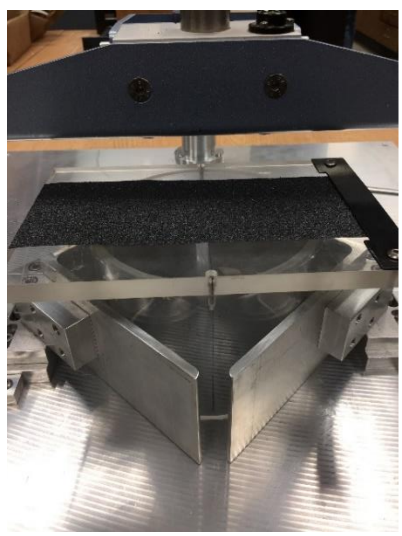


***Figure 10:** Slider Conditioning Apparatus*

- Consistent specimen surface wetting, described in ASTM E303-93. A spray bottle was used to spray a total of 30 sprays for the first swing of the pendulum and 5 sprays for each of the four final swings of the pendulum. Figure 12 displays a specimen following the wetting process. Table 14 provides a quantification of the amount of water used for this process. Approximately 60% of the sprayed water did not cover the specimen surface. This was calculated by subtracting dry paper towel weight from the overspray water weight captured on the towels after wetting a specimen. This is represented in Table 13 as the actual volume of water on the surface.

Figure 11*: Wetted Specimen Surface for BPT Measurements*

Table 14: Amount of Water Used for Specimen Surface Wetting

Number of Sprays	Weight of Water (g)	Volume of Water (mL)	Actual Volume of Water on Surface (mL)
5	4.22	4.22	1.68
30	25.24	25.24	10.04

- Slider failure occurred at approximately 1,200 BPT swings.

- Randomize specimen measurement order to reduce slider wear bias.

BPT Field Procedure Notes

Although not a large portion of the experimental procedure, BPT measurements were also completed in a field environment for laboratory and field comparisons. There is little information in the specification regarding field testing. As such, procedural steps were assumed to parallel laboratory techniques accompanied by additional equipment leveling protocol. Supplementary notes describing the field procedure used in this experiment include:

- Field measurement locations were the fast lane of I-79 in Flatwoods, WV. Additional location details are provided in the Appendix A.

- The BPT was leveled according to each of the five location geometries, Figure 12. Testing locations were chosen based on the corresponding field cored specimens tested in the laboratory. Cored specimens were either extracted from the left or right wheel path. Measurements were recorded in either wheel path (dependent on the core location) and in the center of the lane. Measurements were also recorded in both the uphill and downhill directions due to varying roadway elevations.

Figure 12*: BPT in Field Application*

- Surfaces were wetted with the same technique used in the laboratory. However, it should be noted that precipitation began in the middle of the testing period, which could have influenced measurements. Figure 13 depicts the wetted surface in the field.

***Figure 13**: Wetted BPT Surface in Field*

British Pendulum Number Analysis

Average BPN values were calculated for each specimen using the four recorded measurements after each polishing session. These values were plotted versus the number of wheel passes. Average measurements calculated for each set of replicates was averaged a second time to compute a mixture average. There were three replicates for each mixture. Mixture averages were also plotted and used to create trend lines for data fitting. Specimens were polished until plotted measurements displayed the appearance of a plateau. BPN measurements showed asymptotic behavior varying between 48,000 and 80,000 wheel passes.

Various fitting methods were considered including polynomial, logarithmic, and power functions. Power functions were ultimately chosen due to high R^2 values and visual observation. This was completed for all mixtures and trials throughout the experiment. The slope was calculated for each trend line by inputting the final number of wheel passes ± 100 to determine a asymptotic behavior. For example, 47,900 and 48,100 wheel passes were used for trials with a maximum of 48,000 wheel passes. Plots were then replicated and altered to represent the independent and dependent variables as BPN and the number of wheel passes, respectively. This allowed for the prediction of the number of wheel passes (N_p) required to achieve two BPN limits: BPN=35 (Kowalski et al., 2013) and BPN=47 (Lu and Steven, 2006). For trials where the number of wheel passes exceeded 48,000, slope and BPN calculations were computed at 48,000 wheel passes and the ending number of wheel passes.

Statistical Analysis

BPN measurements were analyzed statistically to determine the significance of variables in the polishing procedure. Data were organized according to various factors and levels. Factors include tire types, tire toe angles, VTM, nominal maximum aggregate size (NMAS), contractor, and environment (lab/field). Factors were broken down into several levels, displayed in Table 15. Table 16 shows the factors and levels and the samples. Various statistical analysis methods were considered for this experiment including t-tests, ANOVA, and regression. These methods were reviewed and discussed in a meeting with a qualified statistician (Pyrialakou, 2020). Based on the layout of the data and the advice from a statistical expert, t-tests were chosen for analyzing BPN data. All t-tests were for two-tail, assumed equal variances, null hypothesis of equal means, and alpha of 0.05.

Table 15: Experimental Factors and Levels

	Factors					
	Tires	**Toe Angles**	**VTM**	**NMAS**	**Contractor**	**Environment**
Levels	Burris B55A	Low	4%	9.5mm	JFA	Laboratory
	Hoosier R80	High	8%	12.5mm	WVP	Field Core
					Greer	Field Measurements

The significance of toe angles was determined first by comparing measurements collected from low and high toe angles with Burris B55A tires. This was followed by analyses for all factors using only data collected with Hoosier R80 tires. Additional testing was performed for laboratory and field specimens obtained from J. F. Allen by comparing initial BPN measurements to determine potential differences in friction behaviors. The same samples were compared using BPN data collected after polishing for 48,000 wheel passes. Final t-tests were performed comparing initial BPN measurements of field core specimens to measurements completed in their corresponding locations on Interstate 79 (I-79). All location details and raw data are located in Appendices A and D, respectively.

Table 16: Testing Parameter Breakdown and Potential Sample Comparisons

Experimental Factors						
Toe	VTM	NMAS	Surface	Contractor	Burris B55A Tires	Hoosier R80 Tires
					Specimens	
Low	4%	9.5	Top	JFA		
				WVP	7T, 8T, 9T	
				Greer		
			Bottom	JFA		
				WVP		31B, 32B, 33B
				Greer		16B, 17B, 18B
		12.5	Top	JFA	4T, 5T, 6T	
				WVP		
				Greer		
			Bottom	JFA		25B, 26B, 27B
				WVP		19B, 20B, 21B
				Greer		
	8%	9.5	Top	JFA		
				WVP	10T, 11T, 12T	
				Greer		
			Bottom	JFA		
				WVP		34B, 35B, 36B
				Greer		13B, 14B, 15B
		12.5	Top	JFA	1T, 2T, 3T	
				WVP		
				Greer		
			Bottom	JFA		28B, 29B, 30B
				WVP		22B, 23B, 24B
				Greer		
High	4%	9.5	Top	JFA		
				WVP		31T, 32T, 33T
				Greer		16T, 17T, 18T
			Bottom	JFA		
				WVP	7B, 8B, 9B	
				Greer		
		12.5	Top	JFA		25T, 26T, 27T
				WVP		19T, 20T, 21T
				Greer		
			Bottom	JFA	4B, 5B, 6B	
				WVP		
				Greer		
	8%	9.5	Top	JFA		
				WVP		34T, 35T, 36T
				Greer		13T, 14T, 15T
			Bottom	JFA		
				WVP	10B, 11B, 12B	
				Greer		
		12.5	Top	JFA		28T, 29T, 30T
				WVP		22T, 23T, 24T
				Greer		
			Bottom	JFA	1B, 2B, 3B	
				WVP		
				Greer		

Chapter 4: Results and Discussion

Mixture and procedure evaluations were completed through BPN trend fitting and statistical methods. Discussed first are friction trend behaviors, followed by a statistical analysis of collected BPN data. All raw data are in Appendix D. Figures and data used for analyses are in Appendices E and F.

BPN Analysis

Trend behaviors were analyzed for specimens tested in trials 2 through 9. Figure 14 displays average BPN data for the JFA 12.5mm SR specimens at 8% VTM, polished with Burris B55A tires. A power function trend line equation and corresponding R^2 value is provided for the average of the three replicates.

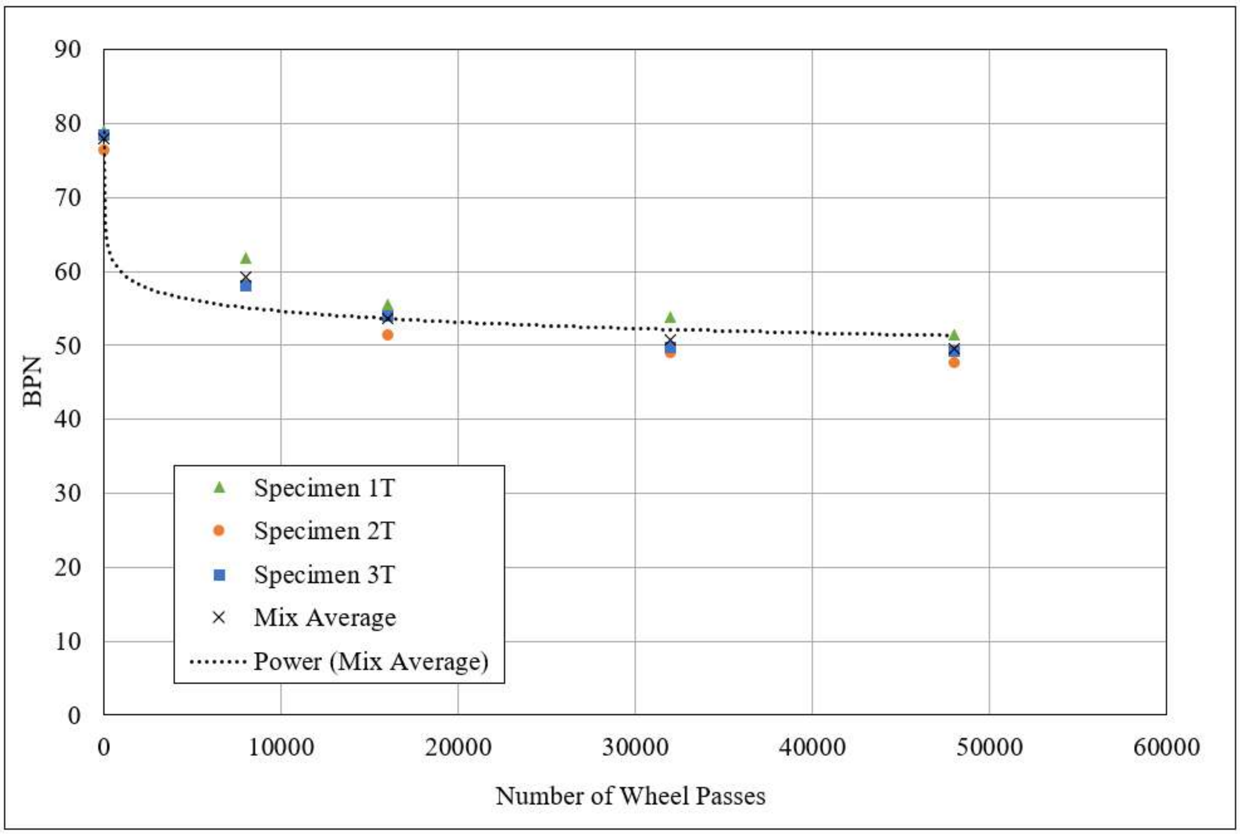


***Figure 14**: Average BPN Measurements for Trial 2 JFA 12.5mm SR (Top Surfaces) 8% VTM Specimens After 48,000 Wheel Passes at Low Toe Angles and Burris B55A Tires*

The behavior on Figure 14 is similar to those reported by Vollor and Hanson (2006) and Kowalski et al. (2010) when polishing with the NCAT TWPD. There are minimal changes in slope after approximately 16,000 wheel passes. The slope of the trend line is 4.27E-05, which is close to a slope of zero and appears to visually fit the data. This indicates minimal change in BPN measurements after 48,000 wheel passes, which could provide insight for determining the number of wheel passes required for sufficient laboratory polishing. Slope values and trend line coefficients are summarized in Table 17.

Table 17: Trend line Coefficients, R2 Values, and Calculated Slopes for General Data and Predicted Number of Wheel Passes at BPN Limits of 35 and 47

Trial	Toe Angles	Tire	Total Wheel Passes	Test Surface	Tested Mixture	Analyzed Wheel Passes	Power Coefficients $y = ax^b$***		R^2	Average Mix Slope	Power Coefficients $y = ax^b$****		R^2	Predicted Number of Required Wheel Passes (N_p)	
							a	b			a	b		BPN = 35	BPN = 47
2	Low	B55A*	48000	Top	JFA 12.5mm SR at 8% VTM	48k	78.883	-0.040	0.9449	4.27E-05	1.50E+45	-23.71	0.9449	2.46E+08	2.26E+05
					JFA 12.5mm SR at 4% VTM	48k	81.228	-0.047	0.983	4.79E-05	3.93E+39	-20.70	0.983	4.36E+07	9.76E+04
					WVP W1-RAP at 8% VTM	48k	84.459	-0.042	0.9679	4.70E-05	7.86E+44	-23.24	0.9679	1.04E+09	1.11E+06
					WVP W1-RAP at 4% VTM	48k	83.334	-0.043	0.9609	4.70E-05	3.49E+43	-22.6	0.9609	3.81E+08	4.87E+05
3	High	B55A*	80000	Bottom	JFA 12.5mm SR at 8% VTM	48k	70.591	-0.035	0.9835	3.53E-05	4.54E+52	-28.45	0.9835	5.89E+08	1.34E+05
						80k	70.102	-0.032	0.9374	3.31E-05	5.06E+53	-28.97	0.9374	9.28E+08	1.81E+05
					JFA 12.5mm SR at 4% VTM	48k	71.27	-0.037	0.9812	3.69E-05	6.98E+49	-26.87	0.9812	2.27E+08	8.24E+04
						80k	70.714	-0.034	0.9257	3.47E-05	3.80E+50	-27.19	0.9257	4.16E+08	1.37E+05
					WVP W1-RAP at 8% VTM	48k	75.967	-0.037	0.9709	3.93E-05	3.16E+49	-26.27	0.9709	8.21E+08	3.56E+05
						80k	75.954	-0.037	0.9721	3.93E-05	3.52E+49	-26.29	0.9721	1.02E+09	4.39E+05
					WVP W1-RAP at 4% VTM	48k	72.284	-0.04	0.9659	4.24E-05	1.52E+46	-24.3	0.9659	6.03E+08	4.67E+05
						80k	78.232	-0.039	0.9705	4.17E-05	4.50E+46	-24.58	0.9705	5.57E+08	3.97E+05
4	High	Hoosier**	48000	Top	WVP 12.5mm SR at 8% VTM	48k	86.716	-0.053	0.9694	5.41E-05	4.53E+35	-18.34	0.9694	2.40E+07	1.08E+05
					WVP 12.5mm SR at 4% VTM	48k	84.523	-0.053	0.9817	5.27E-05	9.57E+35	-18.64	0.9817	1.65E+07	6.79E+04
					Greer W1H at 8% VTM	48k	86.629	-0.054	0.9769	5.19E-05	4.56E+34	-18.04	0.9769	6.98E+06	3.42E+04
					Greer W1H at 4% VTM	48k	84.792	-0.058	0.9643	5.48E-05	2.19E+32	-16.71	0.9643	3.16E+06	2.29E+04

Notes:

* Burris *** $BPN=a(N_p)^b$

** Hoosier **** $N_p=a(BPN)^b$

Trial	Toe Angles	Tire	Total Wheel Passes	Test Surface	Tested Mixture	Analyzed Wheel Passes	Power Coefficients $y = ax^b$***		R^2	Average Mix Slope	Power Coefficients $y = ax^b$****		R^2	Predicted Number of Required Wheel Passes (N_p)	
							a	b			a	b		BPN = 35	BPN = 47
5	Low	Hoosier**	64000	Bottom	WVP 12.5mm SR at 8% VTM	48k	78.666	-0.047	0.9432	4.64E-05	1.98E+38	-20.10	0.9432	1.84E+07	4.92E+04
						64k	79.406	-0.05	0.9137	4.83E-05	6.17E+34	-18.14	0.9137	5.87E+06	2.79E+04
					WVP 12.5mm SR at 4% VTM	48k	78.353	-0.044	0.9502	4.47E-05	9.12E+40	-21.53	0.9502	5.13E+07	8.99E+04
						64k	79.26	-0.048	0.8957	4.72E-05	3.76E+35	-18.53	0.8957	9.78E+06	4.15E+04
					Greer W1H at 8% VTM	48k	76.496	-0.046	0.9531	4.46E-05	6.23E+38	-20.48	0.9531	1.43E+07	3.42E+04
						64k	77.342	-0.05	0.8931	4.70E-05	2.15E+34	-17.97	0.8931	3.58E+06	1.79E+04
					Greer W1H at 4% VTM	48k	77.02	-0.047	0.9393	4.54E-05	1.41E+38	-20.11	0.9393	8.89E+06	2.37E+04
						64k	78.119	-0.052	0.8707	4.83E-05	1.72E+32	-16.78	0.8707	2.46E+06	1.75E+04
6	Low	Hoosier**	48000	Bottom	JFA 12.5mm SR at 8% VTM	48k	76.732	-0.038	0.974	4.03E-05	1.62E+48	-25.53	0.974	7.60E+08	4.10E+05
					JFA 12.5mm SR at 4% VTM	48k	77.795	-0.042	0.9662	4.33E-05	3.15E+43	-22.94	0.9662	1.14E+08	1.32E+05
					WVP W1-RAP at 8% VTM	48k	85.405	-0.044	0.9452	4.87E-05	4.97E+41	-21.49	0.9452	3.29E+08	5.83E+05
					WVP W1-RAP at 4% VTM	48k	86.397	-0.046	0.9501	5.04E-05	1.04E+40	-20.57	0.9501	1.73E+08	4.03E+05
7	High	Hoosier**	48000	Top	JFA 12.5mm SR at 8% VTM	48k	76.37	-0.054	0.9218	4.80E-05	2.55E+32	-17.07	0.9218	1.32E+06	8.60E+03
					JFA 12.5mm SR at 4% VTM	48k	75.42	-0.053	0.9117	4.70E-05	5.29E+32	-17.27	0.9117	1.08E+06	6.64E+03
					WVP W1-RAP at 8% VTM	48k	83.173	-0.059	0.9025	5.41E-05	5.97E+29	-15.33	0.9025	1.28E+06	1.40E+04
					WVP W1-RAP at 4% VTM	48k	80.715	-0.055	0.8709	5.11E-05	2.47E+30	-15.7	0.8709	1.15E+06	1.12E+04
8	High	Hoosier**	48000	N/A	JFA 12.5mm SR Lab Compacted	48k	59.736	-0.03	0.9742	2.70E-05	1.15E+58	-32.64	0.9742	4.00E+07	2.65E+03
					JFA 12.5mm SR Field Core	48k	62.892	-0.035	0.9943	3.14E-05	1.96E+51	-28.51	0.9943	1.90E+07	4.26E+03
9	High	Hoosier**	48000	N/A	JFA 12.5mm SR Field Core	48k	52.53	-0.017	0.6879	1.55E-05	7.12E+71	-41.18	0.6879	1.82E+08	9.73E+02

Notes:

* Burris *** $BPN=a(N_p)^b$

** Hoosier **** $N_p=a(BPN)^b$

Figure 14 shows the conventional way to show polishing data. The trend line equation from this figure can be used to predict the BPN for certain number of wheel applications. For evaluating a mix for skid resistance suitability, a relationship for using BPN limit criteria to compute the number of applications is needed. This relationship is shown on Figure 15.

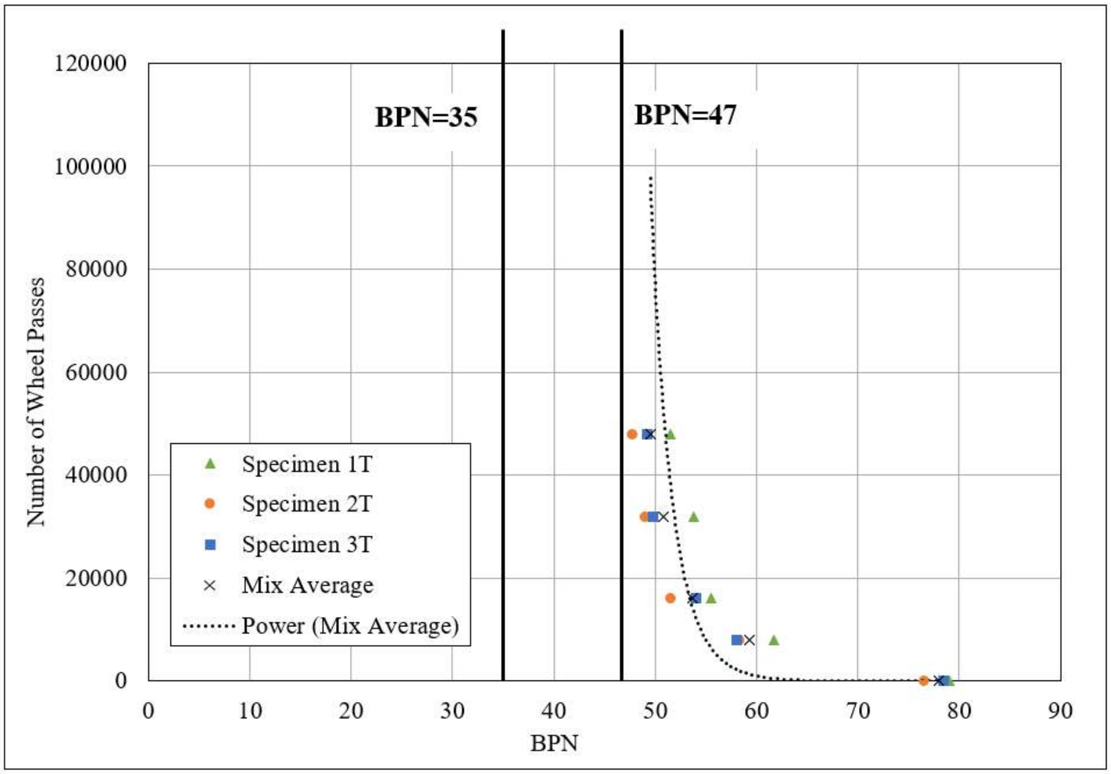


***Figure 15**: Number of Wheel Passes vs. Average BPN Measurements for Trial 2 JFA 12.5mm SR (Top Surfaces) at 8% VTM Specimens at Low Toe Angles and Burris B55A Tire*

For JFA 12.5mm SR specimens 1T through 3T, the number of wheel passes required to reach BPN values of 35 and 47 were calculated to be 2.46E08 and 226,235 passes, respectively. While 2.46E08 passes is significantly larger than those reported in literature, this value was extrapolated from the data, rather than interpolated. Extrapolation can produce inaccurate results in some applications. Additionally, a BPN of 35 was reported by Kowalski et al. (2010) as the BPN limit for roadways intended for 30 mph speeds, which may not be applicable for a majority of roadways. Evaluating at a BPN of 47 produced a more reasonable result, which is more consistent to values reported by Vollor and Hanson (2006) and Kowalski et al. (2010). Therefore, further discussions of results are in reference to those calculated for a BPN limit of 47. Figure 16 shows the predicted number of wheel passes for all mixtures to reach a BPN of 47.

Figure 17 shows the predicted number of wheel passes at BPN=47 for JFA 12.5mm Skid-RAP lab and field core specimens.

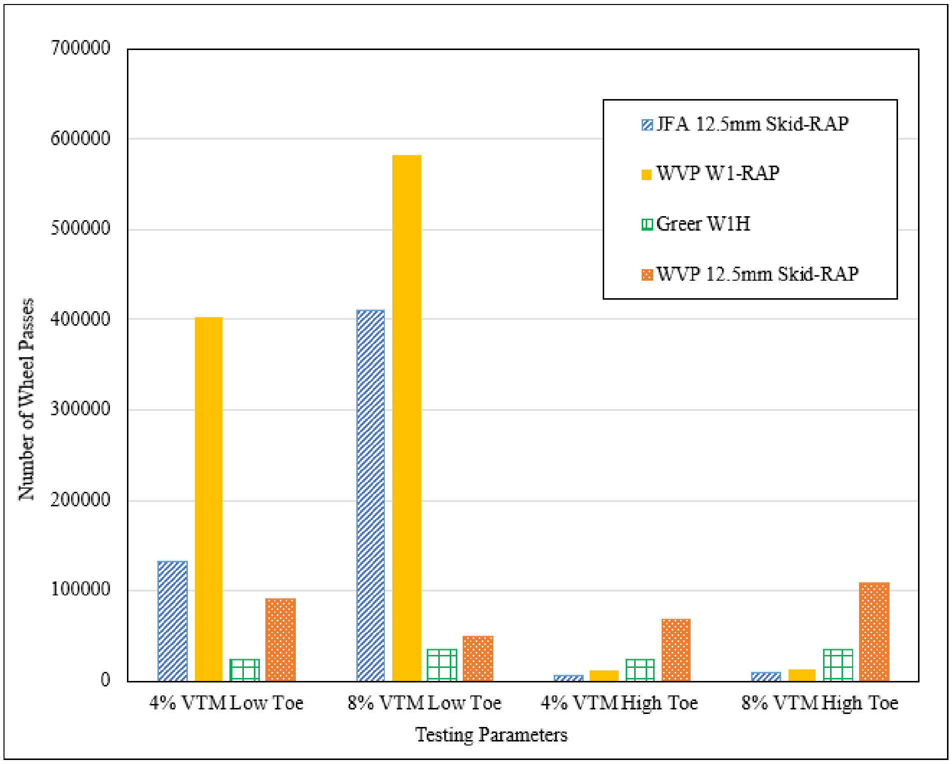


Figure 16*: Predicted Number of Wheel Passes to Achieve BPN of 47 for All Mixtures*

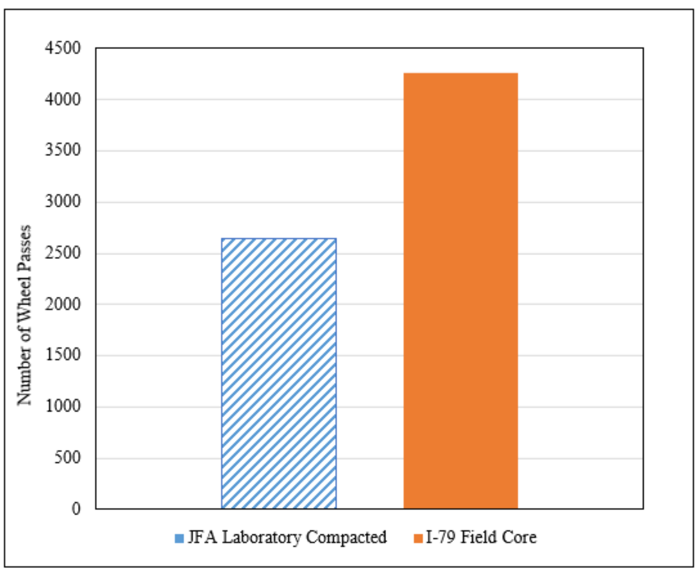


Figure 17*: Predicted Number of Wheel Passes at BPN of 47 for JFA 12.5mm Skid-RAP Laboratory and Field Core Specimens*

The projected number of wheel passes at various friction limits can also be used to evaluate asphalt mixtures in the experiment. An increased number of wheel passes represents a more polish resistant mixture, which could provide insight for asphalt mixture design. From Table 17 and Figure 16, it can be seen that the WVP W1-RAP mixture at 8% VTM in trial 2 resulted in the largest projected number of wheel passes (1.11E06 wheel passes). The five samples with the greatest number of wheel passes were the WVP W1-RAP mixture, suggesting the WVP W1-RAP mixture is more polish resistant than other tested mixtures. Additionally, the majority of mixtures with the largest calculated number of wheel passes were prepared at 8% VTM. This result could indicate that the increased surface texture allows for excess water storage, producing higher friction measurements.

The lowest calculated number of wheel passes resulted from trial 9 JFA 12.5mm SR field core specimens (973 passes). This is significantly lower than the number of passes calculated for WVP W1-RAP specimens, which resulted in the highest calculated values. Lower values could be an indication of differences in compaction for field and laboratory samples. However, additional testing is required to determine a cause. JFA 12.5mm SR specimens represent five of the lowest resulting number of wheel passes, which could suggest that this mixture is the least polish resistant of those tested in this experiment. Figure 16 also shows a generally lower number of wheel passes for trials using high toe angles with Hoosier R80 tires, revealing a potential increase in polishing by implementing higher toe angles.

For trials 3 and 5, wheel pass predictions were also performed using data up to the maximum number of wheel passes (80,000 and 64,000). The majority of these predictions were higher than values computed using data for 48,000 wheel passes. This could indicate that additional data are useful when predicting the number of wheel passes required to achieve BPN limits. Additional testing is needed to determine the value of increased polishing.

When looking at fitted trend equations, some trials have R^2 values less than 0.9. Low R^2 values could indicate that a more complex function is required to properly fit asphalt friction behavior. This is observed visually on Figures 54, 58, 73-76, 81, and 82 in Appendix E. Inadequate fitting functions could have caused unexpected polishing predictions. Predictions of 80,000 passes are not reasonable based on literature (Vollor and Hanson, 2006 and Kowalski et al., 2010) and laboratory observations. Predictions greater than or equal to approximately

400,000 passes is more consistent with values mentioned in literature. Further research is required to develop a more complete conclusion. The BPN figures are in Appendix E.

Statistical Analysis

Table 18 provides a summary of t-test results including the mean, variance, degrees of freedom, and p-values for the tested factors. All raw data and outputs used for the analysis are included in Appendix F. Figure 18 shows comparisons of all parameters and standard errors in the t-test analysis. Toe angles were evaluated for Burris B55A tires using measurements collected from JFA 12.5mm SR and WVP W1-RAP mixtures. The resulting p-value when comparing BPN measurements from low and high toe angles for Burris B55A tires is 0.09645. This results in a failure to reject the null hypothesis of equal means, indicating measurements are statistically similar. Because the influence of toe angles for Burris B55A data was insignificant, toe angles remained in the analysis when analyzing data using Hoosier R80 tires. Remaining analyses were performed only on data using Hoosier R80 tires.

Table 18: Summary of T-test Results

Tire Data Used	Analyzed Factor	Compared Variables	Mean	Variance	df	P-Value	Decision
Burris B55A	Toe Angles	Low Toe	50.0	7.05	22	0.09645	F*
		High Toe	48.5	1.90			
Hoosier R80	VTM	4% VTM	44.7	11.0	46	0.8561	F
		8% VTM	44.9	11.6			
Hoosier R80	Toe Angles	Low Toe	46.7	8.7	46	3.34E-05	R**
		High Toe	43.0	6.8			
Hoosier R80	Contractor	JFA	44.6	17.7	22	0.3337	F
		WVP	45.9	2.1			
		Greer	43.4	0.5	22	0.1593	F
		WVP	45.4	23.1			
Hoosier R80	NMAS	9.5mm	44.4	12.4	46	0.3741	F
		12.5mm	45.3	9.9			
Hoosier R80	Sample Type	Initial Laboratory	59.4	20.8	10	0.4035	F
		Initial Field Core	62.8	66.8			
		Polished Laboratory	42.3	0.8	10	0.1116	F
		Polished Field Core	43.0	0.4			
Hoosier R80	Measurement Type	Field Core	51.9	17.3	8	0.0003	R
		Field Measurement	74.3	53.0			

Notes:

* F = Fail to reject null

** R = Reject null

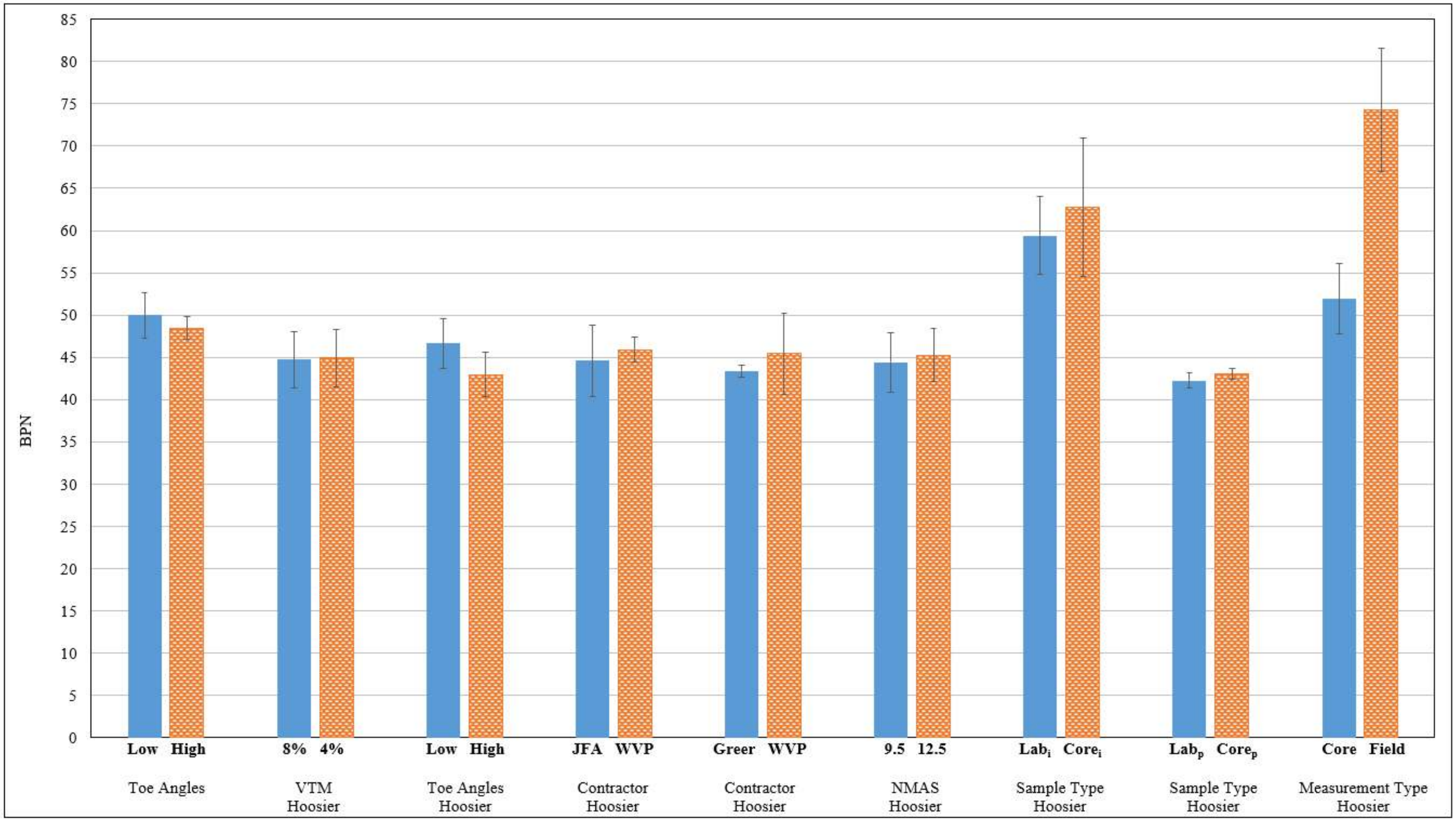


Figure 18: Average BPN Comparison for Tested Parameters

VTM comparisons for data collected using mixtures with only Hoosier R80 tires report similar results. A p-value of 0.8561 indicates a failure to reject the null hypothesis of equal means, or no significant difference between BPN measurements for all mixtures. However, it can be seen from Table 18 that variances for 4% and 8% VTM were 11.0 and 11.6, respectively. High variances may be explained by the lack of direct factor comparisons isolating VTM.

When comparing low and high toe angles for measurements using Hoosier R80 tires, the resulting p-value is 3.342E-05. This results in a rejection of the null hypothesis of equal means, which suggests statistical difference between BPN measurements. This contradicts the previous toe angle analysis using Burris B55A tires. While resulting variances are high, increased toe angles reported a lower variance of 6.81 when compared to the lower toe angle variance of 8.71. This could suggest that higher toe angles produce more consistent polishing and should be used for future testing. When analyzing mean values, the mean BPN value of 42.9 for higher toe angles is several points lower than the mean value of 46.7 reported for lower toe angles. This suggests that there is an increase in the polishing for specimens exposed to higher toe angles, which decreases the testing time required in the laboratory.

Insignificant results were reported when comparing data collected from JFA and WVP 12.5mm SR mixtures to determine the influence of contractor on measured BPN values. The resulting p-value is 0.3337, failing to reject the null hypothesis of equal means. However, it is important to note that specimens compacted with the JFA mixture resulted in a variance of 17.7 when compared to WVP specimens with a variance of 2.1. Large variances could be explained by the use of data from both toe angles in the analysis, which reported significant differences between BPN measurements previously using data from Hoosier R80 tires.

Similar results are reported when comparing Greer and WVP contractors for the 9.5mm mixtures. A p-value of 0.1593 suggests no significant difference and a failure to reject the null hypothesis of equal means. For this analysis, specimens compacted using the Greer mixture reported a low variance of 0.5, while data from WVP mixtures resulted in a high variance of 23.1. Low variances using the Greer mixtures suggests that this is a relatively consistent mixture in terms of measured friction values. Data collected from both toe angles were included in the analysis, which could contribute to higher resulting variances.

Analysis performed investigating the influence of NMAS on measured friction values reported insignificant results. When comparing all 9.5mm and 12.5mm mixtures, the resulting p-value is 0.3741, suggesting no significant difference between mean BPN measurements and a failure to reject the null hypothesis. Higher variance is reported for data collected from 9.5mm specimens when compared to the variance reported from 12.5mm specimens, which were 12.4 and 9.9, respectively. However, there are difficulties in determining a cause for high variances and distinct conclusion in terms of significance due to the lack in direct factor comparisons present in the analysis. Additional testing is required to determine more concise results.

Final t-tests were completed for JFA 12.5mm SR field and laboratory data. Data was first compared using initial BPN measurements collected from matching laboratory and field core specimens. Comparing initial BPN measurements resulted in a p-value of 0.4305, indicating a failure to reject the null hypothesis of equal means. This suggests that there is no significance between the laboratory and field samples. However, it should be noted that reported variances are 20.8 and 66.8 for laboratory and field core specimens, respectively. These values are extremely large and could potentially be due to differences in compaction. After polishing for 48,000 wheel passes, the collected measurements were analyzed again, producing a p-value of 0.1116. This also suggests that there is no significant difference between the paired laboratory and field specimens. Reported variances were also less than one, suggesting consistency between measurements.

Measurements were also collected from extracted field core specimens and matching field locations on I-79 in Flatwoods, WV. Table 19 displays differences between average initial field core measurements and corresponding field measurements. For this comparison, the resulting p-value is 0.0003. Because the p-value is less than 0.05, the null hypothesis of equal means is rejected, suggesting a statistical difference between BPN measurements. Variances are also high for field core and field measurements with values of 17.3 and 53.0, respectively. These differences are evident in Table 19 when comparing laboratory and field measurements. Large differences could be explained by varying compaction procedures and difficulties setting up equipment in the field. However, additional testing is required to further analyze potential differences between laboratory and field friction measurements due to inadequate sample sizes.

Table 19: Differences in BPN Measurements for Corresponding I-79 JFA 12.5mm SR Field Core and Field Measurements

Specimen	Average Lab Initial BPN	Average Field BPN	Difference
D1	59.0	74.5	15.5
D2	48.0	69.9	21.9
D3	50.5	67.4	16.9
D4	50.8	73.5	22.8
D5	51.3	86.3	35.1

Chapter 5: Conclusions and Recommendations

Significance of Work

Prior to this thesis experiment, the WVDOH did not employ an accelerated laboratory polishing machine in asphalt pavement evaluation practices. This thesis provides descriptions of best practices in polishing procedures and laboratory friction measuring techniques for continued use within the agency. Data collected from this experiment contributes to information regarding asphalt pavement performance. Findings from this research also provide insight into factors influencing pavement polishing resistance. Results from this experiment and those completed in the future will assist the WVDOH in providing increased safety for the public.

Conclusions

BPN Analysis

The majority of friction behaviors for laboratory compacted specimens was consistent throughout the experiment. BPN measurements decreased as polishing increased. Friction values displayed asymptotic behavior for most specimens and testing periods. Fitting this behavior with power functions allowed for predictions of the number of wheel passes required to achieve BPN limits of 35 and 47. Mixtures with the greatest number of calculated wheel passes at given BPN limits were deemed more polish resistant. For calculations at BPN=47, W1-RAP at 8% VTM had the highest prediction (1.11E06 wheel passes). The WVP W1-RAP mixture made up the majority of predictions with the largest number of wheel passes, suggesting that this is the most polish resistant mixture. The JFA 12.5mm SR field core data in trial 9 displayed the least polish resistant behavior. Five of the lowest computed wheel passes resulted from the JFA 12.5mm SR mixture.

Most JFA 12.5mm SR field core specimens reported increased friction values compared to laboratory samples. These measurements could be due to differences in field compaction. However, limited specimens were available for performing comparisons. Additional comparisons completed on field core and field measurement pairs produced mixed results. When compared to field measurements performed in the same locations, large differences in values were computed. This could be due to variability in BPT procedures in the field.

Statistical Analysis

Statistical analysis procedures were performed on average BPN data to determine the influence of different variables on specimen polishing resistance. A t-test comparing low and high toe angles using Burris B55A tires resulted in a p-value of 0.09645, which suggests that there is no significant difference between mean BPN measurements. However, this tire type is no longer available. Analysis completed for all data using Hoosier R80 tires suggests that toe angles are a significant influence on friction behavior. This was the only factor suggesting significant difference for data using Hoosier R80 tires. T-test outputs indicate the mean friction value reported after polishing with high toe angles is lower than the mean for data at lower toe angles. This suggests increased polishing when using higher toe angles, which could decrease the time needed for testing. Comparisons between VTM, contractor, and NMAS did not result in any statistically significant results. Resulting p-values were 0.8561, 0.3337, 0.1593, and 0.3741, respectively. P-values result in a failure to reject the null hypothesis, suggesting no significant influence from differences in VTM, contractor, or NMAS.

When comparing initial BPN measurements for JFA 12.5mm SR field core and laboratory compacted specimens, a p-value of 0.4305 was reported, suggesting no significant difference. A similar result is reported when comparing the same specimens after polishing for 48,000 wheel passes. This comparison resulted in a p-value of 0.1116, which again results in a failure to reject the null hypothesis of equal means. Comparisons between JFA 12.5mm SR field core specimens and corresponding field locations on I-79 suggest there is a statistical difference between friction values. This result is consistent with the differences calculated in Table 18. Differences in measurements could be a result of difficulties leveling the equipment and compaction variabilities in the field.

It is important to note that sample sizes were limited for a reliable statistical analysis, specifically for field data. Inadequate sample sizes could introduce bias in the results. There were limited comparisons available for the majority of t-tests, which could have skewed the results. A limited sample size is also the cause of higher reported variances, which minimizes the reliability of the results. Because of these implications, a majority of the results could be considered inconclusive. Further testing is needed to address sample size and variance issues and provide better observations.

Recommendations

In terms of equipment, Hoosier R80 tires are recommended for future testing because they appear to provide adequate sample surface polishing and maintain their integrity for extended testing durations. Following the completion of statistical analysis, VTM had no significant influence on BPN measurements. Because of this, it is recommended that specimens are compacted at a VTM most similar to those achieved in field applications (approximately 7%. Additionally, mean friction values reported for higher toe angles were significantly lower than lower toe angles. Higher toe angles are recommended to accelerate the polishing process. Similarly, less frequent friction measurements are suggested to further decrease testing durations. For this experiment, 48,000 wheel passes in the polishing machine was deemed sufficient to reach a stopping point for measurements. Additional testing could also be performed to determine the significance of abrasive on the polishing process. The procedure for applying the silicon carbide abrasive remained constant; specimens were not tested without the use of abrasive. Further analysis is recommended to determine the influence of abrasive.

Testing is also needed to determine the influence of sample testing surface (top and bottom) on average friction measurements. This could provide insight for investing potential influences of laboratory compaction on friction measurements. Additionally, mixtures were limited to three contractors and two aggregate sizes. NMAS values of 9.5mm and 12.5mm mixtures were specific to Marshall and Superpave designs, respectively. Skid and non-skid mixtures were also specific to Marshall and Superpave designs. Alternate mixture designs for these sizes and 4.75mm mixtures are recommended for future testing. Mixtures with varying skid and non-skid designations should also be tested to increase data collection and provide further insight on the polishing behavior of various mixtures.

This experiment also lacked data comparing field and laboratory measurements. The sample size for comparisons was limited to six laboratory-compacted and field extracted specimen pairs and five field core specimens and field measurement pairs. This is an inadequate sample size for proper statistical analysis. Further investigation of field and laboratory friction behaviors is recommended. Upgrading the testing equipment could also provide more insight for developing laboratory and field relationships. Skid resistance becomes a more sensitive issue as vehicles travel at higher speeds. The BPT measures friction a low speeds, which could explain t-test results reporting no significant differences for various factors in the analysis. The DFT is a state-of-the-art friction measuring apparatus that allows for testing at higher speeds (Hall et al., 2009). Upgrading to this equipment would allow for more meaningful comparisons between laboratory and field friction behaviors in the future.

References

Asi, I. M. 2005. “Evaluating skid resistance of different asphalt concrete mixes.” Building and Environment. Vol. 42(1), pp. 325-329. https://doi.org/10.1016/j.buildenv.2005.08.020 (accessed July 27, 2019).

ASTM International. Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire. ASTM E274/E274M-15. West Conshohocken, PA: ASTM International, 2015.

Corley-Lay, J.B. 1998. “Friction and Surface Texture Characterization of 14 Pavement Test Sections in Greenville, North Carolina.” Journal of the Transportation Research Board, Vol. 1639(1), pp. 155-161. https://doi.org/10.3141%2F1639-17 (accessed May 19).

Do, M. T., and M. Kane, and V. Cerezo. 2013. “Laboratory test methods for polishing asphalt surfaces and predicting their skid resistance.” Presented at Transportation Research Board 92nd Annual Meeting. France. https://hal.archives-ouvertes.fr/hal-00851150 (accessed May 26, 2019).

Do, M. T., and Z. Tang, and Malal Kane, and Francois de Larrard. 2007. “Pavement polishing – Development of a dedicated laboratory test and its correlation with road results.” Wear. Vol. 263(1-6), pp. 36-42. https://doi.org/10.1016/j.wear.2006.12.086 (accessed May 26, 2019).

Erukulla, S. 2011. “Refining a Laboratory Procedure to Characterize Change in Hot-Mix Asphalt Surface Friction.” MS Thesis. Auburn University.

Federal Highway Administration Research and Technology. 2015. Evaluation of Pavement Safety Performance. FHWA-HRT-14-065. https://www.fhwa.dot.gov/publications/research/safety/14065/002.cfm (accessed May 11, 2019).

Federal Highway Administration. 2016. “Pavement Friction.” FHWA. https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/ (accessed May 9, 2019).

Friel, S., and M. Kane, and D. Woodward. 2013. “Use of Wehner Schulze to predict skid resistance of Irish surfacing materials.” Presented at 2013 Airfield & Highway Pavement Conference. France. https://www.researchgate.net/publication/269046624_Use_of_Wehner_Schulze_to_Predict_Skid_Resistance_of_Irish_Surfacing_Materials (accessed May 26, 2019).

Gandhi, P. M., B. Colucci, and S. P. Gandhi. 1991. “Polishing of Aggregates and Wet-Weather Accident Rates for Flexible Pavements.” Journal of the Transportation Research Board, (1300), pp. 71-79. http://onlinepubs.trb.org/Onlinepubs/trr/1991/1300/1300-009.pdf (accessed May 11, 2019).

Greer, M. and M. Heitzman. 2017. Evaluation of the AIMS2 and Micro-Deval to Characterize Aggregate Friction Properties. Report 17-02. Auburn University, AL: National Center for Asphalt Technology. http://www.trb.org/Main/Blurbs/175992.aspx (accessed March 26, 2020).

Hall, J.W., and K.L. Smith, and L. Titus-Glover, and J.C. Wambold, and T.J. Yager, and Z. Rado. 2009. Guide for Pavement Friction. NCHRP Project No. 01-43. Transportation Research Board. http://redlightrobber.com/red/links_pdf/Guide-for-Pavement-Friction-NCHRP-108.pdf (accessed July 2, 2019).

Kowalski, K. J., R. S. McDaniel, and J. Olek. 2010. Identification of Laboratory Technique to Optimize Superpave HMA Surface Friction Characteristics. FHWA/IN/JTRP-2010/06. Purdue University, IN: Joint Transportation Research Program and Indiana Department of Transportation. https://engineering.purdue.edu/NCSC/research/PDF%20files/Optimize-Surface-Friction-Characteristics.pdf (accessed May 26, 2019).

Liang, R. Y. 2013. Long Term Validation of an Accelerated Polishing Test Procedure for HMA Pavements. FHWA/OH-2013/3. University of Akron, OH: Ohio Department of Transportation. https://rosap.ntl.bts.gov/view/dot/26789 (accessed May 15, 2019).

Lu, Q. and B. Steven. 2006. "Friction Testing of Pavement Preservation Treatments: Literature Review." Technical Memorandum UCPRC-TM-2006-10. University of California Pavement Research Center. http://www.ucprc.ucdavis.edu/PDF/UCPRC-TM-2006-10.pdf (accessed June 20, 2019).

Michigan Department of Transportation. 2019. Procedures for Aggregate Inspection. https://www.michigan.gov/documents/mdot/MDOT_ProceduresForAggregateAcceptance_386509_7.pdf (accessed May 15, 2019).

Mullen, W. G., and J.K. Whitfield, and T.L Matlock. 1977. Implementation for Use of Variable Speed Friction Tester and Small Wheel Circular Track Wear and Polishing Machine for Pavement Skid Resistance. Project ERSD 110-76-2. Raleigh, NC: North Carolina State University Highway Research Program. PDF.

National Center for Asphalt Technology. 2016. Asphalt Technology News. Vol. 28(2). http://eng.auburn.edu/research/centers/ncat/info-pubs/newsletters/newsfall16.pdf (accessed May 26, 2019).

National Highway Traffic Safety Administration. 2017. "Traffic Safety Facts West Virginia." NHTSA. https://cdan.nhtsa.gov/SASStoredProcess/guest?_program=%2FProduction%2FApps%2FSTSI%2FSTSI (accessed May 9, 2019).

Panagouli, O.K., and A. G. Kokkalis. 1998. "Skid resistance and fractal structure of pavement surface." Chaos, Solitons & Fractals, Vol. 9(3), pp. 493-505. https://doi.org/10.1016/S0960-0779(97)00085-4 (accessed May 11, 2019).

Patrick, J. 2011. "Comparison of the Wehner-Schulze and PSV Test for Estimating the Polishing Resistance of New Zealand Chip Seal Aggregate." Presented at 3rd International Surface Friction Conference, Safer Road Surfaces – Saving Lives. Gold Coast, Australia. https://saferroadsconference.com/wp-content/uploads/2016/05/Arampamoorthy-Comparison-of-the-WehnerSchulze-and-PSC-V-Test.pdf (accessed May 26, 2019).

Pavement Interactive. N. d. “Skid Resistance.” Pavement Interactive. https://www.pavementinteractive.org/reference-desk/pavement-management/pavement-evaluation/skid-resistance/ (accessed May 15, 2019).

Pyrialakou, D. 2020 January 27. Personal interview.

Vollor, T. W., and D. I. Hanson. 2006. Development of Laboratory Procedure for Measuring Friction of HMA Mixtures – Phase I. Report 06-06. Auburn University, AL: National Center for Asphalt Technology. http://www.cyber.auburn.edu/research/centers/ncat/files/reports/2006/rep06-06.pdf (accessed May 26, 2019).

West Virginia Department of Highways. 2018. Aggregate Technician Instruction Manual. Charleston, WV: WVDOH.

West Virginia Department of Highways Materials Control, Soils and Testing Division. Rapid Determination of the Polish Susceptible Carbonate Particle Content in Aggregates. MP 402.02.20. WVDOH, 1995.

Test Methods Used:

American Association of State Highway and Transportation Officials. *Standard Method of Test for Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor*. AASHTO T312-15. Washington, D.C.: AASHTO, 2015.

American Association of State Highway and Transportation Officials. *Standard Method of Test for Bulk Specific Gravity (G_{mb}) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens*. AASHTO T166-16. Washington, D.C.: AASHTO, 2016.

ASTM International. *Standard Practice for Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel, Circular Track Polishing Machine*. ASTM E660-90. West Conshohocken, PA: ASTM International, 2015.

ASTM International. *Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester*. ASTM E303-93. West Conshohocken, PA: ASTM International, 2018.

Appendix A: Mix Design, Specimen Characteristics, and Field Location Information

Mix Design T400 Sheets

WVDOH MCS&T Approval

Recommended for Approval:

P. Cyrus

Approved By:

03/14/2018

T400 SP

04-10

WEST VIRGINIA DIVISION OF HIGHWAYS

JOB MIX FORMULA FOR SUPERPAVE HOT-MIX ASPHALT

Report Number:	1462122	**Date Accepted:**	March 6, 2018
HMA Type:	12,5 mm Skid - RAP	**HMA Code:**	402,002,015
Producer:	J. F. Allen Company	**Plant Location:**	Lorentz, WV
Designed By:	Chadley Miller	**Design Lab:**	J. F. Allen (Elkins, WV)
Plant Type:	Batch	**Plant Make:**	McCarter
Plant Code:	JFA1.02.400	**Design ESALs:**	3 to < 30 Million (3)

MIX COMPOSITION

	Coarse Aggregate Source	Code		Fine Aggregate Source	Code
CA_1	J.F Allen Company (Mashey Gap, WV)	JFA2.01.704	FA_1	J.F Allen Company (Elkins, WV)	JFA2.02.704
CA_2	J.F Allen Company (Mashey Gap, WV)	JFA2.01.704	FA_2		
CA_3			FA_3		

	CA_1	CA_2	CA_3	FA_1	FA_2	FA_3
Agg. Type	#78 Skid	#8 Skid		L. Stone Sand		
Agg. Code	703,001,078	703,001,008		702,003,001		
% Total Agg.	20	37		33		

% RAP Total Agg.:	10	Blended Binder G*/sin delta if > 25% RAP:			
% Binder In RAP Design:	4.7	Binder Type:	PG 64H-22	Binder Code:	705,005,009
Binder Source:	Marathon Petroleum - Floreffe			Binder Source Code:	MPC1,02,705

Sieve Size	Target	Allowable Min.	Allowable Max.	Sieve Size	Target	Allowable Min.	Allowable Max.	Fines / Effective Asphalt Ratio		Tensile Strn. Ratio
								0.9		84.9
2" (50 mm)				#4 (4.75 mm)	52			Temperature Range Completed Mixture (°F)		
1.5" (37.5mm)				#8 (2.36 mm)	35	29	41			
1" (25 mm)				#16 (1.18 mm)	22			Desirable Mean Temp.	Temp. Range Min.	Temp. Range Max.
3/4" (19 mm)	100	100	100	#30 (600 μm)	14					
1/2" (12.5mm)	95	90	100	#50 (300 μm)	9					
3/8" (9.5 mm)	82		90	#200 (75 μm)	4.1	2.0	10.0	316	291	341

JOB MIX FORMULA VALUES

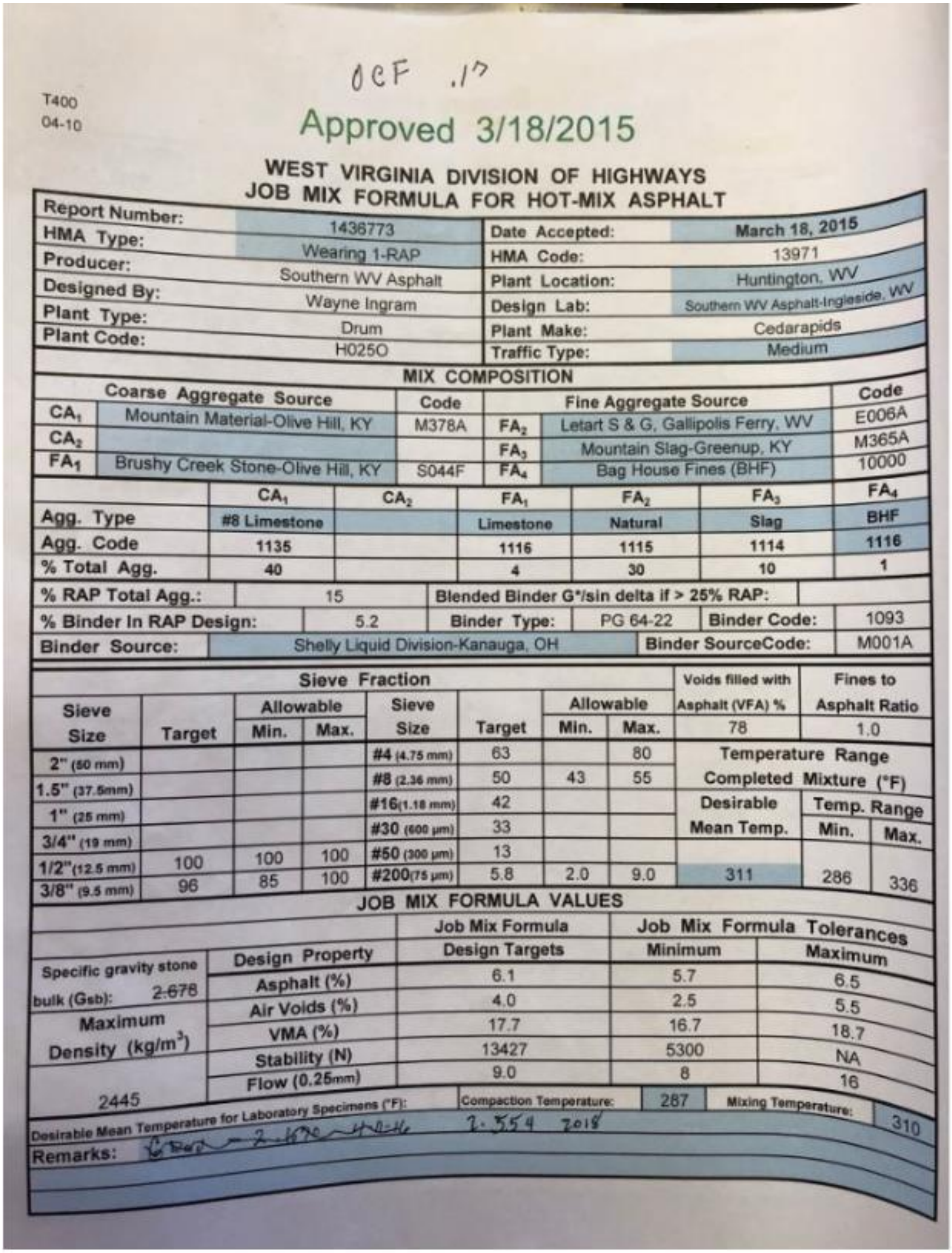
	Design Property	Job Mix Formula Design Targets	Job Mix Formula Tolerances Minimum	Job Mix Formula Tolerances Maximum
Specific gravity stone bulk (Gsb): 2.656	Asphalt (%)	5.4	5.0	5.8
Maximum Density (kg/m³)	Air Voids (%)	4.0	2.8	5.2
	VMA (%)	14.6	14.0	16.0
2498	VFA (%)	73	72	79

Gyrations @ N design:	80	Desirable Mean Temp. for Lab. Specimens (°F) :		Comp. Temp. :	296	Mixing Temp. :	316

Remarks:

Sister Version: 1462123

***Figure 19**: T400 Sheet for JFA 12.5mm SR Mixture*



OCF .17

T400
04-10

Approved 3/18/2015

WEST VIRGINIA DIVISION OF HIGHWAYS
JOB MIX FORMULA FOR HOT-MIX ASPHALT

Report Number:	1436773	Date Accepted:	March 18, 2015
HMA Type:	Wearing 1-RAP	HMA Code:	13971
Producer:	Southern WV Asphalt	Plant Location:	Huntington, WV
Designed By:	Wayne Ingram	Design Lab:	Southern WV Asphalt-Ingleside, WV
Plant Type:	Drum	Plant Make:	Cedarapids
Plant Code:	H025O	Traffic Type:	Medium

MIX COMPOSITION

	Coarse Aggregate Source	Code		Fine Aggregate Source	Code
CA_1	Mountain Material-Olive Hill, KY	M378A	FA_2	Letart S & G, Gallipolis Ferry, WV	E006A
CA_2			FA_3	Mountain Slag-Greenup, KY	M365A
FA_1	Brushy Creek Stone-Olive Hill, KY	S044F	FA_4	Bag House Fines (BHF)	10000

	CA_1	CA_2	FA_1	FA_2	FA_3	FA_4
Agg. Type	#8 Limestone		Limestone	Natural	Slag	BHF
Agg. Code	1135		1116	1115	1114	1116
% Total Agg.	40		4	30	10	1

% RAP Total Agg.:	15	Blended Binder G*/sin delta if > 25% RAP:			
% Binder In RAP Design:	5.2	Binder Type:	PG 64-22	Binder Code:	1093
Binder Source:	Shelly Liquid Division-Kanauga, OH			Binder SourceCode:	M001A

Sieve Fraction

Sieve Size	Target	Allowable Min.	Allowable Max.	Sieve Size	Target	Allowable Min.	Allowable Max.
2" (50 mm)				#4 (4.75 mm)	63		80
1.5" (37.5mm)				#8 (2.36 mm)	50	43	55
1" (25 mm)				#16 (1.18 mm)	42		
3/4" (19 mm)				#30 (600 µm)	33		
1/2" (12.5 mm)	100	100	100	#50 (300 µm)	13		
3/8" (9.5 mm)	96	85	100	#200 (75 µm)	5.8	2.0	9.0

Voids filled with Asphalt (VFA) %	Fines to Asphalt Ratio
78	1.0

Temperature Range Completed Mixture (°F)

Desirable Mean Temp.	Temp. Range Min.	Temp. Range Max.
311	286	336

JOB MIX FORMULA VALUES

	Design Property	Job Mix Formula Design Targets	Job Mix Formula Tolerances Minimum	Job Mix Formula Tolerances Maximum
Specific gravity stone bulk (Gsb): 2.678	Asphalt (%)	6.1	5.7	6.5
	Air Voids (%)	4.0	2.5	5.5
Maximum Density (kg/m³)	VMA (%)	17.7	16.7	18.7
	Stability (N)	13427	5300	NA
2445	Flow (0.25mm)	9.0	8	16

Desirable Mean Temperature for Laboratory Specimens (°F): Compaction Temperature: 287 Mixing Temperature: 310

Remarks: 2.554 2018

Figure 20: *T400 Sheet for WVP W1-RAP Mixture*

WVDOH MCS&T Approval

Recommended for Approval:

P. Cyrus

Approved By:

03/14/2018

T400SP
04-10

WEST VIRGINIA DIVISION OF HIGHWAYS
JOB MIX FORMULA FOR SUPERPAVE HOT-MIX ASPHALT

Report Number:	1462115	**Date Accepted:**	**February 27, 2018**
HMA Type:	12.5 mm Skid-RAP	**HMA Code:**	402.002.015
Producer:	West Virginia Paving, Inc	**Plant Location:**	Dunbar, WV
Designed By:	Jason Frame/Jack Withrow	**Design Lab:**	WV Paving-Dunbar, WV
Plant Type:	Drum	**Plant Make:**	ASTEC
Plant Code:	WVP1.02.400	**Design ESALs**	3 to < 30 million

MIX COMPOSITION

	Coarse Aggregate Source	Code		Fine Aggregate Source	Code
CA_1	Mulzer Stone-Charlestown, IN	MCS2.02.704	FA_1	Mulzer Stone-Cape Sandy, IN	MCS2.01.704
CA_2	Appalachian Aggregates-Beckley, WV	BAC1.01.704	FA_2	Mulzer Stone-New Amsterdam, IN	MCS2.03.704
CA_3			FA_3		
CA_4			FA_4	Bag House Fines	WVP1.02.400

	CA_1	CA_2	CA_3	CA_4	FA_1	FA_2	FA_3	FA_4
Agg. Type	#78 Limestone-Skid	#8 Sandstone			Limestone (W)	Limestone #10 (W)		BHF
Agg. Code	703.001.078	703.001.008			702.003.001	702.003.001		702.003.001
% Total Agg.	22	22			20	20		1

% RAP Total Agg.:	15	**Blended Binder G*/sin delta if > 25% RAP:**	
% Binder In RAP Design:	5.0	**Binder Type:** PG 64H-22	**Binder Code:** 705.005.008
Binder Source:	Shelly Liquid Division-Kanauga, OH		**Binder SourceCode:** SLD1.01.705

Sieve Fraction

Sieve Size	Target	Allowable Min.	Allowable Max.	Sieve Size	Target	Allowable Min.	Allowable Max.
2" (50 mm)				#4 (4.75 mm)	60		
1.5" (37.5mm)				#8 (2.36 mm)	37	31	43
1" (25 mm)				#16 (1.18 mm)	24		
3/4" (19 mm)	100	100	100	#30 (600 μm)	17		
1/2" (12.5 mm)	93	90	100	#50 (300 μm)	12		
3/8" (9.5 mm)	85		90	#200 (75 μm)	5.5	2.0	10.0

Fines/Effective Asphalt Ratio	Tensil Strn. Ratio
1.1	90.3

Temperature Range Completed Mixture (°F)

Desirable Mean Temp.	Temp. Range Min.	Temp. Range Max.
329	304	354

JOB MIX FORMULA VALUES

Specific gravity stone		Design Property	Job Mix Formula Design Targets	Job Mix Formula Tolerances Minimum	Job Mix Formula Tolerances Maximum
bulk (Gsb):	2.612	Asphalt (%)	5.9	5.5	6.3
Maximum Density (kg/m³)		Air Voids (%)	4.0	2.8	5.2
		VMA (%)	15.2	14.2	16.2
2451		VFA (%)	74	72	79

Gyrations @ N_{design}	80	Desirable Mean Temp. for Lab. Specimens (°F):	Comp. Temp.:	308	Mixing Temp.:	329

Remarks: Additional information for this JMF can be found in the accompanying 12.5mm RAP PG 64-22 mix design packet (JMF#1462114).

Figure 21: *T400 Sheet for WVP 12.5mm SR Mixture*

T400
03-00

WEST VIRGINIA DIVISION OF HIGHWAYS
JOB MIX FORMULA FOR HOT-MIX ASPHALT

Report Number:	1360465	**Date Accepted:**	March 9, 2004
HMA Type:	Wearing-1	**HMA Code:**	13966
Producer:	Greer Asphalt	**Plant Location:**	Greer, WV
Designed By:	Rich Nuzum	**Design Lab:**	Clarksburg Asphalt
Plant Type:	Batch	**Plant Make:**	McCarter
Plant Code:	G012A	**Traffic Type:**	Heavy

MIX COMPOSITION

	Coarse Aggregate Source	Code		Fine Agg. / Mineral Filler Source	Code
CA_1	Greer Industries, Greer, WV	G0120	FA_1	Greer Industries, Greer, WV	G0120
CA_2			FA_2	Greer Industries, Greer, WV	G0120
CA_3			FA_3		

	CA_1	CA_2	CA_3	FA_1	FA_2	FA_3
Agg. Type	#8 Limestone			Limestone	Limestone	
Agg. Code	1135			1116	1116	
% Total Agg.	48			32	20	

% RAP Total Agg.:		**Blended Binder G*/sin delta if > 25% RAP:**			
% Binder In RAP Design:		**Binder Type:**	PG 64-22	**Binder Code:**	1093
Binder Source:	Marathon/Ashland Oil, Floreffe, Pa.			**Binder SourceCode:**	A022B

Sieve Fraction								Voids filled with Asphalt"VFA"(%)	Fines to Asphalt Ratio	
Sieve Size	Target	Allowable Min.	Allowable Max.	Sieve Size	Target	Allowable Min.	Allowable Max.	75	0.8	
2" (50 mm)				#4 (4.75 mm)	60		80	Temperature Range Completed Mixture (°F)		
1.5" (37.5mm)				#8 (2.36 mm)	39	33	45	Desirable Mean Temp.	Temp. Range Min.	Temp. Range Max.
1" (25 mm)				#16 (1.18 mm)	23					
3/4" (19 mm)				#30 (600 μm)	12					
1/2" (12.5 mm)	100	100	100	#50 (300 μm)	7					
3/8" (9.5 mm)	95	85	100	#200 (75 μm)	4.4	2.0	9.0	295	270	320

JOB MIX FORMULA VALUES

	Job Mix Formula Targets		Job Mix Formula Tolerances	
Specific gravity stone	Design Property	Accepted Target	Minimum	Maximum
bulk (Gsb): 2.662	Asphalt (%)	5.7	5.3	6.1
Maximum	Air Voids (%)	4.0	2.5	5.5
Density (kg/m³)	VMA (%)	15.7	14.7	16.7
	Stability (N)	10400	8000	NA
2476	Flow (0.25mm)	11	8	14

Remarks: ______________________________

***Figure 22**: T400 Sheet for Greer W1H Mixture*

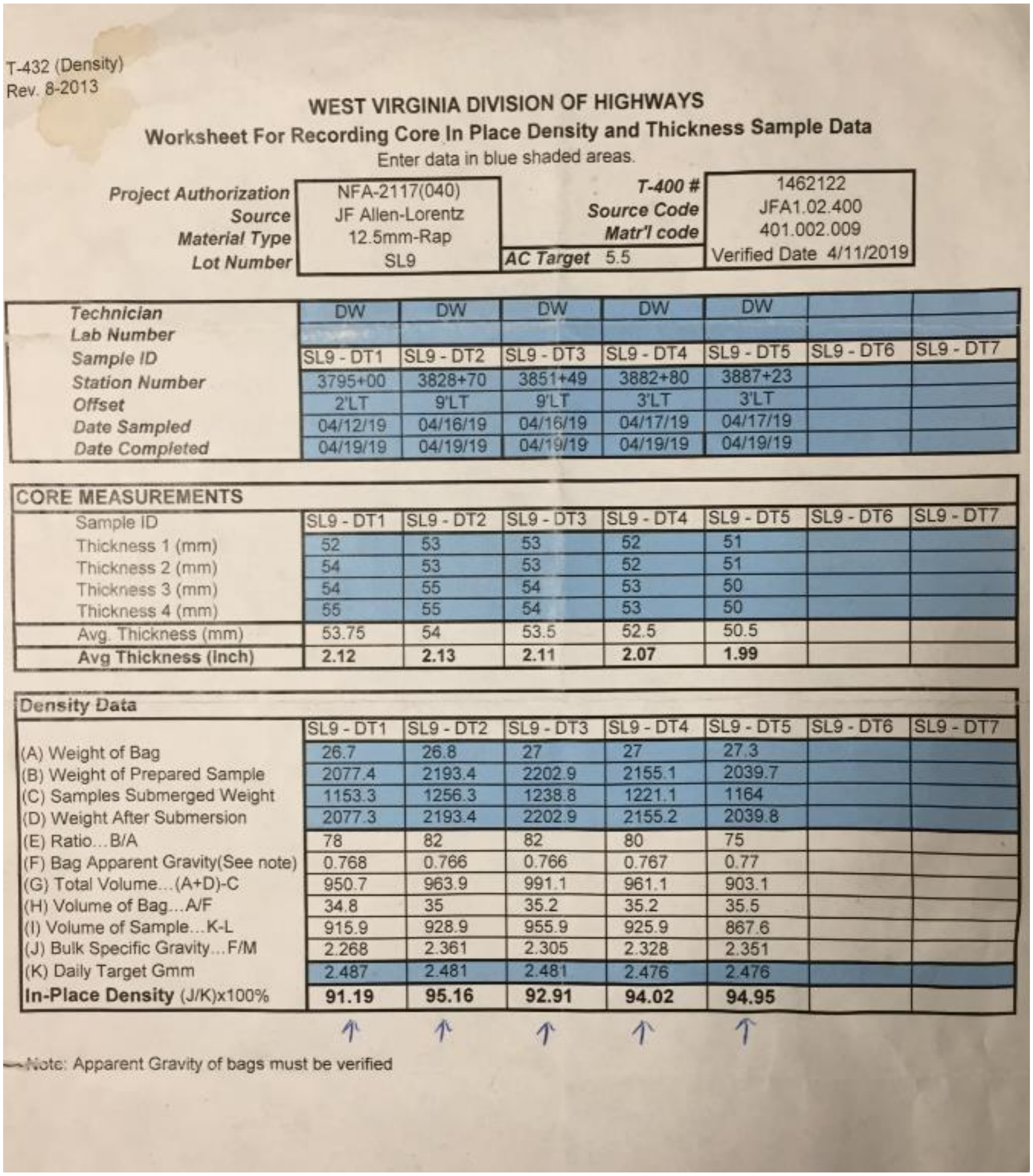
Field Core Specimen and Location Information

J.F. Allen Company - I79 Flatwoods GARVEE Project

Lab Specimen / Field Core Comparison

Date Produced / Placed	Sample ID	Sample Type	Sample Gmb	Sample Gmm	Sample % Compaction	Field Travel Lane	Field Sample Station	Field Sample Offset
4/22/2019	1 - A	Lab Pill	2.392	2.474	96.7	-	-	-
	1 - B	Field Core	2.379		96.2	South - Slow	3771 + 74	7' R cL
4/29/2019	2 - A	Lab Pill	2.357	2.477	95.2	-	-	-
	2 - B	Field Core	2.375		95.9	North - Slow	3798 + 99	9' R cL
4/30/2019	3 - A	Lab Pill	2.378	2.478	96.0	-	-	-
	3 - B	Field Core	2.294		92.6	North - Slow	3838 + 12	7' R cL
4/30/2019	4 - A	Lab Pill	2.401	2.477	96.9	-	-	-
	4 - B	Field Core	2.309		93.2	North - Slow	3931 + 52	3' R cL
5/1/2019	5 - A	Lab Pill	2.379	2.477	96.0	-	-	-
	5 - B	Field Core	2.356		95.1	North - Slow	3961 + 35	4' R cL
5/7/2019	6 - A	Lab Pill	2.361	2.478	95.3	-	-	-
	6 - B	Field Core	2.315		93.4	NB On Ramp	10 + 05	10' R cL

***Figure 23**: JFA 12.5mm SR Laboratory Compacted and Field Core Specimen Information*



T-432 (Density)
Rev. 8-2013

WEST VIRGINIA DIVISION OF HIGHWAYS

Worksheet For Recording Core In Place Density and Thickness Sample Data

Enter data in blue shaded areas.

Project Authorization	NFA-2117(040)	T-400 #	1462122
Source	JF Allen-Lorentz	Source Code	JFA1.02.400
Material Type	12.5mm-Rap	Matr'l code	401.002.009
Lot Number	SL9	AC Target 5.5	Verified Date 4/11/2019

Technician	DW	DW	DW	DW	DW		
Lab Number							
Sample ID	SL9 - DT1	SL9 - DT2	SL9 - DT3	SL9 - DT4	SL9 - DT5	SL9 - DT6	SL9 - DT7
Station Number	3795+00	3828+70	3851+49	3882+80	3887+23		
Offset	2'LT	9'LT	9'LT	3'LT	3'LT		
Date Sampled	04/12/19	04/16/19	04/16/19	04/17/19	04/17/19		
Date Completed	04/19/19	04/19/19	04/19/19	04/19/19	04/19/19		

CORE MEASUREMENTS							
Sample ID	SL9 - DT1	SL9 - DT2	SL9 - DT3	SL9 - DT4	SL9 - DT5	SL9 - DT6	SL9 - DT7
Thickness 1 (mm)	52	53	53	52	51		
Thickness 2 (mm)	54	53	53	52	51		
Thickness 3 (mm)	54	55	54	53	50		
Thickness 4 (mm)	55	55	54	53	50		
Avg. Thickness (mm)	53.75	54	53.5	52.5	50.5		
Avg Thickness (inch)	**2.12**	**2.13**	**2.11**	**2.07**	**1.99**		

Density Data							
	SL9 - DT1	SL9 - DT2	SL9 - DT3	SL9 - DT4	SL9 - DT5	SL9 - DT6	SL9 - DT7
(A) Weight of Bag	26.7	26.8	27	27	27.3		
(B) Weight of Prepared Sample	2077.4	2193.4	2202.9	2155.1	2039.7		
(C) Samples Submerged Weight	1153.3	1256.3	1238.8	1221.1	1164		
(D) Weight After Submersion	2077.3	2193.4	2202.9	2155.2	2039.8		
(E) Ratio...B/A	78	82	82	80	75		
(F) Bag Apparent Gravity(See note)	0.768	0.766	0.766	0.767	0.77		
(G) Total Volume...(A+D)-C	950.7	963.9	991.1	961.1	903.1		
(H) Volume of Bag...A/F	34.8	35	35.2	35.2	35.5		
(I) Volume of Sample...K-L	915.9	928.9	955.9	925.9	867.6		
(J) Bulk Specific Gravity...F/M	2.268	2.361	2.305	2.328	2.351		
(K) Daily Target Gmm	2.487	2.481	2.481	2.476	2.476		
In-Place Density (J/K)x100%	**91.19**	**95.16**	**92.91**	**94.02**	**94.95**		

Note: Apparent Gravity of bags must be verified

***Figure 24**: JFA 12.5mm SR I-79 Field Core and Field Measurement Location Information*

Specimen Information

Table 20: Specimen Characteristics Catalog

Specimen	Mixture	NMAS	VTM	Surface	Toe	Tires
1T	JFA 12.5mm SR	12.5mm	8%	Top	Low	Burris B55A
2T	JFA 12.5mm SR	12.5mm	8%	Top	Low	Burris B55A
3T	JFA 12.5mm SR	12.5mm	8%	Top	Low	Burris B55A
4T	JFA 12.5mm SR	12.5mm	4%	Top	Low	Burris B55A
5T	JFA 12.5mm SR	12.5mm	4%	Top	Low	Burris B55A
6T	JFA 12.5mm SR	12.5mm	4%	Top	Low	Burris B55A
7T	WVP W1-RAP	9.5mm	4%	Top	Low	Burris B55A
8T	WVP W1-RAP	9.5mm	4%	Top	Low	Burris B55A
9T	WVP W1-RAP	9.5mm	4%	Top	Low	Burris B55A
10T	WVP W1-RAP	9.5mm	8%	Top	Low	Burris B55A
11T	WVP W1-RAP	9.5mm	8%	Top	Low	Burris B55A
12T	WVP W1-RAP	9.5mm	8%	Top	Low	Burris B55A
1B	JFA 12.5mm SR	12.5mm	8%	Bottom	High	Burris B55A
2B	JFA 12.5mm SR	12.5mm	8%	Bottom	High	Burris B55A
3B	JFA 12.5mm SR	12.5mm	8%	Bottom	High	Burris B55A
4B	JFA 12.5mm SR	12.5mm	4%	Bottom	High	Burris B55A
5B	JFA 12.5mm SR	12.5mm	4%	Bottom	High	Burris B55A
6B	JFA 12.5mm SR	12.5mm	4%	Bottom	High	Burris B55A
7B	WVP W1-RAP	9.5mm	4%	Bottom	High	Burris B55A
8B	WVP W1-RAP	9.5mm	4%	Bottom	High	Burris B55A

Specimen	Mixture	NMAS	VTM	Surface	Toe	Tires
9B	WVP W1-RAP	9.5mm	4%	Bottom	High	Burris B55A
10B	WVP W1-RAP	9.5mm	8%	Bottom	High	Burris B55A
11B	WVP W1-RAP	9.5mm	8%	Bottom	High	Burris B55A
12B	WVP W1-RAP	9.5mm	8%	Bottom	High	Burris B55A
13T	Greer W1H	9.5mm	8%	Top	High	Hoosier R80
14T	Greer W1H	9.5mm	8%	Top	High	Hoosier R80
15T	Greer W1H	9.5mm	8%	Top	High	Hoosier R80
16T	Greer W1H	9.5mm	4%	Top	High	Hoosier R80
17T	Greer W1H	9.5mm	4%	Top	High	Hoosier R80
18T	Greer W1H	9.5mm	4%	Top	High	Hoosier R80
19T	WVP 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
20T	WVP 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
21T	WVP 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
22T	WVP 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
23T	WVP 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
24T	WVP 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
13B	Greer W1H	9.5mm	8%	Bottom	Low	Hoosier R80
14B	Greer W1H	9.5mm	8%	Bottom	Low	Hoosier R80
15B	Greer W1H	9.5mm	8%	Bottom	Low	Hoosier R80
16B	Greer W1H	9.5mm	4%	Bottom	Low	Hoosier R80
17B	Greer W1H	9.5mm	4%	Bottom	Low	Hoosier R80
18B	Greer W1H	9.5mm	4%	Bottom	Low	Hoosier R80

Specimen	Mixture	NMAS	VTM	Surface	Toe	Tires
19B	WVP 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
20B	WVP 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
21B	WVP 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
22B	WVP 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80
23B	WVP 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80
24B	WVP 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80
25T	JFA 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
26T	JFA 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
27T	JFA 12.5mm SR	12.5mm	4%	Top	High	Hoosier R80
28T	JFA 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
29T	JFA 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
30T	JFA 12.5mm SR	12.5mm	8%	Top	High	Hoosier R80
31T	WVP W1-RAP	9.5mm	4%	Top	High	Hoosier R80
32T	WVP W1-RAP	9.5mm	4%	Top	High	Hoosier R80
33T	WVP W1-RAP	9.5mm	4%	Top	High	Hoosier R80
34T	WVP W1-RAP	9.5mm	8%	Top	High	Hoosier R80
35T	WVP W1-RAP	9.5mm	8%	Top	High	Hoosier R80
36T	WVP W1-RAP	9.5mm	8%	Top	High	Hoosier R80
25B	JFA 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
26B	JFA 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
27B	JFA 12.5mm SR	12.5mm	4%	Bottom	Low	Hoosier R80
28B	JFA 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80

Specimen	Mixture	NMAS	VTM	Surface	Toe	Tires
29B	JFA 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80
30B	JFA 12.5mm SR	12.5mm	8%	Bottom	Low	Hoosier R80
32B	WVP W1-RAP	9.5mm	4%	Bottom	Low	Hoosier R80
33B	WVP W1-RAP	9.5mm	4%	Bottom	Low	Hoosier R80
34B	WVP W1-RAP	9.5mm	8%	Bottom	Low	Hoosier R80
35B	WVP W1-RAP	9.5mm	8%	Bottom	Low	Hoosier R80
36B	WVP W1-RAP	9.5mm	8%	Bottom	Low	Hoosier R80

Appendix B: Polishing Procedure

Polishing

1. Prepare and label 12 specimens at desired VTM using SGC.

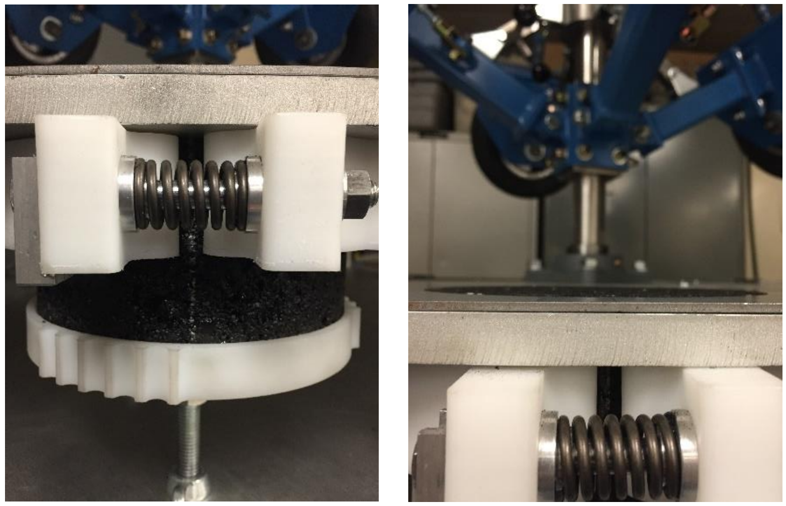
2. Mark specimens with a vertical line for equipment placement, Figure 23.

Figure 25*: Vertical Sample Markings*

3. Perform BPT measurements as per ASTM E303 for each sample prior to placement in the polishing machine.

4. Randomize sample positions in the polishing machine to reduce bias.

5. Place dry specimens in the polishing machine by aligning vertical markings with the clamp opening and adjusting height sample surface to be flush with top plate of machine. Proper specimen placement is pictured below in Figure 25.



(a) (b)

Figure 26: *(a) Specimen Vertical Alignment; (b) Specimen Flushed with Surface Plate*

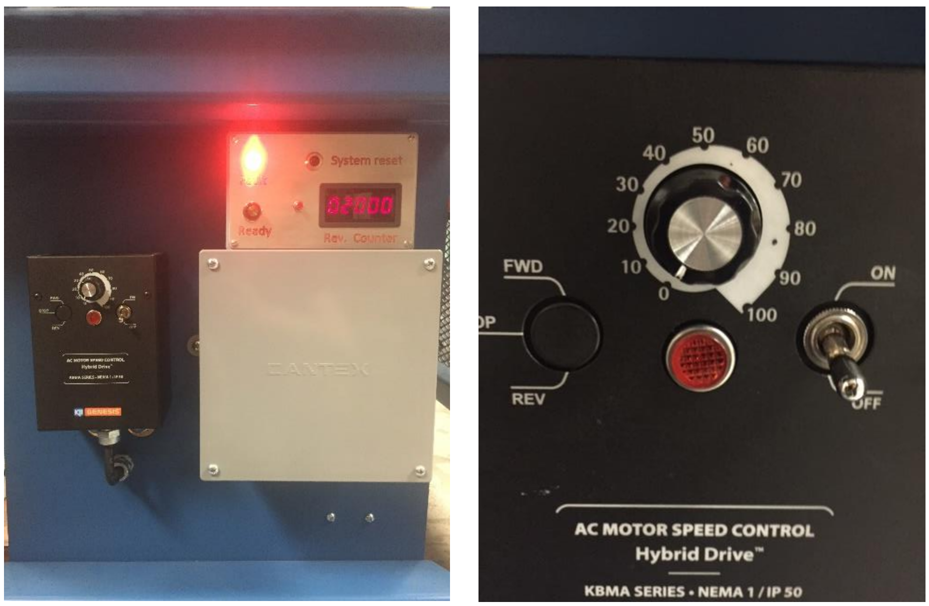
7. Tighten all height adjustment and clamping bolts to ensure zero movement.
8. Record specimen surface temperatures and both the tire tread and sidewall temperatures with an infrared laser thermometer gun for documentation.
9. Measure 2 grams of silicon carbide abrasive powder and distribute over each specimen surface, Figure 26.

Figure 27*: Silicon Carbide Abrasive Distribution on Specimen*

10. Lower the wheel assembly down carefully and place two 25-pound weights on top of each wheel assembly.

11. Latch safety gates and turn the machine on.

12. With the drive (Figure 27) initially set to “zero,” press “system reset” and adjust to desired rotation speed to begin polishing. In this experiment, the desired speed was marked for consistent polishing, Figure 27b. The speed marked was approximately 30 revolutions per minute (rpm).



(a) (b)

Figure 28: *(a) General Equipment Controls; (b) Variable Speed Drive*

13. When desired polishing is achieved, press the “stop” button.

14. When the polishing machine is fully stopped, measure specimen surface and tire temperatures to track initial and final temperatures (if applicable). Examples of these measurements are displayed in the Appendix C.

15. Remove excess abrasive from specimen surfaces. In this experiment, an air hose was used initially to remove abrasive while specimens remained in the machine. Following specimen removal, a vacuum was used to remove any remaining abrasive from surfaces. This is an important step in the procedure to ensure abrasive has no influence on BPT results.

16. Perform BPT measurements.

17. Repeat above steps for each round of polishing until desired ending is reached.

Sample Removal

1. Place wheel arms in the locked position as pictured previously in Figure 28.

2. Loosen clamp assembly to allow sample movement. Note: It is not necessary to loosen the height adjustment mechanism to remove specimens.

3. Using the removal tools (Figure 28), push on specimens in the upward direction via the holes in the plastic holding platens, and lift specimens from the machine. Height adjustments will not be affected.

Figure 29*: Specimen Removal Tools*

Tire Hardness

1. Ensure tires are fully cooled (room temperature) before measuring hardness.
2. Remove tires from machine. This is done by loosening the nuts from the hub and pulling the tire and hub assembly directly from the axle.
3. Assemble durometer by attaching the weight carefully, Figure 29.

***Figure 30**: Durometer with Weight Attached*

4. Make sure durometer needle is located at the “zero” position before performing measurements.
5. Place durometer above tire vertically, and carefully roll over tire surface. Durometer should remain perpendicular to tire surface for proper measurements. Record measurement as per the marking needle. For this experiment, hardness was measured on the outside edge of the tire tread (side with valve pointing outwards), inside edge of the tire tread, center of the tire tread, and the sidewall of the tire. Tire hardness measurements are located in Appendix C.
6. Repeat for all 4 tires.

Additional Procedure Notes

The procedure listed above is a generalized polishing procedure developed using results and observations documented throughout the length of this thesis experiment. It should be noted that a portion of the procedural steps are specific to this particular experiment and can be adjusted according to the scope of testing. Details specific to this experiment and those which can be modified as per user discretion include:

- Polishing wheel pass increments were chosen as 8000, 16000, 32000, and 48000 passes. The number of increments can be increased or decreased dependent on desired outcomes. A total of 48,000 wheel passes were deemed sufficient for analysis during this experiment.

- Corresponding to the chosen polishing increments, tire hardness was monitored prior to use as well as following 16000, 32000, and 48000 wheel passes in the polishing machine.

- Silicon abrasive powder was placed on specimen surfaces prior to each polishing session. This can be altered based on the scope of testing.

- Sample tracking pictures and temperature tracking measurements were taken for documentation purposes throughout the experiment. This can be withdrawn from the procedure if the information is not valuable to the user.

Appendix C: Specimen and Experiment Tracking Data

Specimen Surface Temperature

Table 21: Trial 2 JFA 12.5mm SR and WVP W1-RAP Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment											
		8000			16000			32000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	7T	77.5	82.4	4.9	75.3	80.4	5.1	77.3	82	4.7	76	79.8	3.8
2	6T	77.1	82.9	5.8	75.7	79.7	4	76.6	82	5.4	76	80.2	4.2
3	12T	77.1	83.3	6.2	75.3	80.9	5.6	77	80.6	3.6	76.2	80.2	4
4	9T	77.1	83.1	6	75.7	81.3	5.6	75.9	82.4	6.5	76	79.8	3.8
5	11T	76.6	83.3	6.7	75.7	80.0	4.3	76.6	82	5.4	76	80.2	4.2
6	10T	77.1	83.3	6.2	75.7	80.9	5.2	77.7	80.7	3	76	80.8	4.8
7	4T	76.8	82	5.2	75.7	77.5	1.8	78	82	4	75.9	79.1	3.2
8	2T	76.6	83.3	6.7	75.3	78.4	3.1	77.7	82.4	4.7	75.3	79.8	4.5
9	1T	76.6	83.6	7	75.2	80.9	5.7	76.6	80.6	4	76	80	4
10	8T	77.5	82.4	4.9	75.5	80.4	4.9	75.5	80.6	5.1	75.3	79.7	4.4
11	3T	76.6	83.6	7	75.5	81.1	5.6	77	81.8	4.8	74.3	80.4	6.1
12	5T	77.1	83.6	6.5	75.2	81.1	5.9	75.9	81.1	5.2	75.9	76.6	0.7
		Average		6.1	Average		4.7	Average		4.7	Average		4.0

Table 22: Trial 3 JFA 12.5mm SR and WVP W1-RAP Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment																	
		8000			16000			32000			48000			64000			80000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	7B	74.8	85.8	11	76.1	86.7	10.6	73.4	87.4	14	75.3	87.6	12.3	74.8	86.7	11.9	75.3	84.7	9.4
2	6B	74.3	86.3	12	76.8	86.9	10.1	73	87	14	75.3	87.6	12.3	75	86.3	11.3	76.4	84.7	8.3
3	12B	74.3	85.1	10.8	76.8	85.4	8.6	73	85.3	12.3	76.1	87	10.9	75	85.8	10.8	75	84.3	9.3
4	9B	74.8	86	11.2	76.8	87	10.2	73.4	87.2	13.8	75.7	87.9	12.2	75.3	86.5	11.2	75.3	85.1	9.8
5	11B	74.8	86.3	11.5	76.4	86.7	10.3	73	87.6	14.6	75.7	87.9	12.2	75	87	12	75.3	85.1	9.8
6	10B	74.4	86.7	12.3	76.8	87	10.2	73.7	85.2	11.5	76.4	87.4	11	75.3	85.8	10.5	75.3	84.5	9.2
7	4B	74.3	86	11.7	76.4	87	10.6	73	87.6	14.6	75.7	87.2	11.5	74.8	86.9	12.1	75	85.1	10.1
8	2B	74.8	86	11.2	76.8	86.3	9.5	73	87.2	14.2	75.7	87.6	11.9	75	87	12	74.6	85.1	10.5
9	1B	74.4	85.4	11	76.8	86.7	9.9	73.4	86	12.6	75.7	87.8	12.1	75	86.1	11.1	75.7	84.9	9.2
10	8B	75.2	86.7	11.5	76.4	86.7	10.3	73.4	87.2	13.8	76.4	87.8	11.4	75	87	12	75.3	85.4	10.1
11	3B	74.3	86.7	12.4	76.1	87	10.9	73.4	87.6	14.2	75.7	88.1	12.4	75	87	12	75	84.7	9.7
12	5B	74.3	86	11.7	76.8	86.7	9.9	73	86.3	13.3	76.1	88.1	12	74.8	86.5	11.7	75	83.6	8.6
		Average		**11.5**	**Average**		**10.1**	**Average**		**13.6**	**Average**		**11.9**	**Average**		**11.6**	**Average**		**9.5**

Table 23: Trial 4 WVP 12.5mm SR and Greer W1H Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment											
		8000			16000			32000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	13T	75	89	14	78.2	89.2	11	76.8	90.6	13.8	77.7	89.2	11.5
2	15T	75	88.3	13.3	78.2	88.5	10.3	76.4	90.3	13.9	77.7	89.6	11.9
3	14T	75.3	87.4	12.1	78.2	88.5	10.3	76.4	91	14.6	77.7	87	9.3
4	16T	75	89	14	78.4	89.6	11.2	77	90.3	13.3	78	89.2	11.2
5	24T	75.4	87	11.6	78.8	88.5	9.7	76.6	88.1	11.5	77.7	88.1	10.4
6	18T	74.4	88.1	13.7	78.4	88.7	10.3	76.2	90.1	13.9	77.7	87	9.3
7	21T	74.4	87.6	13.2	78	88.3	10.3	76.2	89.4	13.2	77.7	87.9	10.2
8	23T	75	86.7	11.7	78.4	87.4	9	75.9	88.5	12.6	77.7	87.4	9.7
9	19T	74.4	86.9	12.5	78.2	87.4	9.2	76.8	90.1	13.3	77.7	86.9	9.2
10	22T	74.4	88.5	14.1	78.2	88.3	10.1	76.4	89.4	13	77.7	87	9.3
11	20T	75.3	87.8	12.5	78.2	87.4	9.2	76.4	87.8	11.4	77.7	88.1	10.4
12	17T	74.4	86.9	12.5	78.6	87.9	9.3	76.4	91	14.6	77.7	87.2	9.5
		Average		**12.9**	**Average**		**10.0**	**Average**		**13.3**	**Average**		**10.2**

Table 24: Trial 5 WVP 12.5mm SR and Greer W1H Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment														
		8000			16000			32000			48000			64000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	13B	75	83.6	8.6	78.2	84.5	6.3	75.9	85.4	9.5	78.6	85.8	7.2	75.3	84	8.7
2	15B	75	83.3	8.3	78.2	83.8	5.6	75.5	85.4	9.9	78.2	86.1	7.9	75.3	84	8.7
3	14B	75	82.5	7.5	78.2	83.6	5.4	76.2	83.4	7.2	77.9	86.9	9	76.2	83.8	7.6
4	16B	75	82.2	7.2	78.6	85.2	6.6	76.6	84.5	7.9	78.2	86.1	7.9	75.7	83.4	7.7
5	24B	75.3	81.8	6.5	78.2	83.8	5.6	76.2	84.2	8	78.8	86	7.2	75.9	83.5	7.6
6	18B	74.8	82.9	8.1	78.2	84.5	6.3	75.9	83.3	7.4	78.8	86	7.2	75.9	83.8	7.9
7	21B	75.3	82.2	6.9	78.4	84.5	6.1	76.2	84.2	8	78.4	86.3	7.9	76.2	83.8	7.6
8	23B	75.3	82.2	6.9	78	84.3	6.3	75.9	84.2	8.3	78.8	85.2	6.4	76.1	84	7.9
9	19B	74.8	82.5	7.7	78.6	84.5	5.9	76.2	83.3	7.1	78.6	86	7.4	76.2	83.6	7.4
10	22B	75	82.2	7.2	77.5	84	6.5	75.9	84.5	8.6	78.2	86	7.8	76.2	83.6	7.4
11	20B	75.3	82.9	7.6	78.2	83.3	5.1	75.9	83.8	7.9	78.9	85.8	6.9	76.2	84	7.8
12	17B	74.8	82	7.2	78.2	84.7	6.5	76.6	84.7	8.1	78.2	85.8	7.6	76.6	84.3	7.7
		Average		7.5	Average		6.0	Average		8.2	Average		7.5	Average		7.8

Table 25: Trial 6 JFA 12.5mm SR and WVP W1-RAP Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment											
		8000			16000			32000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	28B	74.3	79.8	5.5	75.5	80.4	4.9	73.4	82.9	9.5	71.9	78.9	7
2	30B	73.9	80.9	7	74.8	82	7.2	74.1	80.4	6.3	71.6	79.7	8.1
3	34B	74.3	80.2	5.9	75.2	81.3	6.1	74.1	82.2	8.1	71.9	79.3	7.4
4	31B	73.9	80	6.1	75.2	80.4	5.2	74.8	82	7.2	71.6	78.6	7
5	32B	73.9	80.6	6.7	74.8	81.6	6.8	74.4	82.2	7.8	71.6	79.3	7.7
6	25B	73.9	80.6	6.7	74.8	80.9	6.1	74.4	82.4	8	71.9	79.7	7.8
7	26B	74.6	80.9	6.3	74.8	81.1	6.3	74.8	82.7	7.9	71.9	79.3	7.4
8	35B	73.9	80.6	6.7	74.4	81.6	7.2	74.1	82.9	8.8	71.6	79.1	7.5
9	33B	73.9	80.2	6.3	74.8	80.9	6.1	74.8	82.4	7.6	71.9	79.1	7.2
10	36B	73.9	80.9	7	75.2	81.6	6.4	74.1	82.9	8.8	72.3	79.5	7.2
11	29B	73.9	80.6	6.7	74.4	80.2	5.8	74.8	82.7	7.9	71.9	79.9	8
12	27B	74.3	80.2	5.9	75.2	80.9	5.7	74.1	82.2	8.1	71.9	79.1	7.2
		Average		6.4	Average		6.2	Average		8.0	Average		7.5

Table 26: Trial 7 JFA 12.5mm SR and WVP W1-RAP Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment											
		8000			16000			32000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	28T	76.6	87.4	10.8	78.4	87.6	9.2	77.3	89.6	12.3	77.3	89.6	12.3
2	30T	76.2	87.2	11	77.7	88.7	11	77.1	90.6	13.5	77.3	82.6	5.3
3	34T	76.2	88.5	12.3	78.4	88.8	10.4	76.8	90.3	13.5	77.3	89.4	12.1
4	31T	76.6	86	9.4	78.4	87.8	9.4	77.5	90.3	12.8	77.3	89.4	12.1
5	32T	77	87.8	10.8	78	88.5	10.5	77.5	90.38	12.88	77	88.1	11.1
6	25T	77	87.8	10.8	78	87.6	9.6	77.9	89.4	11.5	77.3	88	10.7
7	26T	77	87.8	10.8	78	88.1	10.1	77.1	90.6	13.5	77.3	89.4	12.1
8	35T	76.2	87.2	11	77.7	87.6	9.9	77.1	91.4	14.3	77.3	88.3	11
9	33T	75.9	87.2	11.3	78	87.9	9.9	77.5	90.6	13.1	77.3	89.6	12.3
10	36T	76.2	87.2	11	77.7	86.9	9.2	77.1	89.7	12.6	76.6	89.2	12.6
11	29T	76.6	87.9	11.3	77.7	88.3	10.6	76.8	91.7	14.9	77.7	87.9	10.2
12	27T	76.2	87.2	11	78	88.3	10.3	77.3	90.3	13	77.3	89.2	11.9
		Average		**11.0**	**Average**		**10.0**	**Average**		**13.2**	**Average**		**11.1**

Table 27: Trial 8 JFA 12.5mm SR Laboratory Compacted and Field Core Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment								
		8000			24000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	1F	76.8	87.4	10.6	76.1	88.5	12.4	76.2	89.9	13.7
2	3L	76.8	86.9	10.1	75.7	87.6	11.9	75.9	89.6	13.7
3	6F	76.8	86.9	10.1	75.3	88.5	13.2	75.9	88.5	12.6
4	5F	76.6	87	10.4	76.1	87.8	11.7	75.9	89.6	13.7
5	1L	77	86.9	9.9	76.1	88.1	12	76.2	89.2	13
6	2F	76.6	86.5	9.9	76.1	88.5	12.4	75.9	88.7	12.8
7	6L	76.2	86.9	10.7	76.1	87.8	11.7	75.9	89.2	13.3
8	4F	76.2	88.1	11.9	75.7	88.8	13.1	75.5	89.6	14.1
9	2L	76.8	87.4	10.6	75	88.3	13.3	75.5	88.7	13.2
10	4L	76.8	86.5	9.7	75.3	87.8	12.5	75.9	88.8	12.9
11	5L	76.1	87	10.9	75.7	87.9	12.2	75.9	89.4	13.5
12	3F	76.4	87	10.6	75.7	88.3	12.6	75.5	88.3	12.8
		Average		**10.5**	**Average**		**12.4**	**Average**		**13.3**

Table 28: Trial 9 JFA 12.5mm SR I-79 Field Core Initial and Final Surface Temperatures (°F) During Polishing Procedure

Polishing Position	Specimen Number	Surface Temperature at Each Wheel Pass Increment								
		8000			24000			48000		
		Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
3	D4	75.3	87.2	11.9	76.6	90.3	13.7	77.7	90.1	12.4
5	D1	75.5	86.7	11.2	76.6	89.6	13	77.7	90.5	12.8
7	D3	75.3	86.9	11.6	76.8	92.4	15.6	78.4	91.7	13.3
8	D2	75.3	86.3	11	75.9	89.6	13.7	78.4	90.1	11.7
9	D5	75.3	88.5	13.2	76.6	91.4	14.8	78	89.7	11.7
		Average		**11.8**	**Average**		**14.2**	**Average**		**12.4**

Tire Surface Temperature

Table 29: Trial 2 JFA 12.5mm SR and WVP W1-RAP Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature at Each Wheel Pass Increment																
	8000			16000			32000					48000					
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final (Sidewall)	Difference	Tread	Difference	Initial (Sidewall)	Final (Sidewall)	Difference	Initial (Tread)	Final (Tread)	Difference
1	77.9	82.2	4.3	75.2	78.8	3.6	75.5	78.9	3.4	83.1	7.6	76.1	77.3	1.2	76.1	80	3.9
2	78.2	81.8	3.6	75.2	79.1	3.9	75.5	79.7	4.2	83.6	8.1	75	78.2	3.2	75.3	80	4.7
3	78.6	83.3	4.7	75.9	79.5	3.6	75.9	79.3	3.4	84	8.1	74.3	78	3.7	74.8	80.4	5.6
4	77.9	81.8	3.9	75.9	78.2	2.3	75.3	78.9	3.6	82.2	6.9	74.1	77.3	3.2	74.1	78.9	4.8
	Average		**4.1**	**Average**		**3.3**	**Average**		**3.7**	**Average**	**7.7**	**Average**		**2.8**	**Average**		**4.8**

Table 30: Trial 3 JFA 12.5mm SR and WVP W1-RAP Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment																	
	8000			16000			32000			48000			64000			80000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	76.2	80.6	4.4	76.1	81.1	5	74.1	80.2	6.1	75.3	82.5	7.2	75.3	82	6.7	75.7	80.2	4.5
2	75.9	82.4	6.5	76.8	82.5	5.7	74.1	83.4	9.3	75.7	82.9	7.2	75	83.6	8.6	75.7	81.6	5.9
3	75.9	81.3	5.4	76.4	81.8	5.4	73.7	80.6	6.9	75.7	82.2	6.5	75	81.1	6.1	76.1	82.4	6.3
4	76.6	83.1	6.5	76.1	83.4	7.3	74.4	83.3	8.9	75.7	83.6	7.9	75.7	84.2	8.5	75.3	82	6.7
	Average		**5.7**	**Average**		**5.9**	**Average**		**7.8**	**Average**		**7.2**	**Average**		**7.5**	**Average**		**5.9**

Tire	Surface Temperature of Tread at Each Wheel Pass Increment																	
	8000			16000			32000			48000			64000			80000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	76.2	85.8	9.6	76.4	84.9	8.5	74.1	84	9.9	75.7	86.9	11.2	75	86.1	11.1	75.7	83.1	7.4
2	76.6	89.6	13	76.4	88.7	12.3	74.4	88.7	14.3	75.3	88.7	13.4	74.8	87	12.2	76.4	84.7	8.3
3	76.2	82.7	6.5	76.4	84.5	8.1	74.1	84.3	10.2	75.3	85.2	9.9	75.3	83.8	8.5	75.7	83.1	7.4
4	76.6	88.5	11.9	76.1	89.4	13.3	74.1	88.1	14	76.1	88.7	12.6	75.3	86.9	11.6	75	85.1	10.1
	Average		**10.3**	**Average**		**10.6**	**Average**		**12.1**	**Average**		**11.8**	**Average**		**10.9**	**Average**		**8.3**

Table 31: Trial 4 WVP 12.5mm SR and Greer W1H Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	77.1	88.3	11.2	77.9	89.0	11.1	76.8	89.0	12.2	77.3	85.6	8.3
2	77.9	93.0	15.1	77.5	93.5	16.0	77.1	93.7	16.6	77.3	91.4	14.1
3	77.5	89.4	11.9	78.4	89.6	11.2	77.1	89.2	12.1	77.7	87.6	9.9
4	77.1	92.3	15.2	78.0	91.9	13.9	76.6	91.5	14.9	77.3	89.2	11.9
	Average		**13.4**	**Average**		**13.1**	**Average**		**14.0**	**Average**		**11.1**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	77.9	81.8	3.9	77.9	81.8	3.9	76.8	84.9	8.1	77.3	82.4	5.1
2	77.5	85.4	7.9	77.3	84.0	6.7	76.8	86.1	9.3	77.7	84.9	7.2
3	77.9	83.3	5.4	78.0	82.0	4.0	76.4	83.3	6.9	78.4	84.2	5.8
4	77.1	85.2	8.1	78.8	83.4	4.6	76.2	85.6	9.4	77.3	84.5	7.2
	Average		**6.3**	**Average**		**4.8**	**Average**		**8.4**	**Average**		**6.3**

Table 32: Trial 5 WVP 12.5mm SR and Greer W1H Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment														
	8000			16000			32000			48000			64000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	76.4	85.6	9.2	77.9	85.8	7.9	76.6	85.4	8.8	77.9	87.2	9.3	78	84.7	6.7
2	77.1	87.2	10.1	77.9	88.5	10.6	77	87.8	10.8	78.6	89.4	10.8	78.8	85.8	7
3	77.1	84.9	7.8	77.5	86.3	8.8	76.6	85.8	9.2	78.6	86.7	8.1	78	84.2	6.2
4	76.4	86	9.6	77.9	87.4	9.5	76.6	86.1	9.5	78.4	87.4	9	77.7	85.1	7.4
	Average		**9.2**	**Average**		**9.2**	**Average**		**9.6**	**Average**		**9.3**	**Average**		**6.8**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment														
	8000			16000			32000			48000			64000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	76.4	80.9	4.5	77.9	82.4	4.5	77	82.2	5.2	78.2	83.4	5.2	77.1	81.3	4.2
2	76.8	82.2	5.4	78.2	82.9	4.7	77	82.7	5.7	78.2	84	5.8	78	82.4	4.4
3	76.4	81.5	5.1	78.2	82.5	4.3	77	81.8	4.8	78.8	84	5.2	77.7	81.5	3.8
4	76.1	82.5	6.4	78.2	82.9	4.7	76.6	82.4	5.8	78	84.2	6.2	77.7	82	4.3
	Average		**5.4**	**Average**		**4.6**	**Average**		**5.4**	**Average**		**5.6**	**Average**		**4.2**

Table 33: Trial 6 JFA 12.5mm SR and WVP W1-RAP Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	73.9	82.7	8.8	75.2	82.4	7.2	75.5	84.2	8.7	72.6	80.6	8.0
2	73.9	84.7	10.8	75.2	85.6	10.4	75.9	84.3	8.4	72.6	81.8	9.2
3	74.3	82.4	8.1	75.2	83.6	8.4	75.9	83.4	7.5	72.6	80.7	8.1
4	73.9	83.8	9.9	74.4	83.3	8.9	75.2	84.2	9.0	73.0	80.7	7.7
	Average		**9.4**	**Average**		**8.7**	**Average**		**8.4**	**Average**		**8.3**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	73.9	77.9	4.0	75.2	79.7	4.5	75.2	78.8	3.6	72.3	77.0	4.7
2	73.9	76.8	2.9	75.2	80.2	5.0	75.2	80.9	5.7	72.6	77.1	4.5
3	74.3	78.2	3.9	74.8	79.3	4.5	74.8	78.4	3.6	73.0	76.8	3.8
4	73.9	78.4	4.5	74.8	79.8	5.0	74.8	79.7	4.9	72.6	77.7	5.1
	Average		**3.8**	**Average**		**4.8**	**Average**		**4.5**	**Average**		**4.5**

Table 34: Trial 7 JFA 12.5mm SR and WVP W1-RAP Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	76.6	89.0	12.4	78.8	89.4	10.6	77.9	89.9	12.0	77.3	88.8	11.5
2	77.0	94.2	17.2	78.4	92.4	14.0	78.2	92.6	14.4	77.3	90.5	13.2
3	77.3	88.8	11.5	78.0	88.5	10.5	77.9	89.9	12.0	77.7	88.8	11.1
4	77.3	89.9	12.6	78.4	90.8	12.4	78.2	92.8	14.6	77.7	91.0	13.3
	Average		**13.4**	**Average**		**11.9**	**Average**		**13.3**	**Average**		**12.3**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment											
	8000			16000			32000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	77.0	84.0	7.0	78.4	84.7	6.3	77.5	86.5	9.0	77.0	85.1	8.1
2	76.6	84.3	7.7	78.4	84.7	6.3	78.0	87.0	9.0	77.0	86.0	9.0
3	77.0	83.6	6.6	78.4	83.4	5.0	78.2	84.4	6.2	77.3	84.7	7.4
4	77.3	84.7	7.4	78.0	86.1	8.1	78.2	85.1	6.9	77.7	85.8	8.1
	Average		**7.2**	**Average**		**6.4**	**Average**		**7.8**	**Average**		**8.2**

Table 35: Trial 8 JFA 12.5mm SR Laboratory Compacted and Field Core Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment								
	8000			24000			48000		
	Initial	Final	Difference		Final	Difference	Initial	Final	Difference
1	77.5	87.4	9.9	76.8	87.2	10.4	76.6	87.8	11.2
2	78.0	89.6	11.6	76.8	89.6	12.8	77.3	90.3	13.0
3	77.3	87.4	10.1	76.4	87.6	11.2	77.0	87.6	10.6
4	78.2	90.3	12.1	76.4	89.7	13.3	77.3	90.6	13.3
	Average		**10.9**	**Average**		**11.9**	**Average**		**12.0**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment								
	8000			16000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	77.9	83.4	5.5	77.1	82.9	5.8	77.0	81.5	4.5
2	77.3	83.8	6.5	76.8	84.7	7.9	76.6	84.9	8.3
3	77.0	82.5	5.5	76.4	82.6	6.2	76.8	84.2	7.4
4	77.5	84.0	6.5	76.8	83.6	6.8	76.6	83.8	7.2
	Average		**6.0**	**Average**		**6.7**	**Average**		**6.9**

Table 36: Trial 9 JFA 12.5mm SR I-79 Field Core Initial and Final Tire Surface Temperatures (°F) During Polishing Procedure

Tire	Surface Temperature of Tread at Each Wheel Pass Increment								
	8000			24000			48000		
	Initial	Final	Difference		Final	Difference	Initial	Final	Difference
1	75.3	87.8	12.5	77.0	89.2	12.2	77.0	88.7	11.7
2	76.2	91.5	15.3	77.1	94.2	17.1	77.3	92.3	15.0
3	75.7	88.1	12.4	77.3	89.6	12.3	77.7	88.7	11.0
4	75.7	91.4	15.7	77.0	92.4	15.4	77.7	90.5	12.8
	Average		**14.0**	Average		**14.3**	Average		**12.6**

Tire	Surface Temperature of Sidewall at Each Wheel Pass Increment								
	8000			24000			48000		
	Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
1	75.3	83.6	8.3	77.3	85.1	7.8	77.0	83.8	6.8
2	75.9	84.5	8.6	77.1	86.1	9.0	77.7	85.6	7.9
3	75.7	82.4	6.7	77.0	84.0	7.0	76.6	83.3	6.7
4	75.3	84.3	9.0	77.0	86.9	9.9	78.0	85.6	7.6
	Average		**8.2**			**8.4**	Average		**7.3**

Tire Hardness

Table 37: Trial 2 JFA 12.5mm SR and WVP W1-RAP Durometer Measurements During Polishing Procedure for Burris B55A Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	85	85	79	70
	2	85	85	77	73
	3	84	84	73	73
	4	83	82	75	69
32000	1	82	83	79	65
	2	80	81	80	70
	3	79	80	80	65
	4	82	79	78	66
48000	1	83	81	81	68
	2	82	82	80	67
	3	80	78	78	70
	4	83	82	80	66

Table 38: Trial 3 JFA 12.5mm SR and WVP W1-RAP Durometer Measurements During Polishing Procedure for Burris B55A Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	83	81	81	68
	2	82	82	80	67
	3	80	78	78	70
	4	83	82	80	66
32000	1	81	81	81	66
	2	81	80	78	70
	3	79	79	76	74
	4	80	80	77	70
48000	1	79	81	82	69
	2	78	79	82	66
	3	78	78	77	76
	4	81	79	78	69
80000	1	80	81	79	72
	2	80	78	81	71
	3	79	78	77	74
	4	81	79	80	68

Table 39: Trial 4 WVP 12.5mm SR and Greer W1H Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	79	80	81	75
	2	78	79	79	74
	3	79	80	79	74
	4	80	80	79	76
32000	1	76	76	77	75
	2	75	77	77	74
	3	76	75	78	74
	4	76	77	78	73
48000	1	79	79	79	75
	2	78	79	79	73
	3	79	78	79	76
	4	79	79	79	74

Table 40: Trial 5 WVP 12.5mm SR and Greer W1H Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	79	79	79	75
	2	78	79	79	73
	3	79	78	79	76
	4	79	79	79	74
16000	1	76	76	77	73
	2	76	77	78	72
	3	76	77	77	74
	4	76	77	78	74
32000	1	77	78	79	72
	2	77	77	79	76
	3	77	77	78	72
	4	77	78	78	73
48000	1	80	80	80	73
	2	79	80	80	72
	3	80	79	80	74
	4	79	79	79	74
64000	1	79	80	80	76
	2	79	79	80	75
	3	79	79	79	76
	4	79	80	80	76

Table 41: Trial 6 JFA 12.5mm SR and WVP W1-RAP Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	79	80	80	76
	2	79	79	80	75
	3	79	79	79	76
	4	79	80	80	76
16000	1	79	81	80	78
	2	80	79	79	76
	3	81	81	81	77
	4	81	80	81	79
32000	1	81	82	81	77
	2	81	80	81	79
	3	81	80	81	79
	4	80	82	82	80
48000	1	81	81	81	77
	2	80	82	80	77
	3	81	81	81	78
	4	80	81	81	78

Table 42: Trial 7 JFA 12.5mm SR and WVP W1-RAP Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	81	81	81	77
	2	80	82	80	77
	3	81	81	81	78
	4	80	81	81	78
16000	1	79	78	80	79
	2	80	80	81	79
	3	80	82	80	80
	4	79	79	81	78
32000	1	79	79	79	78
	2	78	81	79	80
	3	80	79	80	78
	4	79	79	80	78
48000	1	81	80	80	78
	2	80	80	80	80
	3	79	79	80	80
	4	79	80	80	79

Table 43: Trial 8 JFA 12.5mm SR Laboratory and Field Core Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	81	80	80	78
	2	80	80	80	80
	3	79	79	80	80
	4	79	80	80	79
24000	1	79	81	79	77
	2	80	81	80	78
	3	78	79	81	79
	4	80	81	79	78
48000	1	80	79	81	80
	2	80	81	81	78
	3	81	79	80	78
	4	79	81	81	80

Table 44: Trial 9 JFA 12.5mm SR I-79 Field Core Durometer Measurements During Polishing Procedure for Hoosier R80 Tires

Number of Wheel Passes	Tire	Hardness (Durometer Reading)			
		Outside Edge	Inside Edge	Center	Sidewall
0	1	80	79	81	80
	2	80	81	81	78
	3	81	79	80	78
	4	79	81	81	80
24000	1	78	81	80	78
	2	81	80	81	78
	3	80	79	78	80
	4	80	80	81	81
48000	1	80	79	81	80
	2	80	81	80	79
	3	81	80	81	79
	4	80	81	80	80

Appendix D: Raw Recorded BPN Measurements

Trial 1: WVDOH Specimens (Unknown Mixture)

Table 45: BPN Measurements for Trial 1 WVDOH Specimens (Unknown Mixture) Polished with Burris B44A Tires at Low Toe for 160,000 Wheel Passes

		British Pendulum Number (BPN)					
Number of Wheel Passes	**Specimen**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Average**
8000	2	61	59	57	56	56	57.8
8000	3	60	59	58	56	55	57.6
8000	5	56	56	55	54	53	54.8
8000	6	61	60	58	57	56	58.4
8000	8	54	53	50	49	50	51.2
8000	9	56	55	54	54	53	54.4
8000	11	54	52	52	51	51	52
8000	12	61	59	56	55	54	57
16000	2	52	50	49	48	48	49.4
16000	3	60	58	58	57	56	57.8
16000	5	55	53	52	51	51	52.4
16000	6	53	52	50	49	50	50.8
16000	8	58	55	54	54	53	54.8
16000	9	54	52	51	51	50	51.6
16000	11	50	50	49	48	48	49
16000	12	52	50	49	49	48	49.6
32000	2	72	62	60	59	58	62.2
32000	3	60	59	55	55	54	56.6
32000	5	55	54	54	50	49	52.4
32000	6	56	54	52	54	51	53.4
32000	8	50	49	49	46	46	48
32000	9	53	53	49	48	47	50
32000	11	54	53	51	53	52	52.6
32000	12	56	54	52	51	51	52.8
64000	2	50	47	46	45	45	46.6
64000	3	46	44	42	41	40	42.6
64000	5	52	50	48	48	46	48.8
64000	6	46	44	43	42	42	43.4
64000	8	44	42	41	40	39	41.2

		British Pendulum Number (BPN)					
Number of Wheel Passes	**Specimen**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Average**
64000	9	45	42	42	41	40	42
64000	11	44	42	42	40	40	41.6
64000	12	50	48	46	45	45	46.8
96,508	2	45	43	41	40	39	41.6
96,508	3	51	45	45	43	44	45.6
96,508	5	47	45	42	42	41	43.4
96,508	6	45	43	41	40	38	41.4
96,508	8	42	39	38	36	36	38.2
96,508	9	46	42	40	39	36	40.6
96,508	11	46	43	42	41	40	42.4
96,508	12	47	45	42	42	40	43.2
128000	2	48	45	43	43	42	44.2
128000	3	50	47	45	44	43	45.8
128000	5	46	46	43	43	42	44
128000	6	45	42	42	40	40	41.8
128000	8	41	39	39	36	35	38
128000	9	48	45	45	43	42	44.6
128000	11	47	44	43	42	41	43.4
128000	12	46	43	42	41	41	42.6
160000	2	48	46	43	42	41	44
160000	3	50	47	44	43	42	45.2
160000	5	47	44	41	41	40	42.6
160000	6	47	44	42	40	39	42.4
160000	8	46	45	43	41	40	43
160000	9	45	43	40	38	37	40.6
160000	11	46	44	41	41	38	42
160000	12	50	48	44	43	42	45.4
160000	1	45	42	40	29	37	38.6
160000	4	38	45	35	34	32	36.8
160000	7	40	38	36	36	35	37
160000	10	42	39	37	36	35	37.8

Trial 2: JFA 12.5mm SR and WVP W1-RAP Specimens (Top Surfaces)

Table 46: BPN Measurements for Trial 2 JFA 12.5mm SR and WVP W1-RAP (Top Surface) Specimens Polished with Burris B55A Tires at Low Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 8% VTM	0	1T	81	81	77	77	**79.0**	
	0	2T	77	75	77	77	**76.5**	
	0	3T	81	80	77	76	**78.5**	**78.0**
JFA 12.5mm Skid-RAP 4% VTM	0	4T	84	82	82	81	**82.3**	
	0	5T	85	85	84	81	**83.8**	
	0	6T	77	76	76	75	**76.0**	**80.7**
WV Paving W1-RAP 4% VTM	0	7T	86	78	84	82	**82.5**	
	0	8T	85	82	79	77	**80.8**	
	0	9T	85	85	84	83	**84.3**	**82.5**
WV Paving W1-RAP 8% VTM	0	10T	88	81	80	83	**83.0**	
	0	11T	88	87	85	83	**85.8**	
	0	12T	84	83	82	81	**82.5**	**83.8**
JFA 12.5mm Skid-RAP 8% VTM	8000	1T	65	62	59	61	**61.8**	
	8000	2T	60	58	58	57	**58.3**	
	8000	3T	63	60	55	54	**58.0**	**59.3**
JFA 12.5mm Skid-RAP 4% VTM	8000	4T	58	49	50	55	**53.0**	
	8000	5T	59	56	56	56	**56.8**	
	8000	6T	57	58	57	54	**56.5**	**55.4**
WV Paving W1-RAP 4% VTM	8000	7T	64	61	59	56	**60.0**	
	8000	8T	64	60	60	59	**60.8**	
	8000	9T	64	62	58	61	**61.3**	**60.7**
WV Paving W1-RAP 8% VTM	8000	10T	65	62	61	58	**61.5**	
	8000	11T	63	62	62	60	**61.8**	
	8000	12T	63	63	61	60	**61.8**	**61.7**
JFA 12.5mm Skid-RAP 8% VTM	16000	1T	56	56	55	55	**56**	
	16000	2T	53	52	51	50	**52**	
	16000	3T	56	56	50	54	**54**	**53.7**
JFA 12.5mm Skid-RAP 4% VTM	16000	4T	43	45	49	49	**47**	
	16000	5T	55	51	49	52	**52**	
	16000	6T	51	49	49	52	**50**	**51.1**
	16000	7T	59	54	55	55	**56**	

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
WV Paving W1-RAP 4% VTM	16000	8T	56	55	55	54	**55**	
	16000	9T	59	54	54	52	**55**	**55.2**
WV Paving W1-RAP 8% VTM	16000	10T	58	55	56	55	**56**	
	16000	11T	60	56	58	57	**58**	
	16000	12T	59	51	52	55	**54**	**56.0**
JFA 12.5mm Skid-RAP 8% VTM	32000	1T	55	54	53	53	**53.8**	
	32000	2T	50	49	49	48	**49.0**	
	32000	3T	52	50	49	48	**49.8**	**50.8**
JFA 12.5mm Skid-RAP 4% VTM	32000	4T	52	51	50	49	**50.5**	
	32000	5T	51	50	49	48	**49.5**	
	32000	6T	51	49	48	48	**49.0**	**49.7**
WV Paving W1-RAP 4% VTM	32000	7T	55	53	52	51	**52.8**	
	32000	8T	55	53	52	52	**53.0**	
	32000	9T	54	52	52	52	**52.5**	**52.8**
WV Paving W1-RAP 8% VTM	32000	10T	56	54	54	53	**54.3**	
	32000	11T	55	51	52	52	**52.5**	
	32000	12T	55	56	54	54	**54.8**	**53.8**
JFA 12.5mm Skid-RAP 8% VTM	48000	1T	54	52	50	50	**51.5**	
	48000	2T	50	48	47	46	**47.8**	
	48000	3T	52	50	48	47	**49.3**	**49.5**
JFA 12.5mm Skid-RAP 4% VTM	48000	4T	51	48	47	46	**48.0**	
	48000	5T	48	46	45	44	**45.8**	
	48000	6T	50	48	46	46	**47.5**	**47.1**
WV Paving W1-RAP 4% VTM	48000	7T	54	52	50	49	**51.3**	
	48000	8T	54	52	51	50	**51.8**	
	48000	9T	52	49	48	48	**49.3**	**50.8**
WV Paving W1-RAP 8% VTM	48000	10T	54	52	51	50	**51.8**	
	48000	11T	53	51	49	48	**50.3**	
	48000	12T	58	56	55	54	**55.8**	**52.6**

Trial 3: JFA 12.5mm SR and WVP W1-RAP Specimens (Bottom Surfaces)

Table 47: BPN Measurements for Trial 3 JFA 12.5mm SR and WVP W1-RAP (Bottom Surface) Specimens Polished with Burris B55A Tires at High Toe for 80,000 Wheel Passes

Mix Type	Number of Wheel Passes	Sample	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 8% VTM	0	1B	72	72	69	70	**70.8**	
	0	2B	72	72	71	70	**71.3**	
	0	3B	72	70	69	67	**69.5**	**70.5**
JFA 12.5mm Skid-RAP 4% VTM	0	4B	73	71	70	69	**70.8**	
	0	5B	75	75	74	73	**74.3**	
	0	6B	69	67	67	67	**67.5**	**70.8**
WV Paving W1-RAP 4% VTM	0	7B	80	79	78	77	**78.5**	
	0	8B	79	77	77	75	**77.0**	
	0	9B	80	79	77	73	**77.3**	**77.6**
WV Paving W1-RAP 8% VTM	0	10B	83	81	80	77	**80.3**	
	0	11B	75	74	73	73	**73.8**	
	0	12B	74	73	70	72	**72.3**	**75.4**
JFA 12.5mm Skid-RAP 8% VTM	8000	1B	54	52	51	50	**51.8**	
	8000	2B	55	54	53	52	**53.5**	
	8000	3B	55	54	53	53	**53.8**	**53.0**
JFA 12.5mm Skid-RAP 4% VTM	8000	4B	54	52	51	51	**52.0**	
	8000	5B	56	54	54	53	**54.3**	
	8000	6B	54	53	52	52	**52.8**	**53.0**
WV Paving W1-RAP 4% VTM	8000	7B	60	58	58	57	**58.3**	
	8000	8B	57	56	55	55	**55.8**	
	8000	9B	61	59	58	58	**59.0**	**57.7**
WV Paving W1-RAP 8% VTM	8000	10B	58	56	56	55	**56.3**	
	8000	11B	60	59	58	57	**58.5**	
	8000	12B	59	57	56	56	**57.0**	**57.3**
JFA 12.5mm Skid-RAP 8% VTM	16000	1B	51	49	48	48	**49.0**	
	16000	2B	51	50	48	48	**49.3**	
	16000	3B	51	49	48	47	**48.8**	**49.0**
JFA 12.5mm Skid-RAP 4% VTM	16000	4B	50	48	48	47	**48.3**	
	16000	5B	53	52	51	50	**51.5**	
	16000	6B	50	48	48	47	**48.3**	**50.6**
	16000	7B	56	55	54	53	**54.5**	

Mix Type	Number of Wheel Passes	Sample	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
WV Paving W1-RAP 4% VTM	16000	8B	54	52	52	51	**52.3**	
	16000	9B	56	55	54	53	**54.5**	**53.8**
WV Paving W1-RAP 8% VTM	16000	10B	55	53	52	51	**52.8**	
	16000	11B	54	53	52	52	**52.8**	
	16000	12B	54	53	53	52	**53.0**	**52.8**
JFA 12.5mm Skid-RAP 8% VTM	32000	1B	49	48	47	46	**47.5**	
	32000	2B	54	52	51	50	**51.8**	
	32000	3B	52	51	49	49	**50.3**	**49.8**
JFA 12.5mm Skid-RAP 4% VTM	32000	4B	50	48	47	47	**48.0**	
	32000	5B	51	50	48	48	**49.3**	
	32000	6B	50	48	47	46	**47.8**	**48.3**
WV Paving W1-RAP 4% VTM	32000	7B	53	52	50	49	**51.0**	
	32000	8B	53	51	50	49	**50.8**	
	32000	9B	54	52	52	51	**52.3**	**51.3**
WV Paving W1-RAP 8% VTM	32000	10B	53	51	50	49	**50.8**	
	32000	11B	53	52	51	50	**51.5**	
	32000	12B	53	52	51	50	**51.5**	**51.3**
JFA 12.5mm Skid-RAP 8% VTM	48000	1B	51	49	48	46	**48.5**	
	48000	2B	51	48	47	46	**48.0**	
	48000	3B	52	49	48	47	**49.0**	**48.5**
JFA 12.5mm Skid-RAP 4% VTM	48000	4B	47	45	44	43	**44.8**	
	48000	5B	50	48	47	46	**47.8**	
	48000	6B	50	48	47	46	**47.8**	**46.8**
WV Paving W1-RAP 4% VTM	48000	7B	52	50	48	47	**49.3**	
	48000	8B	51	49	48	47	**48.8**	
	48000	9B	51	49	48	48	**49.0**	**49.0**
WV Paving W1-RAP 8% VTM	48000	10B	52	49	48	48	**49.3**	
	48000	11B	53	50	49	48	**50.0**	
	48000	12B	52	50	49	48	**49.8**	**49.7**
JFA 12.5mm Skid-RAP 8% VTM	64000	1B	52	49	47	46	**48.5**	
	64000	2B	53	49	48	47	**49.3**	
	64000	3B	50	48	47	46	**47.8**	**48.5**
JFA 12.5mm Skid-RAP 4% VTM	64000	4B	54	51	49	47	**50.3**	
	64000	5B	49	48	47	46	**47.5**	
	64000	6B	47	46	45	45	**45.8**	**47.8**
WV Paving W1-RAP 4% VTM	64000	7B	55	52	49	47	**50.8**	
	64000	8B	53	50	48	47	**49.5**	

Mix Type	Number of Wheel Passes	Sample	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
	64000	9B	55	52	51	49	**51.8**	**50.7**
WV Paving W1-RAP 8% VTM	64000	10B	53	50	48	47	**49.5**	
	64000	11B	53	50	48	47	**49.5**	
	64000	12B	53	51	49	47	**50.0**	**49.7**
JFA 12.5mm Skid-RAP 8% VTM	80000	1B	55	52	49	47	**50.8**	
	80000	2B	57	53	51	49	**52.5**	
	80000	3B	57	53	50	49	**52.3**	**51.8**
JFA 12.5mm Skid-RAP 4% VTM	80000	4B	55	52	49	48	**51.0**	
	80000	5B	56	53	50	48	**51.8**	
	80000	6B	57	54	51	49	**52.8**	**51.8**
WV Paving W1-RAP 4% VTM	80000	7B	54	50	48	47	**49.8**	
	80000	8B	55	52	49	48	**51.0**	
	80000	9B	54	51	48	47	**50.0**	**50.3**
WV Paving W1-RAP 8% VTM	80000	10B	56	52	50	48	**51.5**	
	80000	11B	53	50	48	47	**49.5**	
	80000	12B	55	52	50	48	**51.3**	**50.8**

Trial 4: WVP 12.5mm SR and Greer W1H Specimens (Top Surfaces)

Table 48: BPN Measurements for Trial 4 WVP 12.5mm SR and Greer W1H (Top Surface) Specimens Polished with Hoosier R80 Tires at High Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
Greer W1 Heavy 8% VTM	0	13T	83	82	81	80	**81.5**	
	0	14T	84	84	83	82	**83.3**	
	0	15T	82	81	80	80	**80.8**	**81.8**
Greer W1 Heavy 4% VTM	0	16T	85	84	84	83	**84.0**	
	0	17T	88	88	87	86	**87.3**	
	0	18T	85	85	83	82	**83.8**	**85.0**
WV Paving 12.5mm Skid-RAP 4% VTM	0	19T	85	83	83	81	**83.0**	
	0	20T	87	85	84	82	**84.5**	
	0	21T	85	85	83	83	**84.0**	**83.8**
	0	22T	86	86	85	84	**85.3**	

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
WV Paving 12.5mm Skid-RAP 8% VTM	0	23T	88	89	88	87	**88.0**	
	0	24T	86	85	84	82	**84.3**	**85.8**
Greer W1 Heavy 8% VTM	8000	13T	55	54	53	53	**53.8**	
	8000	14T	55	54	54	54	**54.3**	
	8000	15T	53	53	52	52	**52.5**	**53.5**
Greer W1 Heavy 4% VTM	8000	16T	52	51	50	50	**50.8**	
	8000	17T	55	53	53	52	**53.3**	
	8000	18T	56	55	54	53	**54.5**	**52.8**
WV Paving 12.5mm Skid-RAP 4% VTM	8000	19T	57	56	55	54	**55.5**	
	8000	20T	58	56	55	55	**56.0**	
	8000	21T	57	56	55	54	**55.5**	**55.7**
WV Paving 12.5mm Skid-RAP 8% VTM	8000	22T	60	59	58	57	**58.5**	
	8000	23T	60	58	57	56	**57.8**	
	8000	24T	59	57	57	56	**57.3**	**57.8**
Greer W1 Heavy 8% VTM	16000	13T	50	49	48	47	**48.5**	
	16000	14T	50	49	49	48	**49.0**	
	16000	15T	52	51	50	50	**50.8**	**49.4**
Greer W1 Heavy 4% VTM	16000	16T	48	47	46	45	**46.5**	
	16000	17T	48	47	46	46	**46.8**	
	16000	18T	50	48	48	47	**48.3**	**47.2**
WV Paving 12.5mm Skid-RAP 4% VTM	16000	19T	52	51	50	50	**50.8**	
	16000	20T	52	51	50	49	**50.5**	
	16000	21T	52	51	49	49	**50.3**	**50.5**
WV Paving 12.5mm Skid-RAP 8% VTM	16000	22T	54	53	52	52	**52.8**	
	16000	23T	54	53	52	51	**52.5**	
	16000	24T	50	49	48	48	**48.8**	**51.3**
Greer W1 Heavy 8% VTM	32000	13T	47	47	46	45	**46.3**	
	32000	14T	47	46	46	45	**46.0**	
	32000	15T	51	49	48	48	**49.0**	**47.1**
Greer W1 Heavy 4% VTM	32000	16T	47	46	46	45	**46.0**	
	32000	17T	46	45	44	44	**44.8**	
	32000	18T	48	47	46	46	**46.8**	**45.8**
WV Paving 12.5mm Skid-RAP 4% VTM	32000	19T	48	47	46	46	**46.8**	
	32000	20T	48	48	47	46	**47.3**	
	32000	21T	53	51	50	49	**50.8**	**48.3**
WV Paving 12.5mm Skid-RAP 8% VTM	32000	22T	53	51	50	49	**50.8**	
	32000	23T	52	50	49	48	**49.8**	

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
	32000	24T	51	50	49	48	**49.5**	**50.0**
Greer W1 Heavy 8% VTM	48000	13T	45	43	42	42	**43.0**	
	48000	14T	45	44	43	42	**43.5**	
	48000	15T	47	45	44	43	**44.8**	**43.8**
Greer W1 Heavy 4% VTM	48000	16T	46	45	44	43	**44.5**	
	48000	17T	45	43	43	42	**43.3**	
	48000	18T	44	43	42	42	**42.8**	**43.5**
WV Paving 12.5mm Skid-RAP 4% VTM	48000	19T	48	47	45	45	**46.3**	
	48000	20T	48	46	45	44	**45.8**	
	48000	21T	50	48	47	46	**47.8**	**46.6**
WV Paving 12.5mm Skid-RAP 8% VTM	48000	22T	49	48	47	46	**47.5**	
	48000	23T	48	47	45	45	**46.3**	
	48000	24T	49	48	46	45	**47.0**	**46.9**

Trial 5: WVP 12.5mm SR and Greer W1H Specimens (Bottom Surfaces)

Table 49: BPN Measurements for Trial 5 WVP 12.5mm SR and Greer W1H (Bottom Surface) Specimens Polished with Hoosier R80 Tires at Low Toe for 64,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
Greer W1 Heavy 8% VTM	0	13B	77	75	76	74	**75.5**	
	0	14B	77	76	75	74	**75.5**	
	0	15B	76	76	75	74	**75.3**	**75.4**
Greer W1 Heavy 4% VTM	0	16B	77	77	77	75	**76.5**	
	0	17B	77	76	74	74	**75.3**	
	0	18B	77	77	76	75	**76.3**	**76.0**
WV Paving 12.5mm Skid-RAP 4% VTM	0	19B	79	78	77	77	**77.8**	
	0	20B	79	78	78	77	**78.0**	
	0	21B	77	77	77	75	**76.5**	**77.4**
WV Paving 12.5mm Skid-RAP 8% VTM	0	22B	80	81	80	79	**80.0**	
	0	23B	76	75	74	74	**74.8**	
	0	24B	79	79	77	77	**78.0**	**77.6**

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
Greer W1 Heavy 8% VTM	8000	13B	56	55	54	53	**54.5**	
	8000	14B	56	55	54	54	**54.8**	
	8000	15B	55	54	54	53	**54.0**	**54.4**
Greer W1 Heavy 4% VTM	8000	16B	53	52	52	52	**52.3**	
	8000	17B	55	54	54	53	**54.0**	
	8000	18B	56	55	54	54	**54.8**	**53.7**
WV Paving 12.5mm Skid-RAP 4% VTM	8000	19B	57	56	56	55	**56.0**	
	8000	20B	59	57	56	56	**57.0**	
	8000	21B	56	55	55	54	**55.0**	**56.0**
WV Paving 12.5mm Skid-RAP 8% VTM	8000	22B	56	56	55	55	**55.5**	
	8000	23B	56	55	54	54	**54.8**	
	8000	24B	56	56	55	54	**55.3**	**55.2**
Greer W1 Heavy 8% VTM	16000	13B	52	51	50	49	**50.5**	
	16000	14B	54	52	52	51	**52.3**	
	16000	15B	50	50	48	48	**49.0**	**50.6**
Greer W1 Heavy 4% VTM	16000	16B	51	50	49	49	**49.8**	
	16000	17B	53	52	51	50	**51.5**	
	16000	18B	52	52	50	50	**51.0**	**50.8**
WV Paving 12.5mm Skid-RAP 4% VTM	16000	19B	55	54	54	53	**54.0**	
	16000	20B	54	53	51	51	**52.3**	
	16000	21B	52	51	50	49	**50.5**	**52.3**
WV Paving 12.5mm Skid-RAP 8% VTM	16000	22B	54	53	52	52	**52.8**	
	16000	23B	52	51	50	50	**50.8**	
	16000	24B	53	52	51	50	**51.5**	**51.7**
Greer W1 Heavy 8% VTM	32000	13B	50	48	47	47	**48.0**	
	32000	14B	48	47	47	46	**47.0**	
	32000	15B	48	47	46	46	**46.8**	**47.3**
Greer W1 Heavy 4% VTM	32000	16B	49	48	47	47	**47.8**	
	32000	17B	49	48	47	47	**47.8**	
	32000	18B	48	47	47	46	**47.0**	**47.5**
WV Paving 12.5mm Skid-RAP 4% VTM	32000	19B	51	49	49	48	**49.3**	
	32000	20B	52	50	49	48	**49.8**	
	32000	21B	50	49	48	47	**48.5**	**49.2**
WV Paving 12.5mm Skid-RAP 8% VTM	32000	22B	50	47	47	46	**47.5**	
	32000	23B	50	48	47	47	**48.0**	
	32000	24B	48	47	46	46	**46.8**	**47.4**

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
Greer W1 Heavy 8% VTM	48000	13B	46	44	43	42	**43.8**	
	48000	14B	43	43	42	42	**42.5**	
	48000	15B	46	44	43	42	**43.8**	**43.3**
Greer W1 Heavy 4% VTM	48000	16B	45	43	42	42	**43.0**	
	48000	17B	44	43	42	42	**42.8**	
	48000	18B	45	43	42	42	**43.0**	**42.9**
WV Paving 12.5mm Skid-RAP 4% VTM	48000	19B	47	46	45	44	**45.5**	
	48000	20B	50	48	47	45	**47.5**	
	48000	21B	46	44	44	43	**44.3**	**45.8**
WV Paving 12.5mm Skid-RAP 8% VTM	48000	22B	46	44	43	42	**43.8**	
	48000	23B	45	44	43	42	**43.5**	
	48000	24B	47	46	45	45	**45.8**	**44.3**
Greer W1 Heavy 8% VTM	64000	13B	42	40	39	39	**40.0**	
	64000	14B	42	41	40	39	**40.5**	
	64000	15B	42	40	39	39	**40.0**	**40.2**
Greer W1 Heavy 4% VTM	64000	16B	41	39	39	37	**39.0**	
	64000	17B	40	38	37	37	**38.0**	
	64000	18B	40	38	38	37	**38.3**	**38.4**
WV Paving 12.5mm Skid-RAP 4% VTM	64000	19B	44	43	42	41	**42.5**	
	64000	20B	44	42	42	41	**42.3**	
	64000	21B	42	40	39	39	**40.0**	**41.6**
WV Paving 12.5mm Skid-RAP 8% VTM	64000	22B	43	41	40	39	**40.8**	
	64000	23B	45	42	41	40	**42.0**	
	64000	24B	44	42	41	41	**42.0**	**41.6**

Trial 6: JFA 12.5mm SR and WVP W1-RAP Specimens (Bottom Surfaces)

Table 50: BPN Measurements for Trial 6 JFA 12.5mm SR and WVP W1-RAP (Bottom Surface) Specimens Polished with Hoosier R80 Tires at Low Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 4% VTM	0	25B	78	79	79	77	**78.3**	
	0	26B	75	76	76	76	**75.8**	
	0	27B	78	75	76	80	**77.3**	**77.1**

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 8% VTM	0	28B	73	74	73	73	**73.3**	
	0	29B	77	77	80	80	**78.5**	
	0	30B	76	79	76	76	**76.8**	**76.2**
WV Paving W1-RAP 4% VTM	0	31B	85	86	87	87	**86.3**	
	0	32B	81	85	85	85	**84.0**	
	0	33B	86	86	86	85	**85.8**	**85.3**
WV Paving W1-RAP 8% VTM	0	34B	85	86	85	84	**85.0**	
	0	35B	83	82	82	81	**82.0**	
	0	36B	87	86	85	86	**86.0**	**84.3**
JFA 12.5mm Skid-RAP 4% VTM	8000	25B	58	56	56	56	**56.5**	
	8000	26B	58	57	57	56	**57.0**	
	8000	27B	58	56	56	55	**56.3**	**56.6**
JFA 12.5mm Skid-RAP 8% VTM	8000	28B	59	57	57	56	**57.3**	
	8000	29B	56	55	54	54	**54.8**	
	8000	30B	61	59	58	58	**59.0**	**57.0**
WV Paving W1-RAP 4% VTM	8000	31B	63	62	62	61	**62.0**	
	8000	32B	63	62	61	60	**61.5**	
	8000	33B	63	62	61	61	**61.8**	**61.8**
WV Paving W1-RAP 8% VTM	8000	34B	64	63	61	61	**62.3**	
	8000	35B	63	62	61	60	**61.5**	
	8000	36B	63	61	60	60	**61.0**	**61.6**
JFA 12.5mm Skid-RAP 4% VTM	16000	25B	53	52	51	51	**51.8**	
	16000	26B	52	51	51	50	**51.0**	
	16000	27B	54	52	52	51	**52.3**	**51.7**
JFA 12.5mm Skid-RAP 8% VTM	16000	28B	53	52	51	51	**51.8**	
	16000	29B	54	53	52	51	**52.5**	
	16000	30B	55	54	53	53	**53.8**	**53.1**
WV Paving W1-RAP 4% VTM	16000	31B	56	55	54	53	**54.5**	
	16000	32B	57	56	54	54	**55.3**	
	16000	33B	58	56	55	54	**55.8**	**55.2**
WV Paving W1-RAP 8% VTM	16000	34B	59	56	56	55	**56.5**	
	16000	35B	59	56	56	56	**56.8**	
	16000	36B	58	57	56	56	**56.8**	**56.7**
JFA 12.5mm Skid-RAP 4% VTM	32000	25B	50	48	48	47	**48.3**	
	32000	26B	52	50	49	48	**49.8**	
	32000	27B	52	50	50	49	**50.3**	**49.4**
	32000	28B	52	50	49	49	**50.0**	

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 8% VTM	32000	29B	52	51	50	49	**50.5**	
	32000	30B	54	53	53	52	**53.0**	**51.2**
WV Paving W1-RAP 4% VTM	32000	31B	55	53	53	52	**53.3**	
	32000	32B	54	52	52	51	**52.3**	
	32000	33B	54	53	52	51	**52.5**	**52.7**
WV Paving W1-RAP 8% VTM	32000	34B	55	53	53	52	**53.3**	
	32000	35B	55	54	53	52	**53.5**	
	32000	36B	56	55	53	53	**54.3**	**53.7**
JFA 12.5mm Skid-RAP 4% VTM	48000	25B	49	48	47	46	**47.5**	
	48000	26B	49	47	47	46	**47.3**	
	48000	27B	51	49	48	47	**48.8**	**47.8**
JFA 12.5mm Skid-RAP 8% VTM	48000	28B	52	50	49	48	**49.8**	
	48000	29B	51	50	48	47	**49.0**	
	48000	30B	52	50	48	47	**49.3**	**49.3**
WV Paving W1-RAP 4% VTM	48000	31B	53	51	50	49	**50.8**	
	48000	32B	51	49	48	47	**48.8**	
	48000	33B	52	51	50	49	**50.5**	**50.0**
WV Paving W1-RAP 8% VTM	48000	34B	53	51	50	49	**50.8**	
	48000	35B	53	51	49	48	**50.3**	
	48000	36B	51	49	48	47	**48.8**	**49.9**

Trial 7: JFA 12.5mm SR and WVP W1-RAP Specimens (Top Surfaces)

Table 51: BPN Measurements for Trial 7 JFA 12.5mm SR and WVP W1-RAP (Top Surface) Specimens Polished with Hoosier R80 Tires at High Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
JFA 12.5mm Skid-RAP 4% VTM	0	25T	74	74	73	73	**73.5**	
	0	26T	77	76	76	75	**76.0**	
	0	27T	74	73	72	71	**72.5**	**74.0**
JFA 12.5mm Skid-RAP 8% VTM	0	28T	80	79	77	78	**78.5**	
	0	29T	74	73	73	73	**73.3**	
	0	30T	76	74	75	75	**75.0**	**75.6**
WV Paving W1-RAP 4% VTM	0	31T	81	80	80	79	**80**	
	0	32T	80	82	82	83	**81.8**	

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
	0	33T	77	74	74	73	**74.5**	**78.8**
WV Paving W1-RAP 8% VTM	0	34T	82	82	80	80	**81.0**	
	0	35T	81	86	81	81	**82.3**	
	0	36T	79	82	81	81	**80.8**	**81.3**
JFA 12.5mm Skid-RAP 4% VTM	8000	25T	52	51	50	50	**50.8**	
	8000	26T	55	53	53	52	**53.3**	
	8000	27T	53	52	52	51	**52.0**	**52.0**
JFA 12.5mm Skid-RAP 8% VTM	8000	28T	53	51	51	50	**51.3**	
	8000	29T	53	52	52	51	**52.0**	
	8000	30T	53	52	51	51	**51.8**	**51.7**
WV Paving W1-RAP 4% VTM	8000	31T	57	56	55	54	**55.5**	
	8000	32T	57	56	55	54	**55.5**	
	8000	33T	57	55	54	54	**55.0**	**55.3**
WV Paving W1-RAP 8% VTM	8000	34T	55	54	53	53	**53.8**	
	8000	35T	57	56	55	55	**55.8**	
	8000	36T	53	55	55	54	**54.3**	**54.6**
JFA 12.5mm Skid-RAP 4% VTM	16000	25T	48	47	47	46	**47.0**	
	16000	26T	48	47	47	46	**47.0**	
	16000	27T	50	48	48	47	**48.3**	**47.4**
JFA 12.5mm Skid-RAP 8% VTM	16000	28T	48	47	47	46	**47.0**	
	16000	29T	49	47	47	47	**47.5**	
	16000	30T	49	47	47	47	**47.5**	**48.6**
WV Paving W1-RAP 4% VTM	16000	31T	54	53	52	51	**52.5**	
	16000	32T	52	50	49	48	**49.8**	
	16000	33T	53	51	51	49	**51.0**	**51.1**
WV Paving W1-RAP 8% VTM	16000	34T	51	50	48	47	**49.0**	
	16000	35T	56	51	53	53	**53.3**	
	16000	36T	52	50	49	48	**49.8**	**50.7**
JFA 12.5mm Skid-RAP 4% VTM	32000	25T	41	39	39	38	**39.3**	
	32000	26T	42	41	41	40	**41.0**	
	32000	27T	42	41	41	40	**41.0**	**40.4**
JFA 12.5mm Skid-RAP 8% VTM	32000	28T	40	40	39	39	**39.5**	
	32000	29T	42	41	40	40	**40.8**	
	32000	30T	41	41	40	40	**40.5**	**40.3**
WV Paving W1-RAP 4% VTM	32000	31T	42	40	40	40	**40.5**	
	32000	32T	43	42	41	41	**41.8**	
	32000	33T	43	42	41	41	**41.8**	**41.3**

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Mix Average
WV Paving W1-RAP 8% VTM	32000	34T	42	41	41	40	**41.0**	
	32000	35T	44	43	42	41	**42.5**	
	32000	36T	42	41	41	41	**41.3**	**41.6**
JFA 12.5mm Skid-RAP 4% VTM	48000	25T	42	41	40	38	**40.3**	
	48000	26T	41	41	40	38	**40.0**	
	48000	27T	42	41	41	40	**41.0**	**40.4**
JFA 12.5mm Skid-RAP 8% VTM	48000	28T	42	41	40	39	**40.5**	
	48000	29T	44	42	41	40	**41.8**	
	48000	30T	42	41	40	39	**40.5**	**40.9**
WV Paving W1-RAP 4% VTM	48000	31T	42	41	40	39	**40.5**	
	48000	32T	43	41	40	39	**40.8**	
	48000	33T	43	42	41	40	**41.5**	**40.9**
WV Paving W1-RAP 8% VTM	48000	34T	43	42	41	40	**41.5**	
	48000	35T	42	41	41	40	**41.0**	
	48000	36T	42	41	39	38	**40.0**	**40.8**

Trial 8: JFA 12.5mm SR Laboratory Compacted and Field Core Specimens

Table 52: BPN Measurements for Trial 8 JFA 12.5mm SR Laboratory Compacted and Field Core Specimens Polished with Hoosier R80 Tires at High Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	Specimen Type	British Pendulum Number (BPN)				
				Trial 1	Trial 2	Trial 3	Trial 4	Average
JFA 12.5mm Skid-RAP	0	1L	Lab	60	60	59	58	**59.3**
	0	1F	Field	63	61	61	59	**61.0**
	0	2L	Lab	57	56	54	54	**55.25**
	0	2F	Field	67	66	66	65	**66.0**
	0	3L	Lab	63	62	60	59	**61.0**
	0	3F	Field	75	73	72	71	**72.8**
	0	4L	Lab	56	55	53	53	**54.25**
	0	4F	Field	55	53	53	52	**53.3**
	0	5L	Lab	62	60	59	58	**59.8**
	0	5F	Field	56	54	53	52	**53.8**
	0	6L	Lab	70	67	66	65	**67.0**
	0	6F	Field	72	71	69	67	**69.8**

Mix Type	Number of Wheel Passes	Specimen	Specimen Type	British Pendulum Number (BPN)				
				Trial 1	Trial 2	Trial 3	Trial 4	Average
JFA 12.5mm Skid-RAP	8000	1L	Lab	47	46	45	45	**45.8**
	8000	1F	Field	48	47	46	46	**46.8**
	8000	2L	Lab	48	47	46	45	**46.5**
	8000	2F	Field	48	47	47	47	**47.3**
	8000	3L	Lab	49	47	47	47	**47.5**
	8000	3F	Field	49	47	47	47	**47.5**
	8000	4L	Lab	50	48	48	47	**48.3**
	8000	4F	Field	46	45	45	44	**45.0**
	8000	5L	Lab	49	48	47	47	**47.8**
	8000	5F	Field	48	47	46	46	**46.8**
	8000	6L	Lab	49	48	47	47	**47.8**
	8000	6F	Field	50	47	47	47	**47.8**
JFA 12.5mm Skid-RAP	24000	1L	Lab	46	44	43	43	**44**
	24000	1F	Field	46	45	43	43	**44.25**
	24000	2L	Lab	43	42	42	41	**42.0**
	24000	2F	Field	46	44	43	42	**43.75**
	24000	3L	Lab	45	43	42	42	**43.0**
	24000	3F	Field	45	43	43	42	**43.3**
	24000	4L	Lab	46	44	43	42	**43.8**
	24000	4F	Field	45	43	42	42	**43.0**
	24000	5L	Lab	46	45	45	44	**45.0**
	24000	5F	Field	45	44	43	42	**43.5**
	24000	6L	Lab	48	47	46	45	**46.5**
	24000	6F	Field	46	45	43	43	**44.3**
JFA 12.5mm Skid-RAP	48000	1L	Lab	44	42	41	41	**42**
	48000	1F	Field	46	44	42	42	**43.5**
	48000	2L	Lab	42	41	41	39	**40.75**
	48000	2F	Field	46	44	43	42	**43.75**
	48000	3L	Lab	44	42	42	41	**42.25**
	48000	3F	Field	45	43	42	41	**42.75**
	48000	4L	Lab	46	44	42	42	**43.5**
	48000	4F	Field	44	42	42	40	**42**
	48000	5L	Lab	45	43	41	41	**42.5**
	48000	5F	Field	46	44	42	42	**43.5**
	48000	6L	Lab	44	43	42	41	**42.5**
	48000	6F	Field	45	43	42	41	**42.75**

Trial 9: JFA 12.5mm SR Field Core Specimens and Corresponding Field Measurements

Table 53: BPN Measurements for Trial 9 JFA 12.5mm SR Field Core Specimens Polished with Hoosier R80 Tires at High Toe for 48,000 Wheel Passes

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)				
			Trial 1	Trial 2	Trial 3	Trial 4	Average
JFA 12.5mm Skid-RAP I79 Field Cores	0	D1	63	60	57	56	**59.0**
	0	D2	51	48	47	46	**48.0**
	0	D3	54	51	49	48	**50.5**
	0	D4	53	51	50	49	**50.8**
	0	D5	54	52	50	49	**51.3**
Dummy Samples	0	T2 (JFA)	77	77	78	77	**77.3**
	0	T5 (WVP W1)	72	72	72	71	**71.8**
	0	T6 (WVP W1)	86	85	87	86	**86.0**
	0	T11 (WVP 12.5)	77	78	78	77	**77.5**
	0	T14 (WVP 12.5)	82	84	85	84	**83.8**
	0	S8G (Greer)	74	72	71	70	**71.8**
	0	S11G (Greer)	74	73	73	72	**73.0**
JFA 12.5mm Skid-RAP I79 Field Cores	8000	D1	52	50	48	48	**49.5**
	8000	D2	49	47	47	46	**47.3**
	8000	D3	50	47	47	47	**47.8**
	8000	D4	50	48	48	48	**48.5**
	8000	D5	50	49	48	48	**48.8**
Dummy Samples	8000	T2 (JFA)	51	49	48	48	**49.0**
	8000	T5 (WVP W1)	57	55	54	54	**55.0**
	8000	T6 (WVP W1)	58	52	51	51	**53.0**
	8000	T11 (WVP 12.5)	55	53	53	52	**53.3**
	8000	T14 (WVP 12.5)	55	53	52	52	**53.0**
	8000	S8G (Greer)	51	50	49	49	**49.8**
	8000	S11G (Greer)	48	47	47	47	**47.3**
JFA 12.5mm Skid-RAP I79 Field Cores	24000	D1	48	46	46	45	**46.3**
	24000	D2	46	46	44	44	**45**
	24000	D3	45	43	42	42	**43.0**
	24000	D4	47	46	45	44	**45.5**

Mix Type	Number of Wheel Passes	Specimen	British Pendulum Number (BPN)				
			Trial 1	Trial 2	Trial 3	Trial 4	Average
	24000	D5	47	45	45	44	**45.3**
Dummy Samples	24000	T2 (JFA)	47	46	46	45	**46.0**
	24000	T5 (WVP W1)	50	48	48	47	**48.3**
	24000	T6 (WVP W1)	51	49	48	48	**49.0**
	24000	T11 (WVP 12.5)	52	50	49	48	**49.8**
	24000	T14 (WVP 12.5)	53	52	51	51	**51.8**
	24000	S8G (Greer)	48	46	46	46	**46.5**
	24000	S11G (Greer)	47	46	46	45	**46.0**
JFA 12.5mm Skid-RAP I79 Field Cores	48000	D1	43	43	41	41	**42**
	48000	D2	43	42	42	41	**42**
	48000	D3	42	40	39	39	**40**
	48000	D4	42	40	40	39	**40.3**
	48000	D5	42	41	40	39	**40.5**
Dummy Samples	48000	T2 (JFA)	41	40	39	38	**39.5**
	48000	T5 (WVP W1)	47	46	45	44	**45.5**
	48000	T6 (WVP W1)	45	43	43	42	**43.3**
	48000	T11 (WVP 12.5)	47	45	44	44	**45.0**
	48000	T14 (WVP 12.5)	46	45	44	44	**44.8**
	48000	S8G (Greer)	42	41	41	41	**41.3**
	48000	S11G (Greer)	41	40	39	38	**39.5**

Trial 10: JFA 12.5mm SR I-79 Field Measurements

Table 54: BPN Measurements for Trial 9 JFA 12.5mm SR I-79 Field Locations

			British Pendulum Number (BPN)						
Location /Core Number	**Downhill/Uphill**	**Location on Lane**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Avg.**	**Lane Avg.**	**Uphill/ Downhill Avg.**
D1	Flat Curve	Right Wheel Path	76	72	73	72	73.25	74.5	**74.5**
		Center	75	76	76	76	75.75		
D2	Uphill	Left Wheel Path	86	84	82	80	83	84.5	**69.9**

			British Pendulum Number (BPN)						
Location /Core Number	**Downhill/Up hill**	**Location on Lane**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Avg.**	**Lane Avg.**	**Uphill/ Downhill Avg.**
		Center	86	86	86	86	86		
	Downhill	Left Wheel Path	56	55	54	54	54.75	55.4	
		Center	56	55	56	57	56		
D3	Uphill	Left Wheel Path	77	75	74	74	75	74.1	**67.4**
		Center	74	74	73	72	73.25		
	Downhill	Left Wheel Path	61	62	61	60	61	60.6	
		Center	61	60	60	60	60.25		
D4	Downhill	Right Wheel Path	55	55	54	53	54.25	55.5	**73.5**
		Center	57	57	57	56	56.75		
	Uphill	Right Wheel Path	93	92	91	92	92	91.5	
		Center	92	92	90	90	91		
D5	Downhill	Right Wheel Path	77	76	75	74	75.5	76.3	**86.3**
		Center	77	77	77	77	77		
	Uphill	Right Wheel Path	96	95	95	94	95	96.4	
		Center	97	99	98	97	97.75		

Appendix E: BPN Analysis

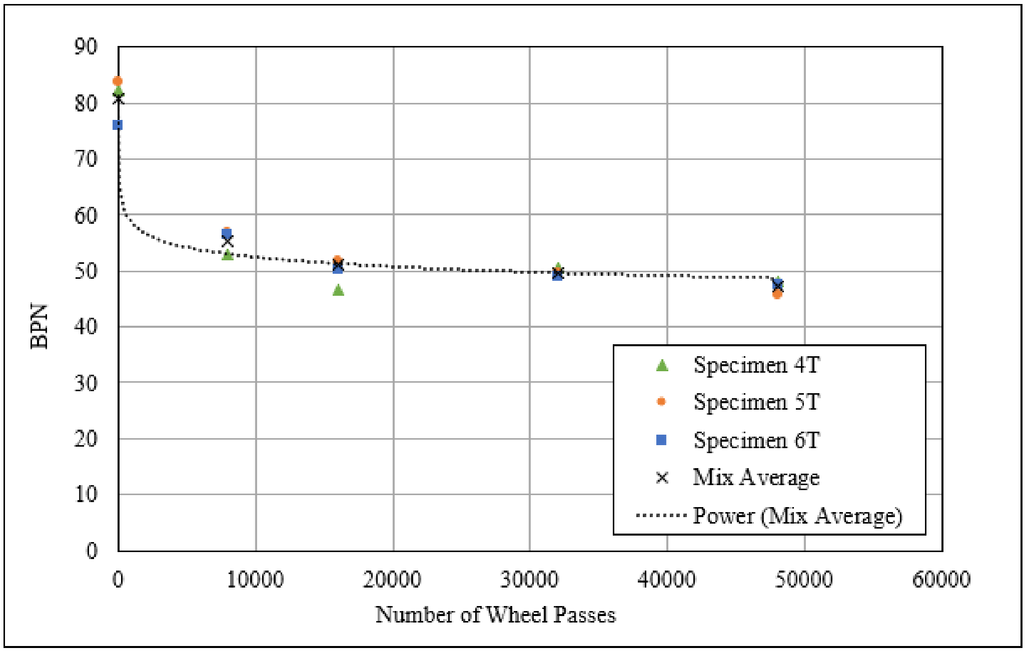


Figure 31: *Trial 2 Average BPN Trend for JFA 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

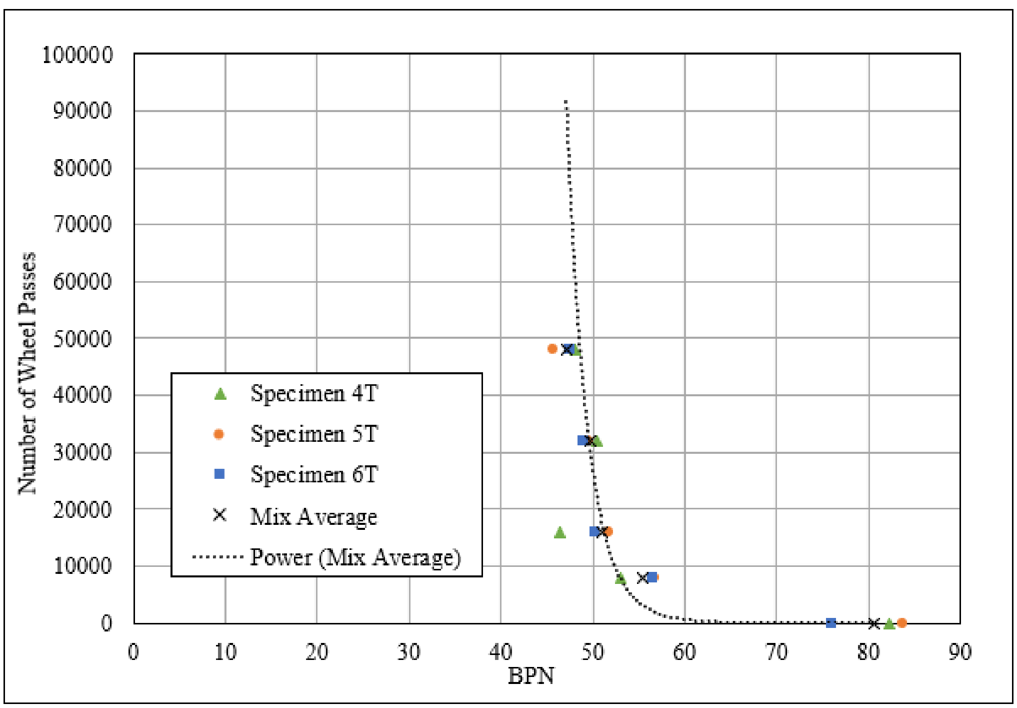


Figure 32: *Trial 2 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

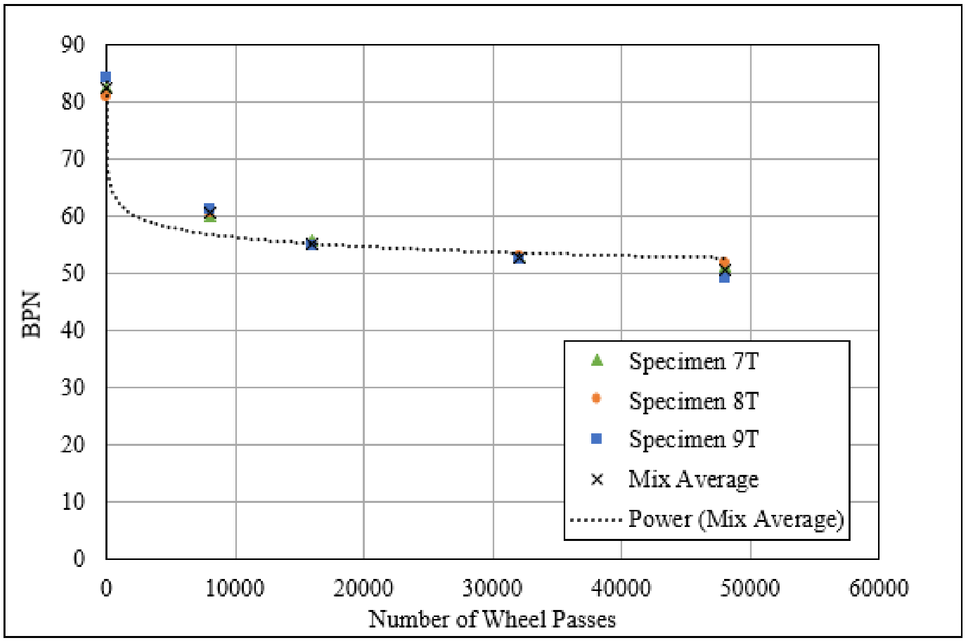


Figure 33*: Trial 2 Average BPN Trend for WVP W1-RAP Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

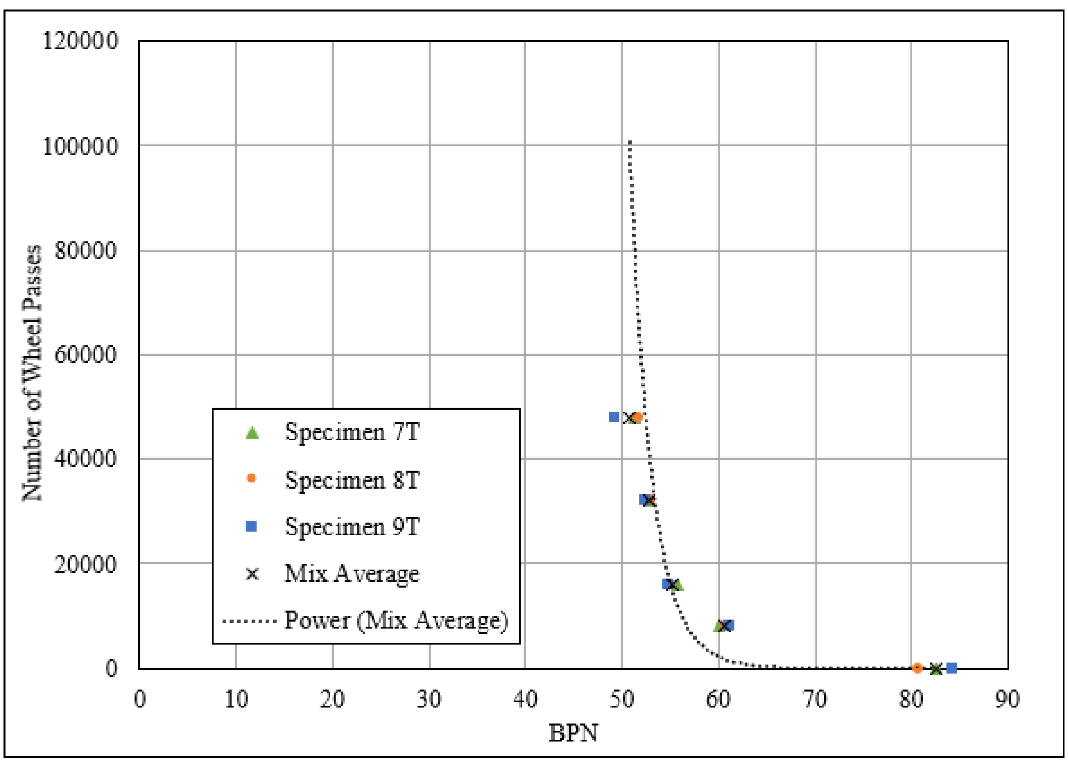


Figure 34*: Trial 2 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

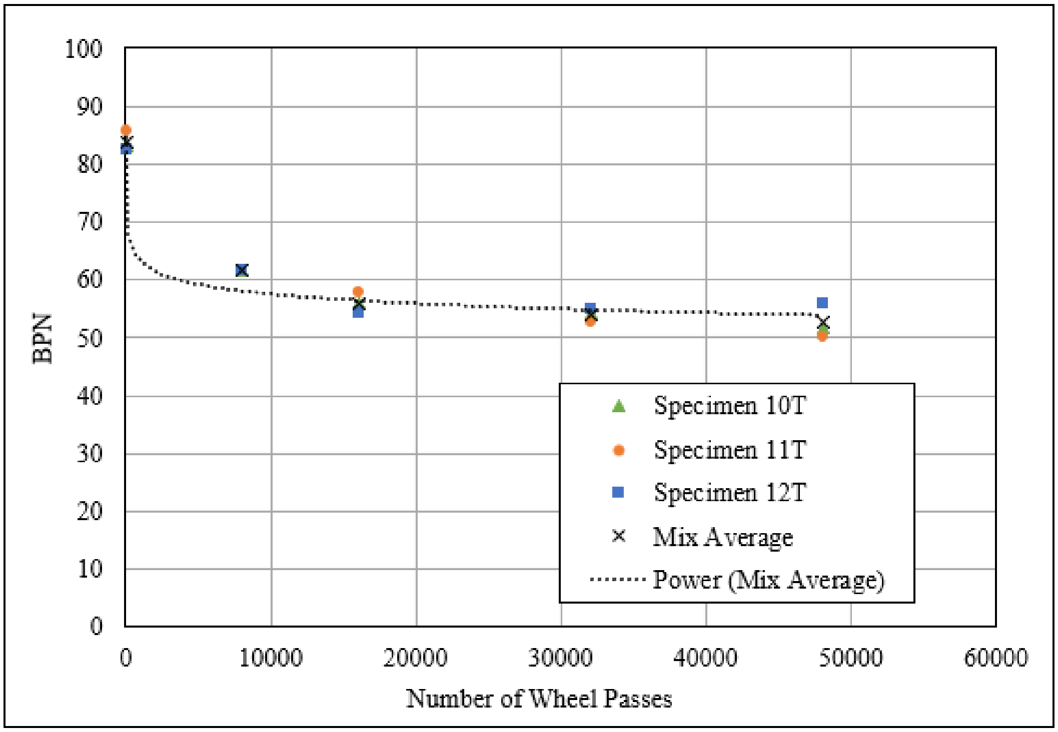


Figure 35*: Trial 2 Average BPN Trend for WVP W1-RAP Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

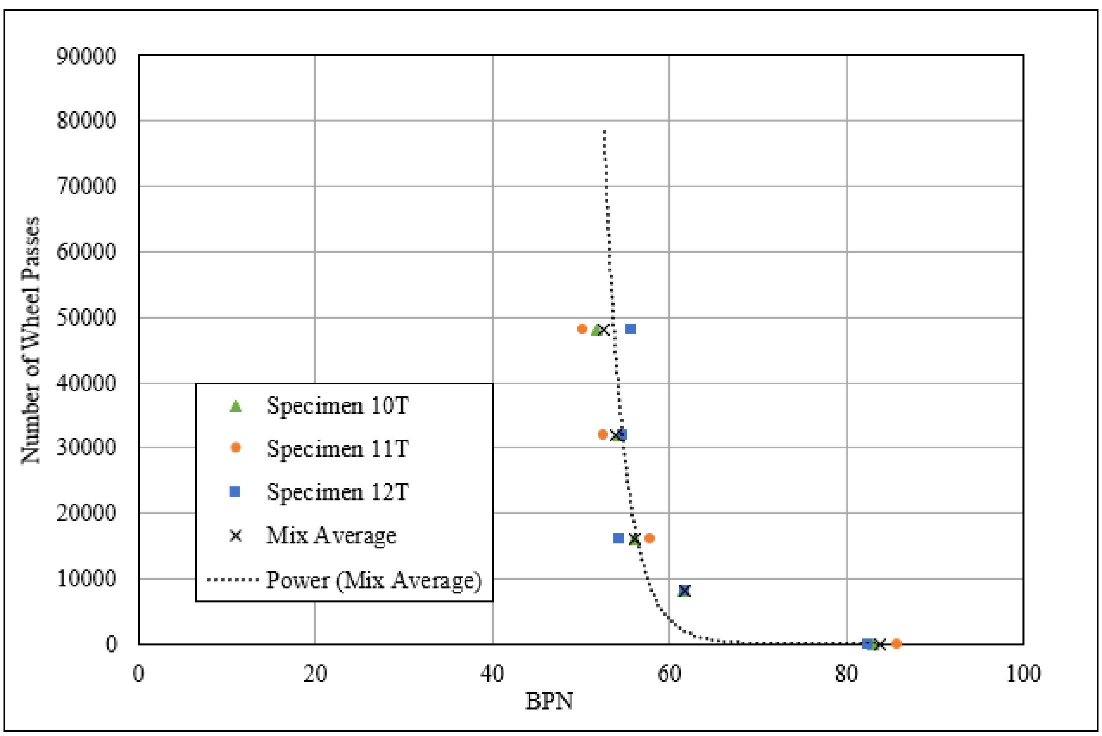


Figure 36*: Trial 2 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

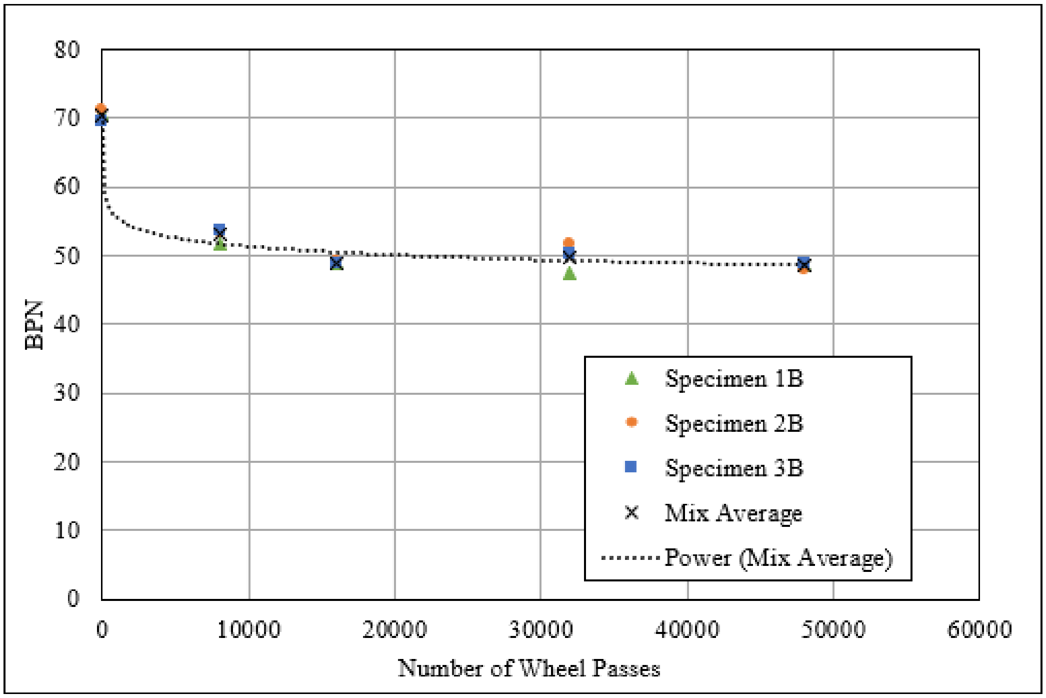


Figure 37: *Trial 3 Average BPN Trend for JFA 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

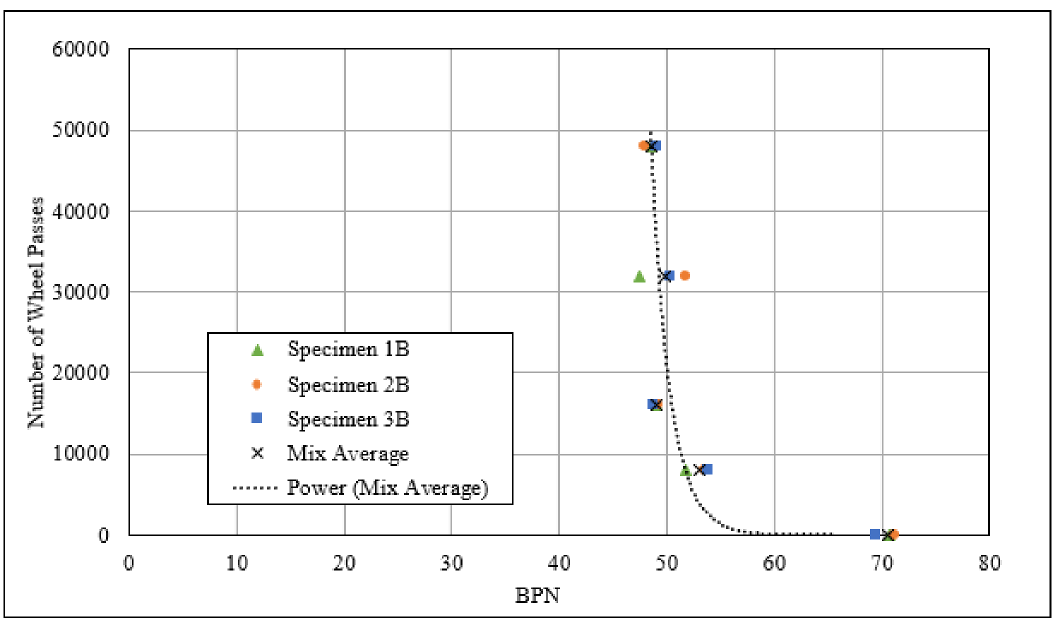


Figure 38: *Trial 3 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

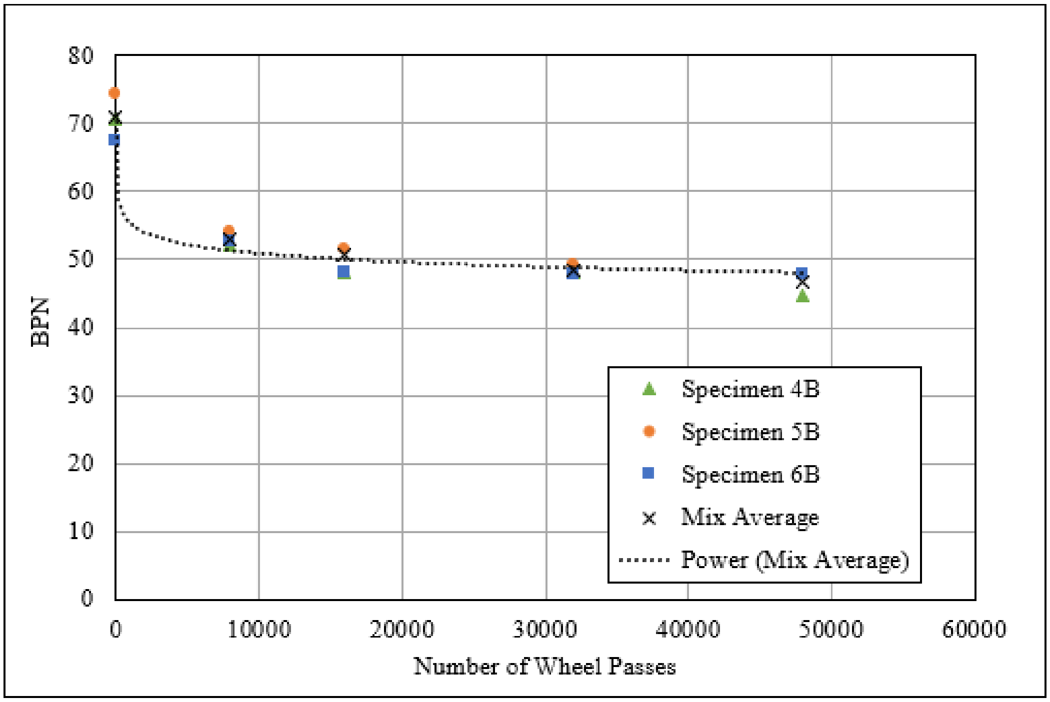


***Figure 39**: Trial 3 Average BPN Trend for JFA 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

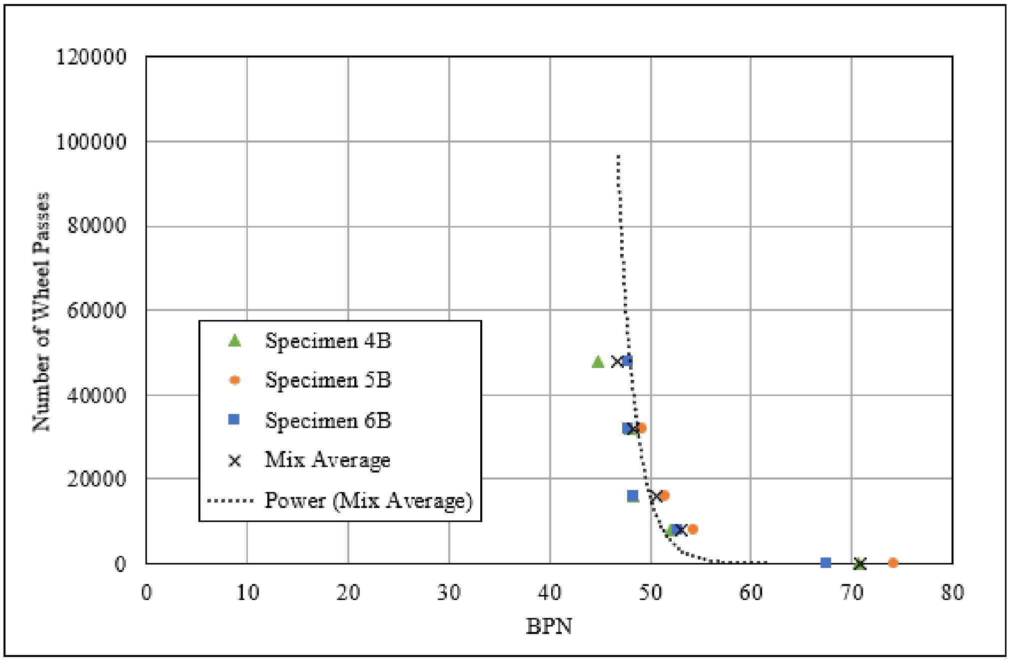


***Figure 40**: Trial 3 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

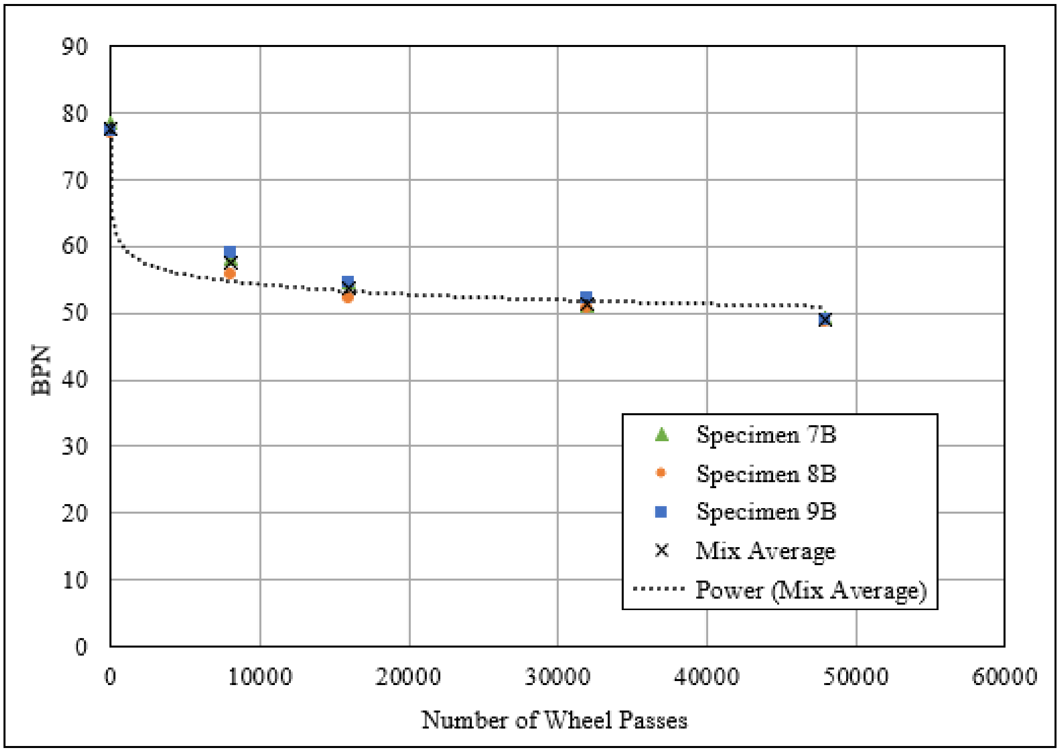


Figure 41*: Trial 3 Average BPN Trend for WVP W1-RAP Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

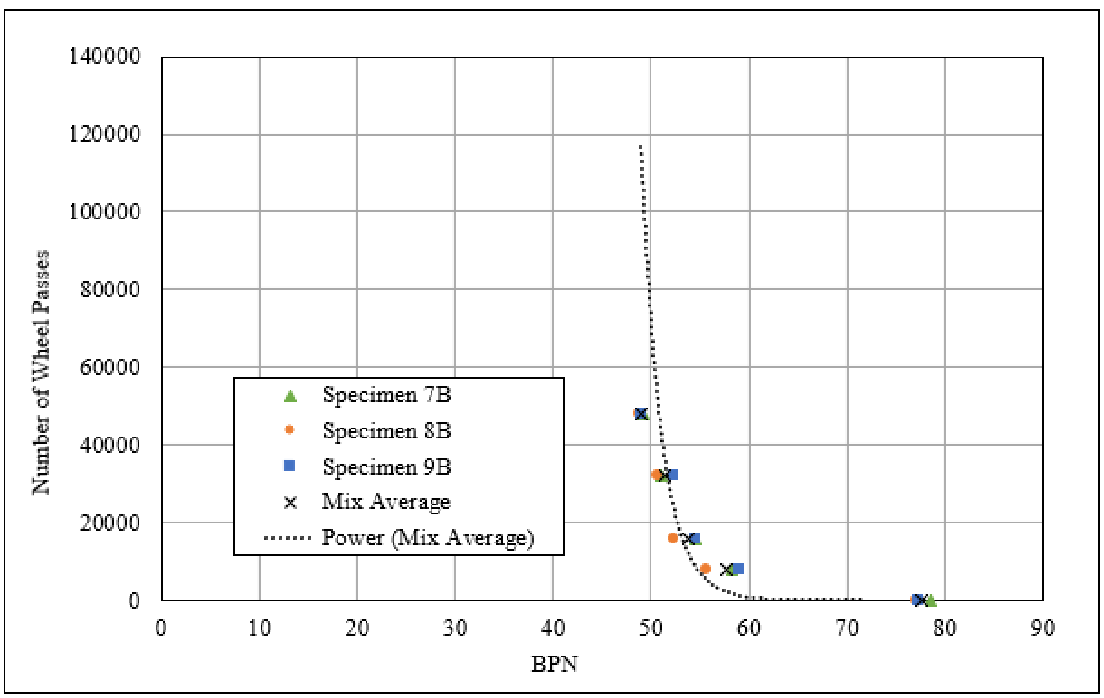


Figure 42*: Trial 3 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

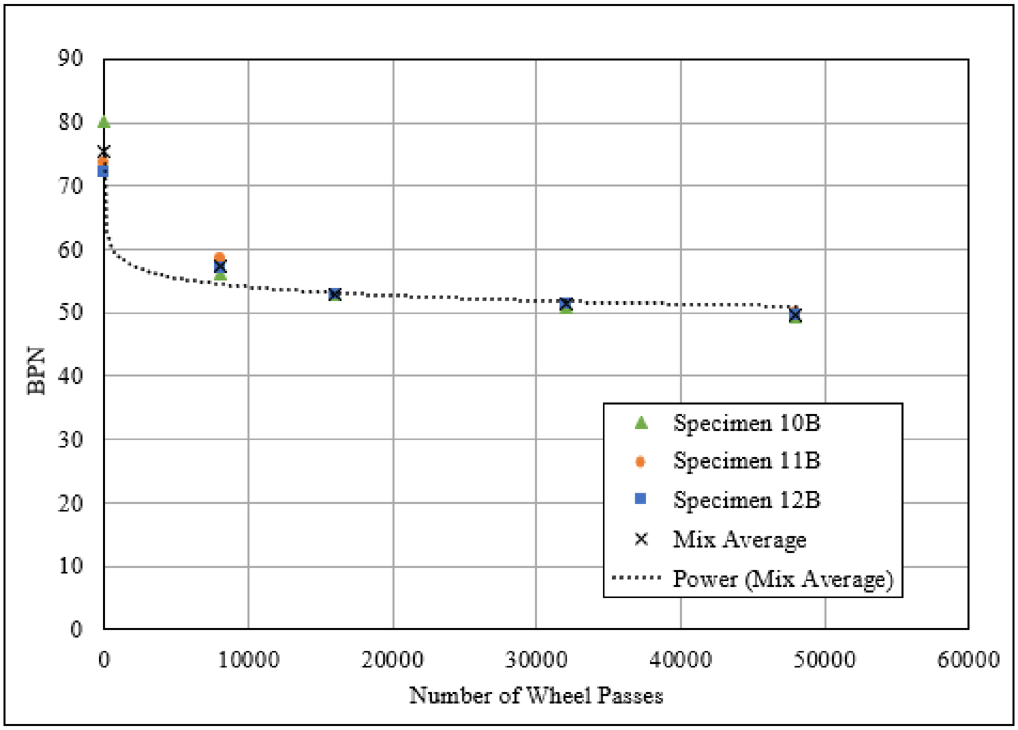


***Figure 43**: Trial 3 Average BPN Trend for WVP W1-RAP Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

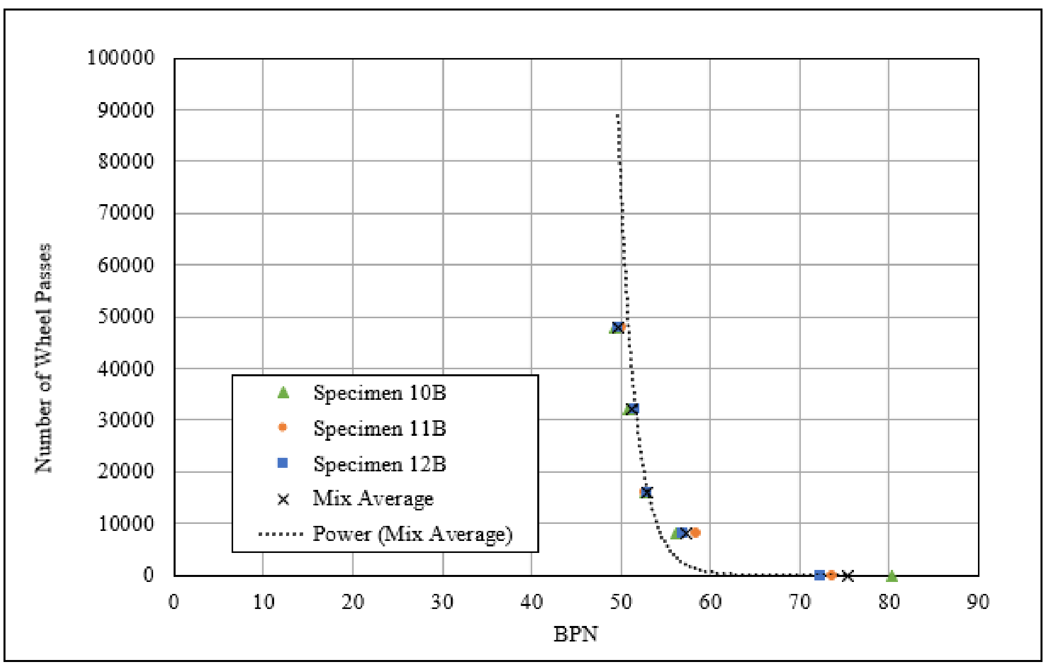


***Figure 44**: Trial 3 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

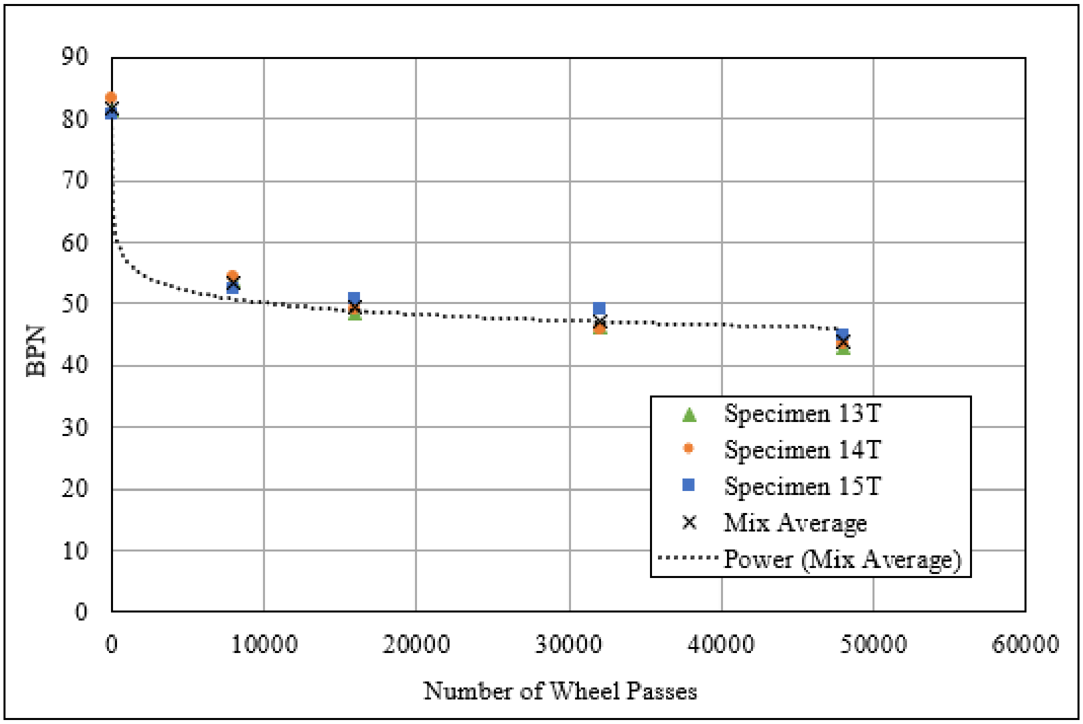


Figure 45: *Trial 4 Average BPN Trend for Greer W1H Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

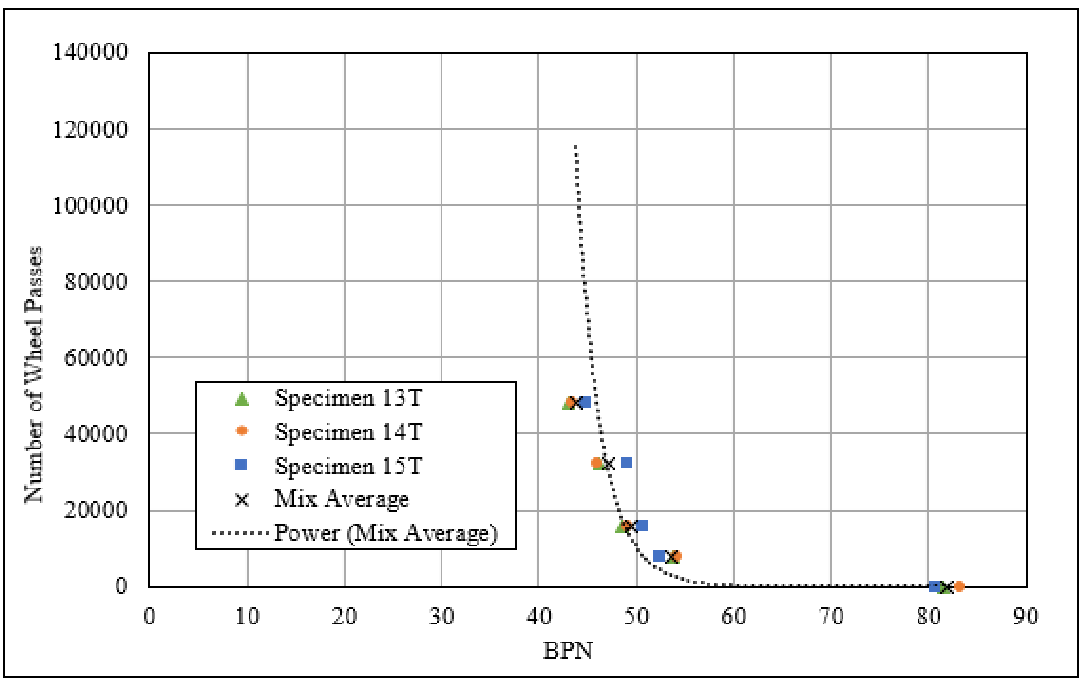


Figure 46: *Trial 4 Prediction of Required Wheel Passes at BPN Limits for Greer W1H Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

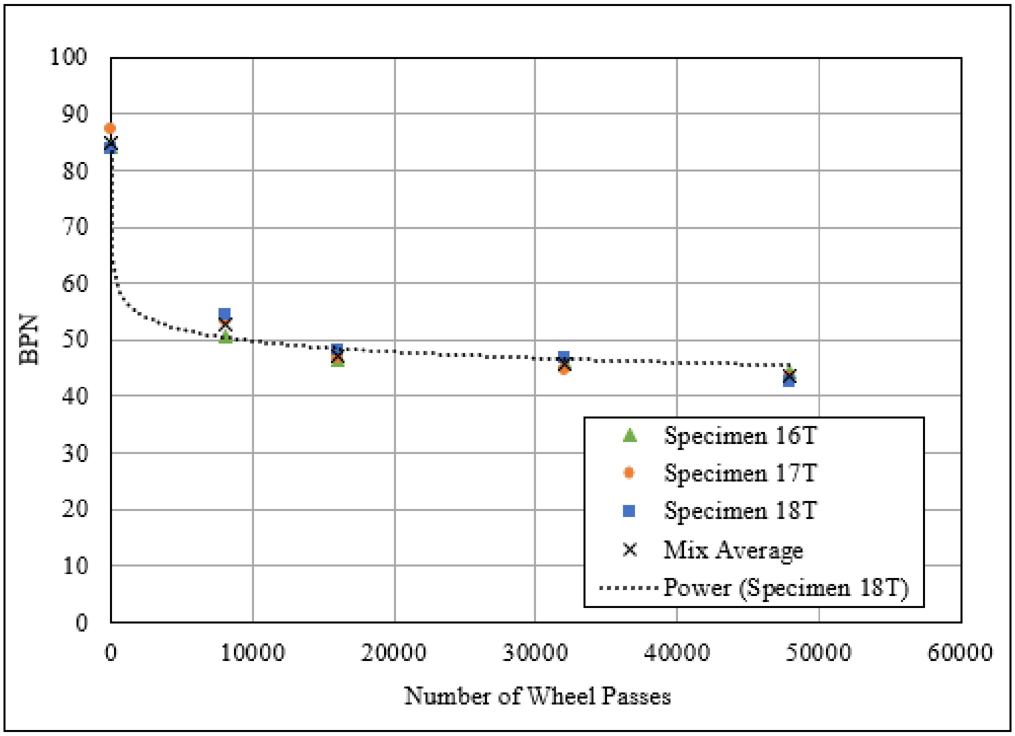


***Figure 47**: Trial 4 Average BPN Trend for Greer W1H Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

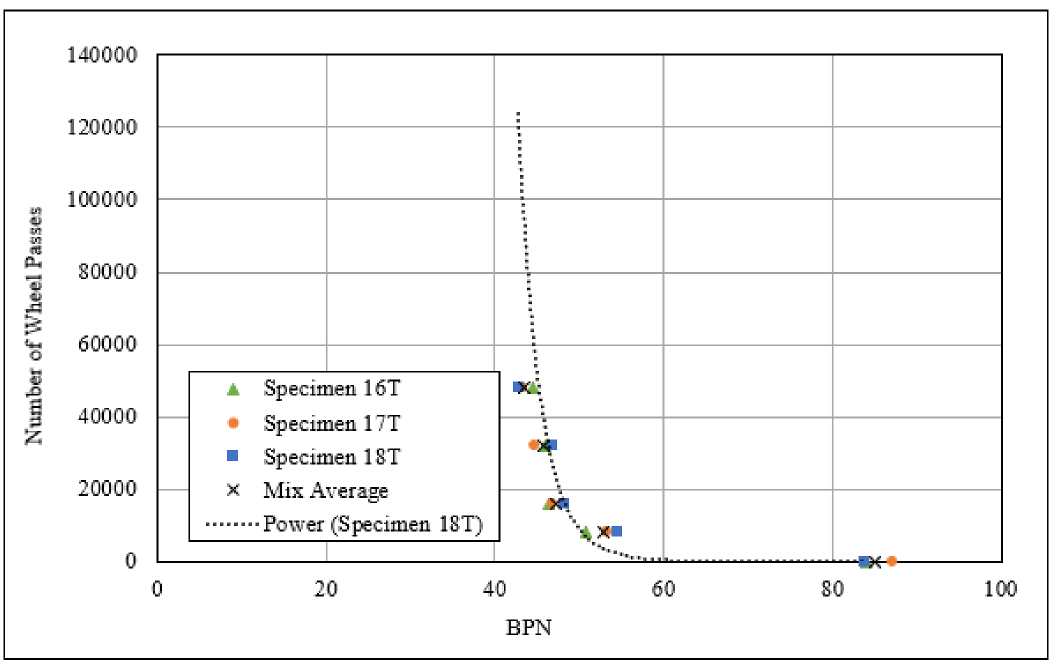


***Figure 48**: Trial 4 Prediction of Required Wheel Passes at BPN Limits for Greer W1H Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

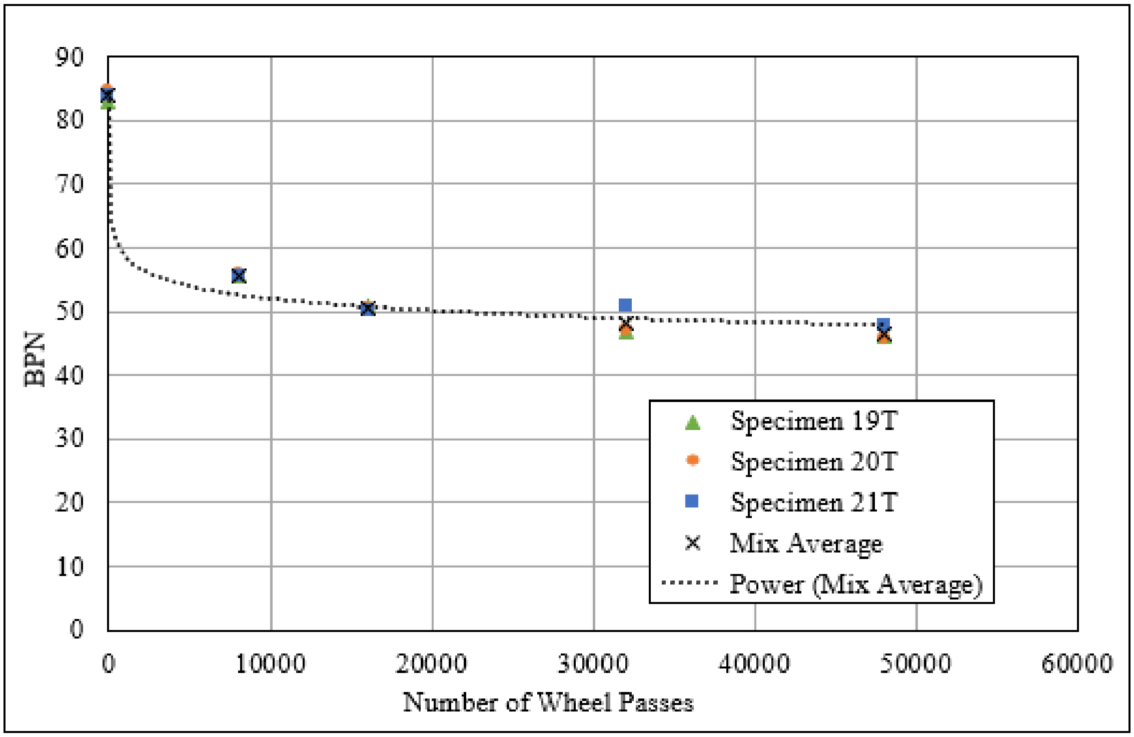


***Figure 49**: Trial 4 Average BPN Trend for WVP 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

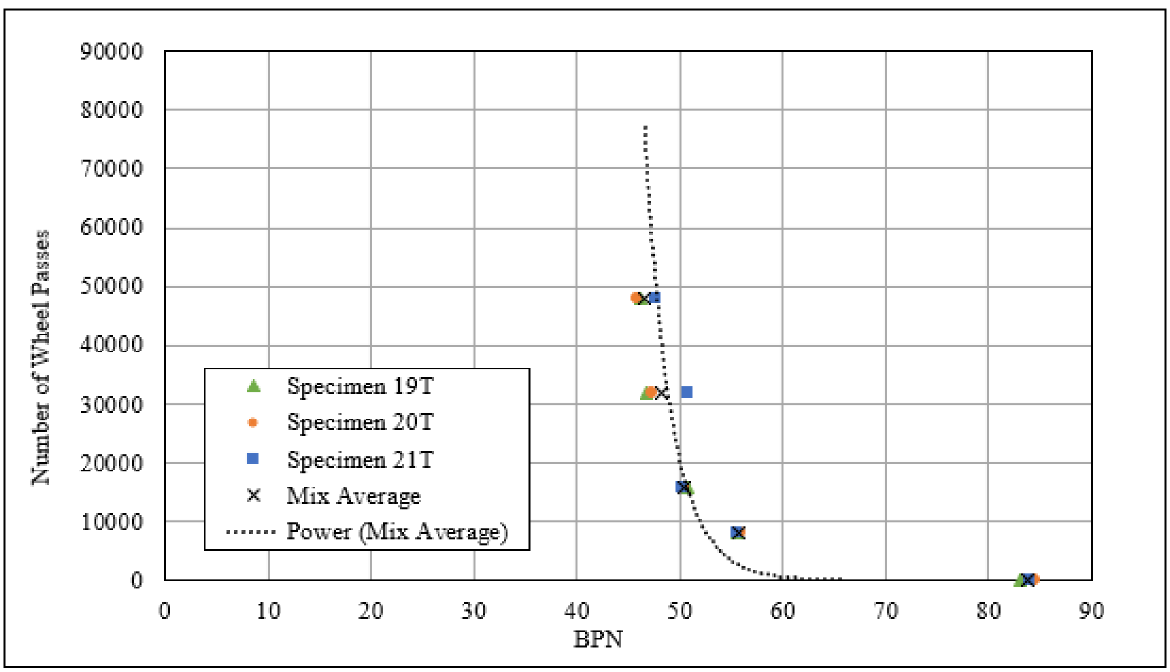


***Figure 50**: Trial 4 Prediction of Required Wheel Passes at BPN Limits for WVP 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

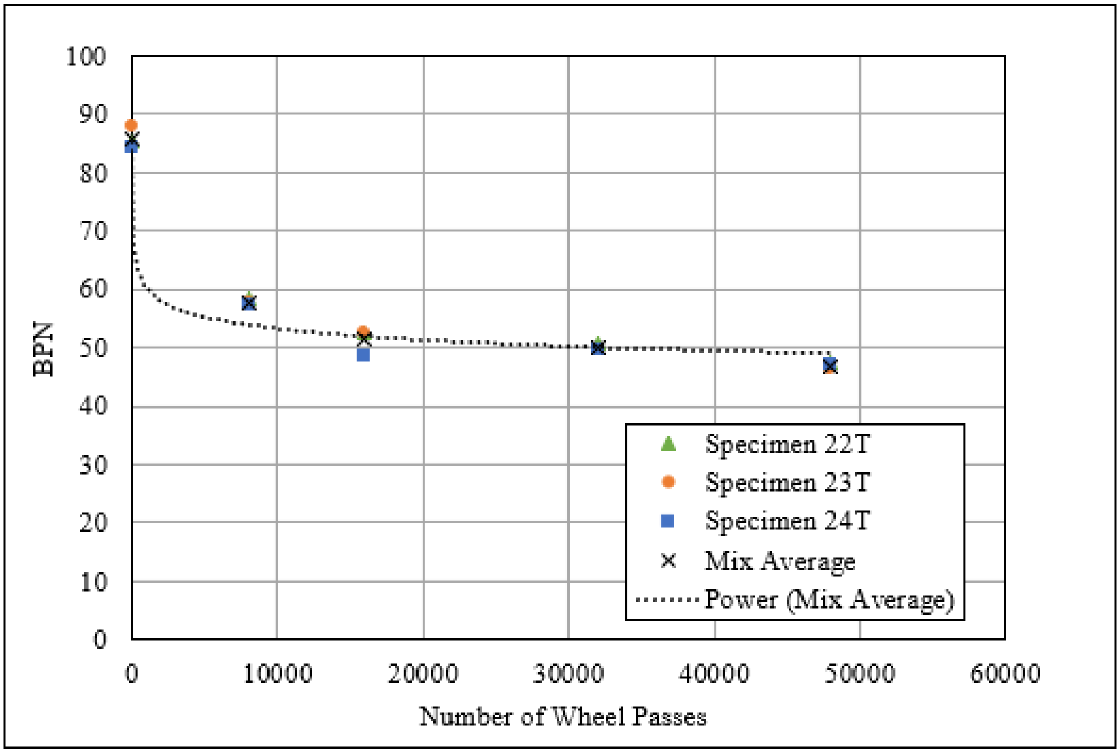


Figure 51: *Trial 4 Average BPN Trend for WVP 12.5mm SR Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

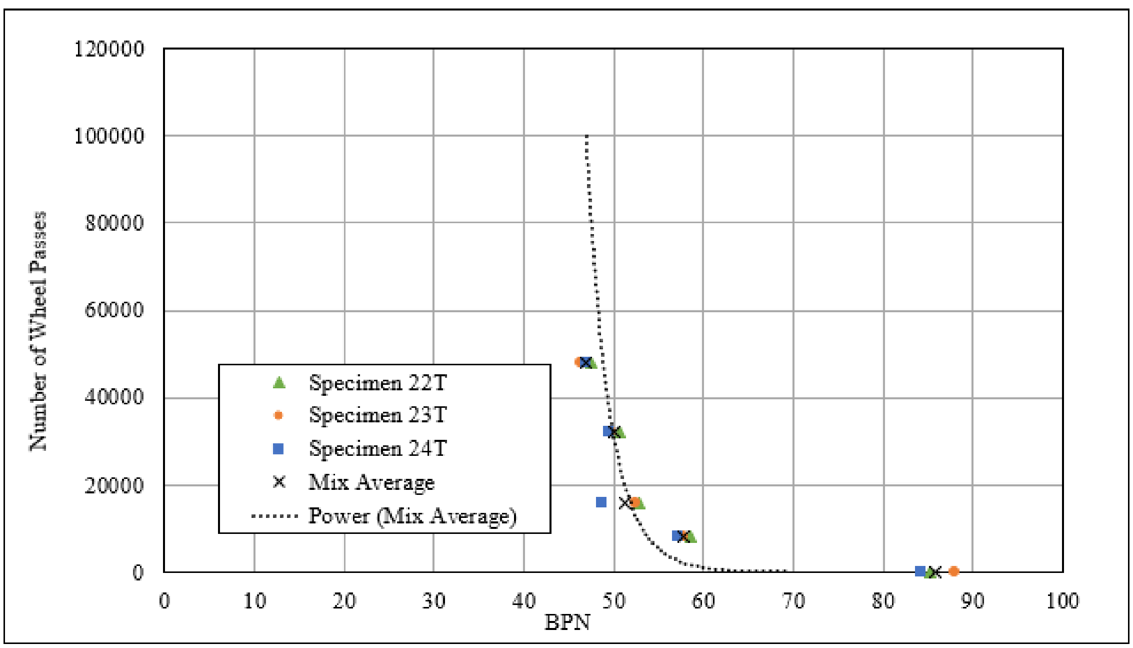


Figure 52: *Trial 4 Prediction of Required Wheel Passes at BPN Limits for WVP 12.5mm SR Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

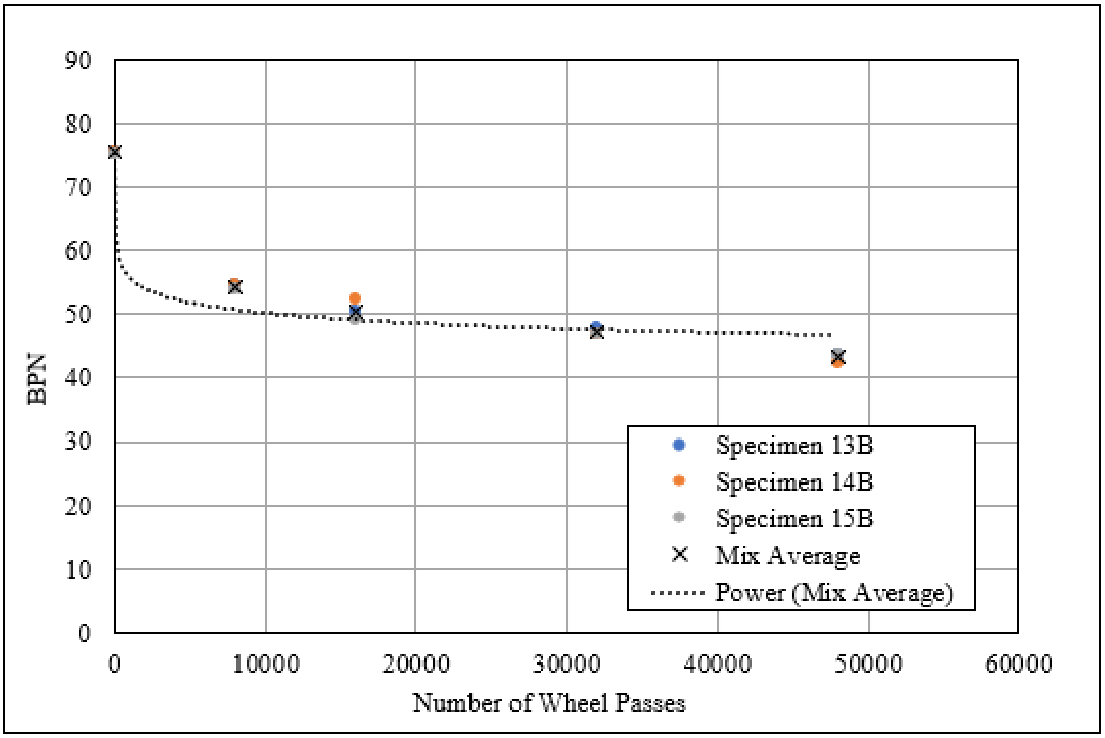


***Figure 53**: Trial 5 Average BPN Trend for Greer W1H Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

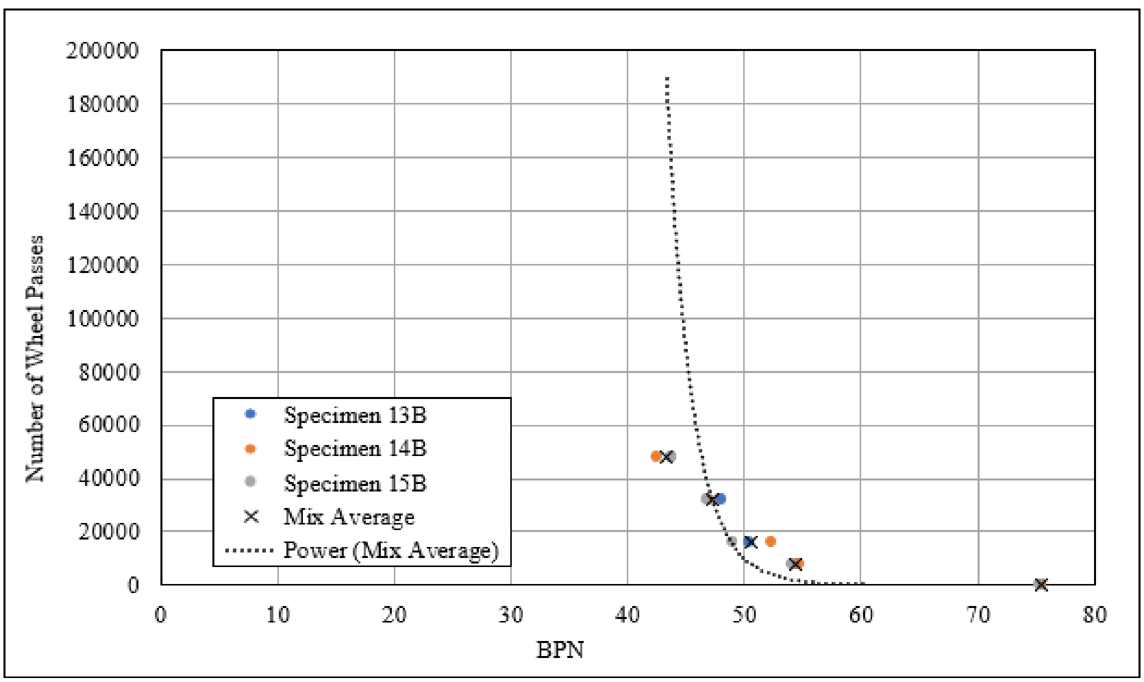


***Figure 54**: Trial 5 Prediction of Required Wheel Passes at BPN Limits for Greer W1H Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

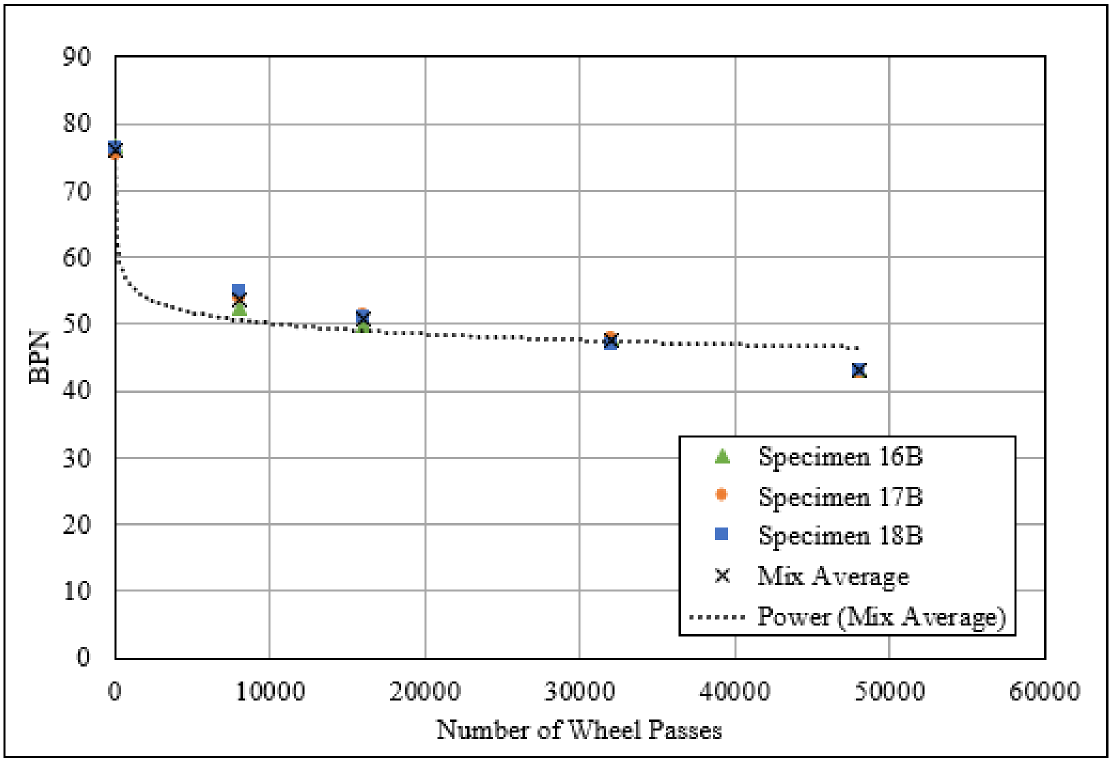


Figure 55: *Trial 5 Average BPN Trend for Greer W1H Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

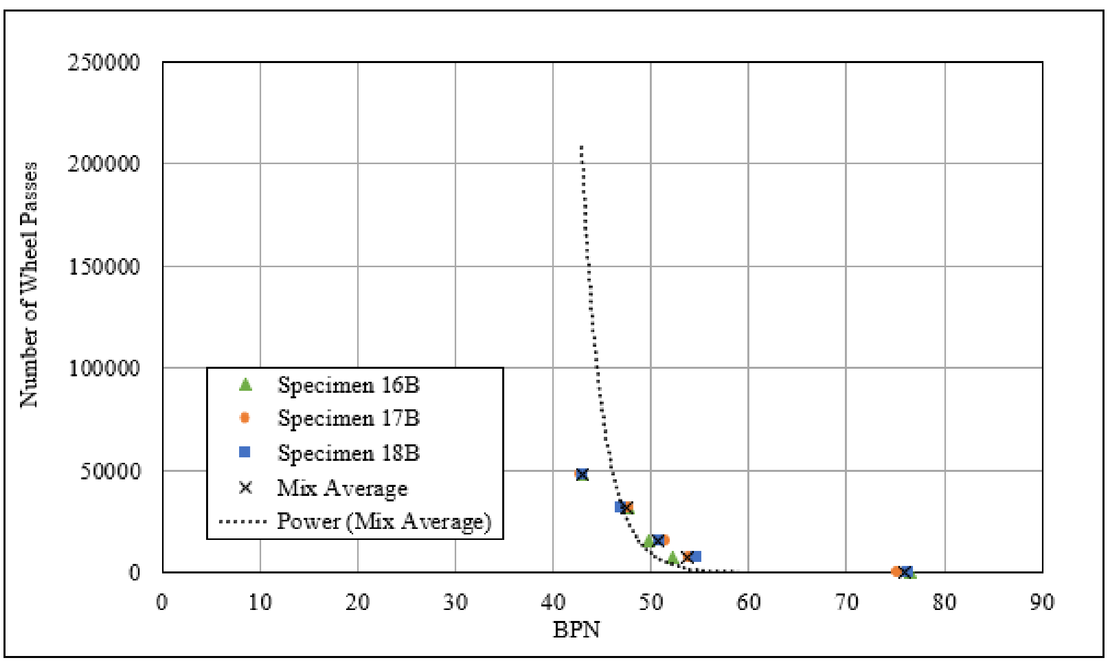


Figure 56*: Trial 5 Prediction of Required Wheel Passes at BPN Limits for Greer W1H Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

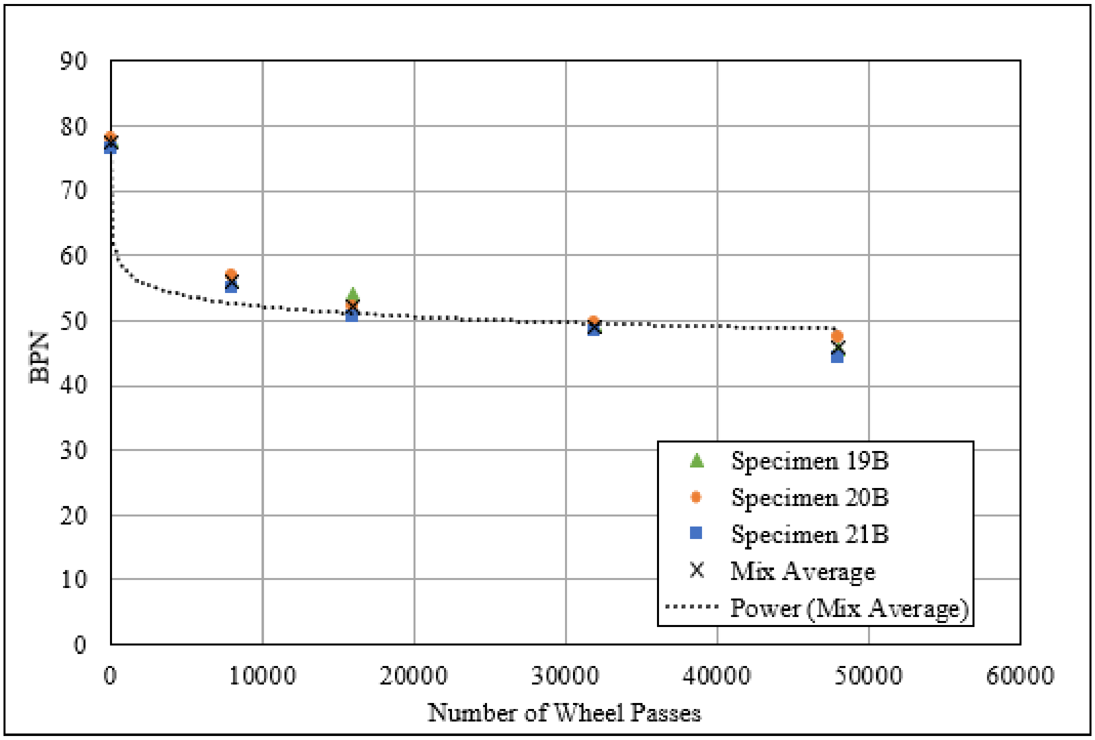


Figure 57*: Trial 5 Average BPN Trend for WVP 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

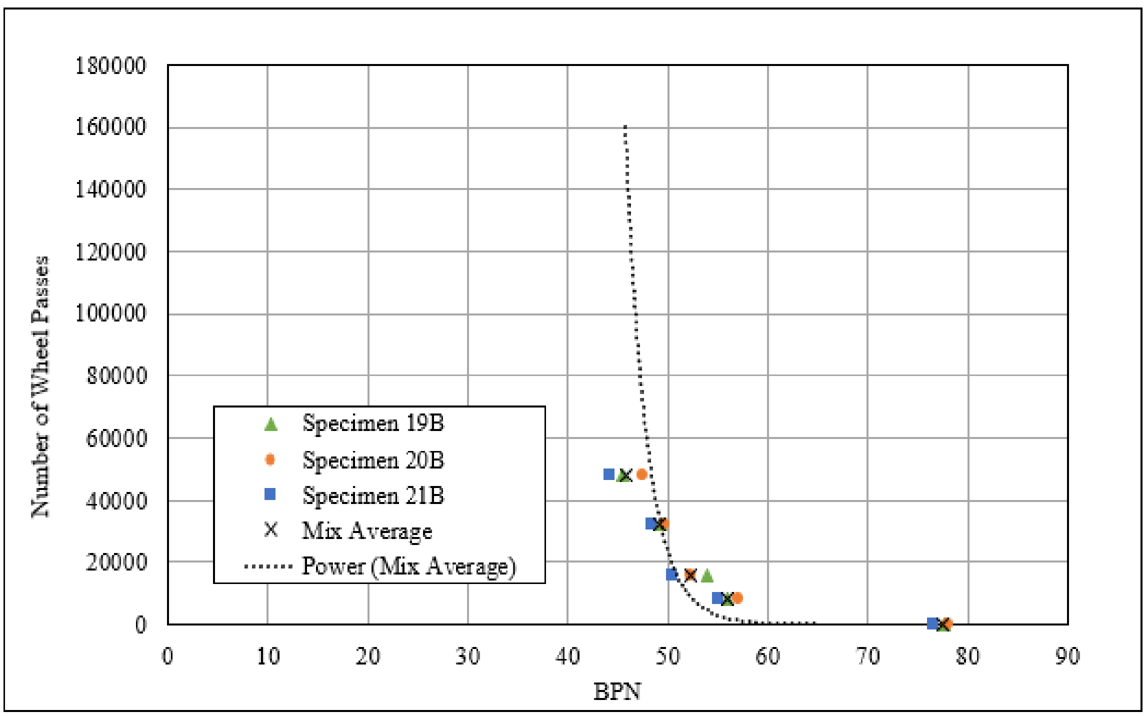


Figure 58*: Trial 5 Prediction of Required Wheel Passes at BPN Limits for WVP 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

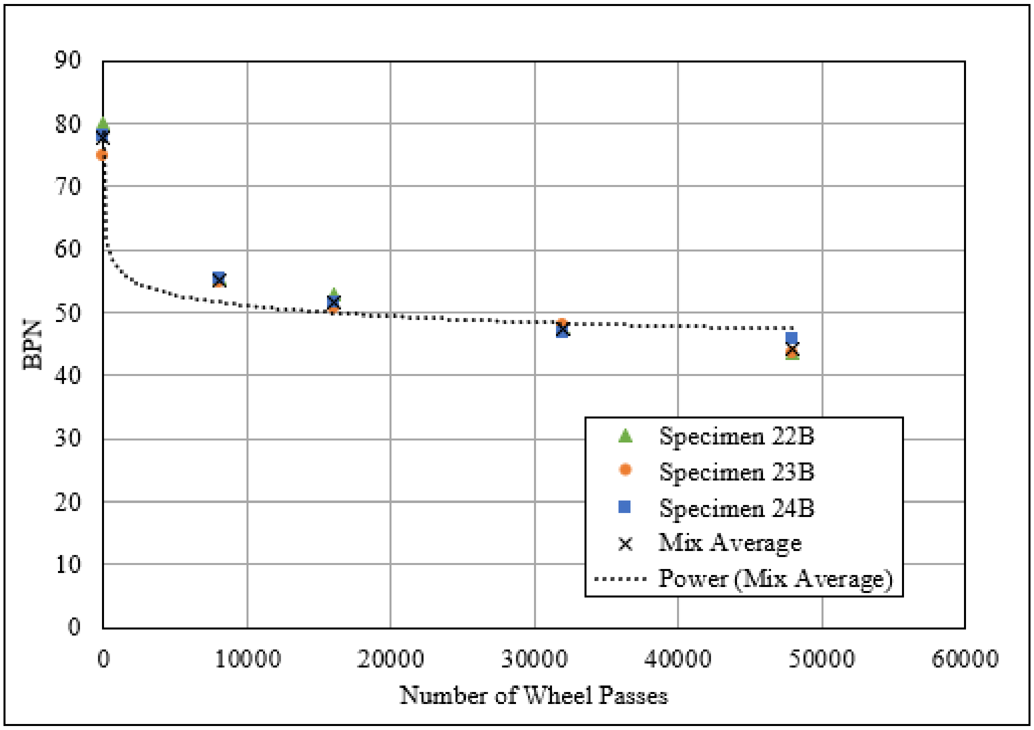


Figure 59: *Trial 5 Average BPN Trend for WVP 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

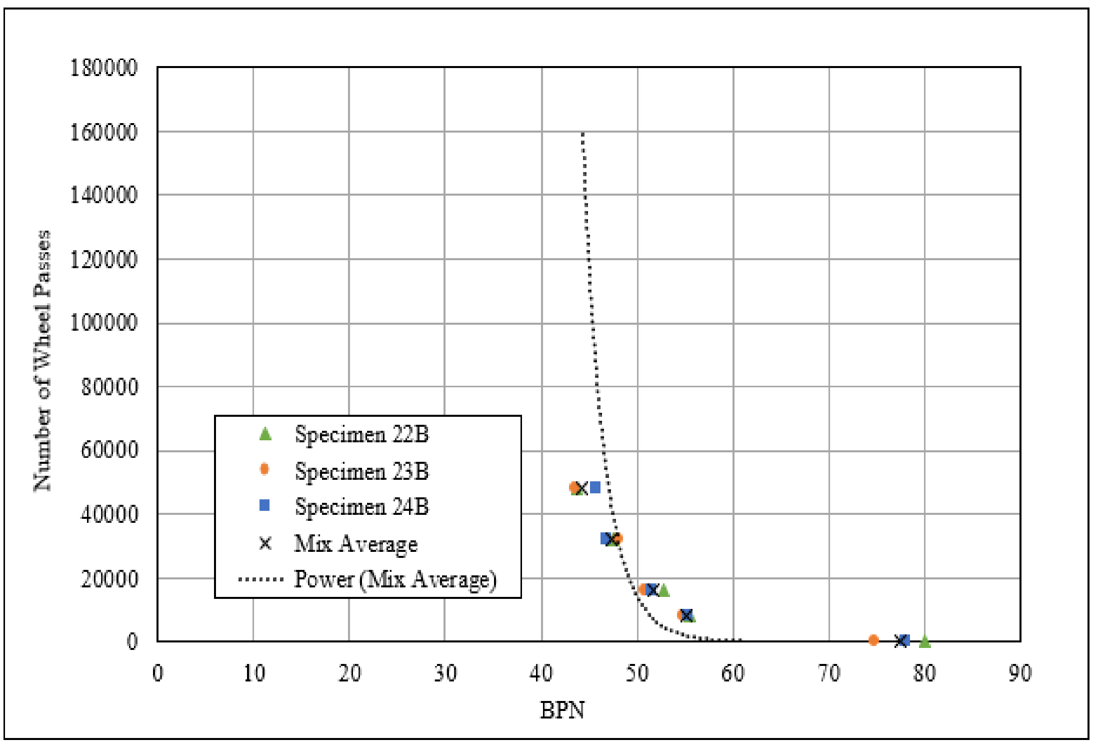


Figure 60: *Trial 5 Prediction of Required Wheel Passes at BPN Limits for WVP 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

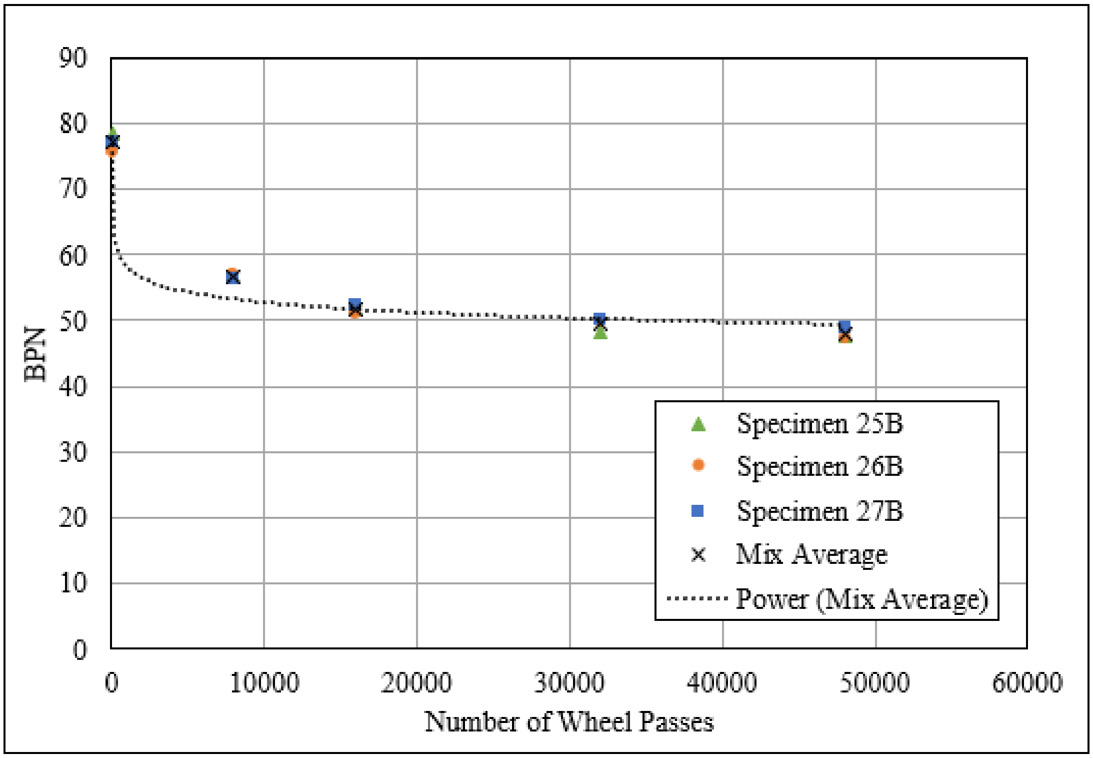


Figure 61*: Trial 6 Average BPN Trend for JFA 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

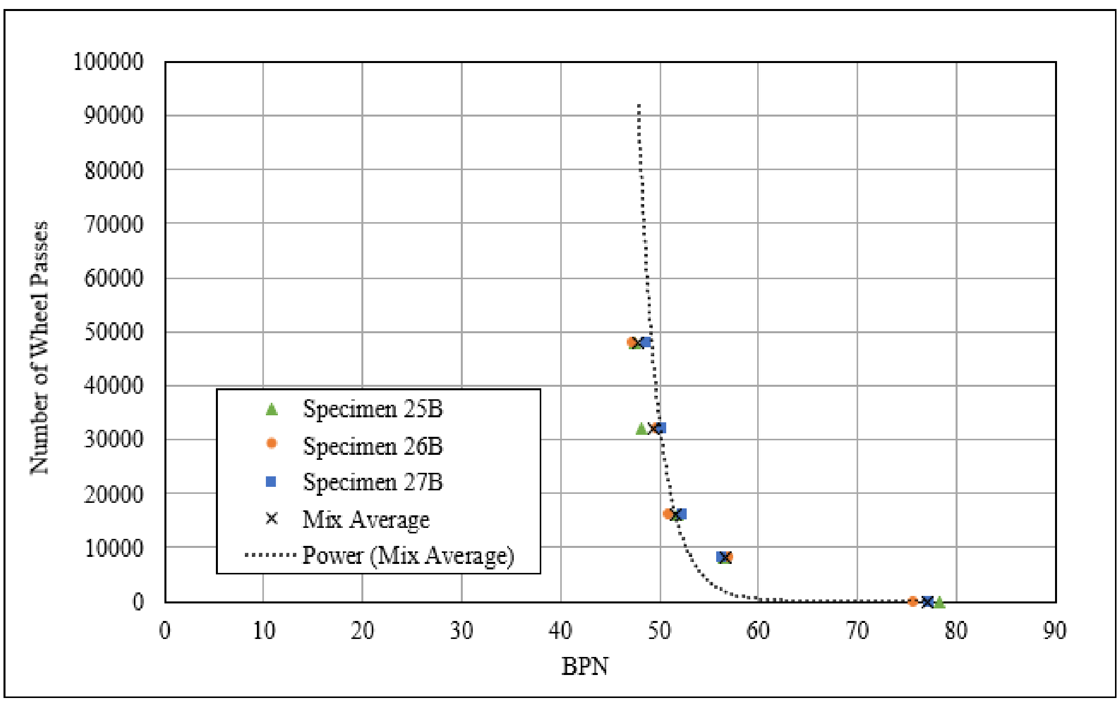


Figure 62*: Trial 6 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

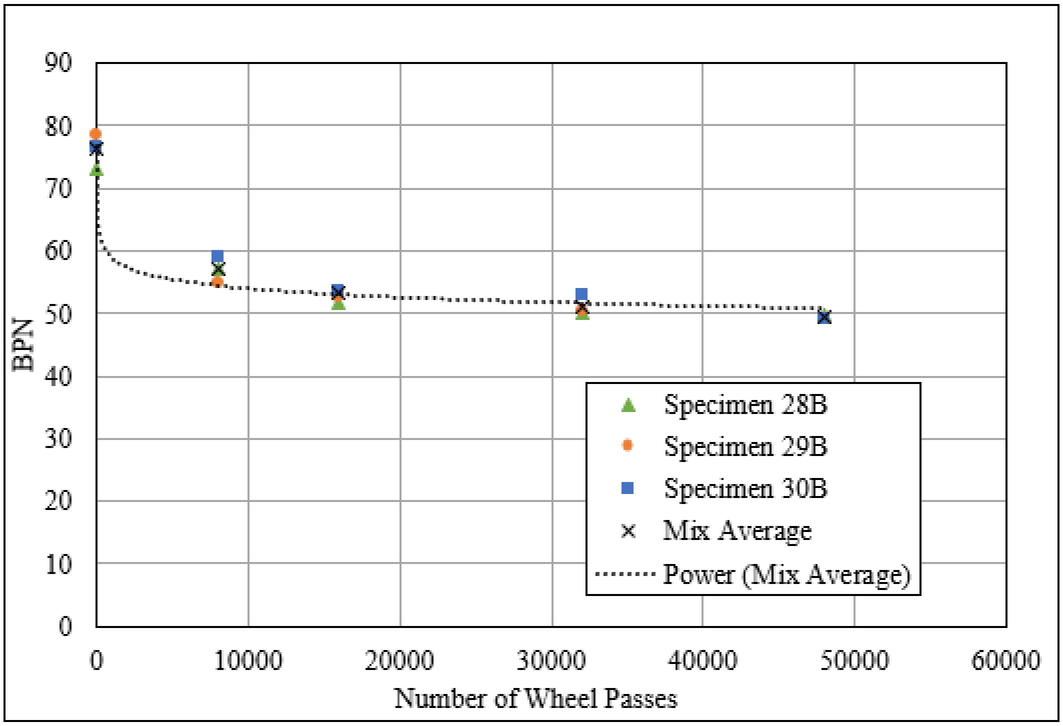


Figure 63*: Trial 6 Average BPN Trend for JFA 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

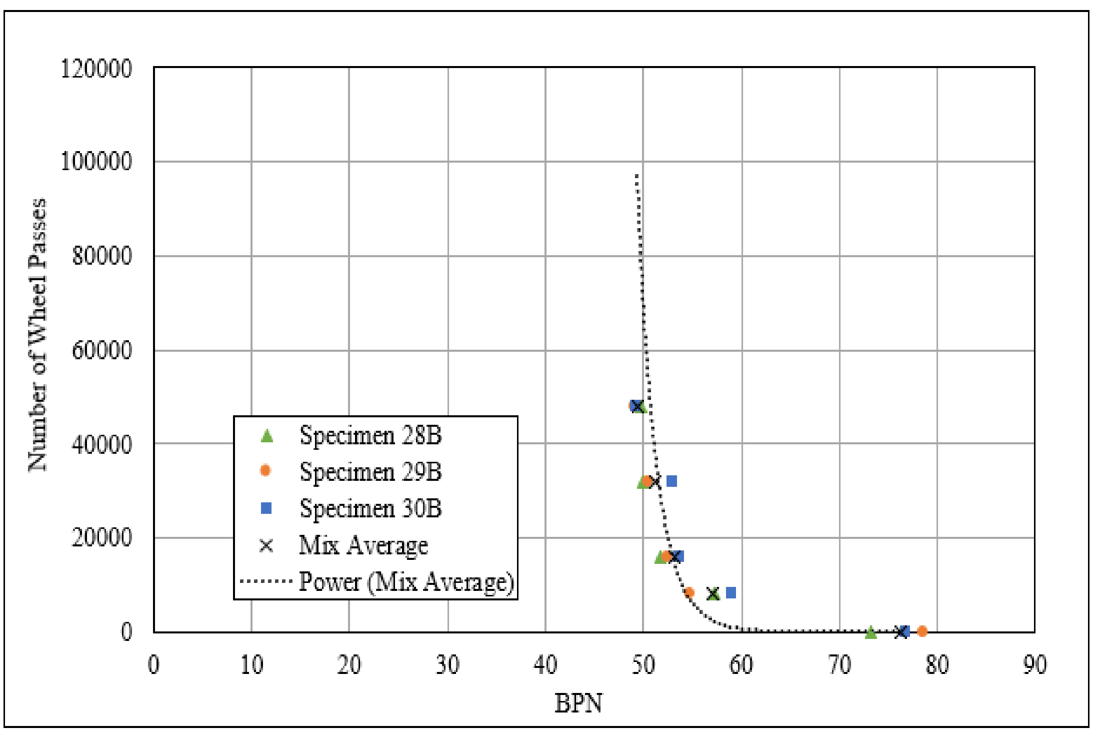


Figure 64*: Trial 6 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

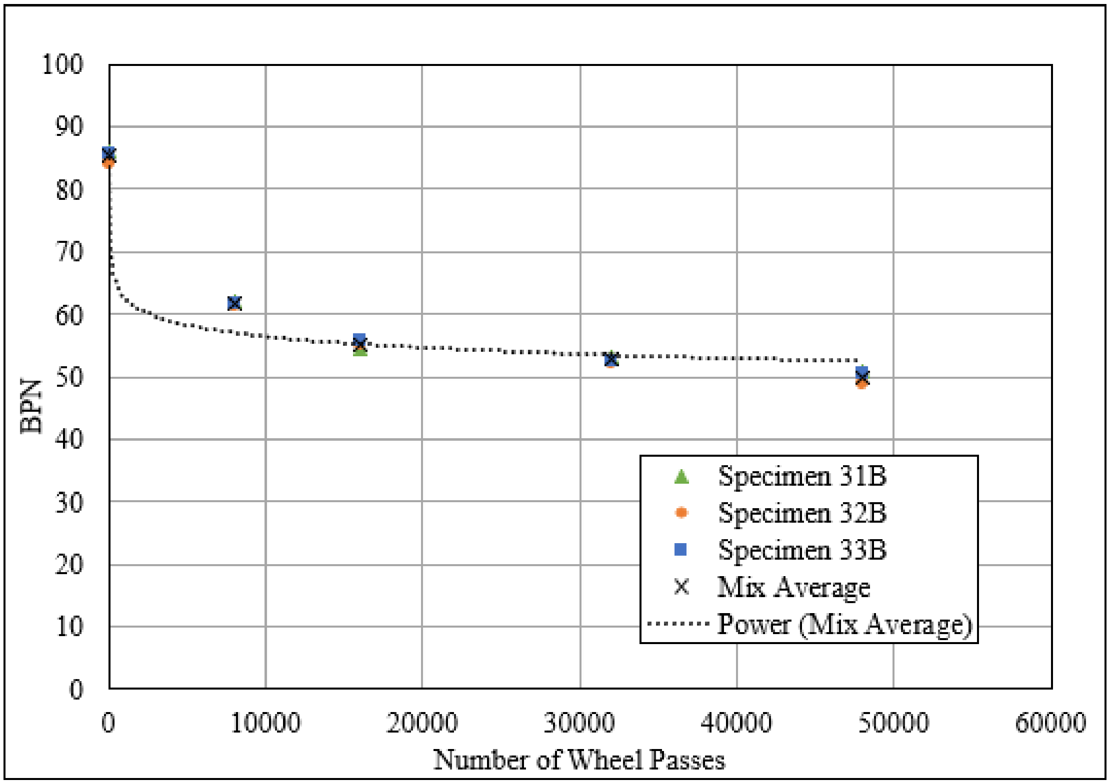


Figure 65*: Trial 6 Average BPN Trend for WVP W1-RAP Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

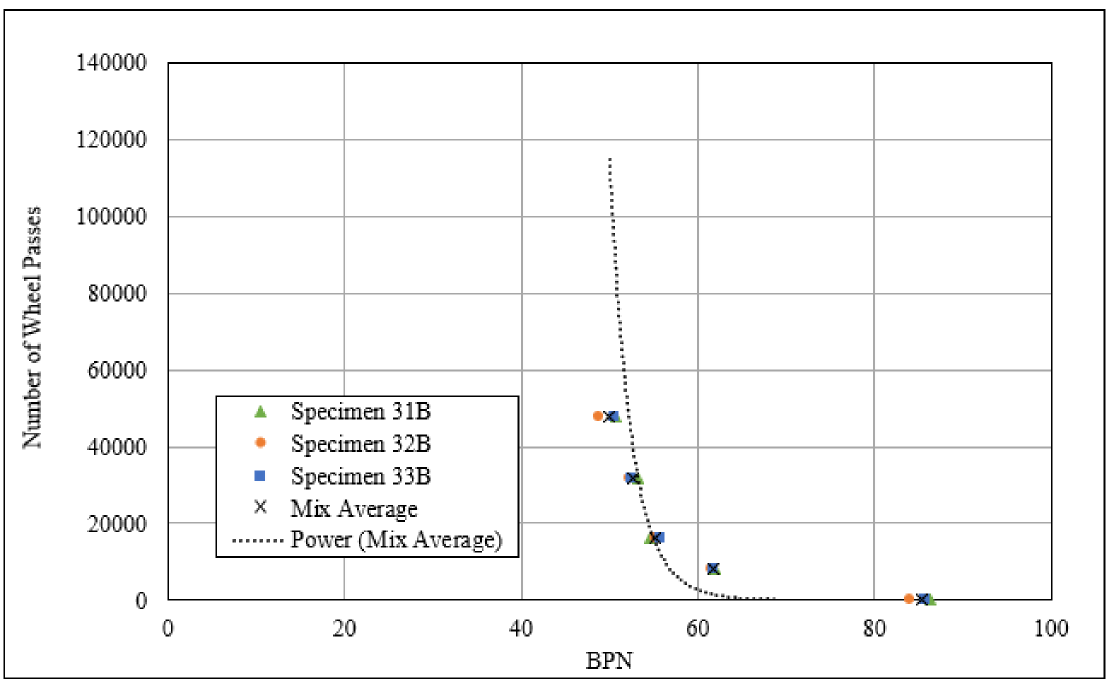


Figure 66*: Trial 6 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Bottom Surfaces) at 4% VTM After 48,000 Wheel Passes*

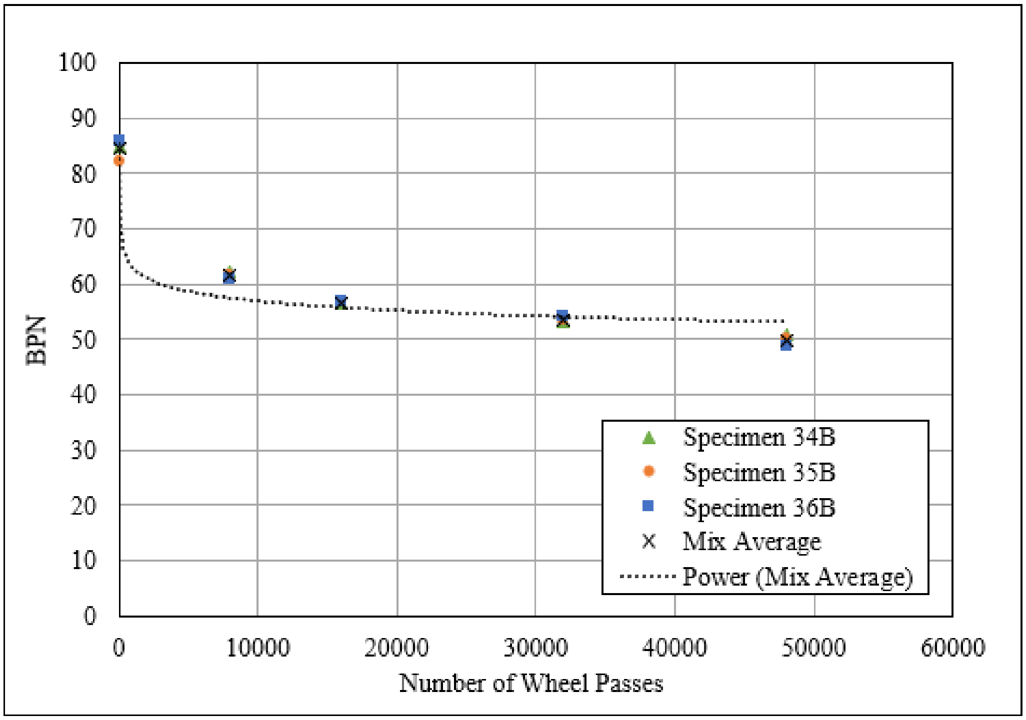


Figure 67: *Trial 6: Average BPN Trend for WVP W1-RAP Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

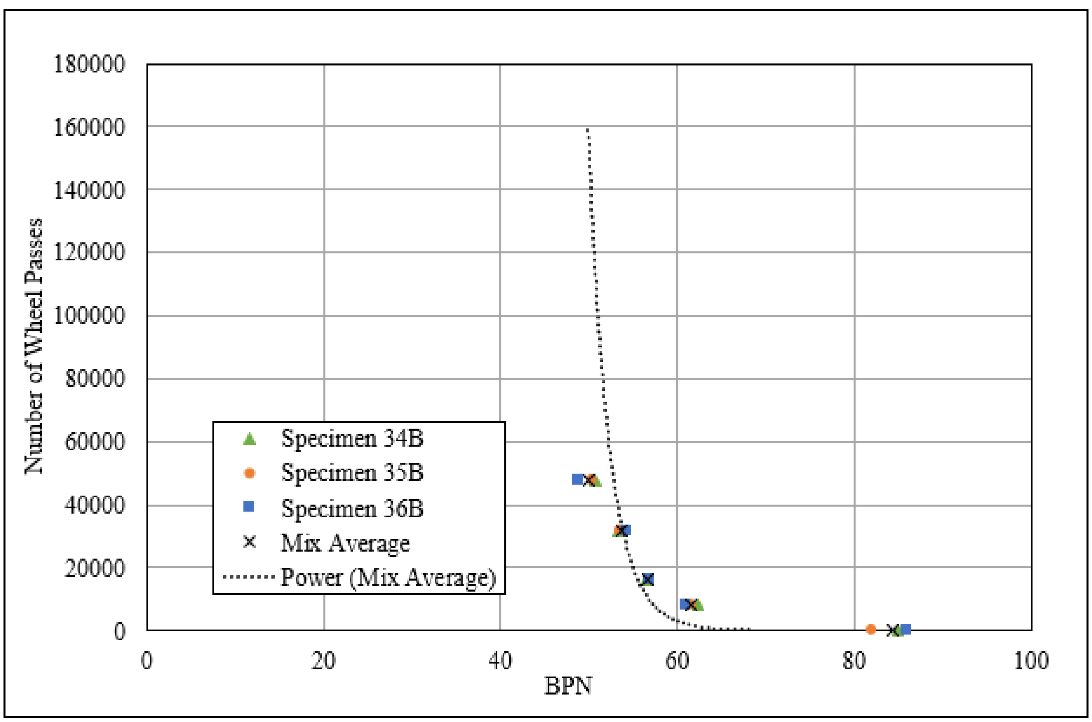


Figure 68: *Trial 6 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Bottom Surfaces) at 8% VTM After 48,000 Wheel Passes*

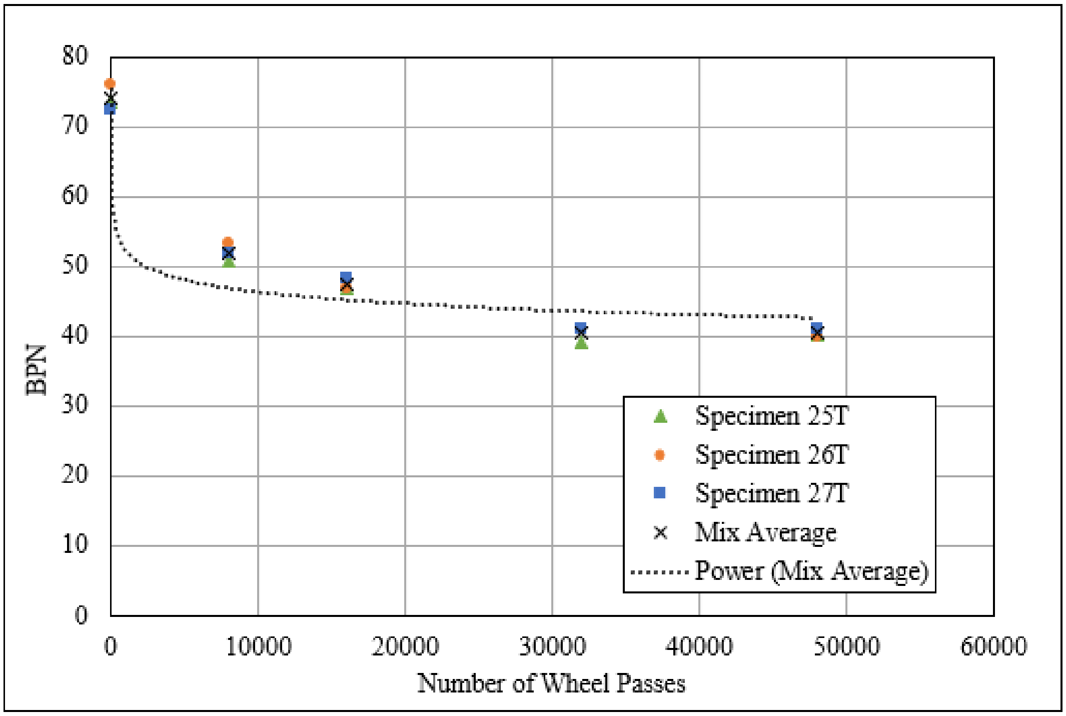


Figure 69: *Trial 7 Average BPN Trend for JFA 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

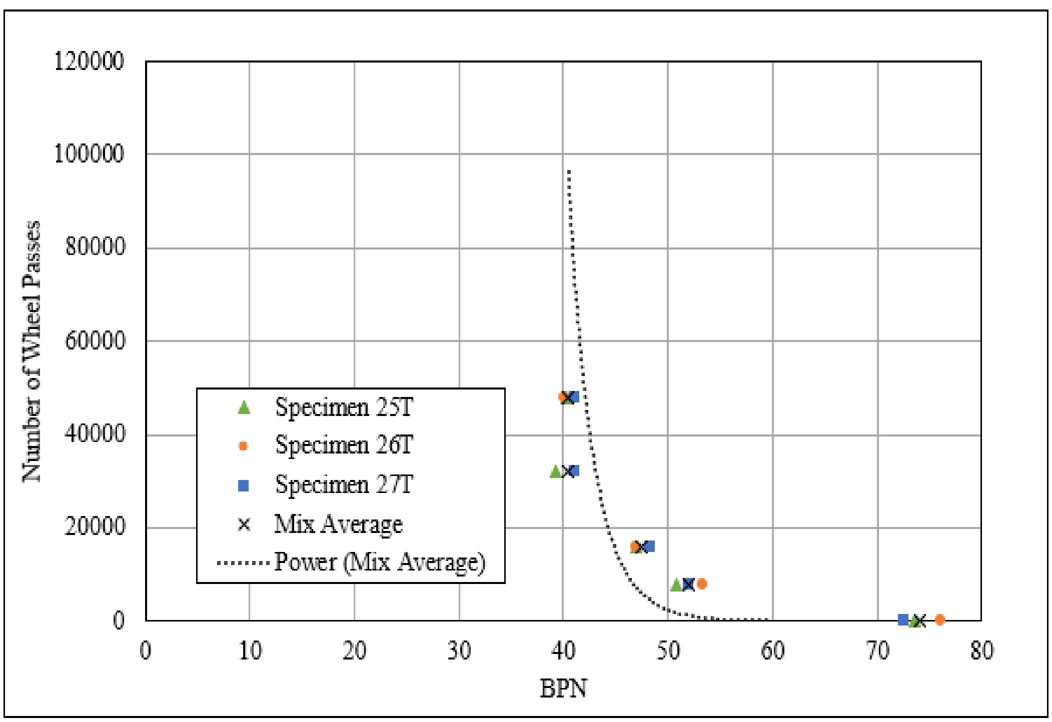


Figure 70: *Trial 7 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

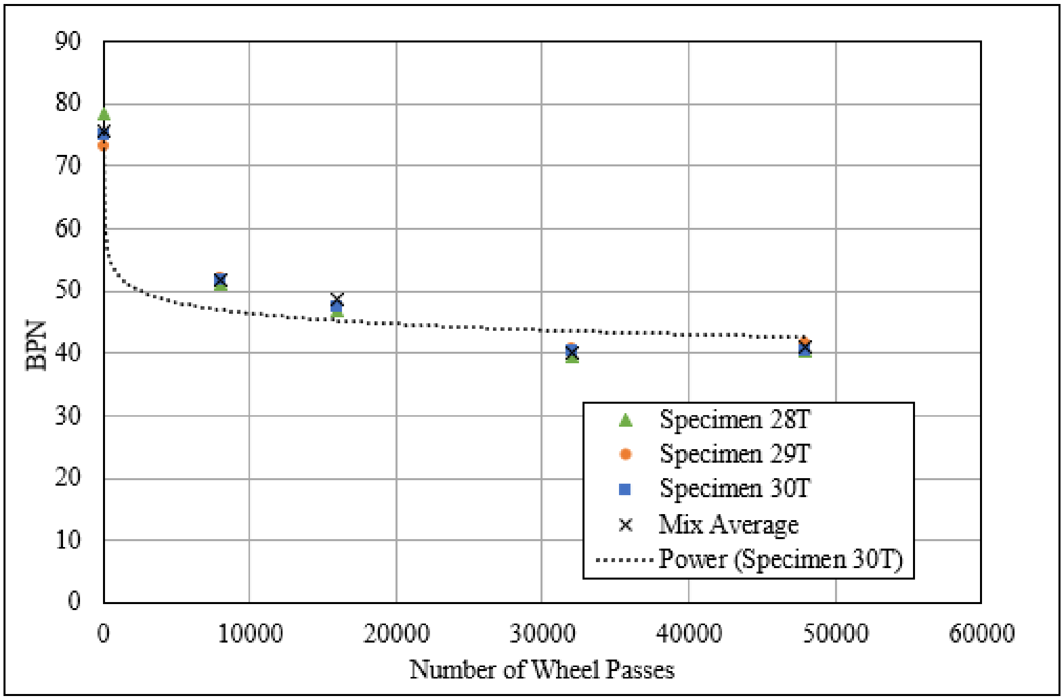


Figure 71: *Trial 7 Average BPN Trend for JFA 12.5mm SR Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

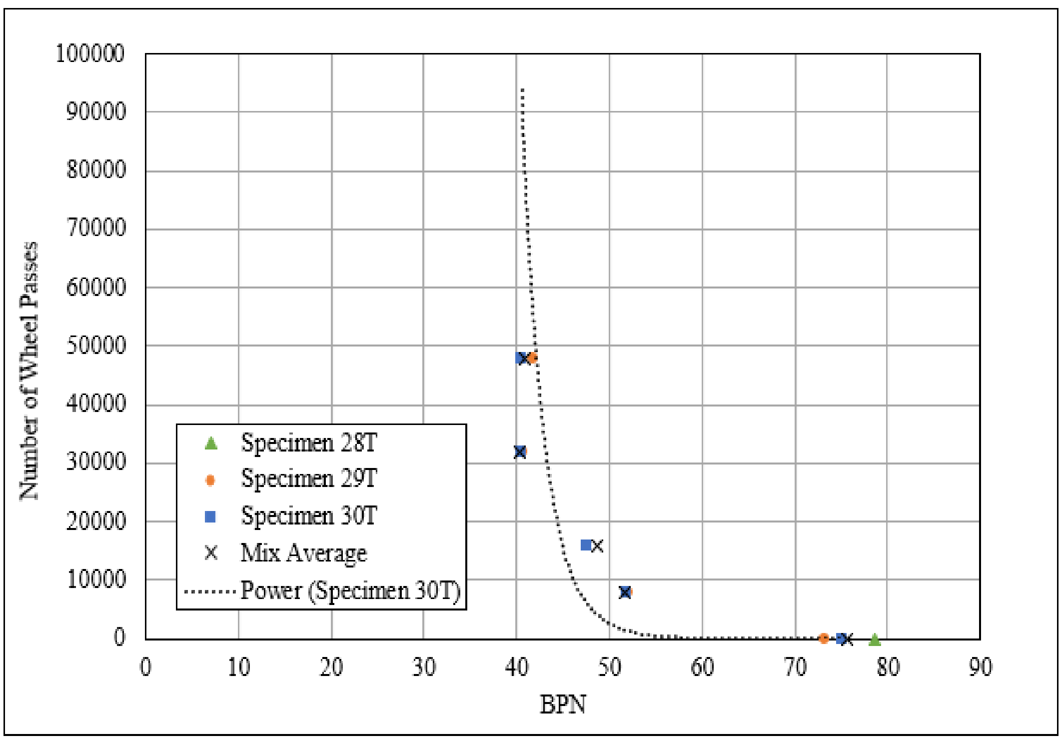


Figure 72: *Trial 7 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

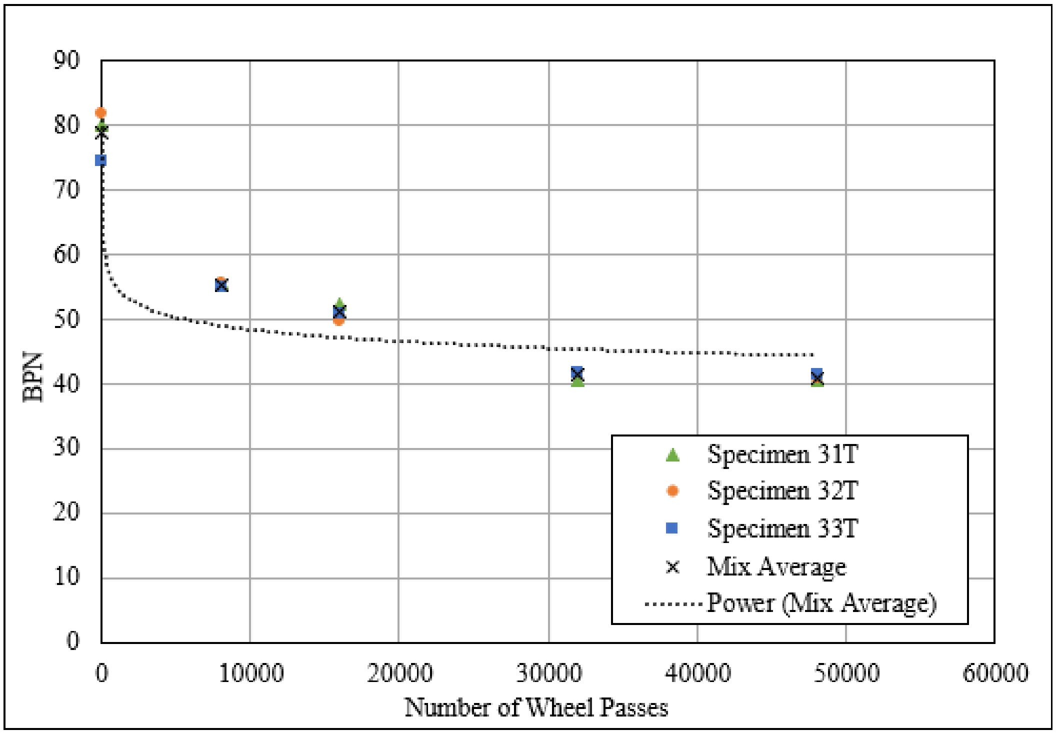


Figure 73: *Trial 7 Average BPN Trend for WVP W1-RAP Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

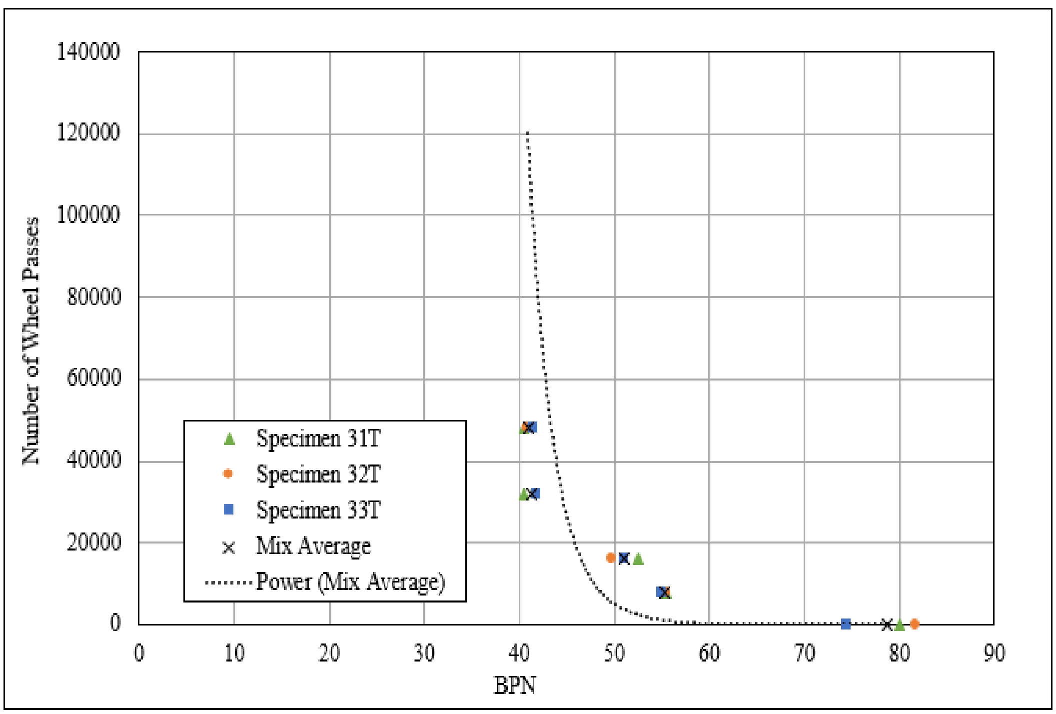


Figure 74: *Trial 7 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Top Surfaces) at 4% VTM After 48,000 Wheel Passes*

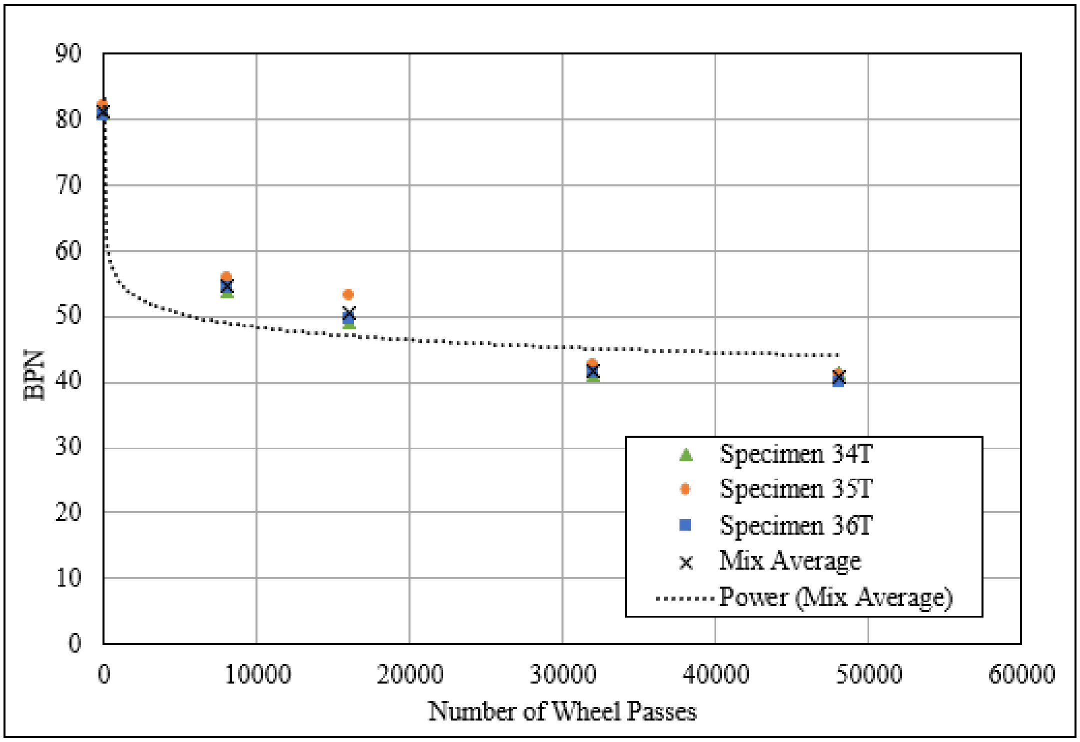


Figure 75*: Trial 7 Average BPN Trend for WVP W1-RAP Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

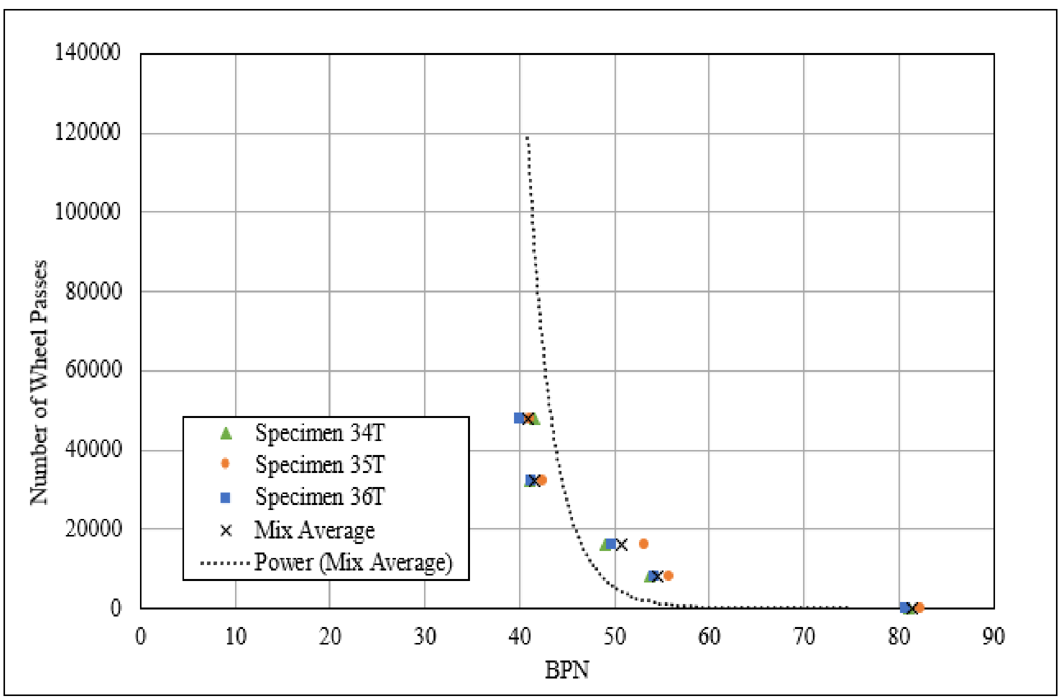


Figure 76*: Trial 7 Prediction of Required Wheel Passes at BPN Limits for WVP W1-RAP Specimens (Top Surfaces) at 8% VTM After 48,000 Wheel Passes*

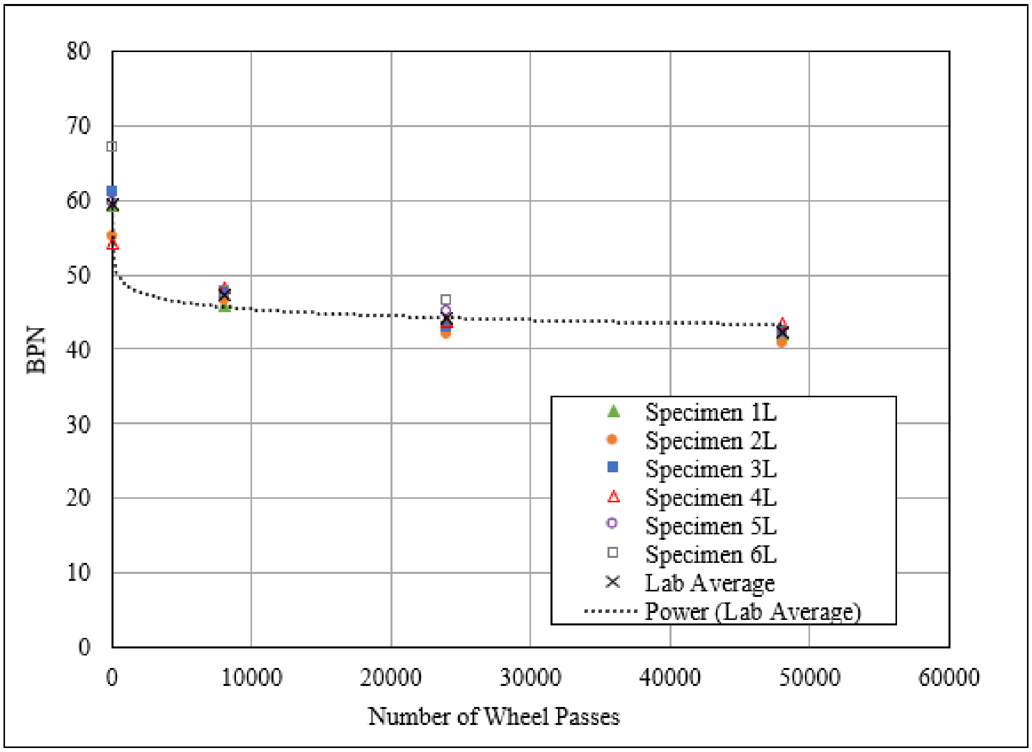


***Figure 77**: Trial 8 Average BPN Trend for JFA 12.5mm SR Laboratory Compacted Specimens After 48,000 Wheel Passes*

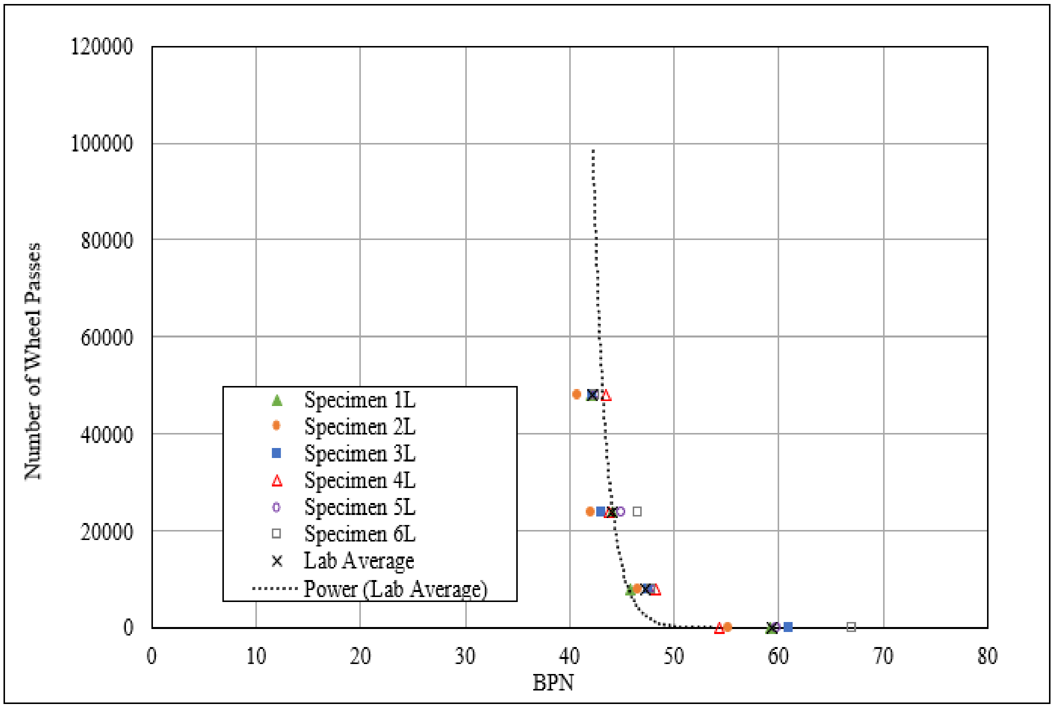


***Figure 78**: Trial 8 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Laboratory Compacted Specimens After 48,000 Wheel Passes*

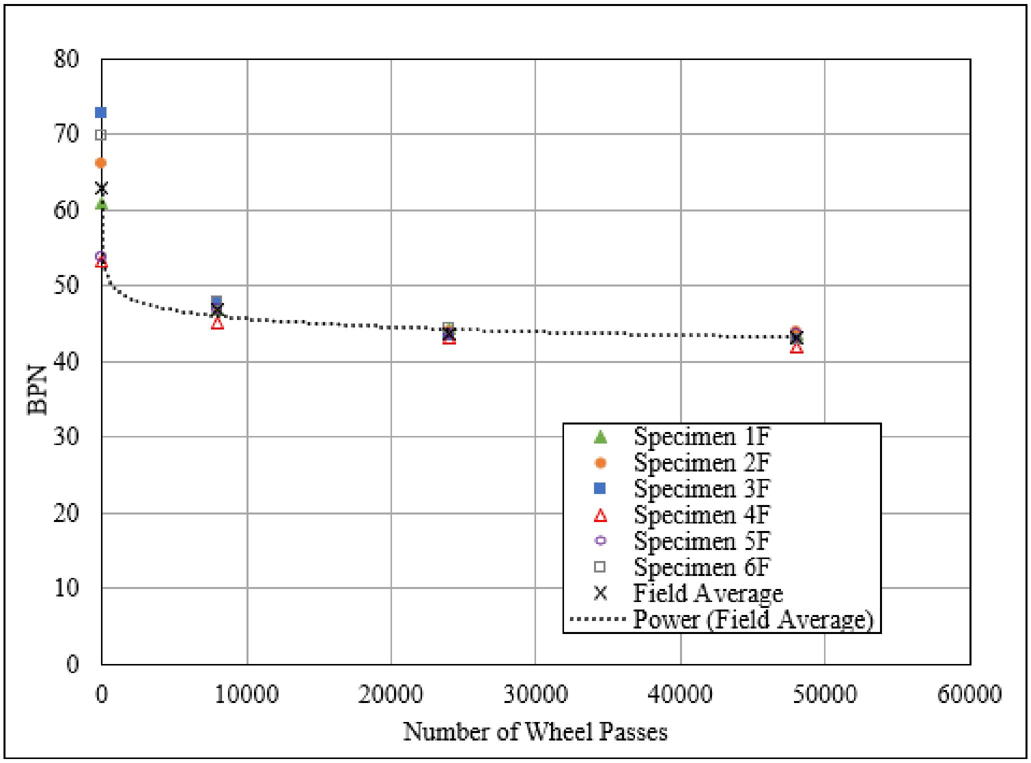


Figure 79*: Trial 8 Average BPN Trends for JFA 12.5mm SR Field Core Specimens After 48,000 Wheel Passes*

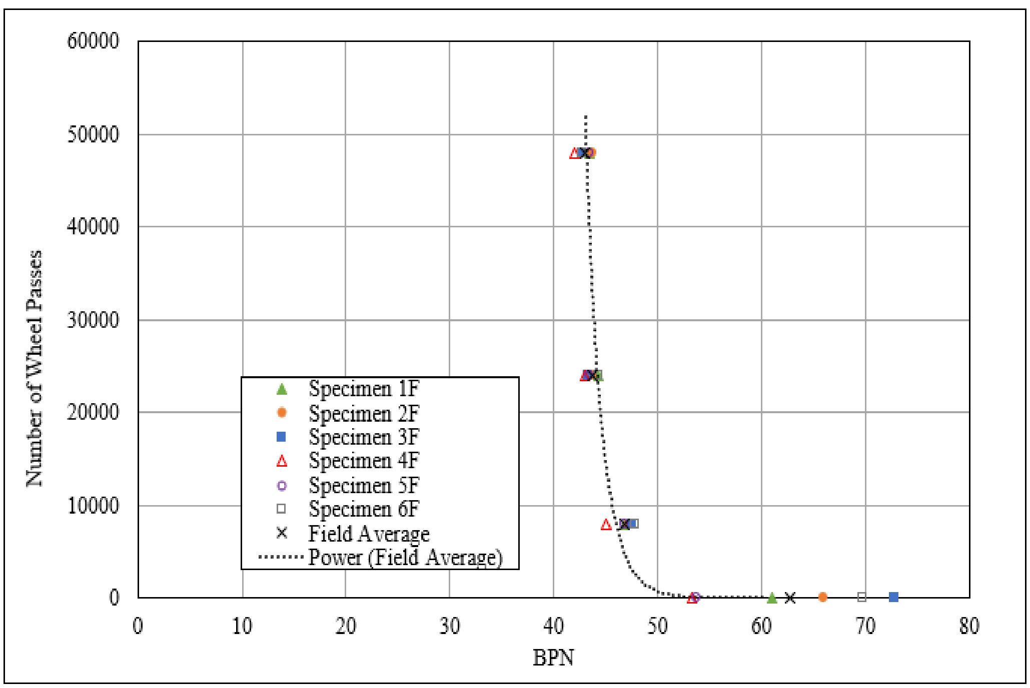


Figure 80: *Trial 8 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Field Core Specimens After 48,000 Wheel Passes*

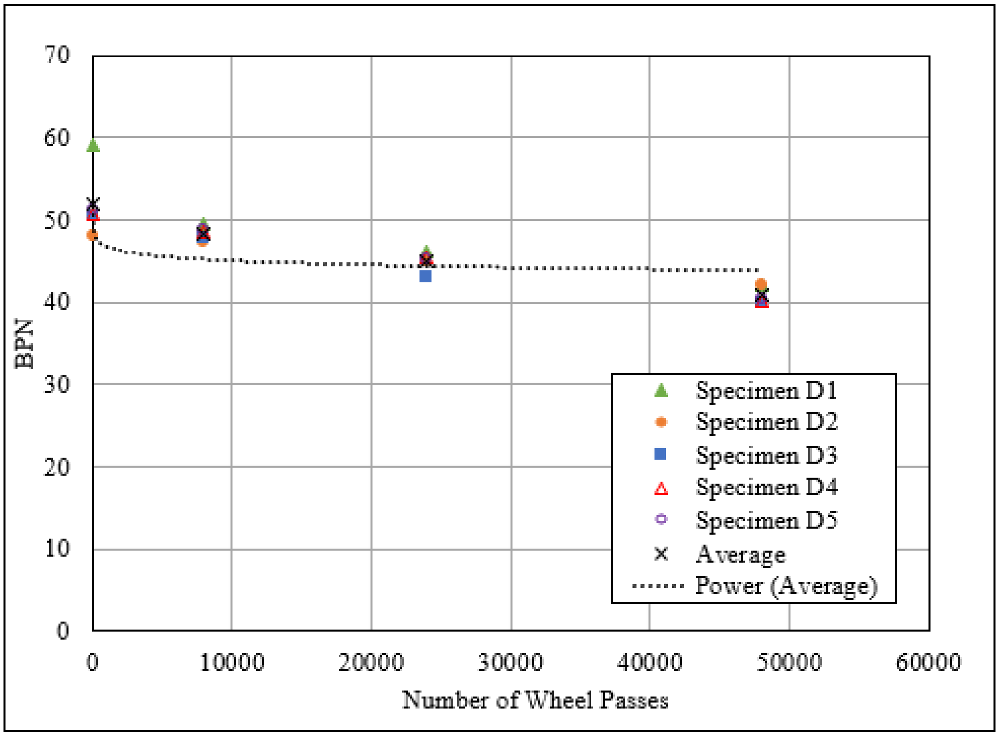


Figure 81:*Trial 9 Average BPN Trends for JFA 12.5mm SR Field Core Specimens After 48,000 Wheel Passes*

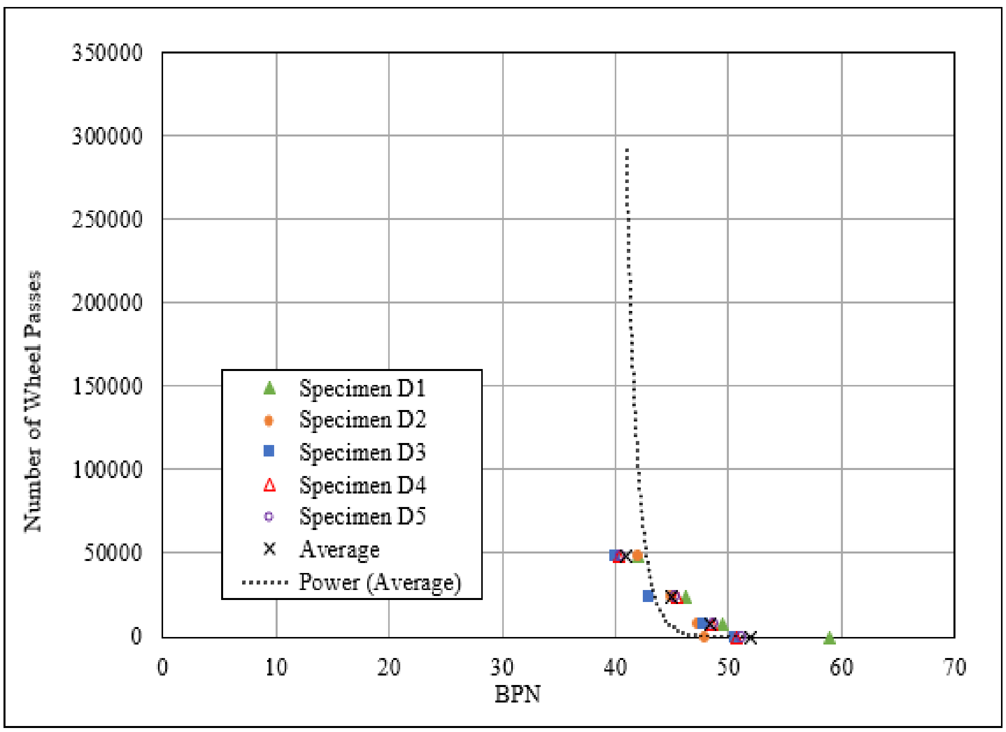


Figure 82: *Trial 9 Prediction of Required Wheel Passes at BPN Limits for JFA 12.5mm SR Field Core Specimens After 48,000 Wheel Passes*

Appendix F: Statistical Analysis Data and T-test Results

Toe Angles (B55A Tire Data)

Table 55: Data and Excel Output for JFA 12.5mm SR and WVP W1-RAP Polished with Burris B55A Tires at Low and High Toe Angles

	Mix	Sample	BPN_{48000}
Low Toe	JFA 12.5	4T	48
	JFA 12.5	5T	45.75
	JFA 12.5	6T	47.5
	JFA 12.5	1T	51.5
	JFA 12.5	2T	47.75
	JFA 12.5	3T	49.25
	WVP W1	7T	51.25
	WVP W1	8T	51.75
	WVP W1	9T	49.25
	WVP W1	10T	51.75
	WVP W1	11T	50.25
	WVP W1	12T	55.75
High Toe	JFA 12.5	4B	44.75
	JFA 12.5	5B	47.75
	JFA 12.5	6B	47.75
	JFA 12.5	1B	48.5
	JFA 12.5	2B	48
	JFA 12.5	3B	49
	WVP W1	7B	49.25
	WVP W1	8B	48.75
	WVP W1	9B	49
	WVP W1	10B	49.25
	WVP W1	11B	50
	WVP W1	12B	49.75

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	49.979167	48.479167
Variance	7.0506629	1.9029356
Observations	12	12
Pooled Variance	4.4767992	
Hypothesized Mean Difference	0	
df	22	
t Stat	1.7365331	
P(T<=t) one-tail	0.0482271	
t Critical one-tail	1.7171444	
P(T<=t) two-tail	**0.0964541**	
t Critical two-tail	2.0738731	

VTM (Hoosier R80 Tire Data)

Table 56: Data and Excel Output for All Mixtures Polished with Hoosier R80 Tires at 4% and 8% VTM

	Mix	Sample	BPN_{48000}
4% VTM	Greer W1	16B	43
	Greer W1	17B	42.75
	Greer W1	18B	43
	WVP 12.5	18B	45.5
	WVP 12.5	20B	47.5
	WVP 12.5	21B	44.25
	JFA 12.5	25B	47.5
	JFA 12.5	26B	47.25
	JFA 12.5	27B	48.75
	WVP W1	31B	50.75
	WVP W1	32B	48.75
	WVP W1	33B	50.5
	Greer W1	16T	44.5
	Greer W1	17T	43.25
	Greer W1	18T	42.75
	WVP 12.5	18T	46.25
	WVP 12.5	20T	45.75
	WVP 12.5	21T	47.75
	JFA 12.5	25T	40.25
	JFA 12.5	26T	40
	JFA 12.5	27T	41
	WVP W1	31T	40.5
	WVP W1	32T	40.75
	WVP W1	33T	41.5
8% VTM	Greer W1	13B	43.75
	Greer W1	14B	42.5
	Greer W1	15B	43.75
	WVP 12.5	22B	43.75
	WVP 12.5	23B	43.5
	WVP 12.5	24B	45.75
	JFA 12.5	28B	49.75
	JFA 12.5	29B	49
	JFA 12.5	30B	49.25
	WVP W1	34B	50.75
	WVP W1	35B	50.25
	WVP W1	36B	48.75
	Greer W1	13T	43
	Greer W1	14T	43.5
	Greer W1	15T	44.75
	WVP 12.5	22T	47.5
	WVP 12.5	23T	46.25
	WVP 12.5	24T	47
	JFA 12.5	28T	40.5
	JFA 12.5	29T	41.75
	JFA 12.5	30T	40.5
	WVP W1	34T	41.5
	WVP W1	35T	41
	WVP W1	36T	40

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	44.739583	44.916667
Variance	11.018909	11.623188
Observations	24	24
Pooled Variance	11.321048	
Hypothesized Mean Difference	0	
df	46	
t Stat	-0.1823161	
P(T<=t) one-tail	0.4280679	
t Critical one-tail	1.6786604	
P(T<=t) two-tail	**0.8561358**	
t Critical two-tail	2.0128956	

Toe Angles (Hoosier R80 Tire Data)

Table 57: Data and Excel Output for All Mixtures Polished with Hoosier R80 Tires at Low and High Toe Angles

	Mix	Sample	BPN_{48000}
Low Toe	WVP 12.5	19B	45.5
	WVP 12.5	20B	47.5
	WVP 12.5	21B	44.25
	WVP 12.5	22B	43.75
	WVP 12.5	23B	43.5
	WVP 12.5	24B	45.75
	Greer W1	16B	43
	Greer W1	17B	42.75
	Greer W1	18B	43
	Greer W1	13B	43.75
	Greer W1	14B	42.5
	Greer W1	15B	43.75
	JFA 12.5	25B	47.5
	JFA 12.5	26B	47.25
	JFA 12.5	27B	48.75
	JFA 12.5	28B	49.75
	JFA 12.5	29B	49
	JFA 12.5	30B	49.25
	WVP W1	31B	50.75
	WVP W1	32B	48.75
	WVP W1	33B	50.5
	WVP W1	34B	50.75
	WVP W1	35B	50.25
	WVP W1	36B	48.75
High Toe	WVP 12.5	19T	46.25
	WVP 12.5	20T	45.75
	WVP 12.5	21T	47.75
	WVP 12.5	22T	47.5
	WVP 12.5	23T	46.25
	WVP 12.5	24T	47
	Greer W1	16T	44.5
	Greer W1	17T	43.25
	Greer W1	18T	42.75
	Greer W1	13T	43
	Greer W1	14T	43.5
	Greer W1	15T	44.75
	JFA 12.5	25T	40.25
	JFA 12.5	26T	40
	JFA 12.5	27T	41
	JFA 12.5	28T	40.5
	JFA 12.5	29T	41.75
	JFA 12.5	30T	40.5
	WVP W1	31T	40.5
	WVP W1	32T	40.75
	WVP W1	33T	41.5
	WVP W1	34T	41.5
	WVP W1	35T	41
	WVP W1	36T	40

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	46.677083	42.979167
Variance	8.7145607	6.8093297
Observations	24	24
Pooled Variance	7.7619452	
Hypothesized Mean Difference	0	
df	46	
t Stat	4.5979311	
P(T<=t) one-tail	1.671E-05	
t Critical one-tail	1.6786604	
P(T<=t) two-tail	**3.342E-05**	
t Critical two-tail	2.0128956	

NMAS (Hoosier R80 Tire Data)

Table 58: Data and Excel Output for All Mixtures Polished with Hoosier R80 Tires Comparing 9.5mm and 12.5mm NMAS

	Mix	Sample	BPN_{48000}
9.5mm	WVP W1	31B	50.75
	WVP W1	32B	48.75
	WVP W1	33B	50.5
	WVP W1	34B	50.75
	WVP W1	35B	50.25
	WVP W1	36B	48.75
	WVP W1	31T	40.5
	WVP W1	32T	40.75
	WVP W1	33T	41.5
	WVP W1	34T	41.5
	WVP W1	35T	41
	WVP W1	36T	40
	Greer W1	13B	43.75
	Greer W1	14B	42.5
	Greer W1	15B	43.75
	Greer W1	16B	43
	Greer W1	17B	42.75
	Greer W1	18B	43
	Greer W1	13T	43
	Greer W1	14T	43.5
	Greer W1	15T	44.75
	Greer W1	16T	44.5
	Greer W1	17T	43.25
	Greer W1	18T	42.75
12.5mm	WVP 12.5	19B	45.5
	WVP 12.5	20B	47.5
	WVP 12.5	21B	44.25
	WVP 12.5	22B	43.75
	WVP 12.5	23B	43.5
	WVP 12.5	24B	45.75
	WVP 12.5	19T	46.25
	WVP 12.5	20T	45.75
	WVP 12.5	21T	47.75
	WVP 12.5	22T	47.5
	WVP 12.5	23T	46.25
	WVP 12.5	24T	47
	JFA 12.5	25B	47.5
	JFA 12.5	26B	47.25
	JFA 12.5	27B	48.75
	JFA 12.5	25T	40.25
	JFA 12.5	26T	40
	JFA 12.5	27T	41
	JFA 12.5	28B	49.75
	JFA 12.5	29B	49
	JFA 12.5	30B	49.25
	JFA 12.5	28T	40.5
	JFA 12.5	29T	41.75
	JFA 12.5	30T	40.5

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	44.395833	45.26042
Variance	12.358243	9.910213
Observations	24	24
Pooled Variance	11.134228	
Hypothesized Mean Difference	0	
df	46	
t Stat	-0.8975681	
P(T<=t) one-tail	0.1870449	
t Critical one-tail	1.6786604	
P(T<=t) two-tail	**0.3740897**	
t Critical two-tail	2.0128956	

Contractor (Hoosier R80 Tire Data)

Table 59: Data and Excel Output for 12.5mm Mixtures Polished with Hoosier R80 Tires Comparing JFA and WVP Contractors

	Mix	Sample	BPN_{48000}
JFA	JFA 12.5	25B	47.5
	JFA 12.5	26B	47.25
	JFA 12.5	27B	48.75
	JFA 12.5	25T	40.25
	JFA 12.5	26T	40
	JFA 12.5	27T	41
	JFA 12.5	28B	49.75
	JFA 12.5	29B	49
	JFA 12.5	30B	49.25
	JFA 12.5	28T	40.5
	JFA 12.5	29T	41.75
	JFA 12.5	30T	40.5
WVP	WVP 12.5	19B	45.5
	WVP 12.5	20B	47.5
	WVP 12.5	21B	44.25
	WVP 12.5	19T	46.25
	WVP 12.5	20T	45.75
	WVP 12.5	21T	47.75
	WVP 12.5	22B	43.75
	WVP 12.5	23B	43.5
	WVP 12.5	24B	45.75
	WVP 12.5	22T	47.5
	WVP 12.5	23T	46.25
	WVP 12.5	24T	47

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	44.625	45.89583
Variance	17.721591	2.118845
Observations	12	12
Pooled Variance	9.9202178	
Hypothesized Mean Difference	0	
df	22	
t Stat	-0.9883337	
P(T<=t) one-tail	0.1668677	
t Critical one-tail	1.7171444	
P(T<=t) two-tail	**0.3337353**	
t Critical two-tail	2.0738731	

Table 60: Data and Excel Output for 9.5mm Mixtures Polished with Hoosier R80 Tires Comparing Greer and WVP Contractors

	Mix	Sample	BPN_{48000}
Greer	Greer W1	13B	43.75
	Greer W1	14B	42.5
	Greer W1	15B	43.75
	Greer W1	16B	43
	Greer W1	17B	42.75
	Greer W1	18B	43
	Greer W1	13T	43
	Greer W1	14T	43.5
	Greer W1	15T	44.75
	Greer W1	16T	44.5
	Greer W1	17T	43.25
	Greer W1	18T	42.75
WVP	WVP W1	31B	50.75
	WVP W1	32B	48.75
	WVP W1	33B	50.5
	WVP W1	34B	50.75
	WVP W1	35B	50.25
	WVP W1	36B	48.75
	WVP W1	31T	40.5
	WVP W1	32T	40.75
	WVP W1	33T	41.5
	WVP W1	34T	41.5
	WVP W1	35T	41
	WVP W1	36T	40

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	43.375	45.41667
Variance	0.4943182	23.07197
Observations	12	12
Pooled Variance	11.783144	
Hypothesized Mean Difference	0	
df	22	
t Stat	-1.4569004	
P(T<=t) one-tail	0.0796349	
t Critical one-tail	1.7171444	
P(T<=t) two-tail	**0.1592698**	
t Critical two-tail	2.0738731	

Environment (Laboratory vs. Field)

Table 61: Data and Excel Output Comparing Initial BPN Measurements for JFA 12.5mm SR Laboratory Compacted and Corresponding Field Core Specimens Polished with Hoosier R80 Tires

	Sample	BPN_0
JFA 12.5mm SR Laboratory Compacted	1L	59.3
	2L	55.3
	3L	61.0
	4A	54.3
	5L	59.8
	6L	67.0
JFA 12.5mm SR I-79 Field Cores	1F	61.0
	2F	66.0
	3F	72.8
	4F	53.3
	5F	53.8
	6F	69.8

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	59.41666667	62.75
Variance	20.84166667	66.775
Observations	6	6
Pooled Variance	43.80833333	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.87229023	
P(T<=t) one-tail	0.201753992	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	**0.403508**	
t Critical two-tail	2.228138852	

Table 62: Data and Excel Output Comparing BPN Measurements After Polishing 48,000 Wheel Passes for JFA 12.5mm SR Laboratory Compacted and Corresponding Field Core Specimens Polished with Hoosier R80 Tires

	Sample	BPN_{48000}
JFA 12.5mm SR Laboratory Compacted	1L	42
	2L	40.8
	3L	42.3
	4A	43.5
	5L	42.5
	6L	42.5
JFA 12.5mm SR I-79 Field Cores	1F	43.5
	2F	43.8
	3F	42.8
	4F	42.0
	5F	43.5
	6F	42.8

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	42.25	43.0416667
Variance	0.8	0.43541667
Observations	6	6
Pooled Variance	0.617708333	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.74466182	
P(T<=t) one-tail	0.055820236	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	**0.1116405**	
t Critical two-tail	2.228138852	

Table 63: Data and Excel Output for JFA 12.5mm SR Field Core Specimens and Corresponding Average Field Measurements

	Sample	BPN
*Field Cores	D1	59
	D2	48
	D3	50.5
	D4	50.75
	D5	51.25
**Avg. Field Measurements	D1	74.5
	D2	69.9
	D3	67.4
	D4	73.5
	D5	86.3

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	51.9	74.325
Variance	17.33125	52.9910156
Observations	5	5
Pooled Variance	35.16113281	
Hypothesized Mean Difference	0	
df	8	
t Stat	-5.97958477	
P(T<=t) one-tail	0.000165422	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	**0.0003308**	
t Critical two-tail	2.306004135	

Notes:

*Initial BPN measurement (no polishing)

**BPN measured after approximately 3 weeks of traffic and averaged between wheel path and center measurements and downhill and uphill measurements in the North bound fast lane