Mixture Sampling and Determination of Asphalt Binder Content for Slurry Surfacing Systems

by

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ABSTRACT

Slurry seals and micro surfacing are two of the main preventative maintenance methods used by state and local agencies. However, there is a lack of methods for quality control/quality assurance for slurry surfacing systems. The purpose of this work is to propose a method of quality control binder content determination for slurry surfacing systems and to develop a standardized, representative field sampling procedure. The focus is to provide an accurate and timely method to ensure test results can be obtained the same day during construction.

The study evaluated the feasibility of using the ignition furnace test method to determine the residual asphalt binder content of the mixes and developed a sampling conditioning protocol to eliminate moisture from the system and improve accuracy. The results showed that the ignition method can be used in combination with microwave drying of the samples to obtain rapid, reliable results. Overall, after drying, the ignition method results in an asphalt content tolerance of ±0.426% for within laboratory testing and ±1.051% for between laboratory testing of slurry surfacing materials.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt content
AHTD	Arkansas State Highway and Transportation Department
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
Austroads	Apex Organisation of Road Transport and Traffic Agencies in Australia
CF	Correction factor
$\widetilde{d_\iota}$	Laboratory deviation of laboratory i
d_i	Laboratory deviation
DOH	Division of Highways
DOT	Department of Transportation
EC	Emulsion content
F	F0.995(ni-1, N-p-ni+1), the 99th percentile of the F-distribution with n_i-1 and N-p-n_i+1 degrees of freedom
GDOT	Georgia Department of Transportation
h	Between laboratory consistency statistic
h_i	Between-laboratory consistency statistics for laboratory i
HMA	Hot mix asphalt
i	Laboratory number
ILS	Interlaboratory study
ISSA	International Slurry Surfacing Association
j	Replicate number
JMF	Job mix formula
$k_{c,i}$	Critical value of ki for laboratory i
k_i	Within-laboratory consistency statistic for laboratory i

LWT	Loaded wheel test
M_c	Initial mass of container
MC	Moisture content
M_f	Final mass of specimen
M_i, M_0	Initial mass of specimen
MS	Micro surfacing
N	Total number of test result data for the material
n^*	The operational number of replicates for each material
NAC	Nuclear asphalt content
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Project
n_i	Number of replicates submitted from laboratory i
NMAS	Nominal maximum aggregate size
NMSHTD	New Mexico State Highway Transportation Department
p	Number of laboratories in the data set
P_b	Measured asphalt binder content
$P_{b,t}$	Theoretical binder content
PF	Pay Factor
PG	Preservation Group
p_i	(N-p)/(ni-1)
QA	Quality assurance
QC	Quality control
QC/QA	Quality control/quality assurance
RAP	Reclaimed asphalt pavement
rpm	Revolutions per minute
RR	Residual rate of emulsion
s_i	Standard deviation of the test results in laboratory i
s_L	Between laboratory standard deviation
s_L^2	Between laboratory variance

s_r	Repeatability standard deviation
s_R	Reproducibility standard deviation
SS	Slurry seal or Polymer-modified slurry seal
$SS_{\tilde{d}}$	Weighted sum of squares of laboratory deviations
s_x	Standard deviation of laboratory averages
USA	United States of America
VDOT	Virginia Department of Transportation
w_i	Cell weighting factor
WTAT	Wet track abrasion test
$\bar{x}_i$	Average of test results from laboratory i
$\bar{\bar{x}}$	The grand average for each material
$\hat{x}$	Weighted grand average
x_{ij}	The jth individual test result value from laboratory i

CHAPTER I - BACKGROUND

Pavement preservation is used to prevent distresses and restore serviceability without aiding structural performance (Jia et al. 2020). Common, effective preventative maintenance treatments include thin asphalt overlays, slurry seals, micro surfacing, and chip seals (Dong et al. 2018). Limited budgets and increasing traffic volumes are causing agencies to investigate cost and time effective methods to improve pavement maintenance (Dong et al. 2018). Agencies are also subject to inflation, increasing the need to conserve energy and materials (Lee et al. 1980). Proper usage of preventative maintenance and rehabilitation strategies is one of the most effective approaches to extend pavement life (NDOT 2018). Due to their cost-effectiveness and ecological advantages, slurry seals and micro surfacing are two of the main preventative maintenance methods used by state and local agencies (Jia, Dai et al. 2020). Increasing interest in preventative maintenance treatments has resulted in a need to evaluate treatment performance and optimize application methods (Dong et al. 2018).

1.1. Slurry Seals and Micro Surfacing

Slurry surfacing is a nonpolluting, zero-emissions treatment (Broughton et al. 2012). Slurry surfacing methods include slurry seals, polymer-modified slurry seals, and micro surfacing. Often, there is very little distinction between micro surfacing and slurry seals in literature and specifications. Historically, agencies tend to include micro surfacing and slurry seals under the same specification, with little to no differentiation between the two treatments (National Academies of Sciences, Engineering, and Medicine 2010). Slurry seals first originated in 1930s Germany as a mixture of well-graded fine aggregate, emulsion, mineral filler, and water. Typically, slurry seals are applied in a single layer at a single stone thickness (Dong et al. 2018). Increasing traffic demands resulted in a search for asphalt binder performance enhancers within pavement maintenance and rehabilitation. One method to enhance asphalt performance is the use of polymer modifiers (Buss and Pinto 2019). Micro surfacing, a polymer modified version of the slurry seal, was first used in Germany in the 1960s for the purpose of repairing wheel paths while eliminating the need to restripe the roads (Fooladi and Hesami 2020). In the late 1960s and early 1970s, micro surfacing and polymer-modified slurry surfacing became popular in European countries and was introduced to North America by the 1980s (National Academies of Sciences, Engineering, and Medicine 2010).

Micro surfacing is a modified version of a slurry seal consisting of a polymer modifier and better quality, coarser aggregate (Dong et al. 2018). Providing a wide range of benefits while minimizing the environmental impact, reducing costs, and maximizing durability, micro surfacing is a suitable treatment that is ahead of all other similar treatments providing the same durability (Broughton et al. 2012). Micro surfacing is better suited for higher traffic volume areas than slurry seals (Dong et al. 2018). Both micro surfacing and slurry seals can result in a lower roughness than an untreated pavement section (Jia, Dai et al. 2020). Another major benefit of slurry seals and micro surfacing is roads can be opened to traffic soon after placement. For micro surfacing, traffic can be reopened in as little as an hour after placement (Dong et al. 2018). However, micro surfacing and slurry seals provide little aid to structurally compromised pavements (National Academies of Sciences, Engineering, and Medicine 2010).

Slurry seals are economical and can seal aged pavement, fill minor cracks, decrease moisture susceptibility, improve roughness, and improve wear resistance. Treatments such as micro surfacing and slurry seals are also effective in preventing alligator and longitudinal cracking (Jia, Dai et al. 2020). Another benefit is the addition of a wearing surface similar to a new hot mix asphalt (HMA) pavement (Buss and Pinto 2019). Micro surfacing has also been successfully used in rigid pavements to address reflection cracking distresses and pothole repairs (Buss and Pinto 2019). It is one of the few preservation and maintenance treatments with the capability of improving the transverse geometry of a road, improving rutting (National Academies of Sciences, Engineering, and Medicine 2010). From a preventative maintenance viewpoint, micro surfacing rivals thin hot mix asphalt overlay treatments for durably treating a wide range of pavement defects (Broughton et al. 2012). However, milling an existing surface and placing a thin-HMA overlay typically requires 8 to 12 hours before the road can be opened again (National Academies of Sciences, Engineering, and Medicine 2010). Micro surfacing is used on a routine basis in North America, providing six to seven years of service life extension (National Academies of Sciences, Engineering, and Medicine 2010). In addition to time benefits, micro surfacing and slurry seal mixtures improve pavement surface friction, increasing safety for roadway users. Micro surfacing is one of the most cost-effective preservation treatments, due to the fast production and paving of the mixture (Buss and Pinto 2019).

Micro surfacing and slurry seals also have a smaller environmental impact than HMA, largely reflective of the cold nature of production and user work zone delay minimization. On average, when compared to a 1.5-2.0-inch HMA overlay, micro surfacing reduces energy usage by 83-86% and reduces greenhouse gas emission by 90-92% (National Academies of Sciences, Engineering, and Medicine 2010). It should be noted that although micro surfacing can improve the transverse geometry of the road in applications of rut filling, it cannot be used to treat humps (Broughton et al. 2012). Due to the thin layer being placed, slurry surfacing systems require no corrections to curb lines, manholes, guide rails, or bridge clearances (Broughton et al. 2012). Micro surfacing treatments are more effective than all other treatments when considering strict environmental regulations and budgetary problems (Broughton et al. 2012). Although micro surfacing is considered economical and sustainable, small improvements in the durability of micro surfacing systems could result in significant cost savings and more sustainable design and construction practices (Broughton et al. 2012).

The performance of preventative maintenance methods is relative to the initial pavement condition, environmental factors, and the materials used in production (Dong et al. 2018). Micro surfacing and slurry seals provide little aid to structurally compromised pavements but can significantly improve other distress types (National Academies of Sciences, Engineering, and Medicine 2010). While research has increased for performance of treatments, little research has been conducted on how specific material properties affect pavement preservation performance (Dong et al. 2018). There is a lack of field testing and quality control of slurry surfacing systems. There is a current need to develop tools for monitoring slurry surfacing quality (National Academies of Sciences, Engineering, and Medicine 2010).

1.2. Quality Control

Quality management involves the quality control of all aspects of production and construction of asphalt pavements. Quality control (QC) encompasses the actions needed to control the level of quality being produced in the final product of a project. The continuous improvement of paving activities is paramount to ensuring consistent, quality flexible pavements. As pavement design continues to develop and advance, the quality management system should also be maintained and improved to envelope the vastness of pavement design (Transportation Association of Canada 2016). Complete QC requires a plan of action for acquired materials throughout the process of production and construction. QC is critical to pavement performance as the quality of a pavement must be built in during the development of the pavement, it cannot be added after construction is complete (Transportation Association of Canada 2016). For example, in conventional asphalt concrete paving the asphalt content of a bituminous mixture is one of the most important factors to affect the performance of the mixture, often monitored for acceptance of an HMA pavement (Nikolaides and Manthos 2011).

Current pavement construction and production of HMA requires monitoring of asphalt content for acceptance and quality control. In other mixture types, asphalt content has been shown to affect pavement performance and pavement lifecycle. For HMA, too little asphalt results in a less-durable material, while too much asphalt often causes stability issues (McKeen 1997). Often, an excess in binder leads to rutting while too little binder results in cracking distresses (Neves 2019). Monitoring asphalt content when paving HMA is typical since the asphalt content of HMA is a critical volumetric property from which other material properties are derived (Sinclair and Wenz 2018). Most agencies require asphalt binder content as criterion for acceptance (Rodezno and Brown 2017). An accurate method of determining binder content ensures higher QC during production and construction of HMA (Nikolaides and Manthos 2011).

Unlike for HMA, agencies are currently deterred by the quality control and quality assurance (QC/QA) practices in pavement maintenance (National Academies of Sciences, Engineering, and Medicine 2010). According to a 2018 survey of contractors by the Nevada Department of Transportation, raveling is the most common distress for slurry seals and micro surfacing (NDOT 2018). Raveling occurs when a micro surfacing system or slurry seal does not have enough residual asphalt to form adequate bonds. The lack of bonds results in moisture susceptibility. As the emulsion content is reduced, the resistance to raveling is reduced. However, as emulsion content of a slurry seal or micro surfacing mixture increases, cohesive strength increases. The higher emulsion content results in more residual asphalt binder to bond aggregates together, increasing raveling resistance and durability (Buss and Pinto 2019). Micro surfacing mixtures with excessive emulsion content results in flushing and shoving. Flushing results in a slick black surface while shoving results in treatment displacement under normal traffic loading (National Academies of Sciences, Engineering, and Medicine 2010). However, despite designing slurry surfacing mixtures based on residual AC, there is currently a lack of rigorous field testing for micro surfacing and slurry seals. Field testing methods are needed to determine measurable micro surfacing properties for correlation with treatment performance, especially AC (National Academies of Sciences, Engineering, and Medicine 2010).

Project selection, materials selection, mixture design, and construction procedures are instrumental to providing successful maintenance and rehabilitation treatments (NDOT 2018). Quality slurry seals can be produced with suitable materials that are properly designed, evaluated, and applied (Lee et al. 1980). Slurry surfacing is a highly specialized process, reliant on the experience of contractors and suppliers (National Academies of Sciences, Engineering, and Medicine 2010). State-of-the-practice for slurry seals deems slurry surfacing consistency more critical than application rates. Agencies often assume slurry seal mixture consistency is a direct indicator of the material proportions, allowing changes to the job mix formula (JMF) based on contractor experience (NDOT 2018). Contractor and crew experience is also relied on when field adjustments to the JMF are used to compensate for environmental conditions (Buss and Pinto 2019). Continuously monitoring the aggregate moisture content, asphalt content, application rates, and mix consistency during construction is state-of-the-practice for slurry surfacing systems but testing for QC is not. State-of-the-practice also includes calibrating equipment that continuously and accurately proportions materials. Monitoring the proportions throughout construction is standard for acceptance of most slurry surfacing systems instead of directly testing the mixture (NDOT 2018). Agencies are searching for new QC and quality assurance (QA) methods for pavement preservation and maintenance treatments to ensure quality workmanship and treatment performance (Buss and Pinto 2019).

Better pavement quality control can be ensured with a quick, accurate method of binder content determination (Nikolaides and Manthos 2011). There are currently many specifications and standards for emulsified asphalt mixtures when considering material selection and design. However, few specifications exist to evaluate the construction processes and determine as-placed properties for slurry seals and micro surfacing, particularly AC for slurry surfacing systems (Dong et al. 2018). Recently, projects implementing preventative maintenance treatments revealed a failure to achieve the expected performance when evaluating data from the long-term pavement performance (LTPP) program, failing prior to the expected lifecycle. The data results indicate significantly more degradation than anticipated. A transition is needed from empirical decision-making to decisions based on scientific data to provide better quality treatments (Jia et al. 2020).

1.3. Objectives

The primary objective of this research was to recommend a method of testing for residual asphalt content of slurry surfacing systems. The secondary objectives included the following:

- Develop an accurate field sampling method for slurry surfacing materials.
- Compare sample preparation protocol in the form of drying methods.
- Determine the effect of factors such as mixture type, emulsion grade, aggregate source, etc. on method accuracy

1.4. Scope

To effectively evaluate the accuracy of each test method and complete research objectives, samples were collected from multiple field locations and fabricated in the laboratory to evaluate the effectiveness of different methods of testing and an Interlaboratory Study conducted to establish a precision statement after confirming method accuracy. Samples were collected from multiple field locations, including mixed slurry surfacing materials and raw materials. Field sampling included collecting as-built materials tickets or a JMF, which report the AC, from the suppliers to effectively compare theoretical versus measured AC. Materials tickets were critical because the experience of the contractor is used in the field to adjust the material proportions, including moisture content and AC. Three methods of testing for drying and determination of AC were considered, including conventional drying and extraction, conventional drying and ignition method of AC, and microwave drying and ignition method of AC. The purpose of testing is to evaluate and compare the accuracy of test methods while reducing the cost and time required to achieve results. Finally, samples were fabricated for an interlaboratory study. The interlaboratory study consisted of four mixture designs evaluated by nine different laboratories to determine evaluation tolerance levels with the precision and bias statement. The four mixture designs are from four states, Alabama, Virginia, Tennessee, and California, representing a range of geographic conditions. The conclusions of this study are applicable for slurry surfacing materials applied across varying regions.

1.5. Organization of Thesis

This thesis is organized into five chapters:

- Chapter 1 Background: The background introduces slurry surfacing materials, quality control measures for AC, project objectives, and the scope of conducted research.
- Chapter 2 Literature Review: A literature review on the theory behind drying methods for pavement materials, methods for determining AC, and a comprehensive review of state Department of Transportation (DOT) and international specifications regarding slurry surfacing sampling and AC determination methods.
- Chapter 3 Methodology: A summary of methods for slurry surfacing material collection and distribution, including laboratory sample fabrication, field sample collection, and a complete account of the Interlaboratory Study (ILS). The methodology also includes a summary of methods for evaluating samples, including conventional oven drying, microwave oven drying and ignition furnace method for AC and centrifuge extraction of asphalt for AC determination, and precision & bias statement.
- Chapter 4 Results: Presents a summary of results comparing the theoretical asphalt binder content to measured AC for slurry surfacing materials, conclusions on the effects of slurry surfacing mixture components and subsequent changes in AC, and test method variability within the ILS. Materials evaluated were collected from the field, fabricated in the laboratory, and distributed for the ILS.
- Chapter 5 Conclusions & Recommendations: Presents a summary of the conclusions of results found in the report and makes recommendations for future research in order to address the gaps in slurry surfacing research knowledge.

CHAPTER II - LITERATURE REVIEW

2.1. Slurry Surfacing Systems

A slurry seal is a mixture of fine-graded aggregates, emulsified asphalt, mineral filler, additives, and water. The initial consistency of the mixture is low, easily laid in a thin layer. If the right consistency is achieved, the mixture is pourable, free-flowing and should level itself (Harper et al. 1965). Slurry seals cure through a thermal process (Broughton et al. 2012). The water from the mixture begins to evaporate, causing the emulsion to break. Once the mixture breaks and water evaporates, the remaining mixture is a thin, relatively durable, sealing coat. Often, experience is used in the design of slurry seals, heavily relying on the wisdom of the contractor to provide a quality designed and constructed treatment. If a slurry mixture in the field appears dry, the contractor may increase the emulsion content (Harper et al. 1965). Current slurry seal design is completed according to the International Slurry Surfacing Association (ISSA) guideline A-105, "Recommended Performance Guideline for Emulsified Asphalt Slurry Seal." Polymer-modified slurry seal design is completed according to ISSA A-115, "Recommended Performance Guideline for Polymer-Modified Emulsified Asphalt Slurry Seal."

Micro surfacing mixtures include a combination of dense-graded aggregate, asphalt emulsion, water, polymer additive, and mineral filler. The asphalt emulsion, water, and polymer additive are proportioned according to the dry mass of aggregate. Typical proportions for micro surfacing mixtures use a design residual asphalt content of about 7% (Broughton et al. 2012). Micro surfacing uses polymer additives to chemically control the curing process (Broughton et al. 2012). The use of polymer modifiers, better quality aggregates, and stiffer emulsions allows micro surfacing to be laid at a thickness of two to three times the nominal maximum aggregate size (NMAS) using multiple lifts. Unlike slurry seals, micro surfacing uses additives to create a chemical break. Since breaking is controlled with the use of a polymer modifier, curing and breaking of micro surfacing is largely independent of weather conditions during the acceptable construction season set by the International Slurry Surfacing Association (ISSA). Polymers also improve the softening point of asphalt binder and thermal susceptibility, resulting in a system with better thermal crack resistance than that of the traditional slurry seal (National Academies of Sciences, Engineering, and Medicine 2010).

Micro surfacing mix design currently follows the International Slurry Surfacing Association (ISSA) Guideline A-143: "Recommended Performance Guideline for Micro Surfacing." Four tests are required for determining slurry surfacing proportions. ISSA TB-113, "Test Method for Determining the Mix Time for Slurry Surfacing Systems," determines mixture compatibility and workability. ISSA TB-100, "Laboratory Method for Wet Track Abrasion of Slurry Surfacing Systems," is used to prevent raveling in slurry surfacing mixtures by determining a minimum asphalt content for the design. The maximum asphalt content of the mixture is determined according to ISSA TB-109, "Test Method for Measurement of Excess Asphalt in Bituminous Mixtures by Use of a Loaded Wheel Tester and Sand Adhesion." The maximum asphalt content is specified to avoid severe flushing of surfacing materials under heavy traffic loads. Finally, ISSA TB-147, "Test Method for Measurement of Stability and Resistance to Compaction, Vertical and Lateral Displacement of Multilayered Fine Aggregate Cold Mixes," uses the Loaded Wheel Test (LWT) to determine the rutting resistance of micro surfacing and slurry seal mixtures. The Wet Track Abrasion Test (WTAT) is used to evaluate the raveling resistance and assess moisture susceptibility of slurry surfacing systems (Fooladii and Hesami 2020). The procedure to design a micro surfacing mixture uses mass loss from the 1-hour WTAT and the adhesion values from the LWT to determine the optimum asphalt content and the acceptable range of potential asphalt content (Wang et al 2018).

The 1-hour WTAT and LWT generally reveal an initial decrease, then an increase in displacement as the asphalt content, or emulsion content, of slurry seals and micro surfacing mixtures increases (Wang et al 2018). The emulsion content in a slurry surfacing mixture is critical for mass loss during WTAT (Fooladii and Hesami 2020). The minimum displacement value typically corresponds with the optimum asphalt content for displacement or shear resistance. Shear resistance is critical in slurry surfacing because it affects the pavement bonding properties and the rutting resistance of micro surfacing mixtures (Wang et al. 2018). A 6-day WTAT is used to determine the moisture susceptibility of a micro surfacing or slurry seal mixture. The moisture resistance of slurry surfacing systems is critical to providing an optimized treatment since raveling is one of the most common distresses. However, the design optimum asphalt content is subject to field adjustments based on engineering judgement (Wang et al. 2018).

All slurry surfacing treatments require a clean surface for construction, void of any deleterious material such as dust or debris. Pretreating the surface includes sealing tighter cracks, filling wide cracks, and extensive brooming (Broughton et al. 2012). To control the effects of moisture and temperature of the existing pavement, the surface of the existing roadway must be cleaned and pre-wet before slurry surfacing. High temperatures increase the need for pre-wetting to avoid a premature break as the mixture encounters the existing surface. The emulsion breaks onto the surface of the existing pavement through flocculation, resulting in asphalt films that coalesce into a homogenous, cohesive material. The use of an emulsion allows for a cold-formed adhesive bond between the existing pavement and new treatment (National Academies of Sciences, Engineering, and Medicine 2010).

According to ISSA A-105 and A-115, mixing of slurry seals should be completed in equipment specifically designed for slurry seals. The mixer can be either an automatic-sequenced, self-propelled machine that is truck-mounted or continuously designed. The machine will accurately proportion the materials through a mixer which continuously discharges the mixture into a spreader box with a front seal to ensure no material is lost and a rear seal to provide uniform consistency and application. The rear of the spreader box will have a burlap drag or other appropriate material to texturize the surface. Slurry seal construction requires certification of calibration for equipment at least every 60 days. The QC for both slurry seals and polymer-modified slurry seals includes maintaining the proper mixture consistency. Considering AC, a dry, low AC, or wet, high AC, mix will behave differently. Contractors are expected to make adjustments to the JMF to avoid mixes that are too dry, which will streak, lump, and result in high roughness, and mixes that are too wet, which will flow after being placed.

Micro surfacing mixtures are produced and constructed using a specialized machine to lay the treatment continuously by mixing proportions in a pug mill (National Academies of Sciences, Engineering, and Medicine 2010). Since micro surfacing can be laid at a multi-layer thickness, more robust equipment is needed than for slurry seals. Micro surfacing production is mixed in a continuous-flow mixer that proportions the materials. A twin-shafted paddle or spiral auger is used to mix and provide a uniform flow into the spreader box (Broughton et al 2012). The continuous feeding nature of the machine results in a free-flowing composite material (National Academies of Sciences, Engineering, and Medicine 2010). The continuous-flow mixture is then transported to the spreader box, which spreads the material and strikes it off at the desired treatment thickness (Broughton et al. 2012). The spreader box allows for an evenly spread pavement mixture over the desired width.

Common distresses seen in micro surfacing can be attributed to AC, lack of adhesion between aggregates and asphalt, incompatibility of materials, unsuitable weather conditions during construction, and poor workmanship (Fooladii and Hesami 2020). The mix design procedure for micro surfacing and slurry surfacing is empirical based (Wang et al. 2018). According to Buss and Pinto (2019), small variations of ± 1% moisture content are not significant for cohesion strength. Instead, moisture content affects the workability, consistency, and mixing time of the micro surfacing. Environmental conditions, especially humidity and temperature conditions are highly variable and influence the performance of slurry seal and micro surfacing mixtures (Buss and Pinto 2019). Test strips, often in sections of 500-1000 ft in North America, are constructed to estimate the break and cure time and properties of the mixture when subjected to environmental conditions (National Academies of Sciences, Engineering, and Medicine 2010).

Slurry surfacing is used to rejuvenate weathered pavement surfaces, fill cracks and small depressions in the existing surface, and prevent moisture from entering the pavement system. The most critical component of design is the emulsion content. If too much emulsion is present, the treatment will bleed. If too little asphalt emulsion is used in a slurry seal, the treatment will ravel and wear excessively under loading. Emulsion contents are based on a specified residual AC, using the residual AC of the emulsion to determine the AC of the mixture. The residual AC is critical in the design and construction of slurry surfacing systems because the AC affects the performance of the mixture. As the residual AC of a mixture is increased, the abrasion of the material decreases but the shoving of the material increases. However, proper emulsion content in slurry seals minimizes excessive abrasion and results in minimal shoving (Harper et al. 1965).

Because slurry surfacing is an equipment-intensive practice, properly calibrated and functional equipment is necessary to provide quality slurry surfacing mixtures (National Academies of Sciences, Engineering, and Medicine 2010). Since laboratory conditions are typically humidity and temperature controlled, further research into the effects of adjusting JMF to account for variable environmental factors is needed (Buss and Pinto 2019). Adjustments to slurry surfacing mixtures, even within tolerance limits, results in significant changes in treatment performance. The effectiveness of the treatment depends on the quality control measures taken during construction (Bhargava et al. 2022). Residual AC is critical to design for both slurry seals and micro surfacing. Monitoring AC during construction is essential to providing a quality pavement treatment (Broughton et al. 2012 and Harper et al. 1965).

2.1. Moisture in Slurry Surfacing Systems

Slurry surfacing systems use emulsified asphalt to introduce asphalt into the system, which must break and cure into a continuous asphalt film by flocculation and coalescence of asphalt droplets (James 2006). In a slurry surfacing system, water is displaced to form an asphalt film around aggregates (Bhargava et al 2020). Flocculation and coalescence result in the removal of water, allowing cohesive strength to develop and asphalt to form an adhesive bond to the aggregate. Flocculation is a quick process that discharges some water from the system where particles have enough energy to overcome the charged barrier between the emulsifier and water and the charged particles of asphalt. Coalescence, however, is a slower process where some water becomes trapped within the asphalt itself. Curing does not require all water to evaporate. Instead, the remaining water is removed through mechanical action, compaction or traffic loading, to squeeze water out of the system. The process continues until all the trapped water is diffused from the system. Ideally within slurry surfacing systems, the emulsion droplets should coalesce after contacting the aggregate and paving (James 2006).

Slurry surfacing systems are complex mixtures that can hold water for weeks (National Academies of Sciences, Engineering, and Medicine 2010). However, research has shown that moisture content determination is critical to determining residual AC in the laboratory (Silbernagel et al. 1985). The conventional oven drying method, following AASHTO T 329-15: Standard Method of Test for Moisture Content of Asphalt Mixtures by Oven Method, consists of subjecting a sample to 110°C ± 5°C in an oven until reaching constant mass. Conventional drying is simple and accurate but requires significant time to achieve results. Typically, samples may take anywhere from 4 hours to 24 hours to completely dry in an oven (Usmen and Kheng 1986). A need for a new method to quickly and accurately determine moisture content became apparent (Gaspard 2002). Most highway construction materials are also suitable for drying in a microwave oven, according to ASTM D 4643-17: Standard Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating (Usmen and Kheng 1986).

Microwave ovens are an accurate, efficient, and safe method to determine moisture content in soils based on accuracy, testing time, and cost benefit analysis (Gaspard 2002). Microwaves are highly available and low cost (Usmen and Kheng 1986). In 2002, Gaspard determined that the most expensive portion of the initial costs for microwave drying is the purchase of a scale, a device typically already available to contractors. Compared to the price of purchasing equipment for conventional drying, the microwave oven procedure requires significantly less up-front funding (Gaspard 2002).

The microwave method is a means of rapidly drying unbound materials, common practice in soils. Stabilized materials, particularly those with cement, are especially suitable for use in the microwave oven due to the minimization of hydration during rapid heating (Usmen and Kheng 1986). When studying methods to determine moisture content in soils, the standard microwave oven was determined to be the most feasible device (Gaspard 2002). Microwaves can be reflected, absorbed, or transmitted by a particular material. Only materials that can sufficiently absorb the microwaves will be heated. Water will absorb microwave energy readily, causing the water to heat much faster than most pavement construction materials. The water will boil and evaporate within the microwave with little to no effect on soil properties (Usmen and Kheng 1986).

When studying typical household microwaves, no significant challenges from the usage of the microwave to dry soils were reported. However, it must be noted that the use of a standard microwave oven to dry soils or other atypical materials may result in a manufacturer warranty void (Gaspard 2002). The rate of microwave drying is dependent on the power setting of the microwave and the moisture content of the sample. Porcelain and borosilicate glass (Pyrex) containers work well in the microwave because of the favorable heat transmission of these materials (Usmen and Kheng 1986). To prevent damage to the microwave, a brick or different heat sink can be placed in the microwave oven (Gaspard 2002).

Moisture content testing using microwave ovens on soils resulted in favorable results and significant time savings. It should be noted that moisture contents determined from microwave drying are typically higher than those obtained through conventional drying (Usmen and Kheng 1986). Microwave oven drying produces accurate results in significantly less time than conventional oven drying. For soils, microwave drying enhances the efficiency of laboratory drying. Instead of the standard 24 hours required to dry a sample in a conventional oven, moisture content can be determined in 20-30 minutes (Gaspard 2002).

Unlike conventional drying methods, simultaneously drying multiple samples in a microwave oven is not feasible. More research is needed to standardize the microwave oven drying procedure for moisture content determination (Usmen and Kheng 1986). A need to evaluate different methods of determining moisture content and drying a sample also became apparent for asphalt mixtures. When using microwave ovens, the moisture content was acceptable for HMA. However, a problem with breakage of glass containers resulted in the need for more research (Huber et al. 2002). Nonetheless, moisture content determination is critical to determining AC (Silbernagel et al. 1985).

A 1985 study on HMA samples with variable moisture and ACs was completed. The microwave procedure developed included microwaving HMA for cycles of 10 minutes at 70% power with 10 minutes of rest between. Microwave drying is compared to conventional oven drying for use in AC determination. The study uses extraction methods to determine AC. Overall, the results show highly variable ACs, revealing that neither the conventional nor microwave drying methods removed all moisture. The study ultimately determined that more research is needed to develop a microwave drying procedure suitable for asphalt mixtures. However, significant time savings were observed when drying in the microwave compared to conventional drying (Silbernagel et al. 1985).

Components of micro surfacing and slurry seal mixtures interact with each other to form a chemically complex compound. The dependency of slurry surfacing behavior on AC has been well established. However, there has been limited research on how the changes made during construction affect performance (Bhargava et al. 2020). During material handling and mix production, aggregate gradation, emulsion content, and water content inevitably vary, increasing the risk of premature treatment failure. Furthermore, variation often co-occurs in the field (Bhargava et al. 2022). Most performance parameters for slurry surfacing are based on the residual AC. Since the asphalt binder being introduced to the mixture is an emulsified asphalt, water will leave the system through evaporation and absorption over time, resulting in a surfacing system bonded with the residual asphalt binder (Malladi et al. 2018). The emulsion content of slurry surfacing mixtures is pivotal to ensuring workability and the residual AC is critical to the system durability. Moisture content determination is critical to determining AC from emulsified asphalt mixtures (Bhargava et al. 2020).

2.2. Methods for Determining Asphalt Content

Historically, AC was determined using chlorinated solvents. However, chlorinated solvents caused environmental, economic, health, and safety concerns, resulting in a production ban. New biodegradable solvents replaced chlorinated solvents, but the process is more time consuming and less accurate than chlorinated solvents (Nikolaides and Manthos 2011). One major benefit of solvents is extraction by solvent is the only standard method to allow for binder testing and characterization after determining AC. However, extraction by solvent requires constant technician attention to provide consistent, repeatable results (Hemida et at. 2021). States began searching for a suitable alternative to solvent extraction after the 1990 Clean Air Act, which banned production of trichloroethane, commonly used for extraction by solvent prior to 1990 (Prowell 1998). Prior to the 1990 Clean Air Act, the Virginia Department of Transportation (VDOT), like many other states, relied heavily on trichloroethane to determine AC of mixtures (Prowell 1998).

Centrifuge extraction, per ASTM T 164-14: Quantitative Extraction of Asphalt from Hot Mix Asphalt (HMA), begins with determination of moisture content. The sample is then placed into an extraction bowl and subjected to cycles of adding solvent, soaking, and spinning in the centrifuge. The procedure continues until the extracted material is a light straw color when placed against a white background. The materials are then dried at 110°C ± 5°C to constant mass. The centrifuge method of extraction requires about 3.5 hours to obtain an AC (Hemida et at. 2021). AASHTO T 164 first dates to 1955, when the centrifuge was first used to determine AC. A 1980 study on the emulsion contents of slurry seals revealed highly variable results with extraction, often inconsistent with the JMF (Lee et al. 1980). A 1985 study on AC determination accuracy determined the amount of asphalt that is absorbed and cannot be extracted varies from 0.0 to 0.9%, depending on the aggregate type, when studying HMA (Silbernagel et al. 1985). After developing procedures for new solvents, nuclear asphalt content (NAC) gauges were developed to rapidly determine AC (Nikolaides and Manthos 2011).

NAC gauges operate by thermalizing high-energy neurons or slowing the neurons through atomic collisions. These neutrons can then be detected and registered as a count by a helium-3 detector (Prowell 1998). According to AASHTO T 297-20 (2020): “Asphalt Binder Content of

Asphalt Mixtures by Nuclear Method," a butter batch is used to determine the target weight of the sample. The butter batch, however, is not used in determining the AC, resulting in waste materials. Using the target weight, the gauge pan is filled about halfway, tamped, and overfilled with asphalt. The top is struck off until even, and a leveling pan used to compact the sample. The sample is placed into the gauge, tested, rotated, and tested again. The sample can contain moisture, but the moisture content must be determined after testing in the nuclear gauge.

The NAC gauge method does not allow for aggregate gradation (Nikolaides and Manthos 2011). Nuclear gauges are also not suitable for use on reclaimed asphalt pavement (RAP) (Neves 2019). The NAC gauges require extraction of the binder by solvent to run a gradation or complete further binder testing (Brown et al. 1995). When neither the biodegradable solvents nor the NAC gauge method equivalently replaced the chlorinated solvents, research began into the ignition furnace method of AC determination (Nikolaides and Manthos 2011).

The use of ignition furnaces to determine AC was first investigated by the National Cooperative Highway Research Project (NCHRP) in 1969 but became more popular as the procedure was refined in the early 1990s (Sinclair and Wenz 2018). The NCHRP study determined asphalt binder almost entirely combusts when subjecting HMA to high temperatures. The ignition method focuses on heating the asphalt mixture in an oven at a temperature above the flash point of asphalt binder (Neves 2019). The ignition method is concluded when the change in mass is no greater than 0.01% for three consecutive minutes (Rodezno and Brown 2017). Early ignition methods subjects HMA to temperatures of 843°C (1550°F). Due to the extreme temperature required for testing, aggregate breakdown led to significant errors in AC determination. The temperature was then lowered to 593°C with the development of new equipment. The effects of binder and aggregate types were significantly lowered with the reduction in temperature. Finally, temperatures were lowered to 538°C (Nikolaides and Manthos 2011).

Today, ignition furnaces may take up to three hours to preheat properly, an essential process for accurate results (Sinclair and Wenz 2018). However, asphalt samples in the ignition furnace can completely combust in about 30 minutes. The ignition method also requires no disposal of often harmful solvents (Brown et al. 1995). The addition of lime, a mineral filler, to asphalt mixtures caused no significant difference in the measured AC when using the ignition method for HMA when a correction factor is applied (Rodezno and Brown 2017). The ignition method proved to be sufficient for AC in the field (Brown et al. 1995). Even during research, the early data from the National Center for Asphalt Technology (NCAT) revealed the ignition method promising as a suitable alternative to solvent extraction (Prowell 1998).

VDOT studied four methods as alternatives for solvent extraction: the measurement of nuclear AC of Marshall sample plugs, the measurement of Marshall plugs AC using the ignition method, the nuclear AC of sample pans, and vacuum extraction using biodegradable solvent. VDOT determined extractions by solvent typically require between 1.5 and 2.5 hours of testing. Of the testing time for biodegradable solvent extraction, an operator is expected to constantly monitor the process except for a 45-minute soak in solvent. An additional 1.5 hours is needed to dry the aggregate and filter, resulting in three to four hours before extraction results can be obtained. Biodegradable solvent extraction requires purchasing filter media, solvent, and the residual disposal, increasing the costs associated with testing (Prowell 1998). VDOT's research, as reported by Prowell in 1998, reveals the ignition furnace and a properly calibrated nuclear asphalt content gauge are both more accurate than reflex extraction when determining AC. However, Prowell also discovered that the variance of gauge readings will be affected by operator, aggregate type, and AC, causing greater within-laboratory and between-laboratory variance (Prowell 1998). As a result of the research, VDOT specified the ignition method for AC determination of asphalt mixtures beginning in the 1997 paving season (Prowell 1998).

In New Mexico, a round-robin experiment was conducted, testing extractions by reflux extractor, centrifuge extractor, nuclear asphalt gauge, and ignition furnace. The centrifuge method proved to be the most variable of the four. The study also determined the nuclear asphalt content gauge, reflux method, and ignition method were consistent. However, ignition testing resulted in slightly higher ACs, likely due to aggregate breakdown (McKeen 1997). Based on the results of AC variability testing, prior to the adoption of AASHTO T 308, McKeen recommended the ignition test for AC for routine use on New Mexico State Highway Transportation Department (NMSHTD) projects (McKeen 1997).

In 1995, an ignition furnace accuracy study was conducted, determining both the standard ignition furnaces and infrared furnaces statistically accurate for AC determination (Nikolaides and Manthos 2011). The Florida Department of Transportation State Materials Office investigated a round-robin study to verify the accuracy and precision of the ignition method. The study determined AC could be determined with a high degree of accuracy using the ignition method (Choubane et al. 2006). A 2011 study using absorbent and non-absorptive aggregates revealed significant differences in AC occurred when using solvent extraction versus ignition method for AC determination. For extraction by solvent, as aggregate absorption increased, difference in obtained binder content increased. However, there was no statistically significant change when the ignition method was used. Thus, the ignition method is more precise than the extraction method for absorptive aggregates (Nikolaides and Manthos 2011). Extraction by solvent is expensive, time-consuming, hazardous, and environmentally unfriendly (Neves 2019). The main advantage of extraction is the ability to test the asphalt binder post-extraction. The ignition furnace method is destructive in nature, so no binder recovery is possible (Neves 2019).

The ignition furnace method of AC determination is quick, technically simple, and does not use any solvent (Neves 2019). Overall, the ignition furnace requires much less technician time than extraction by solvent (Brown et al. 1995). The ignition procedure is also more precise than extraction methods. AASHTO T 308 allows for a maximum single operator precision of 0.069% and multi-laboratory precision of 0.117%. AASHTO T 319 allows 0.18%/0.21% and 0.29%, respectively (Rodezno and Brown 2017). The ignition method is the most common method for AC determination, due to testing simplicity and accuracy (Sinclair and Wenz 2018).

2.3. Review of State Specifications and Provisions

As the methods of sampling and AC determination were developed, a review of current specifications for slurry seals and micro surfacing systems was completed. Specifications were first checked for inclusion of a specific micro surfacing or slurry seal general specification or special provision. For those states with either a specification or provision included, each section was reviewed for quality control methods. Specifically, each section was examined for residual AC quality control sampling and testing methods, tolerances for AC, and information about the frequency of testing. A comprehensive review of United States state DOTs standard specifications and special provisions for micro surfacing and slurry seals was completed, consisting of all 50 states within the United States along with the District of Columbia and federal project specifications published by February 2022. Specifications also included Puerto Rico, Alberta, Canada, Australia, South Africa, and Ontario, Canada. Table 1 presents the specification results for all 57 agencies included in the specification and provision inspection, summarized in Figure 1, Figure 2, and Figure 3.

Table 1: Micro Surfacing and Slurry Seal Specification and Provision Summary

Type of Document/Requirement	Number of Agencies	% of Agencies
Specification	29	51%
Special Provision	13	23%
Specification or Special Provision	35	61%
Sample Collection Method	4	7%
QC AC Testing Method	5	9%
AC Needed, No Testing or Collection Provided	1	2%
AC Checked with Calculation	12	21%

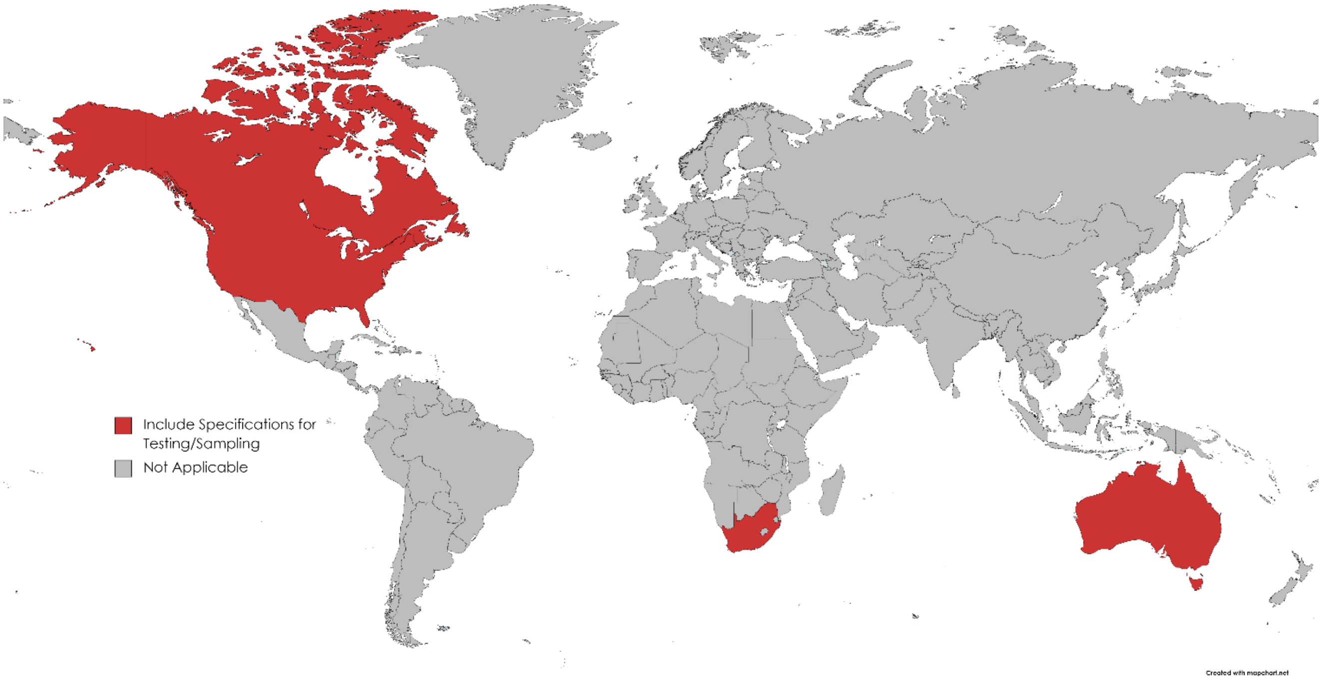

Figure 1: Summary of Specification Review Global Map

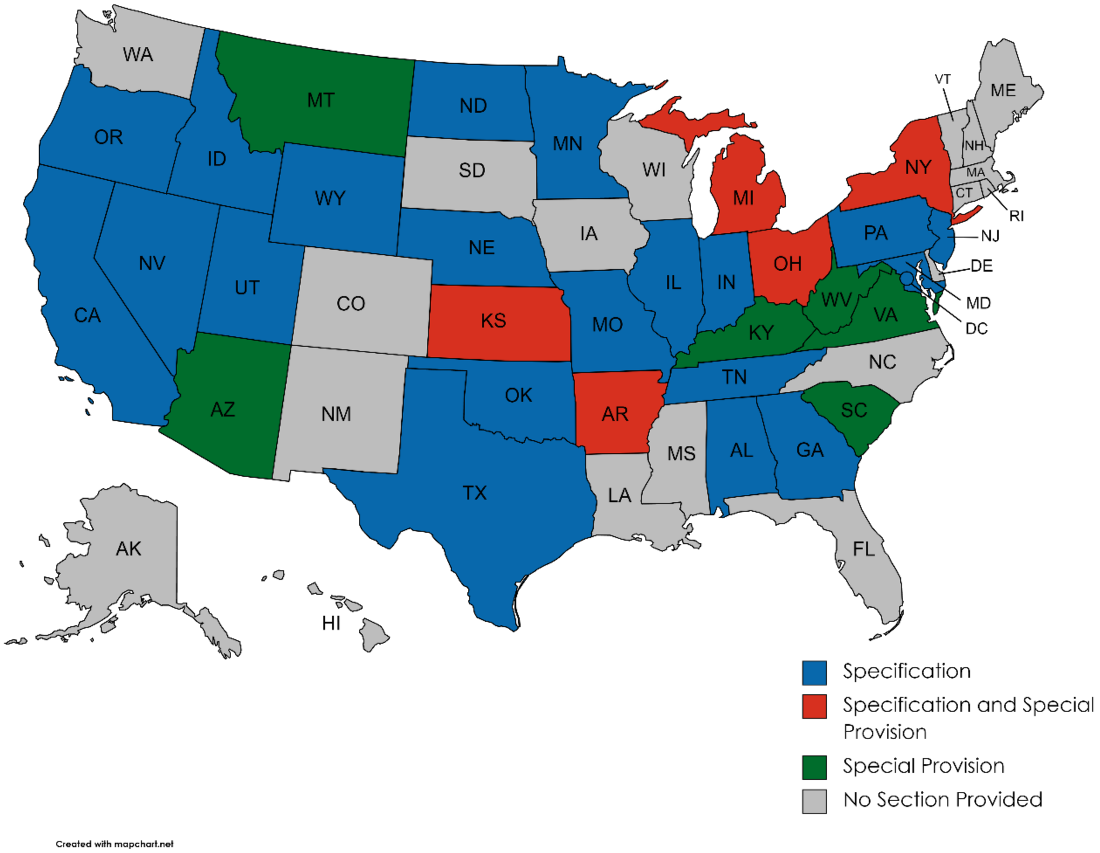

Figure 2: Summary of Specification Review United States Map

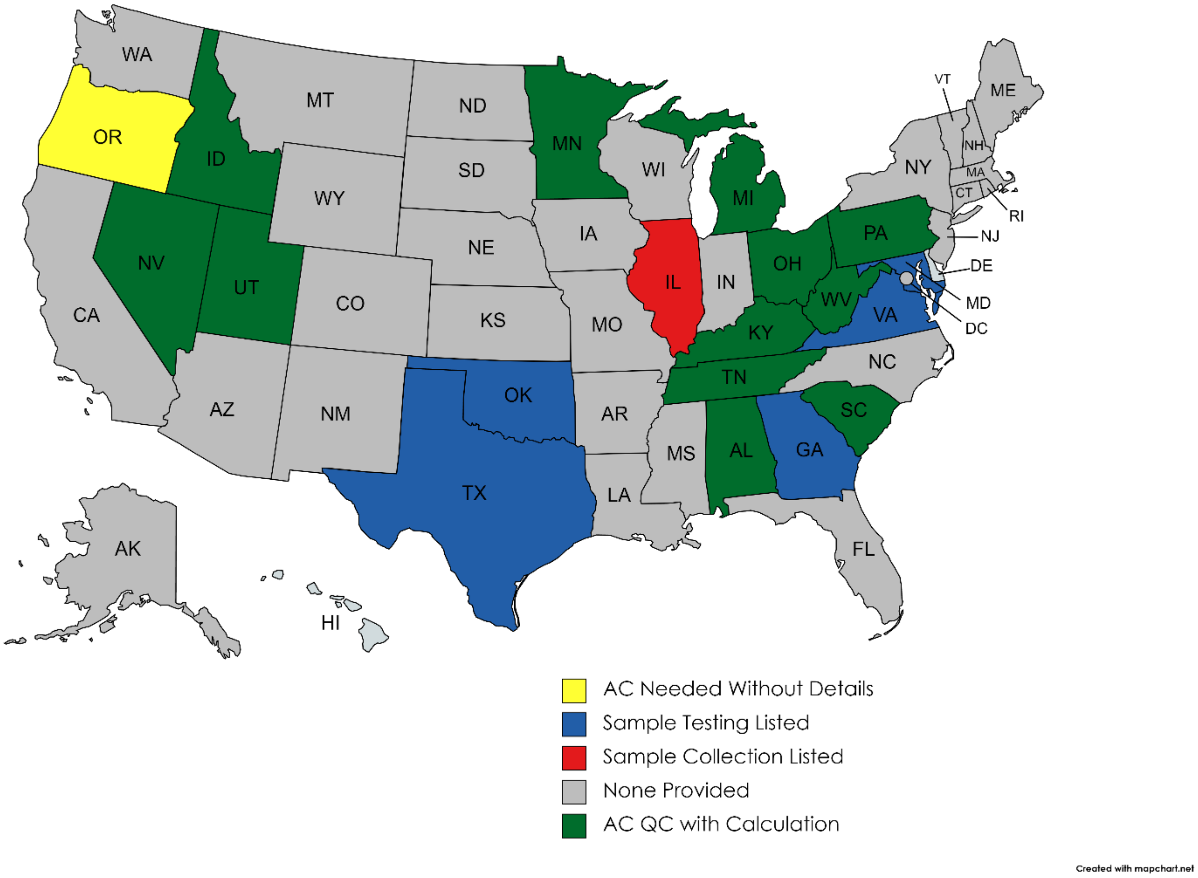

Figure 3: Specification Review Summary of Results United States Map

In Figures 2 and 3, the gray states did not have any information provided while the gray countries are not applicable. Of the 57 specifications reviewed, 29 agencies include a specification for either micro surfacing or slurry seals. Thirteen agencies list micro surfacing or slurry seals in special provisions. Despite numerous agencies including micro surfacing and slurry seals in specifications only four agencies include a specific sample collection method. Five agencies include AC sample testing methods. One agency requires AC testing for QC but does not provide a method of testing or sample collection in the specification, the Texas DOT, specifying test method Tex-236-F (ignition method) with conventional oven drying for QC. Twelve agencies require AC calculations using machine counter proportions for QC.

Three of the five agencies with an AC testing method specified require AC determination by ignition. The fourth agency allows either materials tickets calculation or direct testing with the ignition furnace. Finally, one agency allows AC determination with a NAC gauge, vacuum extraction, centrifuge, or by visually inspecting the consistency during paving, the Arkansas State Highway and Transportation Department (AHTD). Arkansas allows AC determination according to AHTD Test Method 449/449A (nuclear gauge), AHTD 450 or 451 (centrifuge or vacuum extraction), or AHTD 467, the Method of Test for Checking Slurry Seal Consistency. The Virginia DOT allows AC determination by method VTM-102, ignition method, or VTM-93, nuclear gauge method for every 25,000-50,000 square yards. 12 agency specifications require either materials tickets or yield calculations to determine a theoretical as-placed AC. Illinois is the only state agency to provide a sample collection method for micro surfacing or slurry seals. According to the 2022 Illinois State DOT specifications in section 402.12, one sample per JMF is to be collected from the loading shoot of the pug mill prior to being deposited in the drag box. The collected sample is to be placed in a one-gallon bag. However, no testing method is provided for AC. Three other agencies also included sample collection methods including Alberta, Canada (ATT-60/95), Australia (AGPT-T221-18), and South Africa (MB8). Alberta uses a bag-lined can to sample slurry surfacing materials directly from the paving equipment. In AGPT-T221-18, the Apex Organisation of Road Transport and Traffic Agencies in Australia (Austroads) recommends using a ladle capable of collecting at least 1kg samples from the pugmill. Austroads also requires leaving the lid off the container used for sampling until the mixture is set. Finally, South Africa uses a scoop to transfer mix directly from the paving machine to a container.

One agency, the Oregon Department of Transportation, requires AC determination for QC but does not specify a method of sample collection or AC testing. Twelve agencies require checking AC with calculation from machine counter readings for QC of slurry surfacing systems. AASHTO also recommends verifying the application rates of both emulsified asphalt and aggregate through yield checks from the machine at least four times per day. Seven of the twelve also provide tolerances for AC in the specifications. Four of the seven agencies allow ±0.5% AC tolerance. Two agencies, the West Virginia DOT and Michigan DOT allow ±0.5% AC for a single test and ±0.2% AC for a daily average. Finally, the Utah DOT allows ±0.6% AC before adjusting the final pay factor (PF). Four agencies provide tolerance for AC after testing for AC. The Georgia and Texas DOTs allow a deviation of up to 0.5% AC from the JMF. However, the Maryland and Virginia DOTs allow a deviation of 1.5% from the JMF for AC.

Sixteen agencies provide sampling, testing, or calculation frequency. Seven of the sixteen agencies specify testing frequencies. AHTD requires testing at least once per project with testing occurring by the lot (120,000 square yards) and sublot (30,000 square yards). The Georgia DOT (GDOT) tests according to GDT 125, AC by ignition method. GDOT requires sampling twice per day at minimum. The Illinois Department of Transportation specifies at least one QC test for AC per JMF. The Maryland DOT requires one test per lift, allowing ± 1.5% AC for a daily average. ATT-60/95 calls for at least three samples for each day of production while AGPT-T221-18 calls for at least three 1-kilogram samples during each run. Finally, South Africa specifies a minimum of eight samples per batch of slurry surfacing in MB8. Six agencies requiring AC calculation or yield checks for slurry surfacing QC specify a minimum of three checks daily, including the Alabama, Idaho, Kentucky, Michigan, and Tennessee DOTs and the West Virginia Division of Highways (DOH). The District of Columbia specifications require calculating the AC at least once daily. Ohio requires 4 yield checks per day of production. Finally, the South Carolina DOT specifies determining yield calculations for every 1000 feet of paving.

Only 51% of agencies include micro surfacing or slurry seals in general specifications with only 61% providing either a specification or special provision. To effectively implement quality control into slurry surfacing projects, there is a need to include distinct specifications for micro surfacing and slurry seals. Without micro surfacing and slurry seal design specifications, it is impossible to implement consistent quality preservation or maintenance treatments. Of the agencies that included sections specific to slurry surfacing methods, little if any quality control testing is included. A significant portion of the tolerances and frequencies provided by specifications and provisions are based on machine counter readings instead of direct AC testing. There is currently a lack of slurry seal and micro surfacing specifications and a severe lack of methods for AC QC of slurry surfacing systems, despite current slurry surfacing systems' designs based on optimal AC.

2.4. Summary of the Literature Review

Slurry surfacing mixtures consist of aggregate, emulsion, water, and mineral filler. Micro surfacing mixtures also include a polymer-modifier. Slurry surfacing treatments are effective pavement maintenance and preservation treatments, addressing a wide range of distresses in asphalt pavements. Designing slurry surfacing systems is reliant on laboratory testing to determine an optimum emulsion content, resulting in an optimal AC. Treatments are designed at the optimal AC but there are currently no standard methods of verifying the design for QC. A method for QC of slurry surfacing systems is needed for treatment performance. Based on HMA QC for AC, ignition furnace testing is a promising method for AC determination of slurry surfacing materials. Ignition furnace testing is simple, quick, and provides accurate AC results. Since slurry surfacing mixtures can retain water for weeks and MC is critical to determining AC, slurry surfacing specimens must be dried prior to testing AC. Conventional oven drying and microwave drying are suitable for pavement construction materials, with microwave drying providing significant time savings.

CHAPTER III - METHODOLOGY

With the overall objectives of developing procedures for field sampling and asphalt binder content determination of slurry surfacing systems and a lack of guidance from agency specifications, the experimental design relied on research conducted on HMA to determine the suitability of drying procedures and AC determination methods for slurry surfacing systems. A review of 57 agency specifications and provisions revealed a lack of written procedures for both sampling and AC determination for slurry surfacing mixtures. Of the agencies with binder content methods specified, three of the five agencies specify the ignition method of AC determination. Only one agency included sampling information. Since so little information was provided by agencies, the procedure was developed using modified procedures from HMA production and construction.

3.1. Refinement of Protocol

For the purposes of testing AC for QC of slurry surfacing materials, field samples and laboratory samples were obtained and an ILS run. Refining the testing protocol for the ILS, laboratory samples were fabricated and tested at NCAT to determine the appropriate methods of testing.

3.1.1. Factors Considered

A method of testing to determine AC for current slurry seal and micro surfacing projects as a method of quality control was developed. Analysis of the effect of binder content is needed on current pavement preservation methods, particularly slurry seals and micro surfacing. The effects of as-placed binder content on most pavement maintenance and preservation treatments are unknown. Furthermore, there is currently no standardized method to compare theoretical binder content to as-produced binder content. As shown through the study of HMA, binder content is critical to pavement performance and quality control. Slurry seal and micro surfacing mixture design relies on emulsion content based on a design residual AC. However, little QC is available for preservation treatments. The experimental procedure was designed to verify a method of sampling slurry surfacing mixtures and quick, accurate QC testing for asphalt binder content of slurry seal and micro surfacing mixtures.

Since moisture content is critical to AC determination, the overall experiment followed a progression of determining the AC method and drying procedure best suited for slurry seal or micro surfacing mixtures. A method of drying slurry surfacing materials using a microwave was developed and compared to the conventional oven drying method, typically dried at 110°C ± 5°C. Since the ignition method was proven to be accurate, timely, simple, and cost-effective due to the commonality of testing in HMA, the ignition method was considered a highly promising method. To evaluate the accuracy of AC determination, the centrifuge method was also used to extract binder specifically for binder content determination. No further testing was completed on the binder after extraction. The experimental procedure included conventional oven drying, microwave oven drying, ignition furnace testing, and centrifuge extraction of binder to determine the AC of slurry seal and micro surfacing samples from several states within the United States of America.

3.1.2. Sample Fabrication

Laboratory samples were fabricated using six mix designs from contractors in six different states of the Southeastern region, following current JMFs. First, to consider all methods of testing time reduction, sample size was investigated. Smaller samples will break faster than larger specimens consisting of four, quartered samples. Smaller samples were created by first mixing together the aggregate and cement until a uniform distribution of cement occurs. Then, water is added and the mixture is again mixed to a uniform consistency. Finally, the emulsion is proportioned out and immediately mixed at roughly 60 rpm for about 30 seconds until emulsion distribution was uniform. The specimen was mixed until the consistency allowed the material to retain its shape and not flow under normal conditions. There is no need to split the smaller samples, so the sample was transferred to a container for testing, as shown in Figure 4.

Figure 4: Individual Small Sample in Disposable Container

Laboratory mixtures were evaluated to ensure secondary effects from fabrication did not induce error in the ILS. Overall, slurry surfacing materials were evaluated to determine the effects of sample size, mixing the mixture to crumble before splitting, drying prior to determining AC, and storage method on AC. Mixtures were evaluated by first determining the sample size. A smaller specimen consisting of a single sample size was compared to a pan specimen consisting of four samples. By reducing the initial sample size, less time was required to dry and test the AC. However, smaller sampling resulted in higher variability. Ultimately, the increase in variability did not justify the time savings. Therefore, larger specimens, consisting of at least four samples, were collected from the field and larger specimens were fabricated for the ILS.

To ensure same day testing could be completed, methods to reduce the time required to determine AC were investigated. Mixing the sample so that it can be split into four samples requires some breaking and curing of the emulsion. This results in moisture loss from the specimen. In order to reduce time, mixing the sample to crumble is compared to mixing to a sufficient set prior to testing. Mixing to a sufficient set is defined as the point at which a specimen may be split and retain its shape while mixing the sample to crumble is defined as mixing the sample to a state in which the mixture no longer self-consolidates but will condense if pressure is applied. Mixing the sample to crumble results in removal of as much moisture as possible, thereby saving time required to dry the specimen.

Then, sample storage was investigated, comparing the accuracy by storage in a pan, plastic container, or Ziploc bag. Finally, methods of sample conditioning, or drying, are investigated to determine the effect on AC accuracy.

3.1.3. Sample Conditioning

Before testing to determine the residual binder content, samples were dried to constant mass to eliminate moisture added to the mix either from the emulsion or as additional water to provide workability. Sample conditioning included conventional oven drying, microwave oven drying, and hybrid drying to remove moisture in slurry surfacing systems prior to determination of AC.

3.1.3.1 Conventional Oven Drying

The conventional oven drying procedure closely followed AASHTO T 329-15: Standard Method of Test for Moisture Content of Asphalt Mixtures by Oven Method. The method determined the amount of moisture in an HMA sample by conventional oven drying. Initial mass of a specimen was recorded to the nearest 0.1 g. The sample was then placed in a sample container suitable for heating and mass was again recorded to the nearest 0.1 g. To dry the sample as timely as possible, the sample was evenly distributed within the pan using a spatula. An oven, preheated to 110°C ± 5°C, was used to heat the specimen for drying. The samples were dried for 90 ± 5 minutes. A new weight was determined and recorded. Drying continued for cycles of 30 ± 5 minutes until the new mass differed by no greater than 0.05 percent from the initial specimen weight. Samples were cooled to room temperature and a final mass measured. The mass loss, or the moisture content, was calculated according to Equation 1.

$$Moisture\ Content, \% = \frac{M_i - M_f}{M_f} * 100 \qquad \text{(Equation 1)}$$

Where:

M_i = initial mass of specimen, g

M_f = final mass of specimen, g

3.1.3.2 Microwave Oven Drying

To expedite the drying procedure, a method roughly following ASTM D 4643-17: Standard Test method for Determination of Water Content of Soil and Rock by Microwave Oven Heating was developed for slurry seal and micro surfacing mixtures. The method used a standard microwave. The initial mass of a container suitable for microwaves, typically glass or porcelain, was determined. A sample was then added to the container and mass taken again to determine the initial mass of the sample. The initial mass of the specimen was calculated using Equation 2.

$$M_i = M_f - M_c \qquad \text{(Equation 2)}$$

Where:

M_i = initial mass of the specimen, g
M_c = initial mass of container, g
M_f = final mass of specimen and container, g

A heat sink, consisting of a small flask partially filled with standard cooking oil, was placed in the microwave such that the heat sink would not interrupt the microwaving process. The heat sink ensures no microwave damage occurs while microwaving atypical materials. A specimen was placed inside the microwave and heated for consecutive rounds of 360, 300, 240, 180, 120, and 60 seconds. Between each heating cycle, the sample was stirred and weighed to the nearest 0.1 g. Care was taken to ensure almost all material was scraped from the spatula between heating cycles. A folded towel was also placed on the scale surface and tared out when weighing the hot specimens to avoid glass breakage from quick temperature changes. The moisture content of the specimen was calculated according to Equation 3.

$$MC = \frac{\sum_0^i (M_i - M_0)}{M_0} * 100 \qquad \text{(Equation 3)}$$

Where:

MC = total moisture content of the specimen, %
M_i = mass at drying cycle i, g
M_0= initial mass of specimen, g

3.1.3.3 Hybrid Drying

Hybrid drying consisted of following microwave drying with conventional oven drying to determine if more accuracy could be obtained than microwaving alone. First, the procedure for the microwave drying was completed. The final sample weight after microwave drying was then used as the initial weight for the next procedure. The sample was then transferred to an oven at 110°C ± 5°C, following the conventional procedure. It was allowed to dry for one to 1.5 hours and weighed again, determining the final sample weight after testing to the nearest 0.1 grams. The MC was determined according to Equation 1.

3.1.4. Asphalt Content Determination

In addition to comparing sample preparation protocols in the form of drying methods, methods of determining AC were also evaluated and compared for accuracy. Methods of determining AC included the ignition furnace method and centrifuge extraction using Trichloroethylene.

3.1.4.1 Ignition Furnace

The established procedure defined by AASHTO T 308-21: Determining the Asphalt Binder Content of Asphalt Mixtures by the Ignition Method, Method A was closely followed for slurry seal and micro surfacing samples. The NCAT Ignition furnace was preheated to 538°C ± 5°C. An empty ignition basket weight was determined. The sample, weighing roughly 800 ± 100 grams, was split into two, half of the material placed in the bottom basket and half in the top basket. Care was taken to ensure material was at least an inch from the sides of the basket to ensure complete ignition of the asphalt. The final weight of basket and sample was obtained and entered into the ignition furnace controller. The internal balance was zeroed out.

Finally, the sample was placed into the furnace chamber and the combustion blower turned on by pressing the start/stop button. After test completion, the baskets were set aside to cool prior to post-ignition aggregate extraction. After cooling, all material was removed from the baskets and a post-ignition weight obtained. Most of the mixture samples were dried prior to ignition. For those samples not dried however, a companion sample was dried using either the microwave or conventional oven drying method to determine a moisture content. The moisture content of the companion sample was used to determine the final AC of the specimen. The ACs of the specimens were determined according to Equation 4.

$$P_b = \left[\frac{(M_i - M_f)}{M_i} * 100\right] - C_F - MC \qquad \text{(Equation 4)}$$

Where:

P_b = the measured (corrected) asphalt binder content, %

M_i = the total mass of the asphalt mixture specimen prior to ignition, g

M_f = the total mass of aggregate remaining after the ignition, g

C_F = the correction factor, percent by mass of asphalt mixture specimen

MC = the moisture content of the companion asphalt mixture specimen, %

For expediency, there were no correction factors used during testing or analysis. The percent binder determined was then compared to the theoretical binder content of each mixture. The theoretical binder content was obtained by multiplying the emulsion content by the residual rate of emulsion, found either in a JMF or using materials tickets printed as samples were taken. The theoretical binder content was determined according to Equation 5.

$$P_{b,t} = RR * EC * 100 \qquad \text{(Equation 5)}$$

Where:

$P_{b,t}$ = the theoretical asphalt binder content, %

RR = the residual rate of emulsion, %

EC = emulsion content, %

To determine the effectiveness of the drying and testing methods, the theoretical binder content was compared to the measured asphalt binder content using both the percent departure and absolute departure. The percent departure and absolute departure of each sample were calculated according to Equation 6 and 7 below.

$$\%\,Departure = P_b - P_{b,t} \qquad \text{(Equation 6)}$$

Where:

$P_{b,t}$ = the theoretical asphalt binder content, %

P_b = the measured asphalt binder content, %

$$Absolute\ Departure = \left|P_b - P_{b,t}\right| = |\%\,Deviation| \qquad \text{(Equation 7)}$$

Where:

$P_{b,t}$ = the theoretical asphalt binder content, %

P_b = the measured asphalt binder content, %

3.1.4.2 Centrifuge Extraction Method

The asphalt binder content was also obtained according to AASHTO T 164-14 (2018): Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA) Method A. Once moisture content was determined, the sample was placed into an extraction bowl. The sample was then entirely immersed in trichloroethylene and a standard filter weighed. The sample was set aside to allow the extractant to disintegrate the asphalt binder in the specimen. After sitting for sufficient time but allowing no longer than one hour rest, the bowl was placed in an extraction centrifuge. The filter ring was placed in such a way to not lose material as the bowl spins.

The centrifuge was started slowly, increasing to a maximum of 3600 revolutions per minute (rpm). Solvent flow increased from the drain as revolutions were increased. After allowing the centrifuge to stop, 200 mL of solvent was added to the centrifuge bowl. The procedure was repeated for not less than three solvent additions until the extracted material was no darker than a light straw color when placed against a white background. All material, including the filter ring, was carefully transferred to ensure no fine material loss and dried to a constant mass in an oven at 110°C ± 5°C. The final mass of the materials not extracted was determined using initial weights. When ashless filters or felt filters were used, the AC was determined according to Equation 8 and Equation 9, respectively.

$$asphalt\ binder\ content = \frac{(W_1-W_2)-(W_3+W_4)}{W_1-W_2}\ x\ 100 \qquad \text{(Equation 8)}$$

Where:

W_1 = the mass of the test portion,
W_2 = the mass of the water in test portion, g
W_3 = the mass of extracted mineral aggregate, g
W_4 = the mass of the mineral matter in extract, g

$$asphalt\ binder\ content = \frac{(W_1-W_2)-(W_3+W_4)}{W_1-W_2}\ x\ 100 \qquad \text{(Equation 9)}$$

Where:

W_1 = the mass of the test portion, g
W_2 = the mass of the water in test portion, g

W_3 = the mass of extracted mineral aggregate, g

W_4 = the mass of the mineral matter in extract and felt ring, g

Slurry seals and micro surfacing uses material quantities by weight of aggregate. To compare ACs for slurry seals and micro surfacing, the asphalt binder content had to be calculated by weight of aggregate. Therefore, when determining the AC of a mixture by weight of aggregate, Equation 10 was used.

$$asphalt\ binder\ content = \frac{(W_1 - W_2) - (W_3 + W_4)}{W_3 + W_4}\ x\ 100 \qquad \text{(Equation 10)}$$

Where:

W_1 = the mass of the test portion, g

W_2 = the mass of the water in test portion, g

W_3 = the mass of extracted mineral aggregate, g

W_4 = the mass of the mineral matter in extract and felt ring, g

To determine the effectiveness of the centrifuge method using conventional oven drying, the theoretical binder content was compared to the measured asphalt binder content using both the percent departure and absolute departure.

3.2. Interlaboratory Study

An ILS was performed to assess the feasibility of using the ignition furnace method to determine the residual AC of slurry surfacing mixtures and develop a precision and bias statement. As part of this ILS, mix samples were prepared at NCAT and distributed among participating labs for testing. A comprehensive ILS, including 9 laboratories and four slurry surfacing designs was completed. Of the four slurry surfacing designs, one design is a slurry seal, another design is a polymer-modified slurry seal, and the last two designs are micro surfacing mixtures. Care was taken to ensure enough labs were participating to determine the accuracy of testing. The laboratories participating in the study indicated willing participation in determining AC by first drying in a microwave or using conventional methods. AC determination methods included centrifuge extraction by solvent and the ignition furnace method.

Participating laboratories are found in Table 2. Of the nine participants, three laboratories were agencies and seven were industry. Each laboratory received sets of samples consisting of 2 replicates from each mix design.

Table 2: Interlaboratory Study Laboratory Participants and Location

Number	Location
1	Springfield, Illinois
2	Tulsa, Oklahoma
3	Auburn, Alabama
4	Jurupa Valley, California
5	Richland, Mississippi
6	Kansas City, Missouri
7	Charlottesville, Virginia
8	West Sacramento, California
9	Charleston, West Virginia
10	Phoenix, Arizona

The mix designs were provided as JMFs from current construction projects for a slurry seal, polymer-modified slurry seal, or micro surfacing mixture. To ensure the procedure for quality control was effective for different regions within the United States, four different mixture designs typically applied in different locations across the country were used. The mixture designs included in the ILS study are summarized in Table 3 below.

Table 3: Interlaboratory Study Mixture Design Summaries

Material	Classification	Aggregate Type	Emulsion Type	Design Residual AC
1	Micro Surfacing	Limestone	CSS-1HP	6.28%
2	Slurry Seal	Granite	CQS-1H	8.00%
3	Micro Surfacing	Granite	CQS-1HP	7.80%
4	Polymer-Modified Slurry Seal	Olivine Basalt	CQS-1HP	8.99%

Batches of 4 samples were made at a time to simulate the field sampling procedure. For the ILS, 8 batches of 4 samples, resulting in a total of 32 samples per mixture type, were made following the same procedure outlined in the laboratory mixing section. The batches were numbered from 1 to 8 to differentiate between batches. Each batch of samples was quartered and samples from opposite corners paired up. Each quartered sample was assigned a letter A, B, C, or

D according to Figure 5 below.

Figure 5: Quartered Sample Identification

For complete sample identification within the ILS, samples were designated using the ILS mixture identification number followed by either "MS," indicating a micro surfacing mixture, or "SS," indicating a slurry seal or polymer-modified slurry seal. After the mix type designation, the nomenclature for each sample included the batch number followed by the sample identification letter, A through D. The final sample identification followed the order "Mixture Identification Number-Mixture type (MS or SS)-Batch Number (1-8)-Quartered identification (A, B, C, D)." For example, the upper rightmost sample in the first batch of the micro surfacing mixture from mixture one was identified as 1-MS-1-A.

3.2.1. Test Specimens

In general, each mixture design is a current design used in micro surfacing or slurry seal mixtures, submitted as a JMF. Raw materials were obtained from field projects and for the four mixture types included in the ILS. The materials were used to proportion mixtures according to the JMF to mix laboratory samples. Laboratory mixtures were created according to ISSA guidelines for each mixture type. Slurry seal samples were designed and developed using ISSA A-105, Recommended Performance Guideline for Emulsified Asphalt Slurry Seal. Polymer-modified samples were created using ISSA A-115, Recommended Performance Guideline for Polymer-Modified Emulsified Asphalt Slurry. Finally, micro surfacing samples were obtained from JMFs using ISSA A-143, Recommended Performance Guideline for Micro Surfacing. First, the mix time was determined, providing the optimum MC for fabrication.

3.2.1.1 Slurry Surfacing Mix Time

Although the water content is given in the JMF, the recommended range is wide and the percent needed to ensure mix workability depends on various factors and is adjusted in the field. ISSA TB-113: Test Method for Determining Mix Time for Slurry Surfacing Systems was followed to determine the moisture content (MC) of the lab produced mixtures. Roughly 100 grams of dry aggregate was weighed into a mixing bowl. The appropriate amount of mineral filler, cement, was then proportioned and added to the dry aggregate, mixing at 60-70 RPM for at least 10 seconds or until the filler distribution is uniform. The appropriate water was then added. Again, the mixture was mixed at 60-70 RPM for at least 20 seconds, mixing until the consistency is uniform. Finally, addition of emulsion was completed. A timer was started as soon as the emulsion was added to the mixture. Immediately, the specimen was mixed at 60-70 RPM for 30 seconds. After mixing for 30 seconds, half of the mixture was cast onto paper, spreading to a thickness of ¼ - 3/8 inch. The other half of the material was mixed for a maximum of 5 minutes or until the mixture broke. The mix time was recorded in seconds. The cast half of the sample was periodically checked by pressing lightly noting when the specimen hardened in seconds. Finally, a paper towel was pressed lightly onto the cast specimen. Time was recorded when the mixture reached a clear water set, indicated by a wet but clear colored paper towel after dabbing. The optimum MC was noted for sample fabrication.

3.2.1.2 Sample Fabrication and Storage

For each material type and JMF, ILS mixtures were developed following similar steps. First, an appropriately sized mixing bowl was tared on a scale accurate to the nearest 0.1 gram. Then, aggregate was proportioned according to the desired sample size and carefully poured into the bowl to prevent the loss of excessive fine material. Aggregate was dried and mixed prior to sampling to ensure representative samples were used in the creation of slurry surfacing samples. All other proportions were designed by weight of the dry aggregate. Next, the mineral filler was weighed and carefully added to the bowl with aggregate, as shown in Figure 6.

Figure 6: Sample Mixing with Aggregate and Mineral Filler

The filler and aggregate were mixed for a minimum of 10 seconds or until the materials were thoroughly combined. Next, water was proportioned and added, mixing at 60-70 revolutions per minute (rpm) for a minimum of 20 seconds. A mixture was created with the addition of water, as shown in Figure 7 below.

Figure 7: Aggregate, Mineral Filler, and Water Mixed

The emulsified asphalt was then weighed and immediately added to the aggregate, cement, and water mixture. The samples were mixed at 60-70 rpm for a minimum of 30 seconds, then mixed at 1 rpm until the sample was crumbly in nature. To mix a sample to crumble, the sample is mixed until the mixture no longer self-consolidates. Instead, the mixture will adhere to itself once pressure is applied, as indicated in Figure 8 and Figure 9.

Figure 8: Slurry Surfacing Sample Mixed to Crumble

Figure 9: Mixed to Crumble Sample Behavior

The sample was then transferred to an aluminum pan for splitting into quarters. By transferring into an aluminum pan, the sample could be split and transferred in the same container. The disposable, aluminum pan was nested inside a rigid pan for support, as shown in Figure 10.

Figure 10: Nested Disposable and Rigid Pan for Stability

Material was carefully and quickly transferred to the aluminum pan to avoid segregation. The sample was lightly mixed and then split with a taping knife. Care was taken to ensure the samples were split as evenly as possible. A split sample and taping knife are shown in Figure 11.

Figure 11: Mixed to Crumble Quartered Sample with Taping Knife

Each quarter was then subject to moisture content and AC determination.

While preparing samples, the technician, time, air temperature, humidity, and mixture proportions were recorded for each batch. Each sample was weighed prior to packaging for shipment. Each batch sample, designated with a letter A, B, C, or D, was carefully placed into a small aluminum pan, labeled, wrapped in cellophane, and taped to ensure no materials were lost during shipping. Samples were then paired off according to their batch number and sample letter. Samples from opposite corners of the pan were designated to be sent to a different lab. Therefore, samples A and C from a single batch were sent to a single laboratory while sample B and D from the same batch were sent to a separate laboratory for testing.

3.2.2. Interlaboratory Study Preliminary Experiment

A preliminary experiment was conducted to confirm the desired sample conditioning procedure and testing method. To reduce variability, all samples were prepared and tested at NCAT. Since the presence of water in slurry surfacing systems can be problematic for AC testing and conventional oven methods require significant time, the feasibility of a microwave oven drying procedure is investigated. The accuracy of the ignition furnace and centrifuge extraction for slurry surfacing systems is also determined. NCAT tested 3 sets of two samples for each mixture design. One set of samples was indicated for microwave drying and ignition testing for AC. Another set of samples was dried using conventional oven drying methods with centrifuge extraction by solvent as the method of AC determination. Finally, the last set of samples was dried using conventional oven drying methods and subjected to ignition furnace testing for AC. Preliminary testing determined which test methods would be appropriate for the ILS.

3.2.3. Precision and Bias

A precision and bias statement for the ILS experiment, using the microwave drying method with the ignition method of AC determination, was determined for the nine laboratories participating in the study. The ILS data set was balanced. Therefore, precision and bias were determined according to ASTM E691-20 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method. The repeatability and reproducibility of the test method was determined. The repeatability represents the variability between independent test results within a single laboratory. The reproducibility is concerned with the variability between independent test results from multiple laboratories. The design of the ILS was kept as simple as possible to avoid secondary effects of variability. Care was also taken to ensure no fewer than six laboratories were represented in the data to avoid bias from a misrepresentative population. The ILS used laboratories familiar with slurry surfacing materials and AC determination. The ILS was completed to determine whether the data was consistent enough for the basis for a test method and to obtain precision statistics for a precision statement. The statistical analysis estimates precision statistics using a one-way analysis of variance (ANOVA) for within-laboratory and between-laboratory testing, carried out for each material type.

Laboratory statistics were calculated for the balanced data set, requiring the same number of replicates from the laboratories for each material. Each laboratory tested two samples per mixture design. Each of the sets of two samples were subjected to ignition furnace AC determination after microwave drying to determine the accuracy of the method of testing. For the data set, the letter i represents the laboratory number in the set while the letter j designates the replicate number. First, the within-laboratory averages and standard deviations were calculated according to Equation 11 and Equation 12, respectively.

$$\bar{x}_i = \sum_{j=1}^{n_i} \frac{x_{ij}}{n_i} \qquad \text{(Equation 11)}$$

Where:

$\bar{x}_i$ = the average of the test results in Laboratory i

x_{ij} = the j^{th} individual test result value from Laboratory i

n_i = the number of test results submitted from Laboratory i

$$s_i = \sqrt{\frac{\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_i)^2}{(n_i - 1)}} \qquad \text{(Equation 12)}$$

Where:

s_i = the standard deviation of the test results in Laboratory i

x_{ij} = the j^{th} individual test result value from Laboratory i

n_i = the number of test results submitted from Laboratory i

The balanced dataset resulted in the need for a grand average, or an average of cell averages. The grand average, or the average of the laboratory averages, was calculated according to Equation 13. To quantify the difference between each laboratory's average binder content and the grand average, the laboratory deviation was calculated according to Equation 14.

$$\bar{\bar{x}} = \sum_{i=1}^{p} \frac{\bar{x}_i}{p} \qquad \text{(Equation 13)}$$

Where:

$\bar{\bar{x}}$ = the grand average
p = the number of laboratories in the data set
$\bar{x}_i$ = the average of the test results in Laboratory i

$$d_i = \bar{x}_i - \bar{\bar{x}} \qquad \text{(Equation 14)}$$

Where:

d_i = laboratory deviation
$\bar{\bar{x}}$ = the grand average
$\bar{x}_i$ = the average of the test results in Laboratory i

Finally, determination of intermediate statistics concluded with evaluating the standard deviation of laboratory averages for a particular material. The standard deviation of laboratory averages for each material was calculated according to Equation 15.

$$s_x = \sqrt{\frac{\sum_{i=1}^{p} {d_i}^2}{(p-1)}} \qquad \text{(Equation 15)}$$

Where:

s_x = the standard deviation of laboratory averages
p = the number of laboratories in the data set
d_i = laboratory deviation

Then, using the intermediate statistics, the precision statistics were calculated. First, repeatability statistics were calculated, then repeatability standard deviation, s_r, was determined. The repeatability standard deviation was determined for each of the four mixture designs. Determining s_r was completed using Equation 16.

$$s_r = \sqrt{\frac{\sum_{i=1}^{p} {s_i}^2}{p}} \qquad \text{(Equation 16)}$$

Where:

s_r = the repeatability standard deviation
p = the number of laboratories in the data set
s_i = the standard deviation of the test results in Laboratory i

The repeatability standard deviation was then used to determine the between laboratory variance, ${s_L}^2$, and the between laboratory standard deviation, s_L. The between laboratory variance was calculated according to Equation 17. The between laboratory standard deviation was calculated using Equation 18.

$${s_L}^2 = {s_x}^2 - \left(\frac{{s_r}^2}{n}\right) \qquad \text{(Equation 17)}$$

Where:

${s_L}^2$ = between laboratory variance
s_x = the standard deviation of laboratory averages
s_r = the repeatability standard deviation
n = the operational number of replicates

$$s_L = \sqrt{{s_L}^2} \qquad \text{(Equation 18)}$$

Where:

s_L = between laboratory standard deviation
${s_L}^2$ = between laboratory variance

Finally, the reproducibility statistics were determined. The reproducibility statistics represent the variability seen between laboratories for the same material. The reproducibility standard deviation, s_R, was calculated using Equation 19 below.

$$s_R = \sqrt{{s_L}^2 + {s_r}^2} \qquad \text{(Equation 19)}$$

Where:

s_R = the reproducibility standard deviation
${s_L}^2$ = between laboratory variance
s_r = the repeatability standard deviation

The subsequent calculations were used to determine the between-laboratory statistic, h. The statistic was determined for each laboratory for individual materials. The between laboratory statistic was determined according to Equation 20 below.

$$h_i = \frac{\widetilde{d_i} \times (p-1)}{s_x} \qquad \text{(Equation 20)}$$

Where:

h_i = the between-laboratory consistency statistics for Laboratory i
$\widetilde{d_i}$ = the laboratory deviation of Laboratory i
p = the number of laboratories in the data set
w_i = the cell weighting factor for the i^{th} cell
$\sum w_j$ = sum of all weighting factors
s_x = the standard deviation of the cell averages

The critical value for h was obtained using Table 5 in the ASTM E 691 – 20 standard. The critical value for h depends on the number of laboratories in the study. With an ILS using 9 laboratories, the critical value for h was 2.23. The between laboratory statistic, h, was then compared to the critical h value. For consistent results, h_i should be lower than the critical h. For any values where the absolute value of h_i was greater than the critical h, the laboratory data was investigated for elimination, and between laboratory statistics calculated again if any changes occur to the dataset.

A similar process was run for the k statistics, the within-laboratory consistency statistic, k. The within-laboratory consistency statistic checks the consistency of cell variances for different laboratories. Each laboratory for each material had a calculated within-laboratory consistency statistic, k_i, determined according to Equation 21.

$$k_i = \frac{s_i}{s_r} \qquad \text{(Equation 21)}$$

Where:

k_i = the within-laboratory consistency statistic
s_i = the standard deviation of the test results in Laboratory i
s_r = the repeatability standard deviation

For a dataset with 9 participating laboratories and 2 operational replicates per material and laboratory, the critical value of k is 2.41. Data was considered consistent when k_i was determined to be lower than $k_{c,i}$. To determine the ILS precision statement, h and k values were compared to critical values on plots. An h-graph and k-graph were created for the entire ILS. Critical values were plotted as lines. For the h statistics, the negative and positive values of the critical h statistic were plotted to account for the absolute value of h in calculations. For the k statistics, only the positive critical value was graphed. In addition to graphing the data, tables were also marked up in which values for h and k exceeding the critical values were highlighted in red. Values approaching the critical value were highlighted in yellow. Tables and figures were created to provide the overall characteristic of the variability of testing, provided in Appendix D through Appendix F. Finally, a precision and bias statement was generated providing the repeatability and reproducibility of the mixtures. An average value for slurry surfacing materials was also calculated.

3.3. Field Sampling

Field sampling methods were also investigated to determine if accurate results can be obtained from a job site, where the environment is not as controlled as the laboratory. However, literature is limited on sampling of slurry surfacing materials. ISSA guidelines for slurry seals, polymer-modified slurry seals, and micro surfacing detail where samples are to be collected from, but not how to sample the material. The slurry sealing guidelines, ISSA A-105 and ISSA A-115, specify material collection directly from the slurry unit, only if samples are required for the slurry seal mixture. Similarly, the micro surfacing guideline, ISSA A-143, indicates sampling directly from the micro surfacing machine. No information is provided on how to achieve a representative sample in the field.

3.3.1. Field Sampling Method A

To ensure representative, accurate sampling was completed, two methods of sampling slurry surfacing systems in the field were developed. There was a procedure developed during construction of micro surfacing test sections by the National Center for Asphalt Technology (NCAT) as part of a pooled fund study, the Preservation Group (PG) Study (Powell 2018). Field sampling procedures roughly followed those developed by NCAT for the PG Study and procedures researched for sampling of HMA. In addition, another method of sampling from the group after construction was investigated. A lack of specified sampling procedures for slurry surfacing materials in literature is apparent. Specifically, only four agencies included a method for sampling, with five agencies indicating how to test for AC of a sample. Prior experience was also used in the development of a field sampling procedure. NCAT developed a method for sampling slurry surfacing mixtures during the PG Study construction of sections in Minnesota. Based on the PG Study method, a new method of field sampling was designed to ensure representative samples were obtained.

Field samples were collected in a disposable aluminum pan, nested inside a rigid pan for stability, as material flows into the spreader box. One important note for sampling was the speed of the paver. The inspector had to be ready to collect samples with minimal notice. Based on the field sampling, slurry surfacing systems are placed quickly. Planning sample collection was critical. It was imperative to have the sample collection pans ready before paving began, near the location of collection along the roadway. When sampling slurry surfacing materials, care was taken to ensure the entire stream of material was interrupted for collection. The materials were then immediately mixed with a metal spatula or spoon at roughly 60-70 rpm until the mixture began to break. Once breaking was evident, mixing rate slowed to roughly 1-5 rpm until the mixture crumbled. Mixture consistency was critical to the breaking and curing time of the slurry surfacing systems. Despite all efforts, some mixtures did not set quickly. For those mixtures, the time required to mix to crumble was significantly increased. Once the sample was crumbly in nature, as shown in Figure 12, it was transferred to a container, an aluminum pan, Ziploc bag, or plastic container for transport.

Figure 12: Slurry Surfacing System Mixed to Crumble

The sample was split into quarters using a metal scraper or a taping knife, a relatively wide bladed knife without a sharp edge. Another concern during sample collection was the consistency between samples. All of the quarters must be the same in composition and similar in size. Care was taken to ensure samples were split as evenly as possible in the field. The sample was either transported in labeled gallon bags or the pan was wrapped in cellophane and then labeled for transport. The samples collected were transported to the laboratory for testing as soon as possible to account for same-day sampling and testing. With the addition of mixing the sample to a crumbly texture instead of mixing the material to a stiff enough mixture to sufficiently split, the need for a nested disposable and rigid pan was eliminated. Mixing the sample to crumble allowed most of the water to evaporate, thereby reducing the drying time. As the mixture breaks and crumbles, the emulsion that would typically be lost on the edges of the pan adheres to the crumbled mixture. The emulsion is collected and incorporated into the sample. Therefore, rigid pans can be used to collect samples without a disposable unit, as seen in Figure 13. However, the materials were still transferred to a disposable pan or Ziploc bags for transport.

Figure 13: Field Sampling Rigid Pan with Breaking Mixture

Prior to gathering any data, the quartered pan samples were then split into two sets of samples. To begin testing, it was assumed that the moisture content of each sample split from the same larger specimen would be the same. Therefore, two, opposite corner samples were obtained with one sample for moisture content determination and the other sample for AC determination. The other two samples, also from opposite corners of the pan, were used tested similarly. A quartered specimen, labeled "sister sample" according to the companion sample, is presented in Figure 14.

Figure 14: Quartered Specimen with Companion Samples Indicated

The companion sample, or “sister sample” for the upper-rightmost sample, sample 1, was sample 3. Similarly, the companion sample for sample 2 was sample 4. So, for sample 1 and 3, one sample was used for moisture content determination while the other was simultaneously subjected to ignition furnace testing. The difference between the bitumen ratio from the ignition furnace ticket and the moisture content was the AC of the specimen.

3.3.2. Field Sampling Method B

As the field results began to diverge, it was obvious that assuming the moisture content of the samples was equivalent was invalid. Based on the field sampling, mixtures with higher moisture contents had more variability. Instead, for accuracy, each sample had to be dried prior to determining the AC. However, the addition of drying the sample prior to AC determination resulted in significantly more time required to test. To investigate methods of minimizing testing time, a method of microwave drying for slurry surfacing samples and the introduction of mixing the mixture to crumble, discovered to save drying time during the research process, in the field was developed. By mixing to crumble, sample segregation and time required to dry were minimized. For complete analysis, field samples were dried using both the conventional drying method and a modified microwave drying procedure. Microwave drying was evaluated for accuracy. Significant time savings were observed by drying in a microwave, compared to conventional oven drying methods. From field sampling and laboratory evaluation of materials, it was determined that the ILS would consist of larger samples that were mixed to crumble, split into quarters, and dried prior to testing.

In addition to sampling from the slurry surfacing machine, another method of sample procurement was investigated. Sampling included sample procurement after the section has been treated. Since laying slurry surfacing materials already requires manhole covering such that no material is transferred onto the manhole after paving is complete, it was proposed to use samples from a covered manhole. The slurry material was placed and allowed to cure and break on the manhole covering. The material was then collected using the disposable manhole covering and transported to the laboratory as soon as possible for testing. The material was scraped from the manhole covering as shown in Figure 15 and Figure 16.

Figure 15: Manhole Cover Prior to Scraping

Figure 16: Manhole Cover After Scraping

Samples for method A were also collected from fabric (plastic or roofing felt) laid down by the contractor at the beginning or end of the run. These samples were collected by cutting the plastic or roofing felt into a square and transferring the material into a Ziploc bag for transport. Field sampling method B samples were reheated in an oven at 110°C ± 5°C until the mixture was crumbly in nature, roughly 20-30 minutes. The entire sample was then mixed and quartered. After quartering, opposite corners of the sample were combined and subjected to testing, that is dried and then AC determined.

3.4. Summary of the Methodology

Slurry surfacing mixtures were testing using laboratory samples fabricated at NCAT, field samples collected from the field, and an ILS. Samples were fabricated using raw materials and JMFs provided by participating contractors. Samples were mixed at NCAT using emulsion, water, aggregates, and Type I/II Portland cement. Specimens were evaluated by first determining the appropriate MC for the mixture using mix time for slurry surfacing systems. To effectively determine the best method for drying slurry surfacing materials, samples were subjected to conventional oven drying, microwave oven drying, and hybrid drying. Then, the AC was determined using extraction by solvent or the ignition furnace. Finally, a precision and bias statement was developed for the ILS.

CHAPTER IV - RESULTS

The first section focuses on the ILS. This section is split into sections regarding the laboratory mixes, preliminary testing, complete ILS results, and precision and bias analysis. The first section of the results chapter presents the findings following laboratory fabricated specimens. Laboratory samples are evaluated based on the sample size, whether the specimen was mixed to crumble prior to drying, drying method, and AC determination method. The second section of the results chapter is focused on presenting the findings of the field sampling procedures. The field sampling is split into separate sections based on the methodology followed in sample collection. Finally, a summary of results is presented in the fourth section of the results chapter.

4.1. Refinement of Protocol

4.1.1. Effect of Sample Preparation and Storage Variables

Laboratory mixes from the field sampled materials were prepared, conditioned, and tested as NCAT to evaluate the effect of several variables on the obtainer error prior to conducting the ILS. Laboratory testing included a total of 80 samples prepared using JMFs from projects executed in different states across the country. Laboratory samples were subjected to conventional and microwave oven drying and ignition furnace method of AC determination.

The results of testing the sample size, consisting of a pan sample split into four samples and a small bowl sample with a single, small sample, are shown in Figure 17.

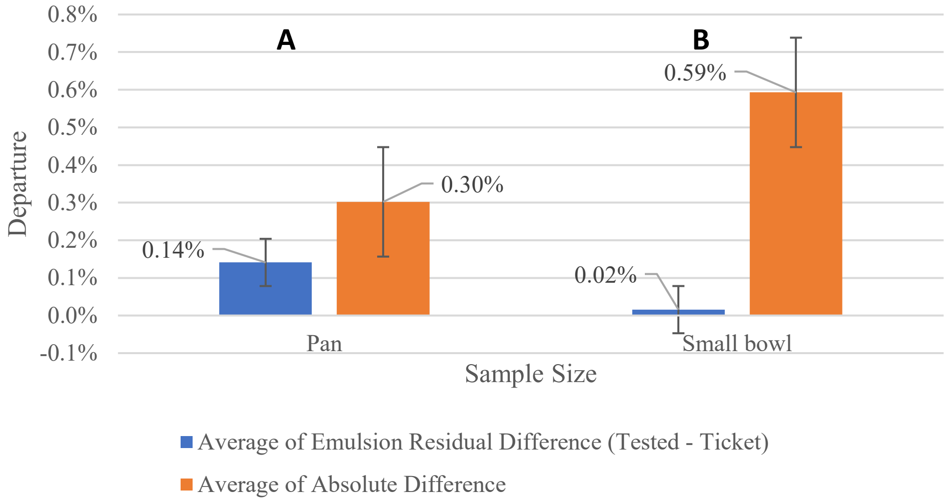

Figure 17: Laboratory Samples by Sample Size

The pan samples, consisting of four smaller specimens, have a percent departure of 0.14% from measured to theoretical and an absolute departure of 0.30%. The smaller bowl samples have a percent departure of 0.02%, significantly smaller than the percent departure of the pan samples. However, the small bowl samples have an absolute departure of 0.59%. Since the absolute departure is much larger than the percent departure, the measured ACs are both higher and lower than the theoretical binder content. The percent departure is small because the average of the samples accounts for both higher and lower measured ACs. However, the absolute departure reveals significant differences in the two methods. The two sample sizes are also statistically different using a Tukey 95% CI method of analysis.

Samples are also analyzed to determine if the drying method affects the accuracy of the AC testing. The results of the laboratory samples by drying method are presented in Figure 18. The microwave oven and the conventional oven have the same absolute departure of 0.38%. The microwave oven has a significantly lower percent departure of 0.02% while the conventional oven has a percent departure of 0.27%.

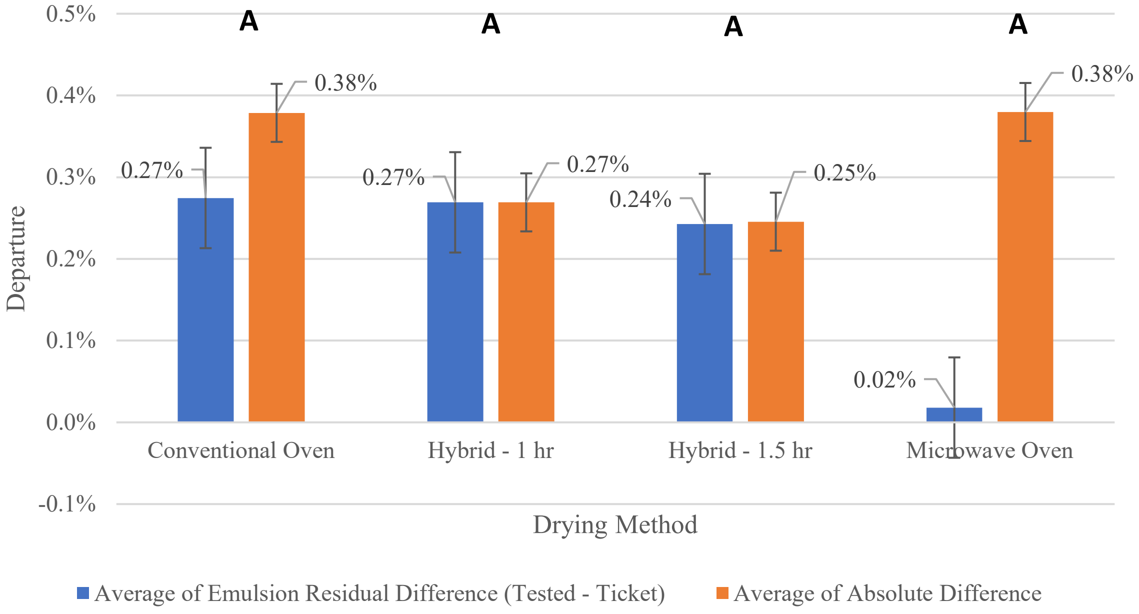

Figure 18: Laboratory Samples by Drying Method

The percent departures reveal that the samples dried using the conventional oven tend to have a measured AC higher than the theoretical with some samples having a lower measured AC than theoretical. Meanwhile, the microwave oven percent departure is extremely low, indicating some of the measured ACs were higher than the theoretical and some were lower. Hybrid drying does not significantly impact the percent or absolute departures, resulting in requiring more time for drying with little more accuracy than conventional or microwave oven methods. Statistically, all of the laboratory drying methods have a Tukey 95% CI grouping of A for all drying methods with a p-value of 0.927. Therefore, all drying methods are statistically not different.

Next, the laboratory sample ACs are analyzed according to whether samples were dried prior to determining the AC and whether the sample was mixed to crumble. The percent and absolute departures according to drying method and mixed to crumble are shown in Figure 19. The errors are significantly higher for those samples not dried prior to AC testing.

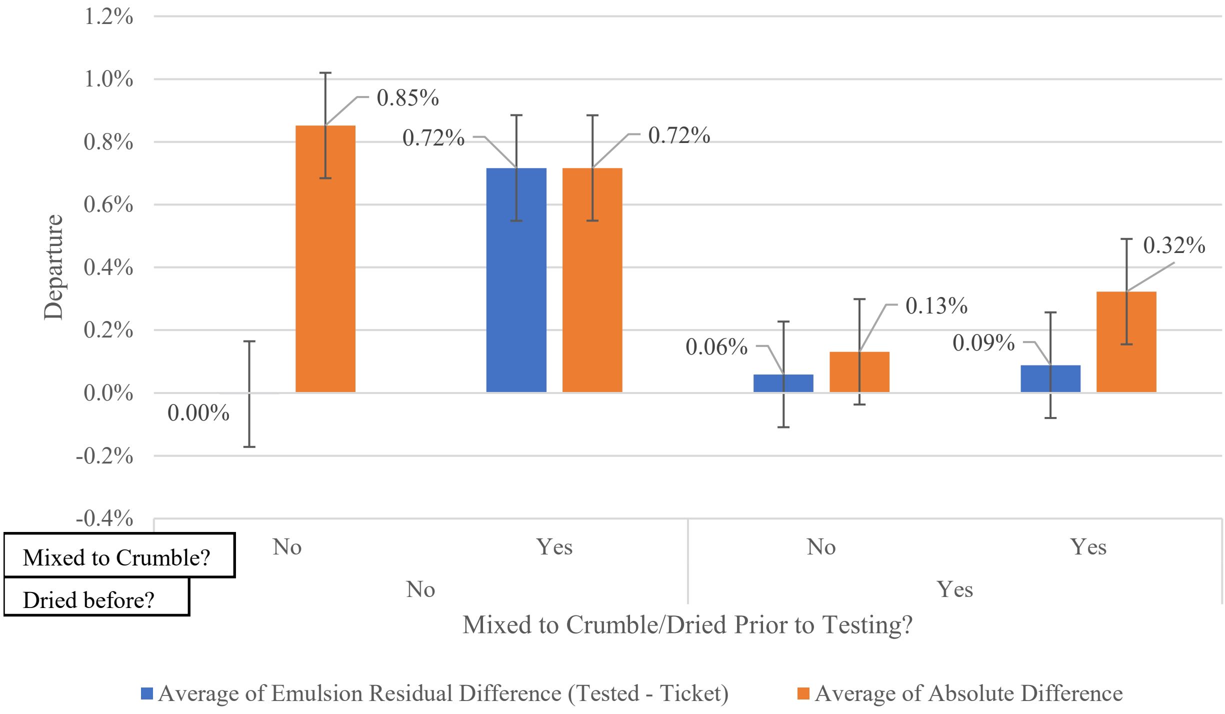

Figure 19: Laboratory Samples by Drying Before Testing and Mixed to Crumble

Since the absolute departures are higher for sample not dried, drying the sample can eliminate some error in the AC determination process, likely due to the nature of moisture in slurry surfacing materials. However, drying the specimen prior to testing reduces the percent departure and the absolute departure observed between the measured and theoretical ACs. Mixing the specimen to a crumbly nature immediately after fabrication increases the departures slightly in those samples dried prior to testing. However, it reduces the departure observed in the samples not dried prior to testing. Overall, mixing the sample to crumble and drying prior to testing result in lower departure for laboratory specimens.

The effect of the type of container used for laboratory sample storage is displayed in Figure 20. For the pan, plastic container, and Ziploc bag storage options, the average percent departure and absolute departure increases. The pan has the lowest percent departure of 0.08% with the plastic container percent departures of 0.13%. Finally, the Ziploc bag has a percent departure of 0.89% and an absolute departure of 0.89%. The pan and plastic container have absolute departures of 0.32% and 0.58%, respectively.

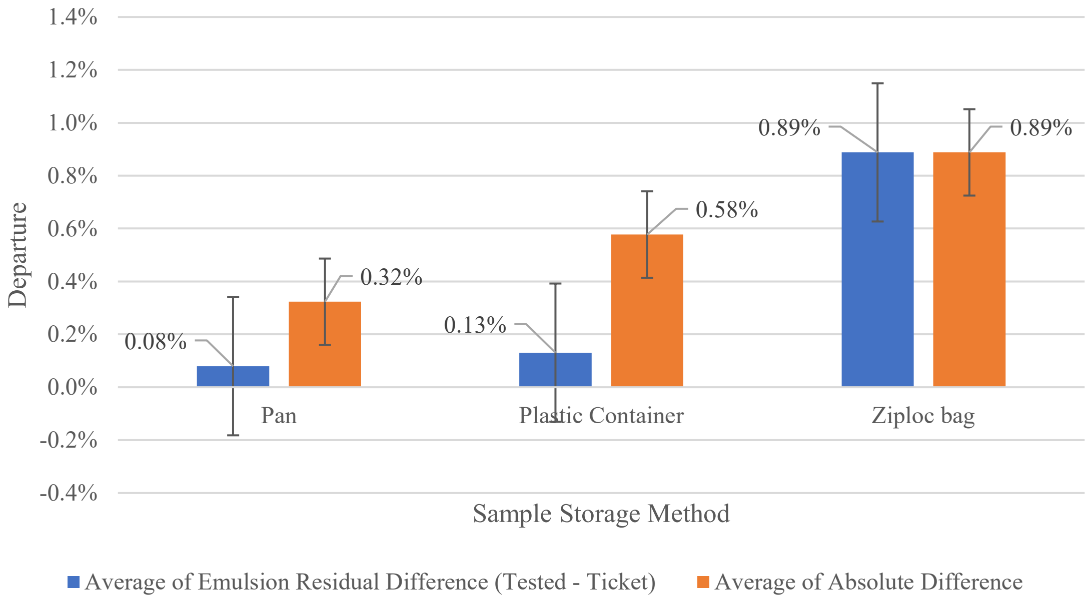

Figure 20: Laboratory Samples by Sample Storage Method

The Ziploc bag storage results in an equivalent absolute departure and percent departure, indicating all samples had a measured AC greater than the theoretical. Both the pan and the plastic container have low percent departures with greater absolute departures, indicating the measured ACs varied between being lower or higher than the theoretical. Overall, the pan is a more accurate method of sample storage than plastic containers or Ziploc bags.

Finally, the deviations according to the emulsion grade are presented in Figure 21 below. Both the CQS-1H and the CSS-1HP emulsion grades have lower absolute departures than the CQS-1HP, the quick setting polymer modified mixture.

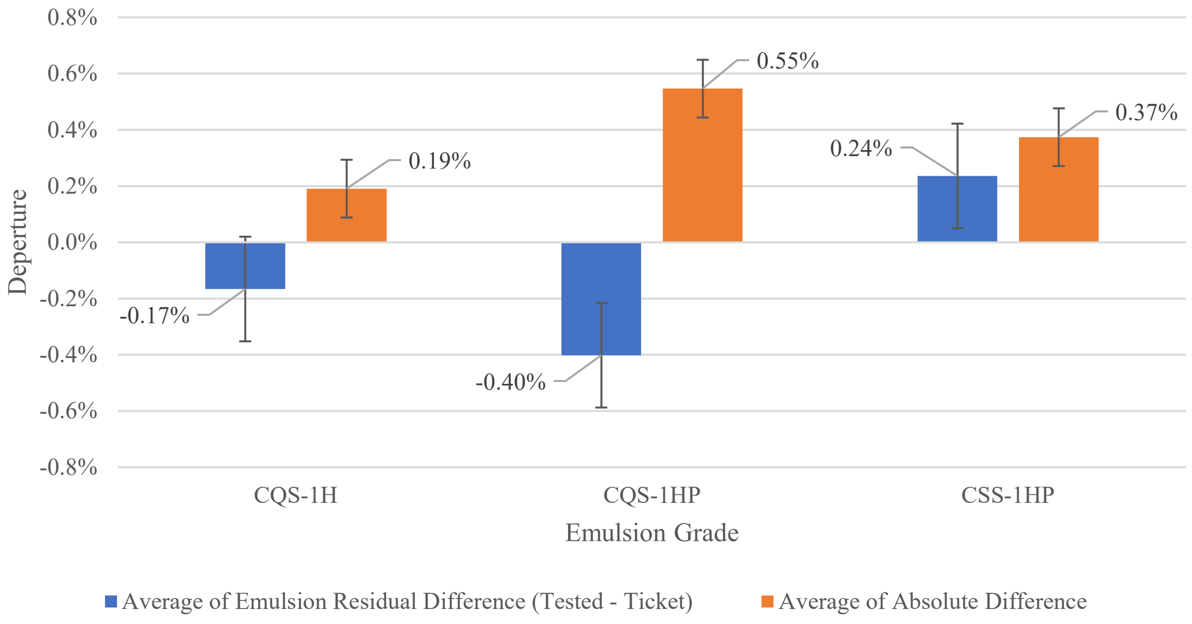

Figure 21: Laboratory Samples by Emulsion Grade

However, the CSS-1HP emulsion mixtures, slow setting emulsions, have a percent departure of 0.24% and an absolute departure of 0.37%, indicating that most of the samples had a higher measured AC compared to theoretical. The CQS-1H mixtures and CQS-1HP mixtures, quick setting, both have a negative percent departure, indicative of a lower average measured AC compared to theoretical.

To further analyze the effect of emulsion grade on slurry surfacing ACs, the emulsion grades are evaluated using the Tukey method, summarized in Table 4 and Figure 22. The CQS-1HP, quick setting polymer modified emulsion, mixtures are statistically different than the CSS-1HP and CQS-1H mixtures, indicated by the Tukey grouping letter assigned.

Table 4: Laboratory Samples Tukey Grouping by Emulsion Grade

Factor	N	Mean	Grouping	
CQS-1HP	11	0.5482	A	
CSS-1HP	42	0.2874		B
CQS-1H	7	0.1971		B

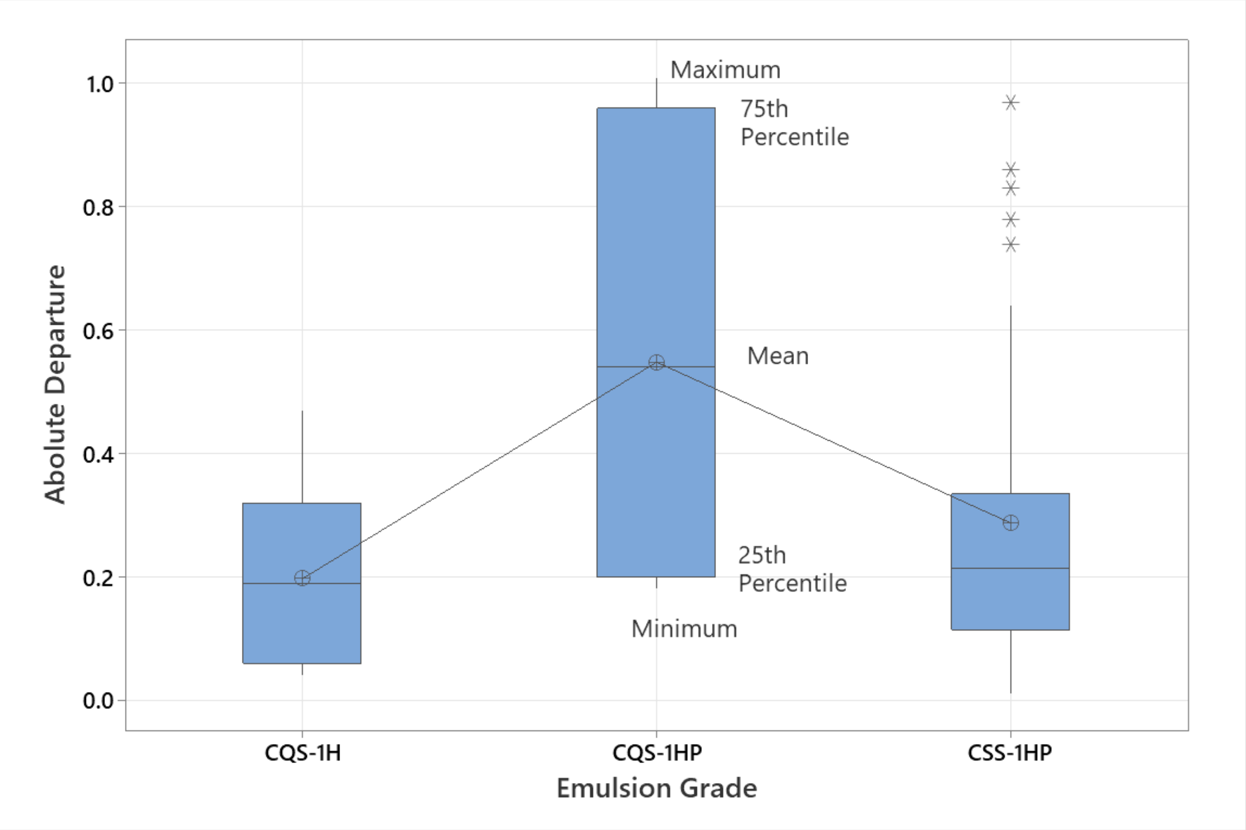

Figure 22: Laboratory Sample Absolute Departure Boxplots per Emulsion Grade

The CQS-1HP mixture is in grouping B while the CSS-1HP and CQS-1H mixtures are in grouping A. The mean for CQS-1HP is 0.55% while the CSS-1HP and CQS-1H means are 0.29% and 0.20%, respectively. The range of ACs measured from the CQS-1HP mixtures is greater than both the CQS-1H and CSS-1HP mixtures, revealing more variability in the quick setting polymer modified emulsions than in the quick setting unmodified emulsions and the slow setting polymer modified emulsions.

4.1.2. Interlaboratory Study Preliminary Testing

The methods of testing, extraction by centrifuge after conventional drying (EC), ignition furnace AC determination with conventional drying (IC), and ignition furnace AC determination with microwave drying (IM) are compared using a line of equality plot. In the plot, one method, Method A, is compared to another, Method B, by directly plotting the determined ACs against each other. The line of equality plot is presented in Figure 23.

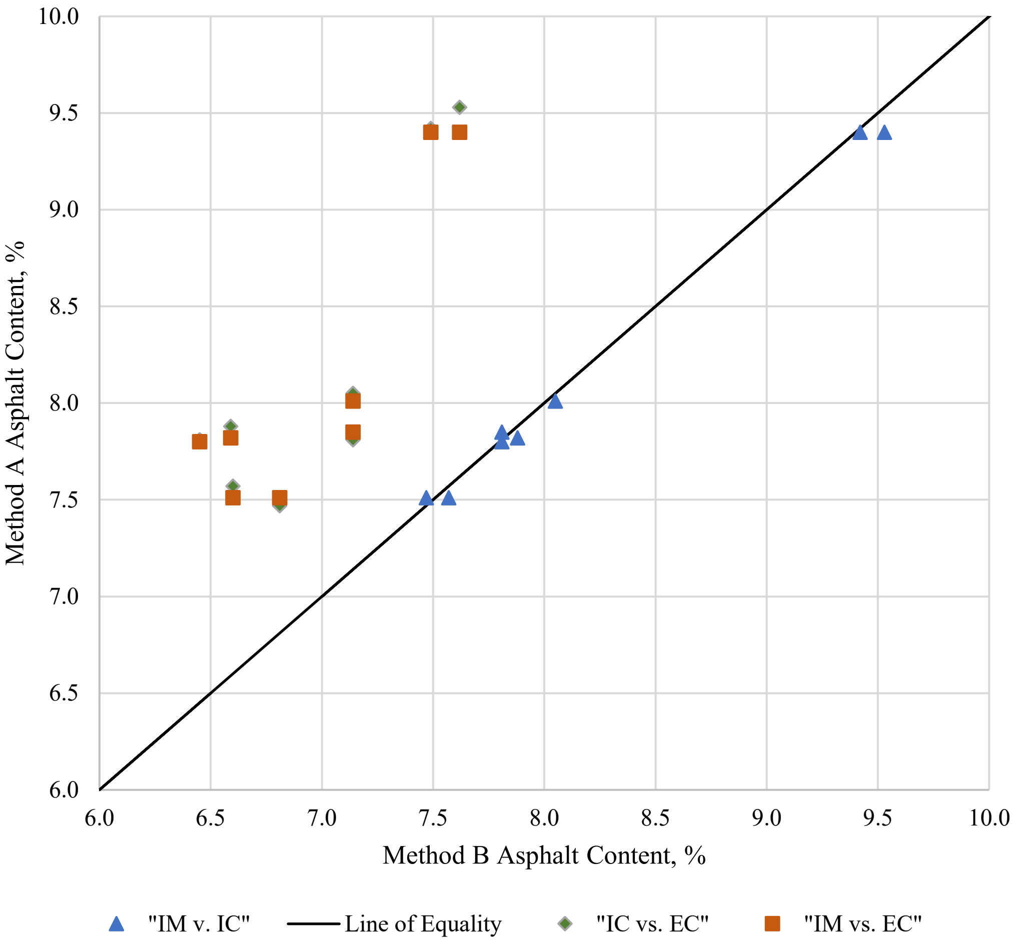

Figure 23: Interlaboratory Study Preliminary Testing Line of Equality

From the plot, the specimens tested using IM versus IC closely follow the line of equality, indicating the methods are almost equivalent. However, when comparing IC or IM versus EC, large deviations from the line of equality are present. For both IC versus EC and IM versus EC, the EC method results in lower ACs. Therefore, EC results in different ACs than IC or IM while IC and IM result in similar ACs. A graph of the percent deviation and absolute deviation per testing method is shown in Figure 24.

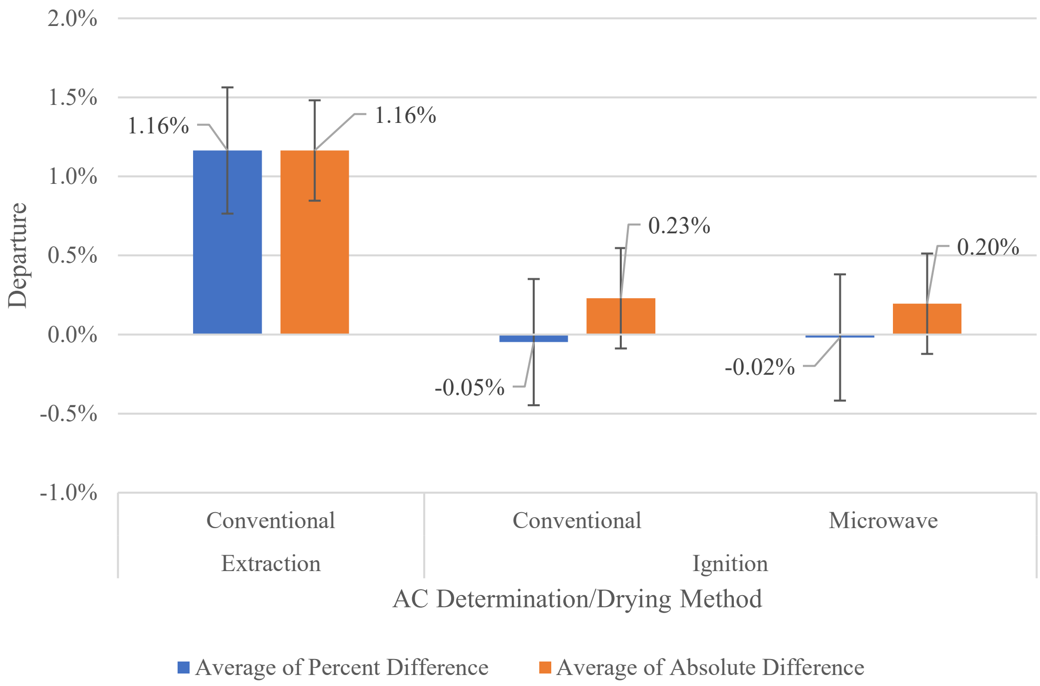

Figure 24: Interlaboratory Study Preliminary Testing Percent Departure by AC Method and Drying Method

The EC method results in an average percent and absolute departure of 1.16%. Conversely, the IC and IM methods result in a small percent departures and absolute departures of roughly 0.2. The conventional drying method results in slightly greater absolute departure than the microwave. Both the percent departure and the absolute departure are significantly greater for the extraction method than either of the ignition methods for preliminary testing within the ILS.

To effectively compare the extraction versus the ignition methods for AC determination, the basic statistics and Tukey 95% CI Analysis Grouping are presented in Table 5. When comparing the averages, the extraction results are over 1% lower than the ignition results.

Table 5: AC Basic Statistics & Tukey 95% CI Analysis of Interlaboratory Study Preliminary Testing by AC Method

Variable	N	Average	SE Mean	StDev	Min	Q1	Median	Q3	Max	Grouping
Extraction	8	7.005	0.16	0.787	6.45	6.592	6.975	7.452	7.62	A
Ignition	16	8.178	0.193	0.537	7.47	7.628	7.835	9.063	9.53	B

The standard deviation for extraction, 0.787, versus for ignition, 0.537, reveal that the ignition results are more precise than the extraction results. Using a Tukey analysis with 95% CI, the extraction and ignition ACs are statistically different, regardless of the drying method used. Statistically similar methods result in the same grouping letter using a Tukey analysis.

For the Tukey analysis, a difference of means for the ILS preliminary testing using the ACs determined by each method is presented in Figure 25. From the Tukey analysis plot, it is apparent that the two methods for AC determination result in statistically different ACs.

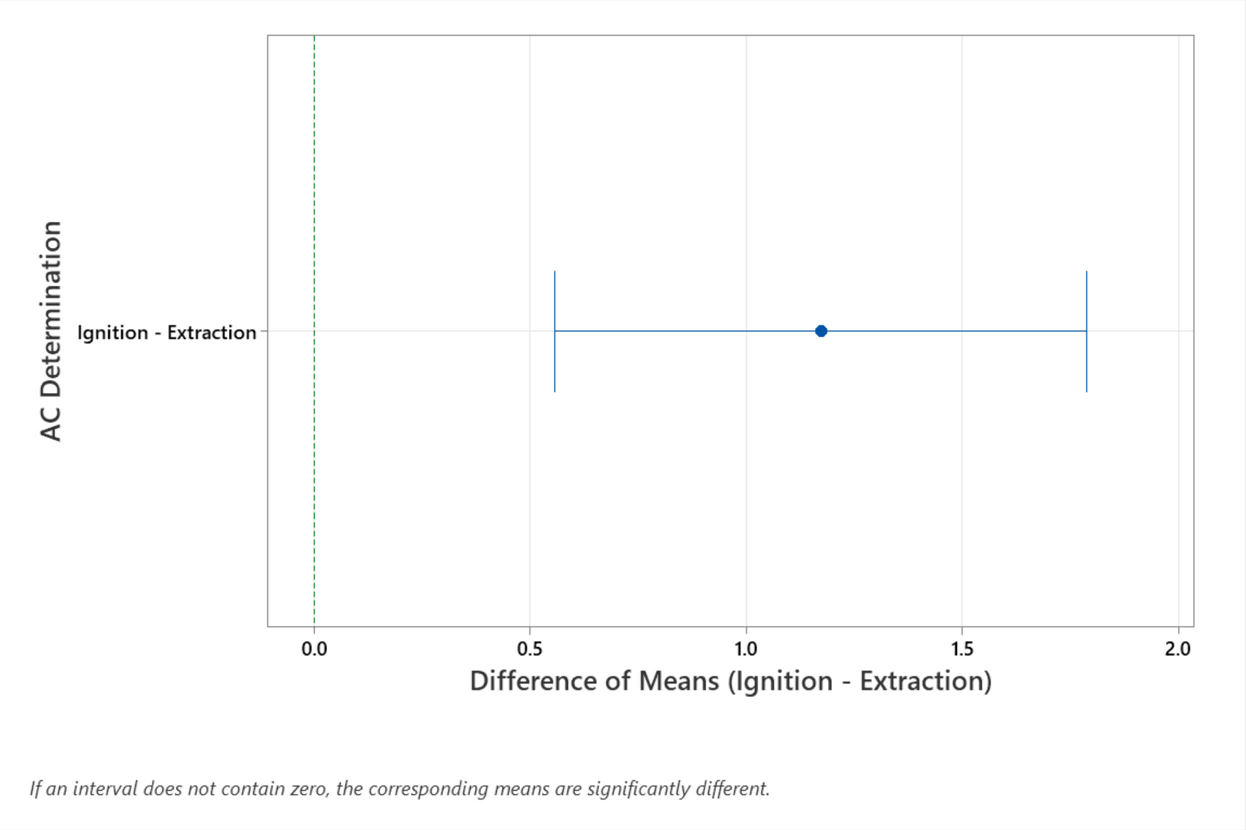

Figure 25: Tukey Analysis for Difference of Means Plot for Extraction ad Ignition AC

The difference of means for the control experiment reveals differences ranging from roughly 0.6 to 1.7. Since the range does not include 0.0, the two methods are statistically different. The range is greater than zero, indicating the ignition method results in higher ACs than the extraction method.

A difference of means from the absolute departure ILS preliminary testing Tukey 95% CI analysis can be seen in Figure 26. In order for the two methods to be considered statistically not different, the difference of means from the absolute error should be zero.

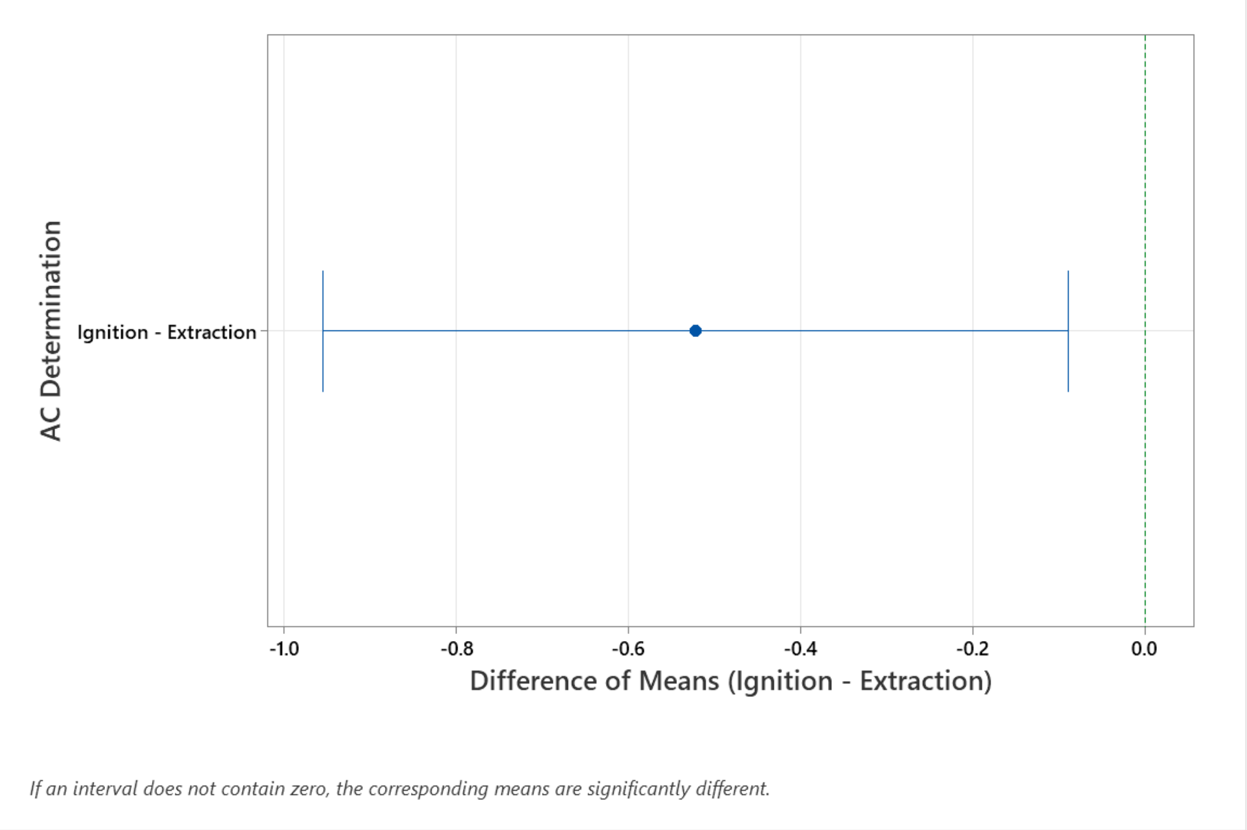

Figure 26: Interlaboratory Study Preliminary Testing Absolute Error Tukey Analysis

From the graph, the ignition and extraction absolute difference of means does not cross 0.0. Therefore, the methods are statistically different. The range, however, ranges from about -0.1 to -0.95. Since the range is negative, the ignition absolute departure is less than the extraction absolute departure for the ILS preliminary testing.

A boxplot of the ILS preliminary testing absolute deviation analysis based on AC determination method is presented in Figure 27. The absolute departure, or the absolute value of the percent departure observed in ACs, reveals the same trend in data as the AC analysis for the control experiment. The extraction and ignition methods of AC determination are statistically different considering the absolute departure from theoretical binder content.

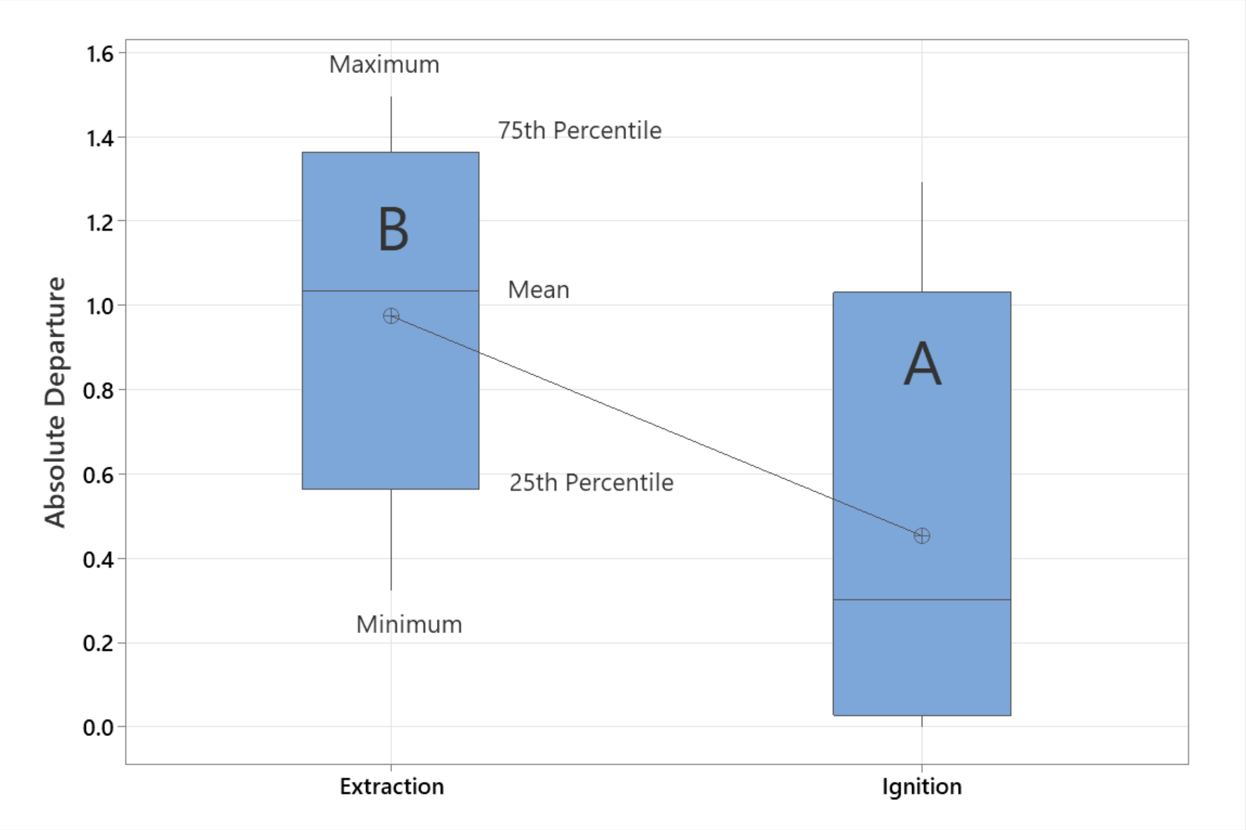

Figure 27: Interlaboratory Study Preliminary Testing Absolute Departure Boxplot

The average absolute departure for extraction is 0.98% while the average absolute departure for ignition furnace testing is 0.45%. Both standard departures are similar. The extraction standard deviation, 0.44%, is slightly lower than the ignition method, 0.50%. Based on the minimum absolute departure, the ignition results are closer to the theoretical AC than the extraction results. Ignition method of AC determination has a minimum of zero while the extraction method minimum is 0.32. Using the Tukey analysis with a 95% CI, the two methods are statistically different. The absolute departure boxplot reveals significant differences in the two methods. The ignition results are closer to 0.0 than the extraction results for the absolute departure of the ILS preliminary testing, indicating the ignition method is more accurate than the extraction method. The average for extraction is greater than 1% AC. Meanwhile, the average for the ignition method is about 0.3%. For each of the five critical locations on the boxplot, the minimum, maximum, mean, 25th percentile, and 75th percentile, the extraction absolute departure values are higher than the ignition values.

A plot of the percent departure and absolute departure for each mix type and emulsion grade is shown in Figure 28. For the ILS, MS Type II or CSS-1HP is mixture 1, Slurry Seal Type B or CQS-1H is mixture 2, MS Type III or CQS-1HP is mixture 3, and Slurry Seal Type II or CQS-1HP is mixture 4.

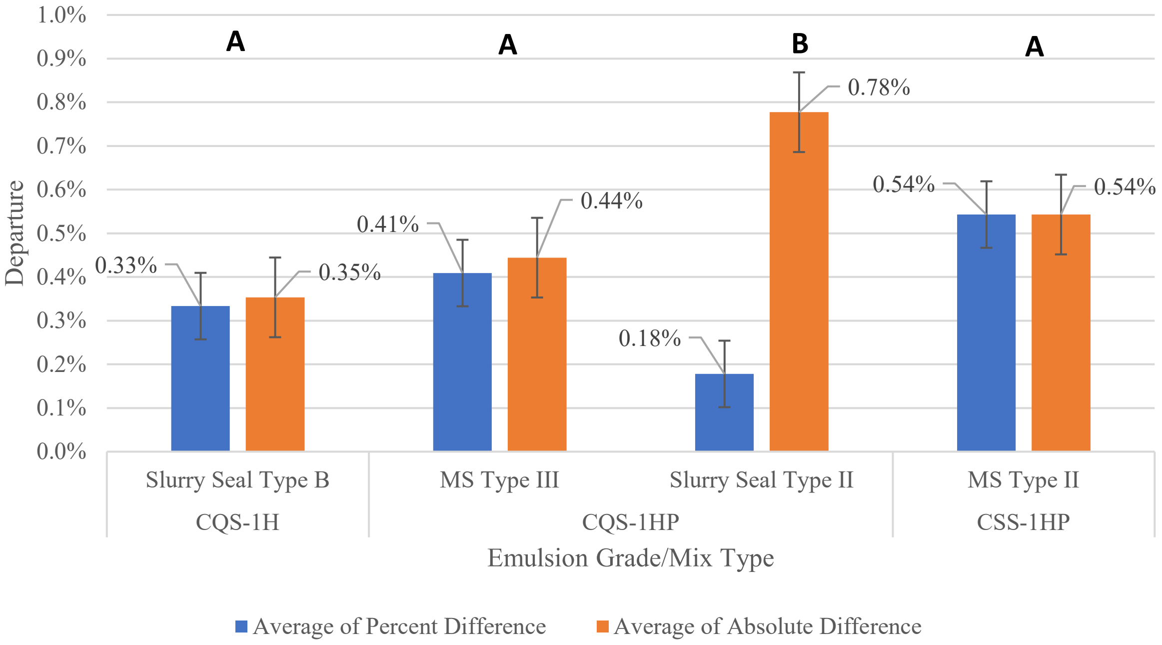

Figure 28: Interlaboratory Study Preliminary Testing Percent and Absolute Departure by Mix Type and Emulsion Grade

From the graph, for preliminary testing, mixture 4 has the highest absolute departure. However, the fourth mixture type also has the second lowest percent departure, indicative of having percent departures less than and greater than zero. Mixture 1 has the second highest absolute departure. Mixture 3 has the lowest percent departure and absolute departure. Mixture 4 is statistically different than the other three mixtures. Mixture 4 is the only quick-setting, polymer modified emulsion. Further research is needed to determine the cause of statistical difference.

The analysis of percent departure of the mixture designs includes EC, IC, and IM tested samples. A boxplot of the ILS preliminary testing is presented in Figure 29.

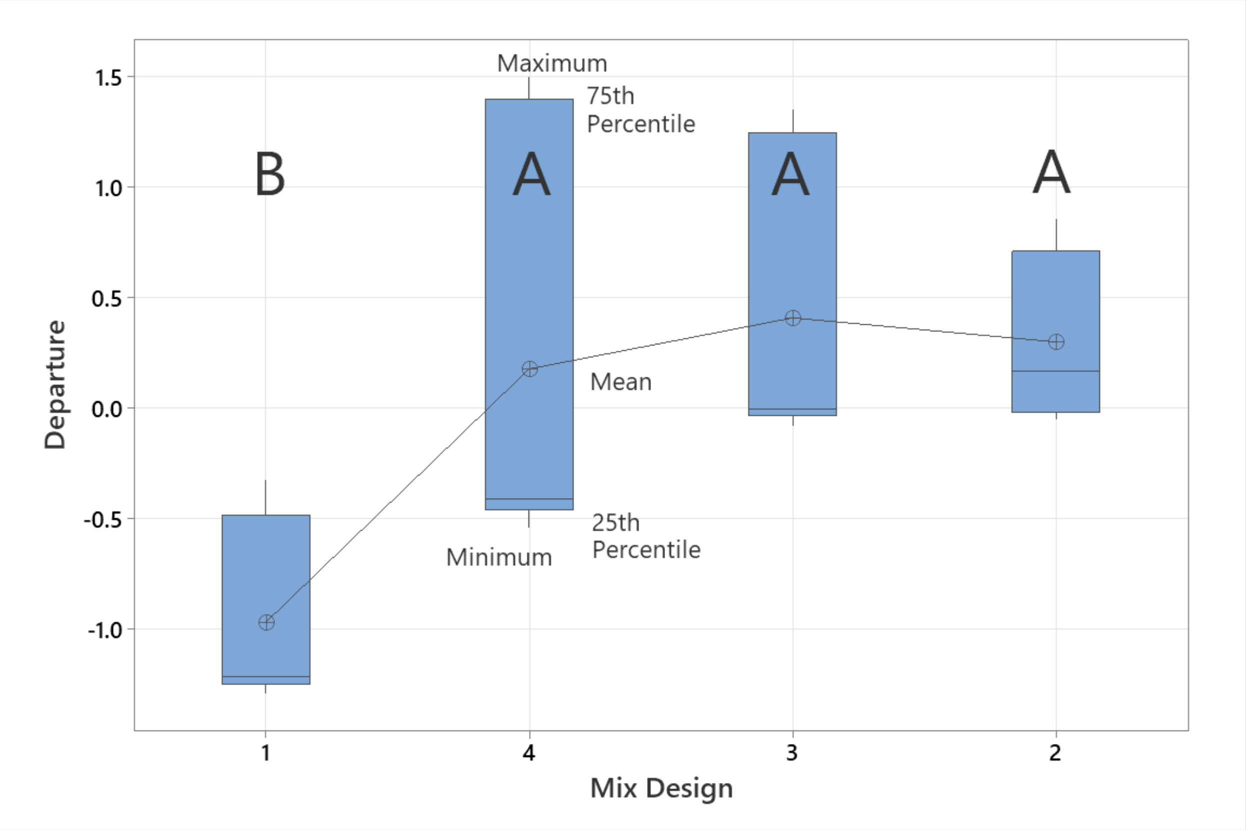

Figure 29: Interlaboratory Study Preliminary Testing Mixture Design Percent Departure Boxplots

From the figure, it can be seen that mixture 1 is the only mixture with a percent departure of less than zero for the entire preliminary testing dataset. It is obvious that mixture 1 behaves differently than mixes 2, 3, and 4 in the control ILS. Mixture 4 has a large range, ranging from about -0.4 to 1.5 percent departure. The mixture 4 range includes both ranges for mixture 3 and 2. Mix 2 has the smallest range of datapoints, indicated by the smaller boxplot. Both mixtures 3 and 2 have a mean greater than zero, indicating a measured AC greater than the theoretical. However, mixture 4 and 1 have a mean of less than zero, meaning the measured AC is less than the theoretical. For the preliminary testing, mix 1 is statistically different compared to the other three mixtures, seen through the Tukey grouping information. This is unexpected and should be researched further to determine why mix 1 behaves statistically different compared to mixtures 2, 3, and 4. It should also be noted that mixture 4 ranges the most considering the minimum and maximum ACs. Mixture 4 also has the highest standard deviation, 0.974. Mix 1 is grouped differently again, likely due to the nature of the aggregate, a limestone aggregate which breaks down easily.

However, regardless of the material behavior, time savings using the modified microwave procedure can be seen in Figure 30. The drying time, as opposed to the total testing times, are shown.

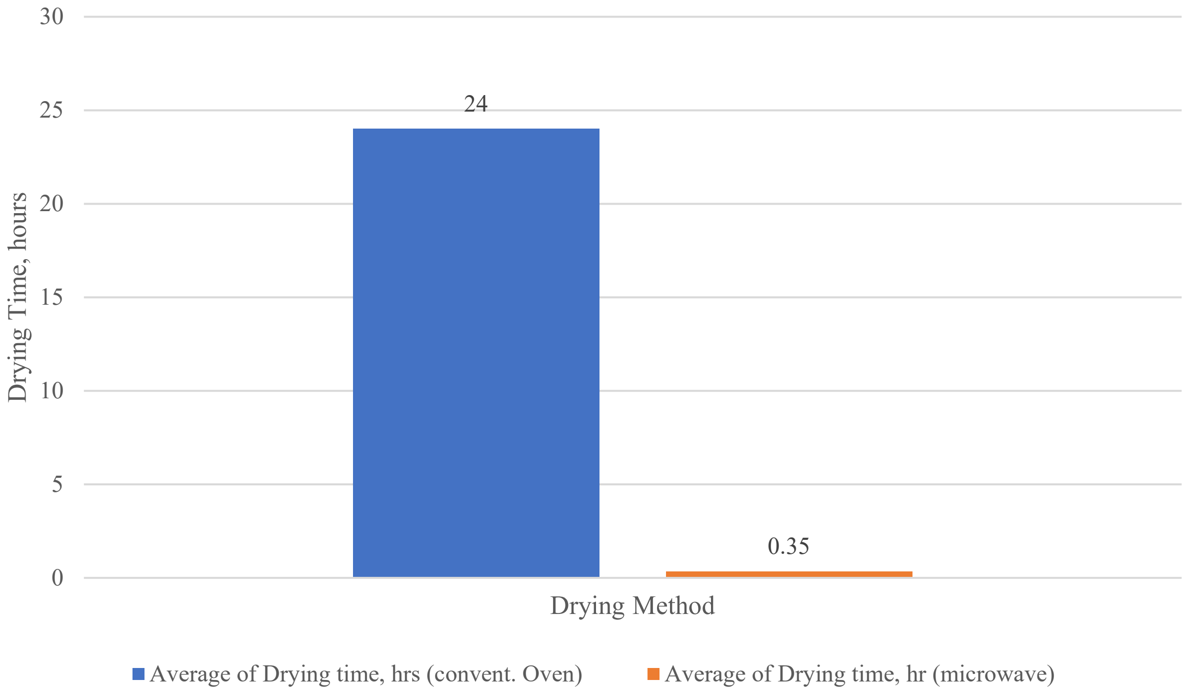

Figure 30: Interlaboratory Study Preliminary Testing Microwave Drying Time Savings

From Figure 22, it is apparent that microwave drying requires significantly less time to complete than conventional oven drying. For the ILS preliminary testing, conventional drying requires an average of approximately 24 hours to dry slurry surfacing materials. However, using the microwave procedure results in a time savings of roughly 23 hours. On average, the microwave drying time is less than 1 hour.

Overall, preliminary testing reveals ignition furnace method of AC determination more accurate than the extraction method. For this reason, the ILS was completed using either drying method with ignition furnace testing for AC. Mixture 1 likely behaves statistically different from the other three mixtures, but needs more replicates than the control experiment. Drying with the microwave method results in significant time savings, thereby providing faster results than the conventional oven drying method. Since laboratory samples confirmed all drying methods to be statistically not different and the microwave procedure requires less time, participants in the ILS were asked to complete microwave drying and ignition furnace testing.

4.1.3. Interlaboratory Study

The ILS is also evaluated. First, the batches are evaluated to determine if any of the batches behave statistically dissimilar to the other batches. The basic statistics and Tukey 95% CI analysis based on the batch number is presented in Table 6.

Table 6: Interlaboratory Study Batch Statistics and Tukey 95% CI Grouping

Batch	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Group
1	12	7.546	0.153	0.53	6.844	7.338	7.39	7.69	8.65	A
2	14	7.663	0.267	1	6.4	6.824	7.359	8.673	9.4	A
3	12	7.813	0.272	0.941	6.45	7.48	7.58	8.29	9.53	A
4	11	7.837	0.366	1.215	6.619	6.8	7.38	8.73	9.93	A
5	11	7.764	0.252	0.837	6.65	7.23	7.48	8.83	9	A
6	12	7.62	0.103	0.357	6.95	7.438	7.715	7.873	8.05	A
7	14	7.727	0.222	0.832	6.6	7.037	7.547	8.644	9.09	A
8	12	7.552	0.203	0.702	6.76	6.89	7.345	8.4	8.51	A

Each of the eight batches are statistically not different with a Tukey grouping of A for every batch. This is expected since each mixture design in the ILS is represented by eight batches. Therefore, each batch should behave statistically not different when considering the AC since all mixture designs are represented in each of the batches. Analysis is also completed for the quartered specimens in the ILS.

The Tukey 95% grouping and basic statistics based on the quartered specimen can be seen in Table 7.

Table 7: Interlaboratory Study Specimen Quarter Statistics and Tukey 95% CI Grouping

Quarter	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Group
A	25	7.623	0.135	0.674	6.619	7.02	7.51	8.125	9	A
B	25	7.76	0.187	0.933	6.4	7.245	7.48	8.48	9.79	A
C	26	7.642	0.119	0.609	6.76	7.232	7.52	7.982	8.74	A
D	25	7.725	0.201	1.004	6.45	6.945	7.46	8.555	9.93	A

Despite the differences observed in the standard deviations and the means, the quartered specimens behave statistically not different with a Tukey grouping of A for each quarter. Since all specimens behave statistically not different within the ILS, analysis was completed for the entire ILS to determine specific trends in the data and a precision and bias statement completed.

First, a line of equality plot for the ILS measured AC versus theoretical AC is illustrated in Figure 31. IC and IM results are similar, largely resulting in some data points below the line of equality and above the line of equality. EC is not included in the ILS analysis.

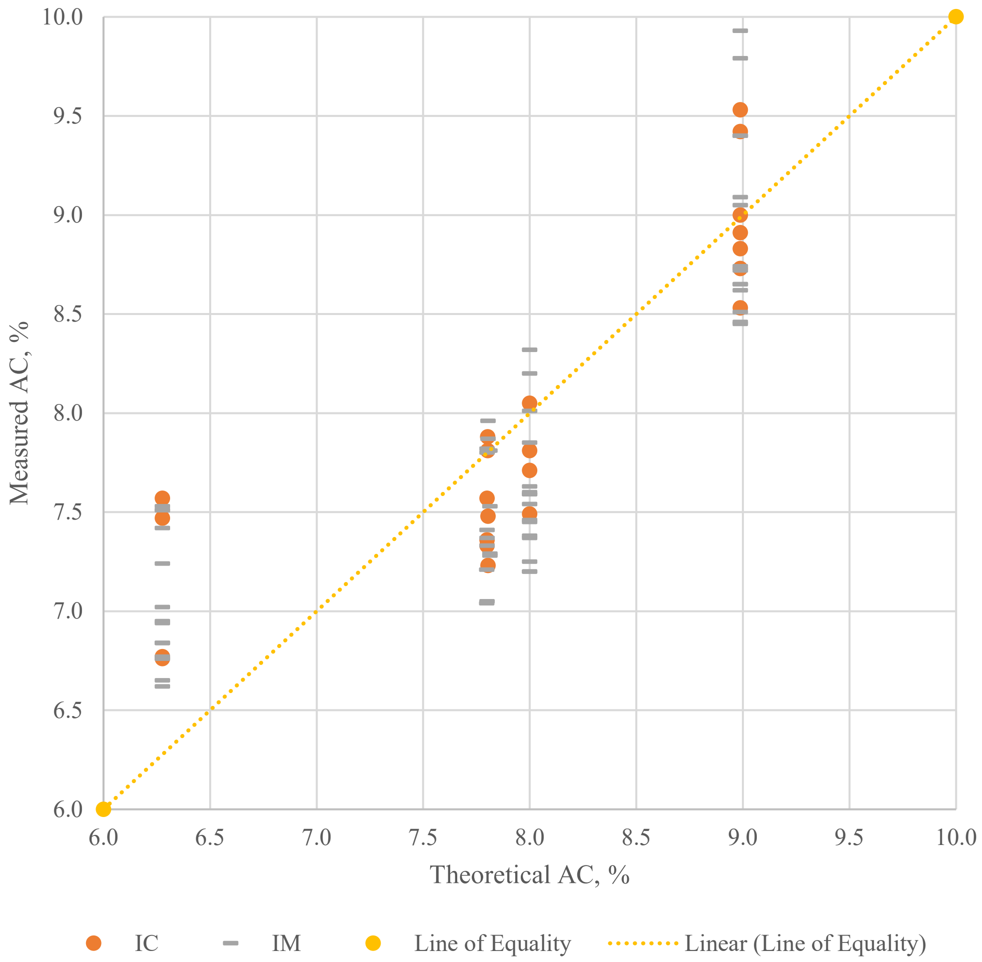

Figure 31: Interlaboratory Study Line of Equality

However, for the mixture 1 design with a theoretical AC of 6.28%, all three methods of AC determination result in a higher measured AC than theoretical. For mixture 4, with a theoretical AC of 8.99%, mixture 2 with theoretical AC of 8.00%, and mixture 3 with theoretical AC of 7.80%, IC and IM methods result in a grouping of datapoints with some below and some above the line of equality. This is expected since slurry surfacing materials are inherently variable. IC and IM methods result in groupings close to the line of equality. A bar chart of the three methods based on each mixture design in the ILS is seen in Figure 32.

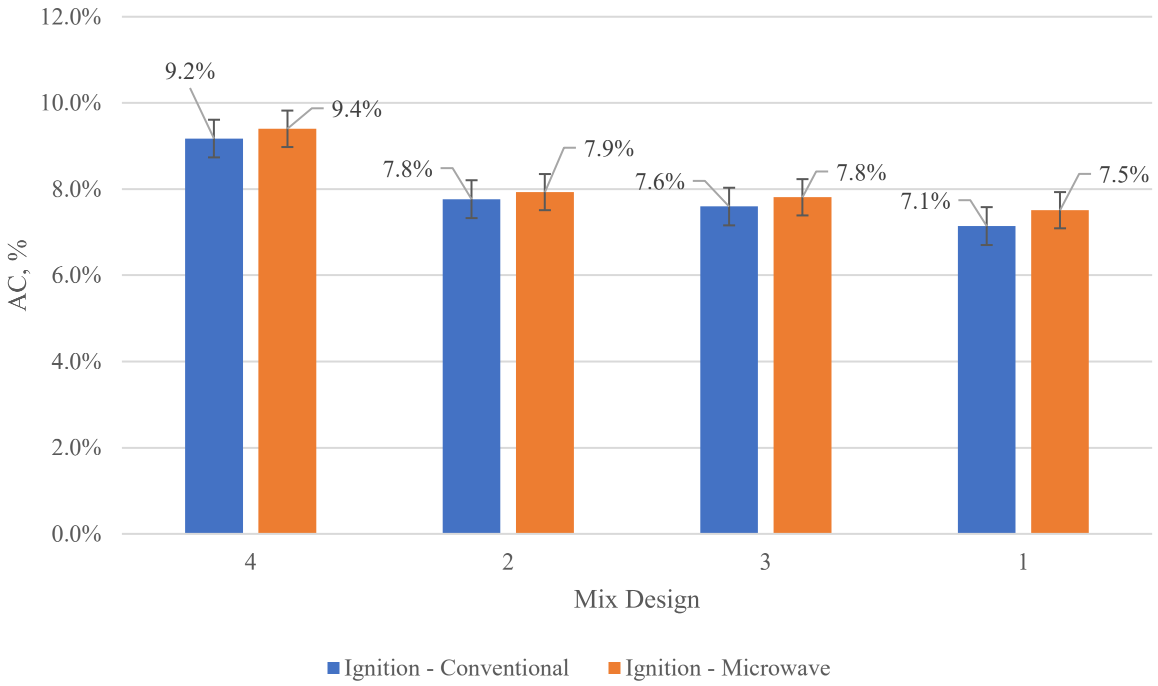

Figure 32: Interlaboratory Study Mixture Design AC by Drying and AC Determination Methods

For all four ILS mixture designs, IM tends to result in marginally higher ACs than IC. Statistically, mix 1 is different than mixes 2, 3, and 4. Since preliminary testing revealed statistical differences in the mix designs, several trends are investigated. The measured versus theoretical AC based on aggregate type is illustrated in Figure 33.

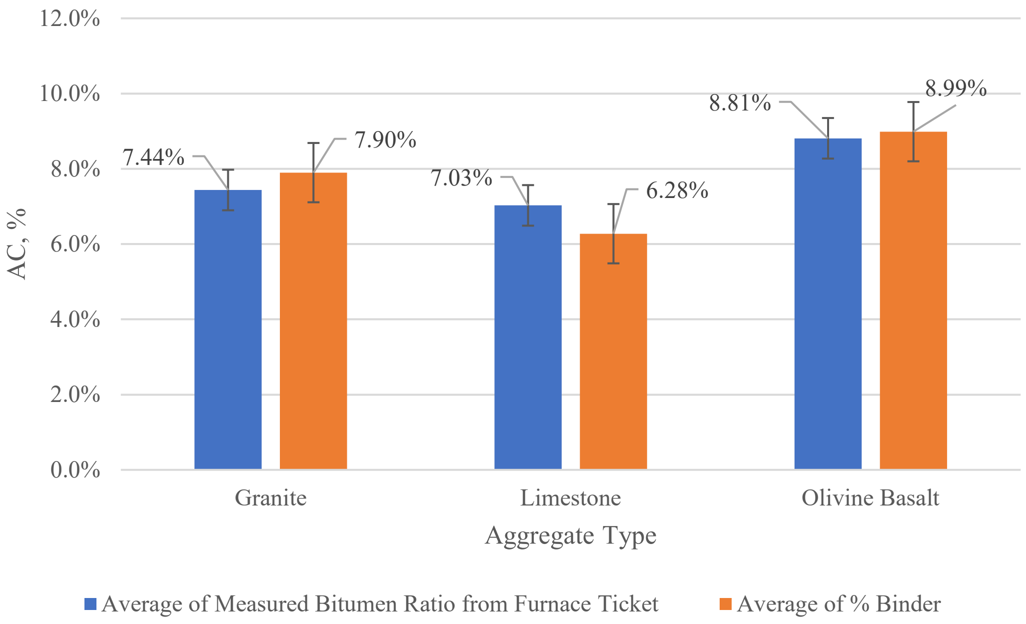

Figure 33: Interlaboratory Study Aggregate Type Theoretical versus Measured AC

Granite and limestone mixtures result in significant differences in AC. However, only a departure of 0.08% in the average measured AC and theoretical AC exists for the olivine basalt mixture. The limestone mixtures have a higher average measured AC compared to the theoretical while the granite and olivine basalt mixtures have a lower measured AC compared to the theoretical. The limestone mixture revealed more aggregate breakdown during ignition testing than the granite and olivine basalt mixtures. Further research into the impact of aggregate type on slurry surfacing ACs needs to be addressed. For the four mixture designs, the differences in percent departure and absolute departure for each design is seen in Figure 34.

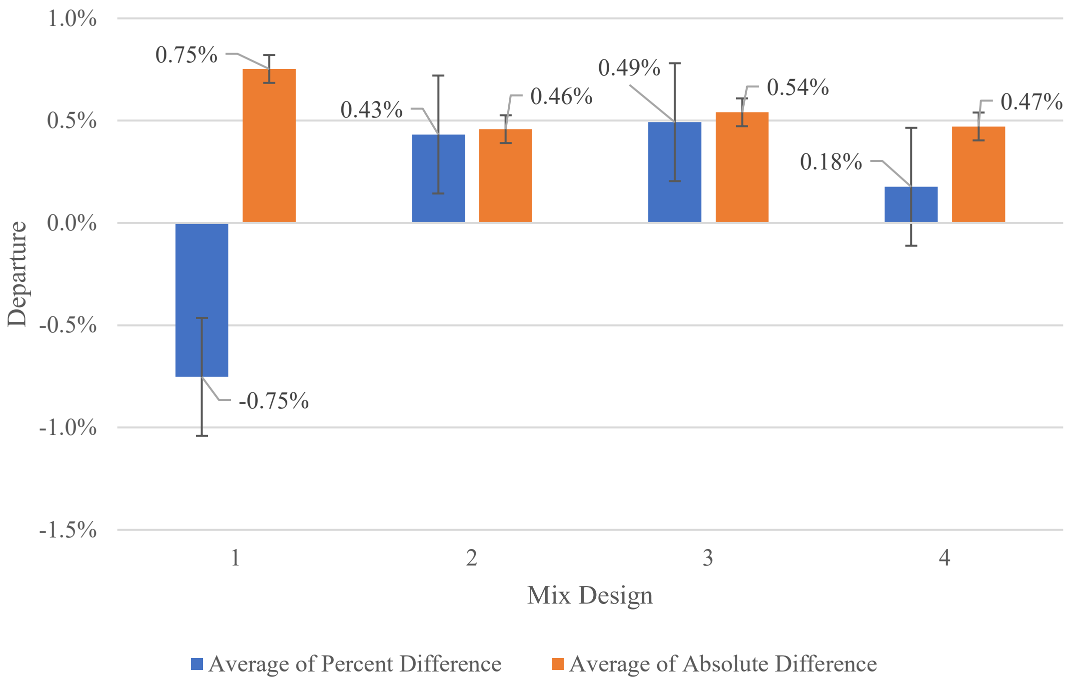

Figure 34: Interlaboratory Mixture Type Percent and Absolute Departure in AC

It should be noted that mixture 1's percent difference is -0.75 and absolute departure is 0.75. Since the two numbers are equidistant, all mix 1 measured ACs are greater than the theoretical AC. For all three other mixtures, the percent departure is less than the absolute departure, indicating some instances where the measured ACs are greater than the theoretical AC. For mixtures 3 and 2, since the percent departures are slightly less than the absolute, fewer specimens result in a measured AC greater than the theoretical AC compared to the mixture 4. All four mixes reveal variability.

4.1.4. Precision & Bias

The h-statistics, the between laboratory consistency statistics, can help determine any statistical outliers for the ILS. The critical h-statistic value for an ILS with 9 laboratories is 2.23. The h-statistics for each material, based on the testing laboratory are presented in Table 8, summarized in Figure 35.

Table 8: Final h-Statistics for Precision & Bias

Lab	Mixture 1	Mixture 2	Mixture 3	Mixture 4
1	-0.71	-0.01	-0.42	-0.10
2	0.18	-0.33	0.77	0.34
3	1.69	1.06	1.28	1.07
4	-0.95	-0.80	-1.22	-0.80
5	-0.58	-0.67	-0.45	-0.54
6	-0.31	-0.35	-0.38	-0.62
7	0.00	-0.02	-0.98	-0.48
8	1.58	2.13	1.66	2.07
9	-0.90	-1.01	-0.25	-0.94

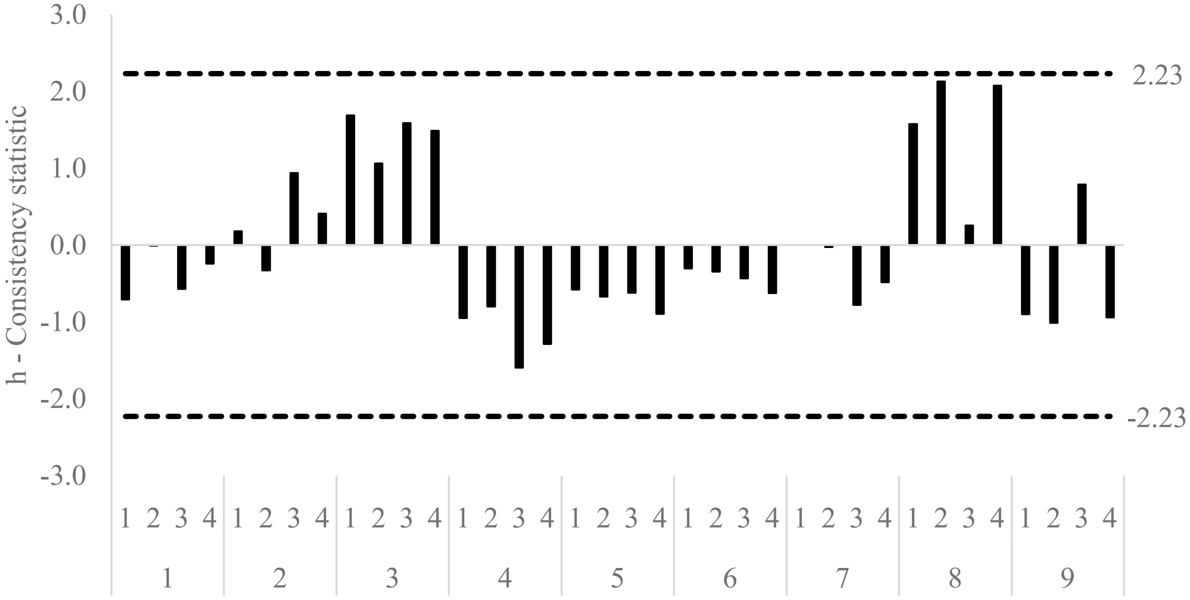

Figure 35: ILS h-Statistic Graph

For the final h-statistics, lab 2 for mixture 1 does not have a calculated h-statistic. It should be noted that lab 8 results in mixture 4 h-statistics close to the critical h-value. Similarly, lab 8 for mixture 2 is approaching the limit. Labs 3 and 8 have all positive h-statistics while labs 2 and 9 have both positive and negative h-statistics. Finally, labs 1, 4, 5, 6, 7 and 9 have all negative h-statistics. Since the h-statistics range from all negative, all positive, or both, the data is considered valid for precision and bias testing.

The final k-statistics are shown in Table 9. The critical k value is 2.41 for the ILS. Values approaching the critical k-statistic are highlighted in yellow while values exceeding the critical k-value are highlighted in red. The k-statistics, by laboratory and mix, are presented in Figure 36.

Table 9: Final k-Statistics for Precision & Bias

Lab	Mixture 1	Mixture 2	Mixture 3	Mixture 4
1	0.06	1.05	0.08	0.67
2	2.54	1.24	0.75	0.34
3	0.00	0.77	0.05	0.00
4	0.89	1.01	0.45	1.68
5	0.44	1.87	0.24	0.84
6	0.63	0.43	0.67	1.68
7	0.44	0.05	0.27	0.75
8	0.70	0.57	2.43	1.17
9	0.70	0.86	1.33	0.42

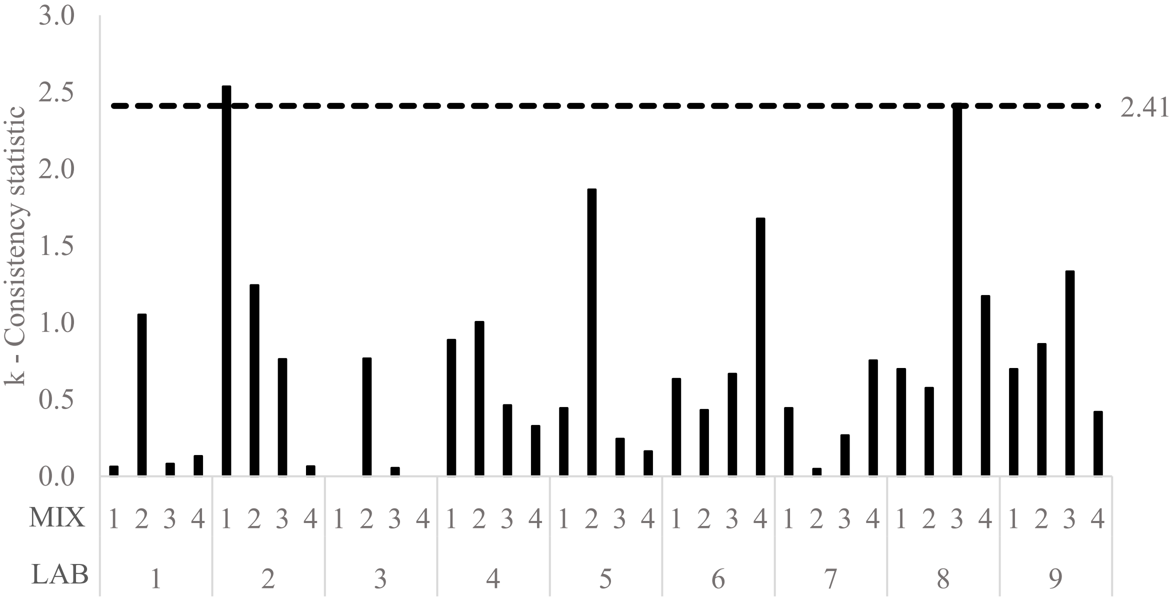

Figure 36: k-Statistic Graph

For lab 2 mix 1, the k-statistic is higher than the critical. Meanwhile, for mix 3, labs 2 and 7 have k-statistics approaching the critical value. No data is eliminated from the dataset. All data used in determining the precision and bias has a k-statistic lower than the critical. Therefore, the adjusted dataset, excluding and a single result from lab 6 mix 4 due to the accompanying sample glass container busting, is valid for precision and bias determination. Several instances of glass container breakage occurred while ILS testing. Breakage is likely due to extreme temperature changes between the hot specimen and glass container and the cold surface it is placed. To eliminate breakage, a folded towel should be placed on each cold location the dish will be placed, including the scale used for weighing. Since the glass containers and slurry surfacing materials retain heat for a long time, a towel is needed for each location the sample will be placed, even if the sample has started cooling.

The final precision and bias for the ILS is presented in Table 10. The two SS mixtures, mixtures 2 and 4, have higher reproducibility standard deviations than the two MS mixtures. However, all of the reproducibility standard deviations are significantly greater than the repeatability standard deviations.

Table 10: Interlaboratory Study Precision & Bias

Mix	$\bar{X}$	**Theoretical AC**	$s_{\bar{X}}$	**Sr**	**SR**	**SL**	**r**	**R**
1	6.99	6.28%	0.311	0.111	0.328	0.309	0.312	0.919
2	7.60	8.00%	0.309	0.148	0.339	0.305	0.414	0.949
3	7.46	7.80%	0.275	0.265	0.372	0.260	0.743	1.040
4	8.91	8.99%	0.456	0.084	0.463	0.455	0.236	1.296
Average	7.74	7.77%	0.338	0.152	0.375	0.332	0.426	1.051

The average repeatability for AC testing of slurry surfacing mixtures is 0.426%. Therefore, the allowable deviation between two tests from the same laboratory is 0.426% for AC. For HMA, the repeatability for AC testing is 0.426% so these results are comparable to those obtained in the hot mix industry. The average reproducibility for AC testing of slurry surfacing mixtures is 1.051%. The allowable deviation between two tests from different laboratories is 1.051%. For HMA, the reproducibility is 0.330%. The reproducibility for slurry surfacing systems is significantly greater than the HMA reproducibility, indicating more variability in data between laboratories. Further research into the method will likely reveal a smaller reproducibility.

Overall, drying slurry surfacing specimens and determining AC with the ignition furnace is a valid method for single-laboratory and single-operator testing with an expected tolerance of ±0.426% AC.. Another ILS is needed to address the large variability for between-laboratory testing because of the large reproducibility, or expected tolerance between laboratories, of ±1.051% AC. The repeatability is too large to consider testing between laboratories for slurry surfacing materials. Though microwaving is quick compared to conventional drying methods, a significant breakage of glass containers was observed. It was determined that breakage can be mitigated by placing a folded cloth wherever the hot specimen will be set down on a cold surface, including the scale.

4.2. Field Sampling

4.2.1. Method A

Field sampling method A analyzes samples with moisture correction, or the sister-sample method. A total of 46 samples, defined by the street, are presented in Figure 37.

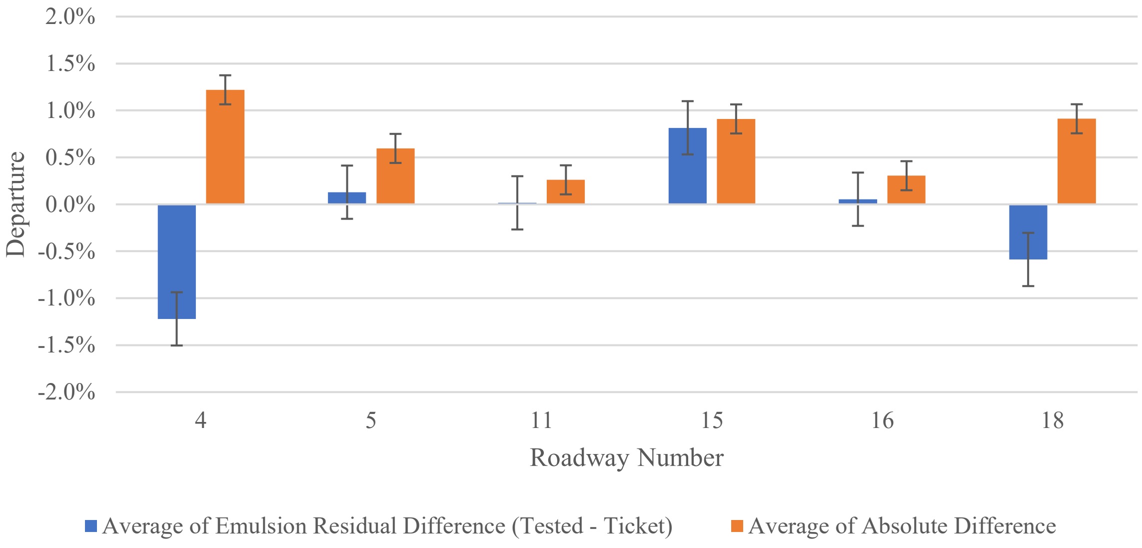

Figure 37: Field Sampling Method A Percent and Absolute Difference by Roadway

Method A has an overall average percent departure of -0.03% but an absolute departure of 0.72%. Field sampling method A results in significant absolute departures for a majority of the roadways, greater than 0.5%. While 5 of the 6 roadways result in an average percent departure and average absolute departure of less than 1%, only 2 of the roadways, 33.33%, result in a percent departure and absolute departure of less than 0.5%. Sampling is highly variable across different roadways. For most cases, the percent departure is positive, indicating measured ACs higher than the theoretical. The mixtures have a higher AC than expected.

The percent departure and absolute departure of ACs by material type is shown in Figure 38. Method A only tested micro surfacing mixtures.

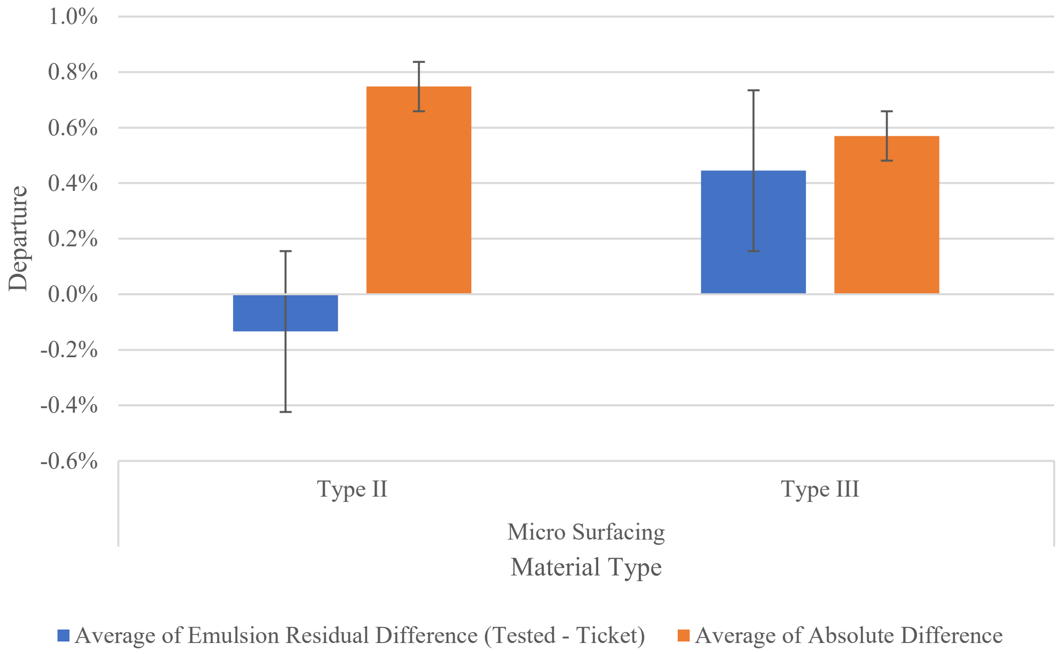

Figure 38: Field Sampling Method A Percent and Absolute Departure by Material Type

The type II material has a lower percent departure but a higher absolute departure than the type III materials. A negative percent departure is seen more in type II materials than for type III materials. However, the absolute departures and error bars indicate significant variability when field sampling. Since the results are so variable for Method A, Method B is investigated.

4.2.2. Method B- Drying Samples

Method B, drying prior to AC determination, by roadway is presented in Figure 39. A total of 119 specimens were evaluated. Overall, Method B field results reveal significant variability in testing as well.

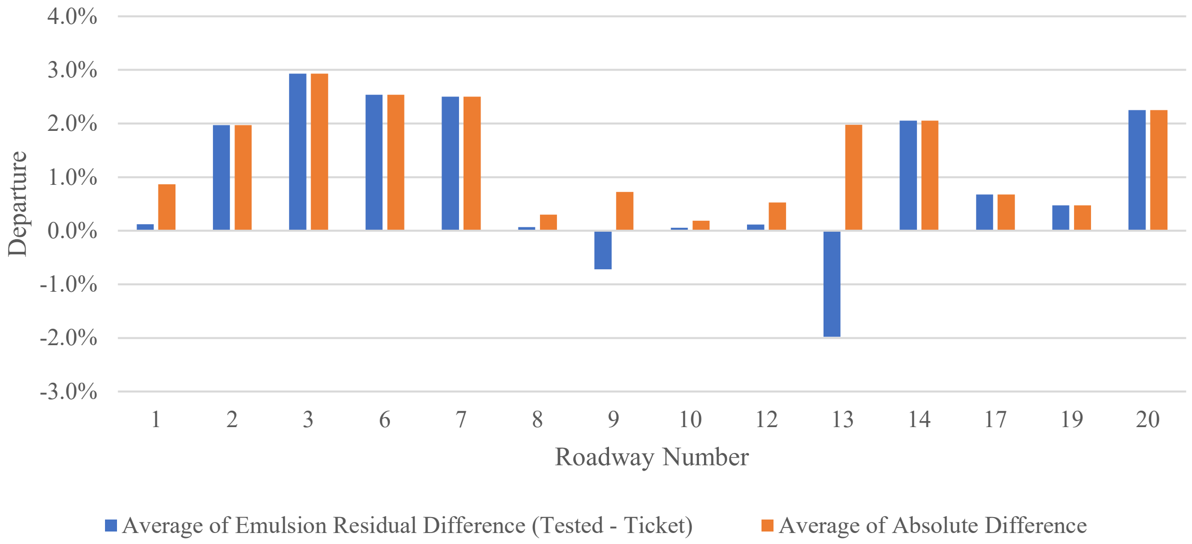

Figure 39: Method B Percent and Absolute Departure by Roadway

Method B has an overall average percent departure of 0.74% but an absolute departure of 1.12%. A majority of the roadways have a percent and absolute departure of greater than zero, indicating more AC on average than theoretical. While roadways 1, 8, 9, 10, 12, 17, and 19 have departures of less than 1%, 7 of the roadways had roughly 1% or greater error compared to the theoretical. Overall, Method B testing is variable per roadway.

Method B mixture type results in percent departures and absolute departures shown in Figure 40.

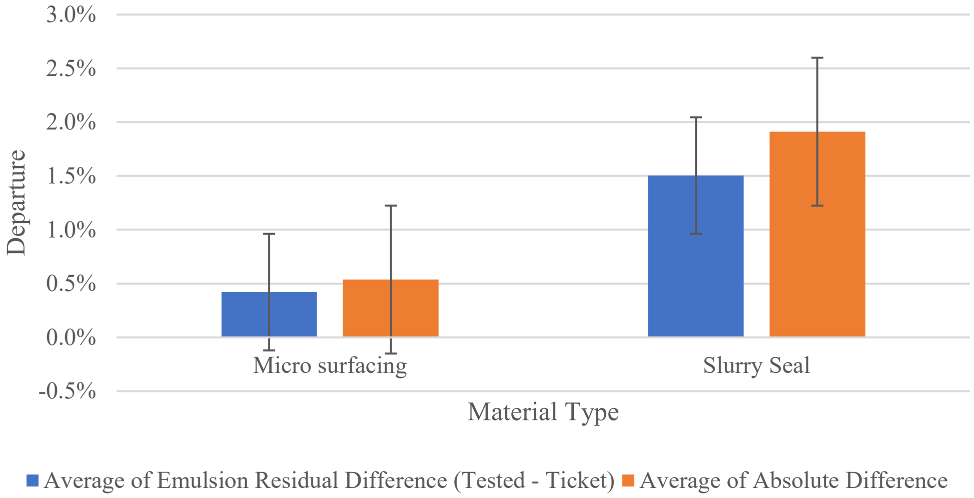

Figure 40: Method B Material Type Percent and Absolute Departures

Again, the mixtures are highly variable. The micro surfacing mixtures have a much lower percent departure and absolute departure compared to the slurry seal. The micro surfacing is, however, still variable. To further investigate potential causes of error, the percent and absolute departures observed by mixture size are shown in Figure 41.

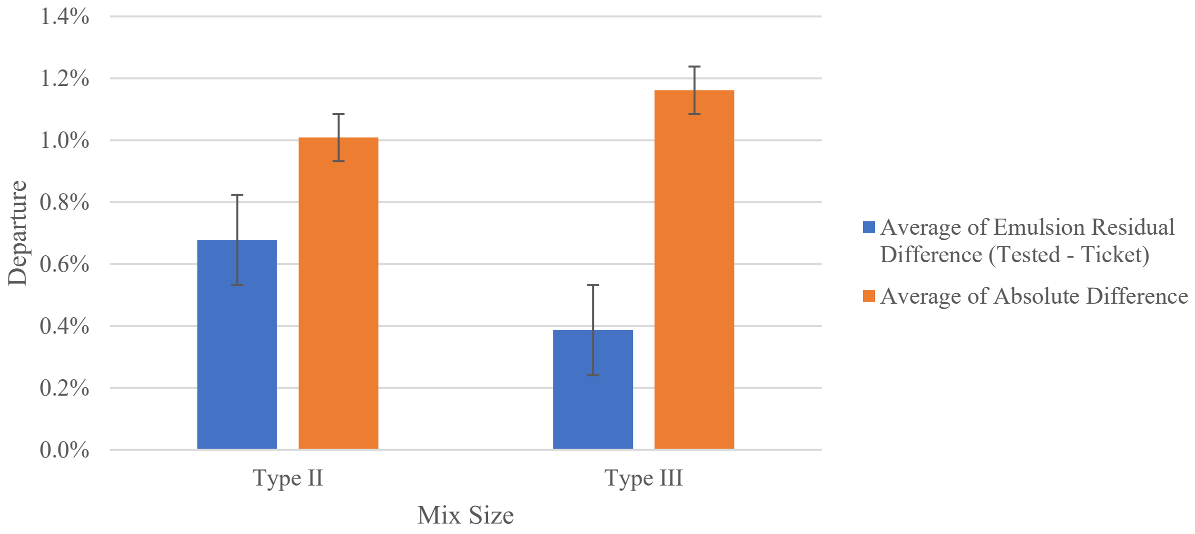

Figure 41: Method B Mixture Size Percent and Absolute Departures

Overall, mixture size, type II or type III, does not significantly impact samples for Method B, drying prior to AC determination. The percent departure is smaller for type III than for type II but type III has a greater absolute departure. However, the variability is lower than that observed when observing the percent and absolute departures by material type. Finally, the total drying and testing times are presented in Figure 42.

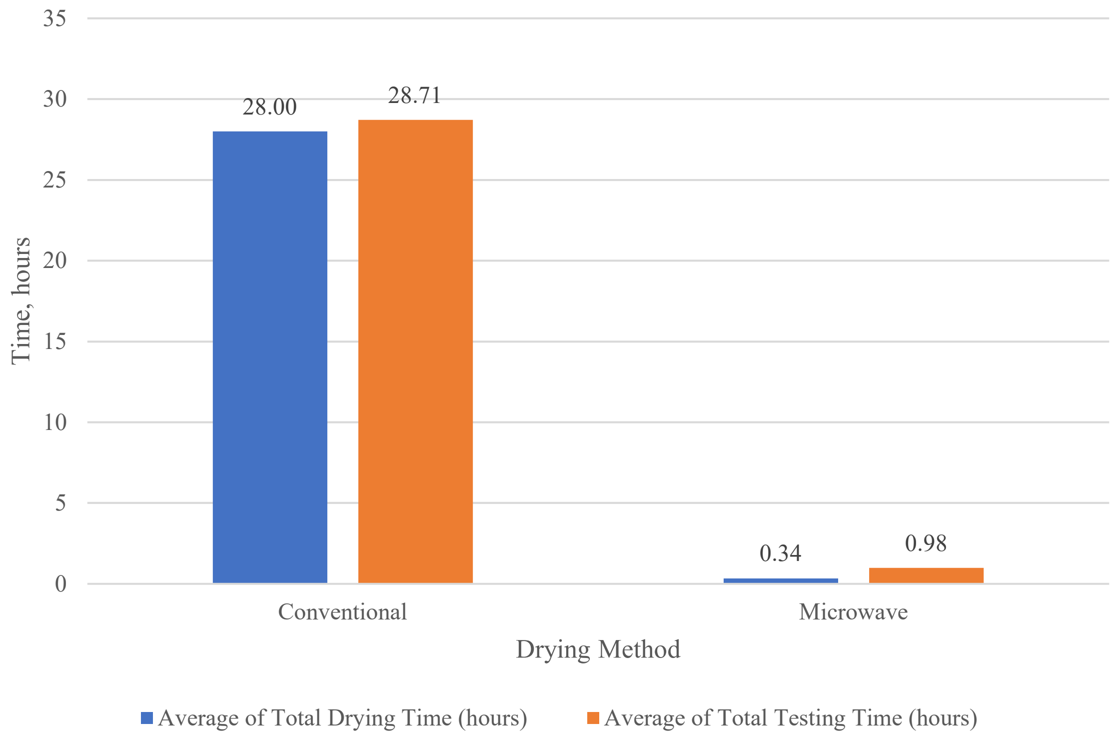

Figure 42: Method B Drying and Testing Time by Drying Method

Again, the time savings observed by microwave drying opposed to conventional drying is significant. The total testing time for microwaved samples is less than 1 hour, while conventional samples required, on average, 28.71 hours of total testing time to achieve results. However, field results vary significantly. Further research is needed to develop an accurate, standardized sampling method for slurry surfacing materials. Neither Method A nor Method B result in differences small enough to consider the sampling methods accurate.

Summary of Results

The laboratory samples reveal than pan samples, consisting of four smaller samples, are more accurate than fabrication of smaller samples for each JMF. The drying method does not impact the accuracy, but the microwave drying procedure requires less time for results. However, mixing the sample to crumble and drying prior to AC testing of slurry surfacing materials is recommended and results in more accurate results while testing.

In the ILS, the repeatability is 0.196% and the reproducibility is 1.073%. Results from the laboratories are similar but between laboratories vary. Limestone mixtures are subject to more aggregate breakdown during ignition testing. Microwave drying requires significantly less time to achieve results when compared to the conventional method. Overall, the ignition furnace method for AC determination is accurate and time effective. The method of extraction by centrifuge is less accurate and time efficient than ignition testing.

ACs observed while field sampling are highly variable. Neither Method A nor Method B resulted in departures accurate enough to consider either sampling method effective. More research is needed to determine a method of sampling slurry surfacing.

CHAPTER V - CONCLUSIONS & RECOMMENDATIONS

6.1. Conclusions

The following conclusions were made based on analysis and observations throughout the study:

- The presence of moisture in the mixture must be accounted for to estimate the residual binder content. Conventional drying methods have long been used to determine the moisture content and dry asphalt mixtures. However, conventional drying can be time consuming and delay results of testing by roughly 24 hours. Hybrid drying results in slightly smaller departures than microwave drying between the measured and theoretical ACs. However, the small improvement in accuracy with hybrid drying does not justify the extra time needed for testing, 1 hour or 1.5 hours. Microwave drying is considered statistically not different than conventional oven drying and results in similar errors compared to conventional methods. Due to the significant time savings, microwave drying is suitable for slurry surfacing materials. Microwave drying specimens, on average, require less than 30 minutes to dry. Using a sister sample to estimate the moisture content of the tested sample is not recommended, as the assumption that all samples from the same mix retain water at the same rate appears to be incorrect and can alter the results. Mixing the sample to crumble removes as much of the mixture water as possible before drying, allowing drying to occur faster compared to natural slurry surfacing breaking and curing.
- The ignition furnace method is typically used for determining the AC of asphalt mixtures, especially HMA. The ignition furnace method can also be successfully implemented as a slurry surfacing method for quality control/quality assurance. Ignition furnace testing is simple, quick, and accurate. Overall, ignition furnace testing is significantly more accurate compared to extraction by centrifuge. When combined with a microwave drying procedure to eliminate sample moisture, testing can be conducted within 1 hour, allowing for same day results.
- From the ILS, it was estimated that ignition furnace testing after drying slurry surfacing specimens has a repeatability of 0.426% and a reproducibility of 1.051%. Therefore, the method is valid for single-laboratory, single-operator testing with an expected tolerance of ±0.426%. However, the reproducibility is 1.051%, significantly greater than the

reproducibility of HMA. Testing between laboratories is highly variable as the expected tolerance is ±1.051%. Since errors are large for between laboratory testing, testing between laboratories is not suitable for quality control/quality assurance.

- Field sampling is highly variable for slurry surfacing, regardless of sampling from the machinery or the pavement surface. Field adjustments, presence of moisture in aggregate stockpiles, etc. can affect mix proportioning and induce error when comparing the results to the design JMF. More accurate results can be obtained by using the theoretical AC based on machine production tickets to account for field adjustments. In general, the proposed procedures tend to overestimate the residual binder content. The average departure of all field sampled specimens is 0.53% with an absolute departure of 1.01%. Method A, using a sister sample for moisture content, has a percent departure of -0.03% but an absolute departure of 0.72% while Method B, drying prior to AC determination, has a percent and absolute departure of 0.74% and 1.12%, respectively. Since the observed error is high, the sampling procedures, Method A and Method B, are not suitable for slurry surfacing materials.
- In the field, micro surfacing mixtures have lower departures than slurry seal materials. However, laboratory testing reveals no significant departures between micro surfacing and slurry seal mixtures. Aggregate type, particularly those with low durability, impacts AC testing. Limestone mixtures often result in a negative percent departure while basalt and granite mixtures result in a positive percent departure.

6.2. Recommendations

The following recommendations should be considered for sampling and determining AC from slurry surfacing systems:

- Breakage of Pyrex or glass containers can occur when placing the hot microwaved dish and sample onto a cold surface. This is likely due to extreme temperature changes between the specimen and glass and the surface it is being places. To eliminate the breakage, a folded towel should be placed on each cold location the dish will be placed, including the scale used for weighing.
- The ignition furnace method is recommended for use in determining AC of slurry surfacing systems. The ignition furnace method of AC determination is more accurate than the

extraction method. To ensure accurate results, drying specimens prior to AC determination is also recommended as slurry surfacing systems retain significant amounts of water. Microwaving specimens followed by the ignition method is also recommended for same day testing as results can be achieved quickly.

- Depending on aggregate type, a correction factor may be obtained to improve ignition furnace results. However, adding this step will increase the time required to obtain results. More accurate and consistent results can be achieved using a correction factor for the ignition oven. The agency should evaluate whether this is necessary based on the desired tolerances.
- The ILS showed promising results, with good repeatability, however reproducibility error was still high. Testing variability among laboratories may be reduced through technician training and certification programs.

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APPENDIX A: LABORATORY SAMPLES

Table 11: Laboratory Sample Database Part A

Specimen ID	Sample Fabrication Date	Sample Testing Date	Sample mixing	Sample Storage	Mixed to crumble?	Dried before tested?
1	3/12/2021	3/17/2021	Small bowl	Plastic Container	No	No
2	3/12/2021	3/17/2021	Small bowl	Plastic Container	No	No
3	3/12/2021	3/19/2021	Small bowl	Plastic Container	No	Yes
4	3/12/2021	3/17/2021	Small bowl	Ziploc bag	No	No
5	3/12/2021	3/19/2021	Small bowl	Ziploc bag	No	Yes
6	3/19/2021	3/20/2021	Small bowl	Plastic Container	No	Yes
7	3/19/2021	3/20/2021	Small bowl	Plastic Container	No	No
8	3/19/2021	3/21/2021	Bucket	Pan	No	No
9	3/19/2021	3/21/2021	Bucket	Pan	No	No
10	3/19/2021	3/21/2021	Bucket	Pan	No	Yes
11	3/19/2021	3/22/2021	Bucket	Pan	No	Yes
12	3/25/2021	3/26/2021	Bucket	Pan	No	No
13	3/25/2021	3/27/2021	Bucket	Pan	No	Yes
14	3/25/2021	3/27/2021	Bucket	Pan	No	Yes
15	3/25/2021	3/26/2021	Bucket	Pan	No	No
16	4/22/2021	4/24/2021	Small bowl	Plastic Container	Yes	Yes
17	4/22/2021	4/23/2021	Small bowl	Plastic Container	Yes	No
18	4/22/2021	4/23/2021	Small bowl	Plastic Container	Yes	No
19	4/22/2021	4/24/2021	Small bowl	Plastic Container	Yes	Yes
20	4/26/2021	4/26/2021	Bucket	Pan	Yes	No
21	4/26/2021	4/27/2021	Bucket	Pan	Yes	Yes
22	4/26/2021	4/27/2021	Bucket	Pan	Yes	Yes
23	4/26/2021	4/26/2021	Bucket	Pan	Yes	No
24	5/1/2021	5/4/2021	Small bowl	Plastic Container	Yes	Yes
25	5/1/2021	5/4/2021	Small bowl	Plastic Container	Yes	Yes
26	5/2/2021	5/4/2021	Small bowl	Plastic Container	Yes	Yes
27	5/2/2021	5/4/2021	Small bowl	Plastic Container	Yes	Yes
28	5/2/2021	5/4/2021	Bucket	Pan	Yes	Yes
29	5/2/2021	5/4/2021	Bucket	Pan	Yes	Yes
30	5/2/2021	5/4/2021	Bucket	Pan	Yes	Yes
31	5/2/2021	5/4/2021	Bucket	Pan	Yes	Yes
32	5/11/2021	5/11/2021	Bucket	Pan	Yes	Yes
33	5/11/2021	5/11/2021	Bucket	Pan	Yes	Yes
34	5/11/2021	5/12/2021	Bucket	Pan	Yes	Yes
35	5/11/2021	5/12/2021	Bucket	Pan	Yes	Yes
36	5/16/2021	-	Bucket	Pan	Yes	Yes
37	5/16/2021	-	Bucket	Pan	Yes	Yes
38	5/16/2021	-	Bucket	Pan	Yes	Yes
39	5/16/2021	-	Bucket	Pan	Yes	Yes
40	5/16/2021	-	Bucket	Pan	Yes	Yes
41	5/16/2021	5/20/2021	Bucket	Pan	Yes	Yes
42	5/16/2021	5/21/2021	Bucket	Pan	Yes	Yes
43	5/16/2021	5/21/2021	Bucket	Pan	Yes	Yes
44	5/16/2021	5/21/2021	Bucket	Pan	Yes	Yes
45	5/16/2021	5/22/2021	Bucket	Pan	Yes	Yes
46	5/16/2021	5/22/2021	Bucket	Pan	Yes	Yes
47	5/16/2021	5/22/2021	Bucket	Pan	Yes	Yes
48	5/16/2021	5/22/2021	Bucket	Pan	Yes	Yes
49	5/16/2021	5/22/2021	Bucket	Pan	Yes	Yes
50	5/16/2021	-	Bucket	Pan	Yes	Yes
51	5/16/2021	-	Bucket	Pan	Yes	Yes
52	5/16/2021	-	Bucket	Pan	Yes	Yes
53	5/16/2021	-	Bucket	Pan	Yes	Yes
54	5/17/2021	5/24/2021	Bucket	Pan	Yes	Yes
55	6/1/2021	6/1/2021	Bucket	Pan	Yes	Yes

Table 12: Laboratory Sample Database Part A (Continued)

Specimen ID	Sample Fabrication Date	Sample Testing Date	Sample mixing	Sample Storage	Mixed to crumble?	Dried before tested?
56	6/1/2021	6/2/2021	Bucket	Pan	Yes	Yes
57	6/1/2021	6/2/2021	Bucket	Pan	Yes	Yes
58	6/1/2021	6/2/2021	Bucket	Pan	Yes	Yes
59	6/19/2021	6/19/2021	Bucket	Pan	Yes	Yes
60	6/19/2021	6/19/2021	Bucket	Pan	Yes	Yes
61	6/19/2021	6/19/2021	Bucket	Pan	Yes	Yes
62	6/19/2021	6/19/2021	Bucket	Pan	Yes	Yes
63	11/10/2021	11/10/2021	Bucket	Pan	Yes	Yes
64	11/10/2021	11/10/2021	Bucket	Pan	Yes	Yes
65	11/10/2021	11/10/2021	Bucket	Pan	Yes	Yes
66	11/10/2021	11/10/2021	Bucket	Pan	Yes	Yes
67	9/14/2021	9/15/2021	Small bowl	Pan	Yes	Yes
68	9/14/2021	9/15/2021	Small bowl	Pan	Yes	Yes
69	9/14/2021	9/15/2021	Small bowl	Pan	Yes	Yes
70	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
71	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
72	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
73	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
74	9/16/2021	9/17/2021	Small bowl	Pan	Yes	Yes
75	9/16/2021	9/17/2021	Small bowl	Pan	Yes	Yes
76	9/16/2021	9/17/2021	Small bowl	Pan	Yes	Yes
77	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
78	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
79	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes
80	9/16/2021	9/17/2021	Bucket	Pan	Yes	Yes

Table 13: Laboratory Sample Database Part B

Specimen ID	Material Type	Emulsion Grade
1	Type 2	CSS-1HP
2	Type 2	CSS-1HP
3	Type 2	CSS-1HP
4	Type 2	CSS-1HP
5	Type 2	CSS-1HP
6	Type 2	CSS-1HP
7	Type 2	CSS-1HP
8	Type 2	CSS-1HP
9	Type 2	CSS-1HP
10	Type 2	CSS-1HP
11	Type 2	CSS-1HP
12	Type 2	CSS-1HP
13	Type 2	CSS-1HP
14	Type 2	CSS-1HP
15	Type 2	CSS-1HP
16	Type 2	CSS-1HP
17	Type 2	CSS-1HP
18	Type 2	CSS-1HP
19	Type 2	CSS-1HP
20	Type 2	CSS-1HP
21	Type 2	CSS-1HP
22	Type 2	CSS-1HP
23	Type 2	CSS-1HP
24	Type 2	CSS-1HP
25	Type 2	CSS-1HP
26	Type 2	CSS-1HP
27	Type 2	CSS-1HP
28	Type 2	CSS-1HP

Table 14: Laboratory Sample Database Part B (Continued)

Specimen ID	Material Type	Emulsion Grade
29	Type 2	CSS-1HP
30	Type 2	CSS-1HP
31	Type 2	CSS-1HP
32	Type 2	CSS-1HP
33	Type 2	CSS-1HP
34	Type 2	CSS-1HP
35	Type 2	CSS-1HP
36	Type 2	CSS-1HP
37	Type 2	CSS-1HP
38	Type 2	CSS-1HP
39	Type 2	CSS-1HP
40	Type 2	CSS-1HP
41	Type 2	CSS-1HP
42	Type 2	CSS-1HP
43	Type 2	CSS-1HP
44	Type 2	CSS-1HP
45	Type 2	CSS-1HP
46	Type 2	CSS-1HP
47	Type 2	CSS-1HP
48	Type 2	CSS-1HP
49	Type 2	CSS-1HP
50	Type 2	CSS-1HP
51	Type 2	CSS-1HP
52	Type 2	CSS-1HP
53	Type 2	CSS-1HP
54	Type 3	CSS-1HP
55	Type 2	CQS-1H
56	Type 2	CQS-1H
57	Type 2	CQS-1H
58	Type 2	CQS-1H
59	Type B	CQS-1H
60	Type B	CQS-1H
61	Type B	CQS-1H
62	Type B	CQS-1H
63	Type 3	CQS-1HP
64	Type 3	CQS-1HP
65	Type 3	CQS-1HP
66	Type 3	CQS-1HP
67	Type 2	CSS-1HP
68	Type 2	CSS-1HP
69	Type 2	CSS-1HP
70	Type 2	CSS-1HP
71	Type 2	CSS-1HP
72	Type 2	CSS-1HP
73	Type 2	CSS-1HP
74	Type 2	CQS-1HP
75	Type 2	CQS-1HP
76	Type 2	CQS-1HP
77	Type 2	CQS-1HP
78	Type 2	CQS-1HP
79	Type 2	CQS-1HP
80	Type 2	CQS-1HP

Table 15: Laboratory Sample Database Part C

Specimen ID	**Mass of Original Ignition Sample, g**	**Mass of Aggregate after Ignition, g**	**Measured Bitumen Ratio from Furnace Ticket (INCLUDES MOISTURE)**	**Measured Bitumen Ratio from Hand Calculations (INCLUDES MOISTURE)**
1	1204.6	999.5	16.65%	20.52%
2	1207.4	999.0	20.07%	20.86%
3	1080.8	998.1	7.99%	8.29%
4	1188.0	998.6	18.52%	18.97%
5	1081.0	1000.6	7.95%	8.04%
6	1127.9	1042.7	8.05%	8.17%
7	1199.7	1038.8	14.77%	15.49%
8	1208.0	1075.1	11.89%	12.36%
9	1248.7	1118.9	11.14%	11.60%
10	1079.4	999.8	7.79%	7.96%
11	1054.8	975.5	7.79%	8.13%
12	1325.0	1128.7	15.86%	17.39%
13	1213.0	1125.6	7.67%	7.76%
14	1330.3	1235.8	7.64%	7.65%
15	1580.8	1350.6	16.79%	17.04%
16	1268.8	1177.4	7.76%	7.76%
17	1271.6	1090.9	16.37%	16.56%
18	1293.3	1093.9	17.67%	18.23%
19	1150.1	1066.6	7.65%	7.83%
20	1504.4	1297.9	15.81%	15.91%
21	1080.0	1000.9	7.72%	7.90%
22	1342.3	1243.4	8.04%	7.95%
23	1663.6	1431.1	16.15%	16.25%
24	1134.1	1051.1	7.99%	7.90%
25	1130.0	1046.4	8.10%	7.99%
26	1091.8	1000.7	8.95%	9.10%
27	1080.5	997.5	8.24%	8.32%
28	1322.6	1223.1	8.08%	8.14%
29	1506.1	1386.9	8.52%	8.59%
30	1328.9	1227.6	8.07%	8.25%
31	1239.8	1146.0	8.33%	8.18%
32	1568.6	1444.2	8.61%	8.61%
33	1377.0	1271.1	8.29%	8.33%
34	1498.8	1379.9	8.64%	8.62%
35	1513.0	1393.0	8.42%	8.61%
36	1243.2	1149.6	8.07%	8.14%
37	1237.6	1143.3	8.13%	8.25%
38	743.0	687.2	7.97%	8.12%
39	817.2	755.6	7.97%	8.15%
40	813.0	751.8	8.00%	8.14%
41	1325.3	1227.1	8.02%	8.00%
42	1219.7	1128.5	8.08%	8.08%
43	1172.0	1085.0	8.11%	8.02%
44	1131.9	1047.2	7.86%	8.09%
45	1146.2	1054.0	8.75%	8.75%
46	1173.2	1086.0	8.04%	8.03%
47	946.2	875.5	7.96%	8.08%
48	775.1	718.1	8.05%	7.94%
49	720.3	667.4	7.90%	7.93%
50	1042.5	965.5	7.96%	7.98%
51	1218.3	1128.9	7.94%	7.92%
52	722.3	669.9	7.77%	7.82%
53	970.3	898.9	7.99%	7.94%
54	868.6	804.7	7.93%	7.94%
55	755.7	698.4	8.22%	8.20%
56	790.6	730.0	7.81%	8.30%
57	867.2	800.9	8.38%	8.28%
58	872.4	805.2	8.24%	8.35%
59	778.4	718.5	8.18%	8.34%
60	801.5	739.5	8.31%	8.38%

Table 16: Laboratory Sample Database Part C (Continued)

Specimen ID	Mass of Original Ignition Sample, g	Mass of Aggregate after Ignition, g	Measured Bitumen Ratio from Furnace Ticket (INCLUDES MOISTURE)	Measured Bitumen Ratio from Hand Calculations (INCLUDES MOISTURE)
61	818.7	755.4	8.30%	8.38%
62	839.9	774.4	8.35%	8.46%
63	794.1	735.5	8.00%	7.97%
64	773.0	715.1	7.97%	8.10%
65	867.8	802.8	7.99%	8.10%
66	799.2	739.3	7.99%	8.10%
67	769.8	706.3	7.34%	8.25%
68	765.2	707.5	7.31%	7.54%
69	762.1	704.9	7.45%	7.51%
70	-	-	7.49%	-
71	-	-	7.49%	-
72	-	-	7.46%	-
73	-	-	7.49%	-
74	748.4	694.4	7.13%	7.22%
75	751.7	696.8	7.09%	7.30%
76	753.7	701.2	7.14%	6.97%
77	-	-	7.56%	-
78	-	-	7.50%	-
79	-	-	7.46%	-
80	-	-	7.58%	-

Table 17: Laboratory Sample Database Part D

Specimen ID	Drying Method	Moisture Content of Sister-Sample	Measured Emulsion Residual Rate Based on Furnace Ticket (After Moisture Subtracted)	Measured Emulsion Residual Rate Based on Hand Calculations (After Moisture Subtracted)
1	Conventional Oven	11.61%	5.04%	8.91%
2	Conventional Oven	11.61%	8.46%	9.25%
3	Conventional Oven	0.00%	7.99%	8.29%
4	Conventional Oven	9.13%	9.39%	9.83%
5	Conventional Oven	0.00%	7.95%	8.04%
6	Conventional Oven	0.00%	8.05%	8.17%
7	Conventional Oven	7.00%	7.77%	8.49%
8	Conventional Oven	3.59%	8.30%	8.77%
9	Conventional Oven	3.10%	8.04%	8.50%
10	Conventional Oven	0.00%	7.79%	7.96%
11	Conventional Oven	0.00%	7.79%	8.13%
12	Conventional Oven	8.75%	7.11%	8.64%
13	Conventional Oven	0.00%	7.67%	7.76%
14	Conventional Oven	0.00%	7.64%	7.65%
15	Conventional Oven	8.68%	8.11%	8.36%
16	Conventional Oven	0.00%	7.76%	7.76%
17	Conventional Oven	7.51%	8.86%	9.05%
18	Conventional Oven	9.29%	8.38%	8.94%
19	Conventional Oven	0.00%	7.65%	7.83%
20	Conventional Oven	7.69%	8.12%	8.22%
21	Conventional Oven	0.00%	7.72%	7.90%
22	Conventional Oven	0.00%	8.04%	7.95%
23	Conventional Oven	7.52%	8.63%	8.73%
24	Microwave Oven	0.00%	7.99%	7.90%
25	Microwave Oven	0.00%	8.10%	7.99%

Table 18: Laboratory Sample Database Part D (Continued)

Specimen ID	Drying Method	Moisture Content of Sister-Sample	Measured Emulsion Residual Rate Based on Furnace Ticket (After Moisture Subtracted)	Measured Emulsion Residual Rate Based on Hand Calculations (After Moisture Subtracted)
26	Microwave Oven	0.00%	8.95%	9.10%
27	Microwave Oven	0.00%	8.24%	8.32%
28	Microwave Oven	0.00%	8.08%	8.14%
29	Microwave Oven	0.00%	8.52%	8.59%
30	Microwave Oven	0.00%	8.07%	8.25%
31	Microwave Oven	0.00%	8.33%	8.18%
32	Microwave Oven	0.00%	8.61%	8.61%
33	Microwave Oven	0.00%	8.29%	8.33%
34	Microwave Oven	0.00%	8.64%	8.62%
35	Microwave Oven	0.00%	8.42%	8.61%
36	Hybrid - 1.5 hr	0.00%	8.07%	8.14%
37	Hybrid - 1.5 hr	0.00%	8.13%	8.25%
38	Hybrid - 1.5 hr	0.00%	7.97%	8.12%
39	Hybrid - 1.5 hr	0.00%	7.97%	8.15%
40	Hybrid - 1.5 hr	0.00%	8.00%	8.14%
41	Hybrid - 1 hr	0.00%	8.02%	8.00%
42	Hybrid - 1 hr	0.00%	8.08%	8.08%
43	Hybrid - 1.5 hr	0.00%	8.11%	8.02%
44	Hybrid - 1.5 hr	0.00%	7.86%	8.09%
45	Hybrid - 1.5 hr	0.00%	8.75%	8.75%
46	Hybrid - 1.5 hr	0.00%	8.04%	8.03%
47	Hybrid - 1.5 hr	0.00%	7.96%	8.08%
48	Hybrid - 1.5 hr	0.00%	8.05%	7.94%
49	Hybrid - 1.5 hr	0.00%	7.90%	7.93%
50	Hybrid - 1.5 hr	0.00%	7.96%	7.98%
51	Hybrid - 1.5 hr	0.00%	7.94%	7.92%
52	Hybrid - 1.5 hr	0.00%	7.77%	7.82%
53	Hybrid - 1.5 hr	0.00%	7.99%	7.94%
54	Hybrid - 1.5 hr	0.00%	7.93%	7.94%
55	Microwave Oven	0.00%	8.22%	8.20%
56	Microwave Oven	0.00%	7.81%	8.30%
57	Microwave Oven	0.00%	8.38%	8.28%
58	Microwave Oven	0.00%	8.24%	8.35%
59	Microwave Oven	0.00%	8.18%	8.34%
60	Microwave Oven	0.00%	8.31%	8.38%
61	Microwave Oven	0.00%	8.30%	8.38%
62	Microwave Oven	0.00%	8.35%	8.46%
63	Microwave Oven	0.00%	8.00%	7.97%
64	Microwave Oven	0.00%	7.97%	8.10%
65	Microwave Oven	0.00%	7.99%	8.10%
66	Microwave Oven	0.00%	7.99%	8.10%
67	Microwave Oven	0.00%	7.34%	8.25%
68	Microwave Oven	0.00%	7.31%	7.54%
69	Microwave Oven	0.00%	7.45%	7.51%
70	Microwave Oven	0.00%	7.49%	-
71	Microwave Oven	0.00%	7.49%	-
72	Microwave Oven	0.00%	7.46%	-
73	Microwave Oven	0.00%	7.49%	-
74	Microwave Oven	0.00%	7.13%	7.22%
75	Microwave Oven	0.00%	7.09%	7.30%
76	Microwave Oven	0.00%	7.14%	6.97%
77	Microwave Oven	0.00%	7.56%	-
78	Microwave Oven	0.00%	7.50%	-
79	Microwave Oven	0.00%	7.46%	-
80	Microwave Oven	0.00%	7.58%	-

Table 19: Laboratory Sample Database Part E

Specimen ID	Microwave Drying Time (seconds)	Conventional Oven Drying Time (hours)	Ignition Time (mins)	Total Drying Time (hours)	Total Testing Time (hours)
1	0.00	24.00	43.00	24.00	24.72
2	0.00	24.00	40.00	24.00	24.67
3	0.00	24.00	41.00	24.00	24.68
4	0.00	24.00	40.00	24.00	24.67
5	0.00	24.00	45.00	24.00	24.75
6	0.00	24.00	45.00	24.00	24.75
7	0.00	24.00	39.00	24.00	24.65
8	0.00	24.00	36.00	24.00	24.60
9	0.00	24.00	44.00	24.00	24.73
10	0.00	24.00	43.00	24.00	24.72
11	0.00	24.00	40.00	24.00	24.67
12	0.00	24.00	48.00	24.00	24.80
13	0.00	24.00	47.00	24.00	24.78
14	0.00	24.00	54.00	24.00	24.90
15	0.00	24.00	53.00	24.00	24.88
16	0.00	24.00	52.00	24.00	24.87
17	0.00	24.00	49.00	24.00	24.82
18	0.00	24.00	49.00	24.00	24.82
19	0.00	24.00	49.00	24.00	24.82
20	0.00	24.00	55.00	24.00	24.92
21	0.00	24.00	43.00	24.00	24.72
22	0.00	24.00	56.00	24.00	24.93
23	0.00	24.00	69.00	24.00	25.15
24	1200.00	0.00	46.00	0.33	1.10
25	732.00	0.00	48.00	0.20	1.00
26	840.00	0.00	48.00	0.23	1.03
27	780.00	0.00	42.00	0.22	0.92
28	900.00	0.00	55.00	0.25	1.17
29	900.00	0.00	66.00	0.25	1.35
30	900.00	0.00	50.00	0.25	1.08
31	900.00	0.00	55.00	0.25	1.17
32	900.00	0.00	64.00	0.25	1.32
33	900.00	0.00	53.00	0.25	1.13
34	900.00	0.00	66.00	0.25	1.35
35	900.00	0.00	76.00	0.25	1.52
36	1080.00	1.50	46.00	1.80	2.57
37	1260.00	1.50	47.00	1.85	2.63
38	1260.00	1.50	33.00	1.85	2.40
39	1260.00	1.50	33.00	1.85	2.40
40	1260.00	1.50	33.00	1.85	2.40
41	900.00	1.00	59.00	1.25	2.23
42	960.00	1.00	52.00	1.27	2.13
43	960.00	1.50	51.00	1.77	2.62
44	960.00	1.50	47.00	1.77	2.55
45	860.00	1.50	50.00	1.74	2.57
46	780.00	1.50	44.00	1.72	2.45
47	960.00	1.50	43.00	1.77	2.48
48	960.00	1.50	35.00	1.77	2.35
49	960.00	1.50	32.00	1.77	2.30
50	960.00	1.50	43.00	1.77	2.48
51	960.00	1.50	48.00	1.77	2.57
52	960.00	1.50	32.00	1.77	2.30
53	960.00	1.50	39.00	1.77	2.42
54	960.00	1.50	36.00	1.77	2.37
55	1260.00	0.00	31.00	0.35	0.87
56	1260.00	0.00	43.00	0.35	1.07
57	1260.00	0.00	37.00	0.35	0.97
58	1260.00	0.00	44.00	0.35	1.08
59	1260.00	0.00	45.00	0.35	1.10
60	1260.00	0.00	32.00	0.35	0.88

Table 20: Laboratory Sample Database Part E (Continued)

Specimen ID	Microwave Drying Time (seconds)	Conventional Oven Drying Time (hours)	Ignition Time (mins)	Total Drying Time (hours)	Total Testing Time (hours)
61	1260.00	0.00	33.00	0.35	0.90
62	1260.00	0.00	33.00	0.35	0.90
63	1260.00	0.00	36.00	0.35	0.95
64	1260.00	0.00	29.00	0.35	0.83
65	1260.00	0.00	31.00	0.35	0.87
66	1260.00	0.00	32.00	0.35	0.88
67	1320.00	0.00	44.00	0.37	1.10
68	1320.00	0.00	43.00	0.37	1.08
69	1320.00	0.00	38.00	0.37	1.00
70	-	0.00	42.00	0.00	0.70
71	-	0.00	37.00	0.00	0.62
72	-	0.00	47.00	0.00	0.78
73	-	0.00	46.00	0.00	0.77
74	-	0.00	38.00	0.00	0.63
75	-	0.00	39.00	0.00	0.65
76	-	0.00	44.00	0.00	0.73
77	-	0.00	41.00	0.00	0.68
78	-	0.00	39.00	0.00	0.65
79	-	0.00	43.00	0.00	0.72
80	-	0.00	53.00	0.00	0.88

Table 21: Laboratory Sample Database Part F

Specimen ID	Emulsion Content (Added during sample fabrication)	Cement Content (Added during sample fabrication)	Water Content (Added during sample fabrication)	Residual Rate of Emulsion	Calculated Residual of Emulsion After Water Evaporates
1	12.0%	1.00%	9.0%	64.84%	7.78%
2	12.0%	1.00%	9.0%	64.84%	7.78%
3	12.0%	1.00%	9.0%	64.84%	7.78%
4	12.0%	1.00%	9.0%	64.84%	7.78%
5	12.0%	1.00%	9.0%	64.84%	7.78%
6	12.0%	1.00%	5.0%	64.84%	7.78%
7	12.0%	1.00%	5.0%	64.84%	7.78%
8	12.0%	1.00%	5.0%	64.84%	7.78%
9	12.0%	1.00%	5.0%	64.84%	7.78%
10	12.0%	1.00%	5.0%	64.84%	7.78%
11	12.0%	1.00%	5.0%	64.84%	7.78%
12	12.0%	1.00%	9.0%	64.84%	7.78%
13	12.0%	1.00%	9.0%	64.84%	7.78%
14	12.0%	1.00%	9.0%	64.84%	7.78%
15	12.0%	1.00%	9.0%	64.84%	7.78%
16	12.0%	1.00%	5.0%	64.84%	7.78%
17	12.0%	1.00%	5.0%	64.84%	7.78%
18	12.0%	1.00%	7.0%	64.84%	7.78%
19	12.0%	1.00%	7.0%	64.84%	7.78%
20	12.0%	1.00%	5.0%	64.84%	7.78%
21	12.0%	1.00%	5.0%	64.84%	7.78%
22	12.0%	1.00%	5.0%	64.84%	7.78%
23	12.0%	1.00%	5.0%	64.84%	7.78%
24	12.0%	1.00%	5.0%	64.84%	7.78%
25	12.0%	1.00%	5.0%	64.84%	7.78%

Table 22: Laboratory Sample Database Part F (Continued)

Specimen ID	Emulsion Content (Added during sample fabrication)	Cement Content (Added during sample fabrication)	Water Content (Added during sample fabrication)	Residual Rate of Emulsion	Calculated Residual of Emulsion After Water Evaporates
26	12.6%	1.00%	7.0%	64.84%	8.17%
27	12.0%	1.00%	7.0%	64.84%	7.78%
28	12.0%	1.00%	9.0%	64.84%	7.78%
29	12.0%	1.00%	9.0%	64.84%	7.78%
30	12.0%	1.00%	9.0%	64.84%	7.78%
31	12.0%	1.00%	9.0%	64.84%	7.78%
32	12.0%	1.00%	5.0%	64.84%	7.78%
33	12.0%	1.00%	5.0%	64.84%	7.78%
34	12.0%	1.00%	5.0%	64.84%	7.78%
35	12.0%	1.00%	5.0%	64.84%	7.78%
36	12.0%	1.00%	5.0%	64.84%	7.78%
37	12.0%	1.00%	5.0%	64.84%	7.78%
38	12.0%	1.00%	5.0%	64.84%	7.78%
39	12.0%	1.00%	5.0%	64.84%	7.78%
40	12.0%	1.00%	7.0%	64.84%	7.78%
41	12.0%	1.00%	5.0%	64.84%	7.78%
42	12.0%	1.00%	5.0%	64.84%	7.78%
43	12.0%	1.00%	5.0%	64.84%	7.78%
44	12.0%	1.00%	5.0%	64.84%	7.78%
45	12.0%	1.00%	7.0%	64.84%	7.78%
46	12.0%	1.00%	7.0%	64.84%	7.78%
47	12.0%	1.00%	7.0%	64.84%	7.78%
48	12.0%	1.00%	7.0%	64.84%	7.78%
49	12.0%	1.00%	7.0%	64.84%	7.78%
50	12.0%	1.00%	7.0%	64.84%	7.78%
51	12.0%	1.00%	9.0%	64.84%	7.78%
52	12.0%	1.00%	9.0%	64.84%	7.78%
53	12.0%	1.00%	9.0%	64.84%	7.78%
54	12.0%	1.00%	9.0%	64.84%	7.78%
55	12.7%	2.00%	6.0%	65.20%	8.28%
56	12.7%	2.00%	6.0%	65.20%	8.28%
57	12.7%	2.00%	6.0%	65.20%	8.28%
58	12.7%	2.00%	6.0%	65.20%	8.28%
59	12.8%	1.00%	5.8%	66.40%	8.50%
60	12.8%	1.00%	5.8%	66.40%	8.50%
61	12.8%	1.00%	5.8%	66.40%	8.50%
62	12.8%	1.00%	5.8%	66.40%	8.50%
63	12.00%	1.00%	9.0%	64.90%	7.79%
64	12.00%	1.00%	9.0%	64.90%	7.79%
65	12.00%	1.00%	9.0%	64.90%	7.79%
66	12.00%	1.00%	9.0%	64.90%	7.79%
67	12.0%	0.80%	4.0%	62.00%	7.44%
68	12.0%	0.80%	4.0%	62.00%	7.44%
69	12.0%	0.80%	4.0%	62.00%	7.44%
70	12.0%	0.80%	4.0%	62.00%	7.44%
71	12.0%	0.80%	4.0%	62.00%	7.44%
72	12.0%	0.80%	4.0%	62.00%	7.44%
73	12.0%	0.80%	4.0%	62.00%	7.44%
74	12.73%	0.80%	6.5%	63.60%	8.10%
75	12.73%	0.80%	5.8%	63.60%	8.10%
76	12.73%	0.80%	5.8%	63.60%	8.10%
77	12.73%	0.80%	5.8%	63.60%	8.10%
78	12.73%	0.80%	5.8%	63.60%	8.10%
79	12.73%	0.80%	5.8%	63.60%	8.10%
80	12.73%	0.80%	5.8%	63.60%	8.10%

Table 23: Laboratory Sample Database Part G

Specimen ID	Emulsion Residual Difference (Tested - Ticket)	Absolute Difference
1	-2.74%	2.74%
2	0.68%	0.68%
3	0.21%	0.21%
4	1.61%	1.61%
5	0.17%	0.17%
6	0.27%	0.27%
7	-0.01%	0.01%
8	0.52%	0.52%
9	0.26%	0.26%
10	0.01%	0.01%
11	0.01%	0.01%
12	-0.67%	0.67%
13	-0.11%	0.11%
14	-0.14%	0.14%
15	0.33%	0.33%
16	-0.02%	0.02%
17	1.08%	1.08%
18	0.60%	0.60%
19	-0.13%	0.13%
20	0.34%	0.34%
21	-0.06%	0.06%
22	0.26%	0.26%
23	0.85%	0.85%
24	0.21%	0.21%
25	0.32%	0.32%
26	0.78%	0.78%
27	0.46%	0.46%
28	0.30%	0.30%
29	0.74%	0.74%
30	0.29%	0.29%
31	0.55%	0.55%
32	0.83%	0.83%
33	0.51%	0.51%
34	0.86%	0.86%
35	0.64%	0.64%
36	0.29%	0.29%
37	0.35%	0.35%
38	0.19%	0.19%
39	0.19%	0.19%
40	0.22%	0.22%
41	0.24%	0.24%
42	0.30%	0.30%
43	0.33%	0.33%
44	0.08%	0.08%
45	0.97%	0.97%
46	0.26%	0.26%
47	0.18%	0.18%
48	0.27%	0.27%
49	0.12%	0.12%
50	0.18%	0.18%
51	0.16%	0.16%
52	-0.01%	0.01%
53	0.21%	0.21%
54	0.15%	0.15%
55	-0.06%	0.06%
56	-0.47%	0.47%
57	0.10%	0.10%
58	-0.04%	0.04%
59	-0.32%	0.32%
60	-0.19%	0.19%

Table 24: Laboratory Sample Database Part G (Continued)

Specimen ID	Emulsion Residual Difference (Tested - Ticket)	Absolute Difference
61	-0.20%	0.20%
62	-0.15%	0.15%
63	0.21%	0.21%
64	0.18%	0.18%
65	0.20%	0.20%
66	0.20%	0.20%
67	-0.10%	0.10%
68	-0.13%	0.13%
69	0.01%	0.01%
70	0.05%	0.05%
71	0.05%	0.05%
72	0.02%	0.02%
73	0.05%	0.05%
74	-0.97%	0.97%
75	-1.01%	1.01%
76	-0.96%	0.96%
77	-0.54%	0.54%
78	-0.60%	0.60%
79	-0.64%	0.64%
80	-0.52%	0.52%

APPENDIX B: METHOD A FIELD SAMPLES

Table 25: Field Sampling Method A Database Part A

Roadway	Sample ID	Section	Sample Date	Sampling Method
1	MS-5A	Field	5/17/2022	Roofing Felt
1	MS-5C	Field	5/17/2022	Roofing Felt
1	MS-5D	Field	5/17/2022	Roofing Felt
9	MS-3A	Field	5/17/2022	Plastic
9	MS-3B	Field	5/17/2022	Plastic
9	MS-3C	Field	5/17/2022	Plastic
9	MS-3D	Field	5/17/2022	Plastic
9	MS-4A	Field	5/17/2022	Plastic
9	MS-4B	Field	5/17/2022	Plastic
9	MS-4C	Field	5/17/2022	Plastic
9	MS-4D	Field	5/17/2022	Plastic
8	Man1A	Field	5/25/2022	Manhole
8	Man1B	Field	5/25/2022	Manhole
8	Man1C	Field	5/25/2022	Manhole
8	Man1D	Field	5/25/2022	Manhole
8	Man1E	Field	5/25/2022	Manhole
8	Man1F	Field	5/25/2022	Manhole
8	Man2A	Field	5/25/2022	Manhole
8	Man2B	Field	5/25/2022	Manhole
8	Man3A	Field	5/25/2022	Manhole

Table 26: Field Sampling Method A Database Part B

Roadway	Mix Type	Size	Emulsion Grade	Mixed to crumble?	Dried before testing?	Drying method
1	-	-	-	No	Yes	Microwave
1	-	-	-	No	Yes	Microwave
1	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
9	-	-	-	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave
8	Micro surface	Type 2	CQS-1hLM	No	Yes	Microwave

Table 27: Field Sampling Method A Database Part C

Roadway	Mass of Original Ignition Sample, g	Mass of Aggregate after Ignition, g	Measured Bitumen Ratio from Furnace Ticket (INCLUDES MOISTURE)	Measured Bitumen Ratio from Hand Calculations (INCLUDES MOISTURE)	Moisture Content of Sister-Sample	Measured Emulsion Residual Rate Based on Furnace Ticket (After Moisture Subtracted)	Measured Emulsion Residual Rate Based on Hand Calculations (After Moisture Subtracted)
1	1020.7	961.6	6.14%	6.15%	0.00%	6.14%	6.15%
1	1060.9	999.9	6.10%	6.10%	0.00%	6.10%	6.10%
1	1094.4	1030.2	6.06%	6.23%	0.00%	6.06%	6.23%
9	803.2	750.8	6.88%	6.98%	0.00%	6.88%	6.98%
9	806.2	751.0	7.29%	7.35%	0.00%	7.29%	7.35%
9	640.7	602.9	6.26%	6.27%	0.00%	6.26%	6.27%
9	808.7	760.0	6.43%	6.41%	0.00%	6.43%	6.41%
9	822.0	771.0	6.50%	6.61%	0.00%	6.50%	6.61%
9	693.9	651.0	6.40%	6.59%	0.00%	6.40%	6.59%
9	742.4	697.1	6.44%	6.50%	0.00%	6.44%	6.50%
9	814.7	763.6	6.58%	6.69%	0.00%	6.58%	6.69%
8	679.2	631.0	7.61%	7.64%	0.00%	7.61%	7.64%
8	886.1	821.9	7.57%	7.81%	0.00%	7.57%	7.81%
8	765.6	710.3	7.63%	7.79%	0.00%	7.63%	7.79%
8	823.8	763.4	7.83%	7.91%	0.00%	7.83%	7.91%
8	784.4	727.7	7.73%	7.79%	0.00%	7.73%	7.79%
8	734.1	680.8	7.66%	7.83%	0.00%	7.66%	7.83%
8	837.7	771.1	8.56%	8.64%	0.00%	8.56%	8.64%
8	833.5	766.5	8.58%	8.74%	0.00%	8.58%	8.74%
8	689.9	634.8	8.33%	8.68%	0.00%	8.33%	8.68%

Table 28: Field Sampling Method A Database Part D

Roadway	Microwave Drying Time (seconds)	Conventional Oven Drying Time (hours)	Ignition Time (mins)	Total Drying Time (hours)	Total Testing Time (hours)
1	1200.00	0.00	38.00	0.33	0.97
1	1020.00	0.00	38.00	0.28	0.92
1	1020.00	0.00	41.00	0.28	0.97
9	1200.00	0.00	32.00	0.33	0.87
9	1200.00	0.00	37.00	0.33	0.95
9	1200.00	0.00	28.00	0.33	0.80
9	1200.00	0.00	33.00	0.33	0.88
9	1020.00	0.00	36.00	0.28	0.88
9	1020.00	0.00	28.00	0.28	0.75
9	1020.00	0.00	32.00	0.28	0.82
9	1020.00	0.00	33.00	0.28	0.83
8	1020.00	0.00	31.00	0.28	0.80
8	1020.00	0.00	40.00	0.28	0.95
8	1020.00	0.00	33.00	0.28	0.83
8	1020.00	0.00	36.00	0.28	0.88
8	1020.00	0.00	36.00	0.28	0.88
8	1020.00	0.00	43.00	0.28	1.00
8	1020.00	0.00	45.00	0.28	1.03
8	1020.00	0.00	39.00	0.28	0.93
8	1140.00	0.00	32.00	0.32	0.85

Table 29: Field Sampling Method A Database Part E

Roadway	Emulsion Content (According to Ticket from Micro Machine)	Cement Content (According to Ticket from Micro Machine)	Water Content (According to Ticket from Micro Machine)	Application Rate (According to Ticket from Micro Machine), lb/yd2	Residual Rate of Emulsion	Calculated Residual of Emulsion After Water Evaporates
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
9	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%

Table 30: Field Sampling Method A Database Part F

Roadway	Emulsion Residual Difference (Tested - Ticket)	Absolute Difference
1	-1.18%	1.18%
1	-1.22%	1.22%
1	-1.26%	1.26%
9	-0.44%	0.44%
9	-0.03%	0.03%
9	-1.06%	1.06%
9	-0.89%	0.89%
9	-0.82%	0.82%
9	-0.92%	0.92%
9	-0.88%	0.88%
9	-0.74%	0.74%
8	-0.39%	0.39%
8	-0.43%	0.43%
8	-0.37%	0.37%
8	-0.17%	0.17%
8	-0.27%	0.27%
8	-0.34%	0.34%
8	0.56%	0.56%
8	0.58%	0.58%
8	0.33%	0.33%

APPENDIX C: METHOD B FIELD SAMPLES

Table 31: Field Samples Method B Database Part A

Roadway	Sample Date	Field Sampling Method A or B	Sampling Method	Mix Type	Size
15	9/21/2020	A	Pan	Micro surface	Type 2
15	9/21/2020	A	Pan	Micro surface	Type 2
15	9/21/2020	A	Pan	Micro surface	Type 2
15	9/21/2020	A	Pan	Micro surface	Type 2
11	9/25/2020	A	Pan (shovel)	Micro surface	Type 2
11	9/25/2020	A	Pan (shovel)	Micro surface	Type 2
11	9/25/2020	A	Pan (shovel)	Micro surface	Type 2
11	9/25/2020	A	Pan (shovel)	Micro surface	Type 2
11	9/25/2020	A	Bags	Micro surface	Type 2
16	9/29/2020	A	Pan (shovel)	Micro surface	Type 3
16	9/29/2020	A	Can (Plastic)	Micro surface	Type 3
15	9/21/2020	A	Jug (Plastic)	Micro surface	Type 2
15	9/21/2020	A	Jug (Plastic)	Micro surface	Type 2
15	9/21/2020	A	Jug (Plastic)	Micro surface	Type 2
15	9/21/2020	A	Jug (Plastic)	Micro surface	Type 2
11	9/25/2020	A	Bags	Micro surface	Type 2
11	9/25/2020	A	Bags	Micro surface	Type 2
15	9/21/2020	A	Jug (Plastic)	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 3
5	8/5/2016	A	Pan	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 2
5	8/5/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
18	8/6/2016	A	Pan	Micro surface	Type 2
4	8/6/2016	A	Pan	Micro surface	Type 2
4	8/6/2016	A	Pan	Micro surface	Type 2
14	5/18/2021	A	Bags	Slurry Seal	Type 2
14	5/18/2021	A	Bags	Slurry Seal	Type 2
6	5/18/2021	A	Bags	Slurry Seal	Type 2
6	5/18/2021	A	Bags	Slurry Seal	Type 2
6	5/18/2021	A	Bags	Slurry Seal	Type 2
6	5/18/2021	A	Bags	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
14	5/18/2021	A	Pan	Slurry Seal	Type 2
19	8/6/2016	A	Pan	Micro surface	Type 2
19	8/6/2016	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2

Table 32: Field Samples Method B Database Part A (Continued)

Roadway	Sample Date	Field Sampling Method A or B	Sampling Method	Mix Type	Size
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
10	7/8/2021	A	Pan	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
2	7/8/2021	A	Uline Scoop	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
17	7/10/2021	A	Pan	Micro surface	Type 2
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
12	6/29/2021	A	Pan	Slurry Seal	Type 3
3	6/29/2021	A	Pan	Slurry Seal	Type 2
20	11/17/2021	A	Pan	Slurry Seal Scratch	Type 3
20	11/17/2021	A	Pan	Slurry Seal Scratch	Type 3
20	11/17/2021	A	Pan	Slurry Seal Scratch	Type 3
20	11/17/2021	A	Pan	Slurry Seal Scratch	Type 3
13	11/17/2021	A	Pan	Slurry Seal	Type 3
13	11/17/2021	A	Pan	Slurry Seal	Type 3
13	11/17/2021	A	Pan	Slurry Seal	Type 3
13	11/17/2021	A	Pan	Slurry Seal	Type 3
20	11/17/2021	A	Pan	Slurry Seal	Type 3
20	11/17/2021	A	Pan	Slurry Seal	Type 3
7	11/18/2021	A	Pan	Slurry Seal	Type 2
7	11/18/2021	A	Pan	Slurry Seal	Type 2
7	11/18/2021	A	Pan	Slurry Seal	Type 2
7	11/18/2021	A	Pan	Slurry Seal	Type 2
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
1	5/17/2022	A	Pan	-	-
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2
8	5/25/2022	A	Pan	Micro surface	Type 2

Table 33: Field Samples Method B Database Part B

Roadway	Mixed to crumble?	Dried before testing?	Drying method	Mass of Original Ignition Sample, g	Mass of Aggregate after Ignition, g	Measured Bitumen Ratio from Furnace Ticket (INCLUDES MOISTURE)	Measured Bitumen Ratio from Hand Calculations (INCLUDES MOISTURE)	Moisture Content of Sister-Sample	Measured Emulsion Residual Rate Based on Furnace Ticket (After Moisture Subtracted)	Measured Emulsion Residual Rate Based on Hand Calculations (After Moisture Subtracted)
15	No	No	Conventional	1479.6	1258.2	17.25%	17.60%	9.35%	7.91%	8.25%
15	No	No	Conventional	761.5	645.4	16.59%	17.99%	9.11%	7.48%	8.88%
15	No	No	Conventional	1721.3	1447.7	18.78%	18.90%	10.73%	8.05%	8.17%
15	No	No	Conventional	1632.9	1386.4	17.69%	17.78%	9.75%	7.94%	8.03%
11	No	No	Conventional	1293.5	1113.6	16.14%	16.15%	7.43%	8.71%	8.72%
11	No	No	Conventional	2006.6	1736.5	15.41%	15.55%	6.95%	8.46%	8.60%
11	No	No	Conventional	1732.8	1523.1	13.74%	13.77%	5.37%	8.37%	8.40%
11	No	No	Conventional	1802.0	1572.6	14.50%	14.59%	5.86%	8.64%	8.73%
11	No	No	Conventional	1417.8	1237.8	14.22%	14.54%	5.70%	8.52%	8.84%
16	No	No	Conventional	2790.9	2392.2	16.53%	16.67%	8.73%	7.80%	7.94%
16	No	No	Conventional	1554.7	1330.7	16.85%	16.83%	8.44%	8.41%	8.39%
15	No	No	Conventional	2043.6	1794.2	13.99%	13.90%	4.96%	9.03%	8.94%
15	No	No	Conventional	2120.4	1950.1	8.79%	8.73%	0.05%	8.74%	8.68%
15	No	No	Conventional	2559.2	2133.7	19.77%	19.94%	9.73%	10.04%	10.21%
15	No	No	Conventional	2647.5	2198.9	20.49%	20.40%	10.26%	10.23%	10.14%
11	No	No	Conventional	1497.8	1307.5	14.80%	14.55%	6.95%	7.85%	7.60%
11	No	No	Conventional	1389.5	1203.4	15.61%	15.46%	6.46%	9.15%	9.00%
15	No	No	Conventional	2743.5	2294.8	19.65%	19.55%	10.59%	9.06%	8.96%
5	No	No	Conventional	955.2	794.8	18.02%	20.18%	9.18%	8.84%	11.00%
5	No	No	Conventional	1049.9	877.9	18.65%	19.59%	9.07%	9.58%	10.52%
5	No	No	Conventional	992.7	844.0	17.09%	17.62%	7.90%	9.19%	9.72%
5	No	No	Conventional	999.6	860.6	16.01%	16.15%	7.92%	8.09%	8.23%
5	No	No	Conventional	962.2	822.6	15.72%	16.97%	7.88%	7.84%	9.09%
5	No	No	Conventional	1005.0	874.3	14.81%	14.95%	6.90%	7.91%	8.05%
5	No	No	Conventional	941.1	800.5	16.87%	17.56%	7.98%	8.89%	9.58%
5	No	No	Conventional	1079.4	977.1	10.42%	10.47%	2.14%	8.28%	8.33%
5	No	No	Conventional	542.5	493.9	9.99%	9.84%	1.79%	8.20%	8.05%
5	No	No	Conventional	652.8	594.7	10.03%	9.77%	0.86%	9.17%	8.91%
5	No	No	Conventional	803.6	736.8	8.54%	9.07%	1.00%	7.54%	8.07%
5	No	No	Conventional	641.1	588.0	8.88%	9.03%	0.76%	8.12%	8.27%
18	No	No	Conventional	1113.3	932.1	16.58%	19.44%	8.25%	8.33%	11.19%
18	No	No	Conventional	982.7	844.8	15.96%	16.32%	7.17%	8.79%	9.15%
18	No	No	Conventional	831.0	732.7	13.13%	13.42%	6.66%	6.47%	6.76%
18	No	No	Conventional	965.6	836.3	15.15%	15.46%	6.46%	8.69%	9.00%
18	No	No	Conventional	983.0	860.6	14.00%	14.22%	4.79%	9.21%	9.43%
18	No	No	Conventional	1040.6	901.6	14.99%	15.42%	5.01%	9.98%	10.41%
18	No	No	Conventional	1086.7	958.3	13.13%	13.40%	5.64%	7.49%	7.76%
18	No	No	Conventional	936.4	815.6	14.44%	14.81%	5.64%	8.80%	9.17%
18	No	No	Conventional	1058.5	960.2	10.12%	10.24%	2.77%	7.35%	7.47%
18	No	No	Conventional	681.3	624.4	9.05%	9.11%	1.15%	7.90%	7.96%
18	No	No	Conventional	978.9	893.9	10.10%	9.51%	2.02%	8.08%	7.49%
18	No	No	Conventional	770.5	707.0	8.94%	8.98%	3.05%	5.89%	5.93%
18	No	No	Conventional	903.4	814.8	10.66%	10.87%	3.22%	7.44%	7.65%
18	No	No	Conventional	989.2	887.8	11.55%	11.42%	3.23%	8.32%	8.19%
4	No	No	Conventional	1108.4	945.0	15.61%	17.29%	8.19%	7.42%	9.10%
4	No	No	Conventional	814.3	701.8	14.69%	16.03%	7.27%	7.42%	8.76%
14	Yes	Yes	Microwave	950.8	860.9	10.58%	10.44%	0.00%	10.58%	10.44%
14	Yes	Yes	Microwave	945.1	855.0	10.25%	10.54%	0.00%	10.25%	10.54%
6	Yes	Yes	Microwave	750.0	676.3	10.63%	10.90%	0.00%	10.63%	10.90%
6	Yes	Yes	Microwave	692.9	625.3	10.91%	10.81%	0.00%	10.91%	10.81%
6	Yes	Yes	Microwave	531.7	477.4	10.78%	11.37%	0.00%	10.78%	11.37%
6	Yes	Yes	Microwave	488.8	438.1	11.03%	11.57%	0.00%	11.03%	11.57%
14	Yes	Yes	Conventional	964.1	872.5	10.58%	10.50%	0.00%	10.58%	10.50%
14	Yes	Yes	Microwave	921.2	835.1	10.40%	10.31%	0.00%	10.40%	10.31%
14	Yes	Yes	Microwave	1104.1	1001.0	10.25%	10.30%	0.00%	10.25%	10.30%
14	Yes	Yes	Microwave	897.7	813.7	10.37%	10.32%	0.00%	10.37%	10.32%
14	Yes	Yes	Microwave	608.0	548.2	10.94%	10.91%	0.00%	10.94%	10.91%
14	Yes	Yes	Microwave	632.8	570.7	11.03%	10.88%	0.00%	11.03%	10.88%
14	Yes	Yes	Microwave	651.1	587.8	11.03%	10.77%	0.00%	11.03%	10.77%
14	Yes	Yes	Microwave	672.7	606.7	10.76%	10.88%	0.00%	10.76%	10.88%
14	Yes	Yes	Microwave	802.1	726.4	10.55%	10.42%	0.00%	10.55%	10.42%
14	Yes	Yes	Microwave	801.6	725.9	10.43%	10.43%	0.00%	10.43%	10.43%
14	Yes	Yes	Microwave	809.0	733.6	10.48%	10.28%	0.00%	10.48%	10.28%
14	Yes	Yes	Microwave	731.4	663.5	10.25%	10.23%	0.00%	10.25%	10.23%
14	Yes	Yes	Microwave	930.8	847.5	9.75%	9.83%	0.00%	9.75%	9.83%
14	Yes	Yes	Microwave	1011.7	922.0	9.81%	9.73%	0.00%	9.81%	9.73%
14	Yes	Yes	Microwave	845.1	770.0	9.90%	9.75%	0.00%	9.90%	9.75%
14	Yes	Yes	Microwave	830.0	754.5	10.00%	10.01%	0.00%	10.00%	10.01%
14	Yes	Yes	Microwave	1010.0	918.4	9.92%	9.97%	0.00%	9.92%	9.97%
14	Yes	Yes	Microwave	944.0	858.6	9.83%	9.95%	0.00%	9.83%	9.95%
19	No	Yes	Conventional	921.2	843.2	9.25%	9.25%	0.00%	9.25%	9.25%
19	No	Yes	Conventional	953.6	872.9	8.98%	9.25%	0.00%	8.98%	9.25%
10	Yes	Yes	Microwave	771.7	698.5	10.40%	10.48%	0.00%	10.40%	10.48%
10	Yes	Yes	Microwave	610.8	552.5	10.40%	10.55%	0.00%	10.40%	10.55%
10	Yes	Yes	Microwave	841.4	761.4	10.46%	10.51%	0.00%	10.46%	10.51%

Table 34: Field Samples Method B Database Part B (Continued)

Roadway	Mixed to crumble?	Dried before testing?	Drying method	Mass of Original Ignition Sample, g	Mass of Aggregate after Ignition, g	Measured Bitumen Ratio from Furnace Ticket (INCLUDES MOISTURE)	Measured Bitumen Ratio from Hand Calculations (INCLUDES MOISTURE)	Moisture Content of Sister-Sample	Measured Emulsion Residual Rate Based on Furnace Ticket (After Moisture Subtracted)	Measured Emulsion Residual Rate Based on Hand Calculations (After Moisture Subtracted)
10	Yes	Yes	Microwave	767.2	693.6	10.37%	10.61%	0.00%	10.37%	10.61%
10	Yes	Yes	Microwave	688.0	624.1	10.37%	10.24%	0.00%	10.37%	10.24%
10	Yes	Yes	Microwave	766.2	693.2	10.69%	10.53%	0.00%	10.69%	10.53%
10	Yes	Yes	Microwave	841.6	766.8	9.80%	9.75%	0.00%	9.80%	9.75%
10	Yes	Yes	Microwave	841.5	763.5	10.16%	10.22%	0.00%	10.16%	10.22%
10	Yes	Yes	Microwave	715.9	648.6	10.23%	10.38%	0.00%	10.23%	10.38%
10	Yes	Yes	Microwave	829.5	753.4	9.81%	10.10%	0.00%	9.81%	10.10%
10	Yes	Yes	Microwave	736.6	666.8	10.25%	10.47%	0.00%	10.25%	10.47%
10	Yes	Yes	Microwave	640.9	579.6	10.43%	10.58%	0.00%	10.43%	10.58%
10	Yes	Yes	Microwave	671.8	607.3	10.48%	10.62%	0.00%	10.48%	10.62%
10	Yes	Yes	Microwave	542.4	489.8	10.56%	10.74%	0.00%	10.56%	10.74%
10	Yes	Yes	Microwave	686.5	621.5	10.33%	10.46%	0.00%	10.33%	10.46%
10	Yes	Yes	Microwave	834.2	755.4	10.43%	10.43%	0.00%	10.43%	10.43%
2	Yes	Yes	Microwave	780.6	718.2	8.80%	8.69%	0.00%	8.80%	8.69%
2	Yes	Yes	Microwave	711.2	652.3	8.95%	9.03%	0.00%	8.95%	9.03%
2	Yes	Yes	Microwave	846.8	778.3	8.99%	8.80%	0.00%	8.99%	8.80%
2	Yes	Yes	Microwave	908.0	834.9	8.90%	8.76%	0.00%	8.90%	8.76%
2	Yes	Yes	Microwave	521.8	478.2	9.39%	9.12%	0.00%	9.39%	9.12%
2	Yes	Yes	Microwave	527.4	483.7	9.27%	9.03%	0.00%	9.27%	9.03%
17	Yes	Yes	Microwave	542.1	497.8	8.63%	8.90%	0.00%	8.63%	8.90%
17	Yes	Yes	Microwave	501.1	460.7	8.46%	8.77%	0.00%	8.46%	8.77%
17	Yes	Yes	Microwave	577.6	530.2	9.28%	8.94%	0.00%	9.28%	8.94%
17	Yes	Yes	Microwave	524.1	481.0	9.03%	8.96%	0.00%	9.03%	8.96%
17	Yes	Yes	Microwave	835.2	768.5	8.77%	8.68%	0.00%	8.77%	8.68%
17	Yes	Yes	Microwave	851.9	782.2	8.82%	8.91%	0.00%	8.82%	8.91%
17	Yes	Yes	Microwave	822.9	756.3	8.77%	8.81%	0.00%	8.77%	8.81%
17	Yes	Yes	Microwave	877.2	805.4	8.75%	8.91%	0.00%	8.75%	8.91%
17	Yes	Yes	Microwave	882.6	812.0	8.61%	8.69%	0.00%	8.61%	8.69%
17	Yes	Yes	Microwave	933.8	858.2	8.68%	8.81%	0.00%	8.68%	8.81%
17	Yes	Yes	Microwave	894.4	823.1	8.69%	8.66%	0.00%	8.69%	8.66%
12	Yes	Yes	Microwave	1096.3	1024.5	7.04%	7.01%	0.00%	7.04%	7.01%
12	Yes	Yes	Microwave	1141.8	1068.4	6.92%	6.87%	0.00%	6.92%	6.87%
12	Yes	Yes	Microwave	935.0	877.9	6.38%	6.50%	0.00%	6.38%	6.50%
12	Yes	Yes	Microwave	1048.4	981.5	6.77%	6.82%	0.00%	6.77%	6.82%
12	Yes	Yes	Microwave	1075.2	996.5	8.00%	7.90%	0.00%	8.00%	7.90%
12	Yes	Yes	Microwave	1055.2	976.8	8.24%	8.03%	0.00%	8.24%	8.03%
12	Yes	Yes	Microwave	980.1	911.2	7.56%	7.56%	0.00%	7.56%	7.56%
12	Yes	Yes	Microwave	960.6	894.7	7.54%	7.37%	0.00%	7.54%	7.37%
3	Yes	Yes	Microwave	-	-	12.45%	-	0.00%	12.45%	-
20	Yes	Yes	Microwave	446.9	402.6	11.30%	11.00%	0.00%	11.30%	11.00%
20	Yes	Yes	Microwave	483.4	435.9	10.80%	10.90%	0.00%	10.80%	10.90%
20	Yes	Yes	Microwave	512.8	462.0	11.18%	11.00%	0.00%	11.18%	11.00%
20	Yes	Yes	Microwave	427.4	385.0	10.87%	11.01%	0.00%	10.87%	11.01%
13	Yes	Yes	Microwave	680.7	643.6	5.83%	5.76%	0.00%	5.83%	5.76%
13	Yes	Yes	Microwave	850.6	804.6	5.81%	5.72%	0.00%	5.81%	5.72%
13	Yes	Yes	Microwave	646.7	610.7	5.78%	5.89%	0.00%	5.78%	5.89%
13	Yes	Yes	Microwave	658.4	623.9	5.49%	5.53%	0.00%	5.49%	5.53%
20	Yes	Yes	Microwave	913.0	846.9	7.78%	7.80%	0.00%	7.78%	7.80%
20	Yes	Yes	Microwave	872.5	808.4	7.80%	7.93%	0.00%	7.80%	7.93%
7	Yes	Yes	Microwave	786.5	703.1	11.90%	11.86%	0.00%	11.90%	11.86%
7	Yes	Yes	Microwave	895.7	796.8	12.34%	12.41%	0.00%	12.34%	12.41%
7	Yes	Yes	Microwave	892.8	803.3	11.08%	11.14%	0.00%	11.08%	11.14%
7	Yes	Yes	Microwave	620.2	559.3	10.63%	10.89%	0.00%	10.63%	10.89%
1	Yes	Yes	Microwave	886.5	827.7	7.18%	7.10%	0.00%	7.18%	7.10%
1	Yes	Yes	Microwave	963.4	898.1	7.24%	7.27%	0.00%	7.24%	7.27%
1	Yes	Yes	Microwave	909.8	846.5	7.38%	7.48%	0.00%	7.38%	7.48%
1	Yes	Yes	Microwave	864.8	804.6	7.08%	7.48%	0.00%	7.08%	7.48%
1	Yes	Yes	Microwave	867.0	796.3	8.71%	8.88%	0.00%	8.71%	8.88%
1	Yes	Yes	Microwave	902.4	830.4	8.56%	8.67%	0.00%	8.56%	8.67%
1	Yes	Yes	Microwave	964.1	886.2	8.59%	8.79%	0.00%	8.59%	8.79%
1	Yes	Yes	Microwave	865.5	785.6	8.79%	10.17%	0.00%	8.79%	10.17%
8	Yes	Yes	Microwave	1085.3	1003.0	8.03%	8.21%	0.00%	8.03%	8.21%
8	Yes	Yes	Microwave	1104.5	1020.1	8.10%	8.27%	0.00%	8.10%	8.27%
8	Yes	Yes	Microwave	1140.1	1053.3	8.13%	8.24%	0.00%	8.13%	8.24%
8	Yes	Yes	Microwave	926.5	855.4	8.06%	8.31%	0.00%	8.06%	8.31%
8	Yes	Yes	Microwave	859.1	793.1	8.36%	8.32%	0.00%	8.36%	8.32%
8	Yes	Yes	Microwave	733.0	674.9	8.31%	8.61%	0.00%	8.31%	8.61%
8	Yes	Yes	Microwave	752.4	693.4	8.34%	8.51%	0.00%	8.34%	8.51%
8	Yes	Yes	Microwave	768.4	707.7	8.33%	8.58%	0.00%	8.33%	8.58%

Table 35: Field Samples Method B Database Part C

Roadway	Microwave Drying Time (seconds)	Conventional Oven Drying Time (hours)	Ignition Time (mins)	Total Drying Time (hours)	Total Testing Time (hours)
15	0.00	24.00	41.00	24.00	24.68
15	0.00	24.00	27.00	24.00	24.45
15	0.00	24.00	52.00	24.00	24.87
15	0.00	24.00	49.00	24.00	24.82
11	0.00	24.00	49.00	24.00	24.82
11	0.00	24.00	63.00	24.00	25.05
11	0.00	24.00	53.00	24.00	24.88
11	0.00	24.00	65.00	24.00	25.08
11	0.00	24.00	46.00	24.00	24.77
16	0.00	24.00	48.00	24.00	24.80
16	0.00	24.00	76.00	24.00	25.27
15	0.00	24.00	77.00	24.00	25.28
15	0.00	24.00	74.00	24.00	25.23
15	0.00	24.00	82.00	24.00	25.37
15	0.00	24.00	91.00	24.00	25.52
11	0.00	24.00	50.00	24.00	24.83
11	0.00	24.00	64.00	24.00	25.07
15	0.00	24.00	95.00	24.00	25.58
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
5	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
18	Na	Na	Na	Na	Na
4	0.00	24.00		24.00	24.00
4	0.00	24.00		24.00	24.00
14	1380.00	0.00	45.00	0.38	1.13
14	2220.00	0.00	46.00	0.62	1.38
6	1980.00	0.00	35.00	0.55	1.13
6	1980.00	0.00	36.00	0.55	1.15
6	1980.00	0.00	29.00	0.55	1.03
6	1980.00	0.00	34.00	0.55	1.12
14	0.00	36.00	53.00	36.00	36.88
14	1260.00	0.00	41.00	0.35	1.03
14	1260.00	0.00	50.00	0.35	1.18
14	1260.00	0.00	48.00	0.35	1.15
14	1260.00	0.00	32.00	0.35	0.88
14	1260.00	0.00	31.00	0.35	0.87
14	1260.00	0.00	35.00	0.35	0.93
14	1260.00	0.00	33.00	0.35	0.90
14	1260.00	0.00	37.00	0.35	0.97
14	1260.00	0.00	54.00	0.35	1.25
14	1260.00	0.00	38.00	0.35	0.98
14	1260.00	0.00	37.00	0.35	0.97
14	1260.00	0.00	41.00	0.35	1.03
14	1260.00	0.00	47.00	0.35	1.13
14	1260.00	0.00	42.00	0.35	1.05
14	1260.00	0.00	37.00	0.35	0.97
14	1260.00	0.00	45.00	0.35	1.10
14	1260.00	0.00	40.00	0.35	1.02
19	0.00	24.00	35.00	24.00	24.58

Na = not applicable

Table 36: Field Samples Method B Database Part C (Continued)

Roadway	Microwave Drying Time (seconds)	Conventional Oven Drying Time (hours)	Ignition Time (mins)	Total Drying Time (hours)	Total Testing Time (hours)
10	1260.00	0.00	34.00	0.35	0.92
10	1260.00	0.00	28.00	0.35	0.82
10	1260.00	0.00	38.00	0.35	0.98
10	1260.00	0.00	27.00	0.35	0.80
10	1260.00	0.00	35.00	0.35	0.93
10	1260.00	0.00	38.00	0.35	0.98
10	1260.00	0.00	39.00	0.35	1.00
10	1260.00	0.00	42.00	0.35	1.05
10	1260.00	0.00	43.00	0.35	1.07
10	1260.00	0.00	37.00	0.35	0.97
10	1260.00	0.00	37.00	0.35	0.97
10	1260.00	0.00	41.00	0.35	1.03
10	1260.00	0.00	34.00	0.35	0.92
10	1260.00	0.00	36.00	0.35	0.95
10	1260.00	0.00	31.00	0.35	0.87
10	1260.00	0.00	39.00	0.35	1.00
10	1260.00	0.00	41.00	0.35	1.03
2	1260.00	0.00	41.00	0.35	1.03
2	1260.00	0.00	34.00	0.35	0.92
2	1260.00	0.00	43.00	0.35	1.07
2	1260.00	0.00	43.00	0.35	1.07
2	1260.00	0.00	26.00	0.35	0.78
2	1260.00	0.00	31.00	0.35	0.87
17	1260.00	0.00	24.00	0.35	0.75
17	1260.00	0.00	26.00	0.35	0.78
17	1260.00	0.00	42.00	0.35	1.05
17	1260.00	0.00	27.00	0.35	0.80
17	1260.00	0.00	42.00	0.35	1.05
17	1260.00	0.00	43.00	0.35	1.07
17	1260.00	0.00	46.00	0.35	1.12
17	1260.00	0.00	43.00	0.35	1.07
17	1260.00	0.00	44.00	0.35	1.08
17	1260.00	0.00	45.00	0.35	1.10
17	1260.00	0.00	44.00	0.35	1.08
12	1260.00	0.00	42.00	0.35	1.05
12	1260.00	0.00	49.00	0.35	1.17
12	1260.00	0.00	39.00	0.35	1.00
12	1260.00	0.00	44.00	0.35	1.08
12	1260.00	0.00	53.00	0.35	1.23
12	1260.00	0.00	53.00	0.35	1.23
12	1260.00	0.00	43.00	0.35	1.07
12	1260.00	0.00	56.00	0.35	1.28
3	420.00	0.00	54.00	0.12	1.02
20	1200.00	0.00	37.00	0.33	0.95
20	1200.00	0.00	27.00	0.33	0.78
20	1200.00	0.00	27.00	0.33	0.78
20	1200.00	0.00	25.00	0.33	0.75
13	1200.00	0.00	23.00	0.33	0.72
13	1200.00	0.00	28.00	0.33	0.80
13	1200.00	0.00	20.00	0.33	0.67
13	1200.00	0.00	22.00	0.33	0.70
20	1200.00	0.00	38.00	0.33	0.97
20	1200.00	0.00	35.00	0.33	0.92
7	1200.00	0.00	47.00	0.33	1.12
7	1200.00	0.00	51.00	0.33	1.18
7	1200.00	0.00	51.00	0.33	1.18
7	1200.00	0.00	32.00	0.33	0.87
1	1200.00	0.00	39.00	0.33	0.98
1	1200.00	0.00	40.00	0.33	1.00
1	1200.00	0.00	46.00	0.33	1.10
1	1200.00	0.00	38.00	0.33	0.97
1	1200.00	0.00	42.00	0.33	1.03
1	1200.00	0.00	45.00	0.33	1.08
1	1200.00	0.00	43.00	0.33	1.05
1	1200.00	0.00	41.00	0.33	1.02
8	1200.00	0.00	43.00	0.33	1.05
8	1200.00	0.00	45.00	0.33	1.08
8	1200.00	0.00	50.00	0.33	1.17
8	1140.00	0.00	37.00	0.32	0.93
8	1200.00	0.00	45.00	0.33	1.08
8	1200.00	0.00	32.00	0.33	0.87
8	1200.00	0.00	31.00	0.33	0.85
8	1200.00	0.00	32.00	0.33	0.87

Table 37: Field Samples Method B Database Part D

Roadway	Emulsion Content (According to Ticket from Micro Machine)	Cement Content (According to Ticket from Micro Machine)	Water Content (According to Ticket from Micro Machine)	Application Rate (According to Ticket from Micro Machine), lb/yd2	Residual Rate of Emulsion	Calculated Residual of Emulsion After Water Evaporates
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
16	12.3%	0.57%	0.0%	19	65.45%	8.05%
16	12.3%	0.57%	0.0%	19	65.45%	8.05%
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
15	12.5%	0.50%	-	20	63.23%	7.90%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
11	13.1%	0.79%	1.7%	20.8	64.98%	8.51%
15	12.5%	0.50%	-	20	63.23%	7.90%
5	12.5%	1.41%	4.2%	25.3	64%	8.00%
5	12.5%	1.41%	4.2%	25.3	64%	8.00%
5	12.5%	1.41%	4.2%	25.3	64%	8.00%
5	12.5%	1.41%	4.2%	25.3	64%	8.00%
5	12.5%	1.50%	4.2%	25.7	64%	8.00%
5	12.5%	1.50%	4.2%	25.7	64%	8.00%
5	13.6%	1.00%	2.5%	19.22	64%	8.70%
5	13.6%	1.00%	2.5%	19.22	64%	8.70%
5	13.6%	1.00%	2.5%	19.22	64%	8.70%
5	13.6%	1.00%	2.5%	19.22	64%	8.70%
5	13.5%	0.97%	3.2%	15.84	64%	8.64%
5	13.5%	0.97%	3.2%	15.84	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.01%	3.1%	17.23	64%	8.64%
18	13.5%	1.05%	3.1%	18.6	64%	8.64%
18	13.5%	1.05%	3.1%	18.6	64%	8.64%
18	13.5%	1.05%	3.1%	18.6	64%	8.64%
18	13.5%	1.05%	3.1%	18.6	64%	8.64%
18	13.5%	1.07%	3.3%	19.5	64%	8.64%
18	13.5%	1.07%	3.3%	19.5	64%	8.64%
4	13.5%	1.00%	3.8%	-	64%	8.64%
4	13.5%	1.00%	3.8%	-	64%	8.64%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
6	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
6	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
6	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
6	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
14	12.7%	2.00%	1.7%	20.8	65.20%	8.30%
19	13.5%	1.01%	3.1%	17.23	64.00%	8.64%
19	13.5%	1.05%	3.1%	18.6	64.00%	8.64%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%

Table 38: Field Samples Method B Database Part D (Continued)

Roadway	Emulsion Content (According to Ticket from Micro Machine)	Cement Content (According to Ticket from Micro Machine)	Water Content (According to Ticket from Micro Machine)	Application Rate (According to Ticket from Micro Machine), lb/yd2	Residual Rate of Emulsion	Calculated Residual of Emulsion After Water Evaporates
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
10	16.1%	0.99%	2.8%	17	63.80%	10.27%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
2	11.1%	0.91%	4.0%	17	63.80%	7.08%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
17	12.7%	0.80%	6.6%	16.1	63.60%	8.10%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
12	11.0%	0.51%	10.6%	12.8	65.40%	7.19%
3	14.0%	0.30%	10.0%	-	68.00%	9.52%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
13	12.0%	0.50%	10.0%	-	64.20%	7.70%
13	12.0%	0.50%	10.0%	-	64.20%	7.70%
13	12.0%	0.50%	10.0%	-	64.20%	7.70%
13	12.0%	0.50%	10.0%	-	64.20%	7.70%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
20	12.0%	0.50%	10.0%	-	64.20%	7.70%
7	14.0%	0.50%	9.5%	-	64.20%	8.99%
7	14.0%	0.50%	9.5%	-	64.20%	8.99%
7	14.0%	0.50%	9.5%	-	64.20%	8.99%
7	14.0%	0.50%	9.5%	-	64.20%	8.99%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
1	11.60%	1.03%	7.70%	18.8	63.10%	7.32%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%
8	-	1.00%	-	-	-	8.00%

Table 39: Field Samples Method B Database Part E

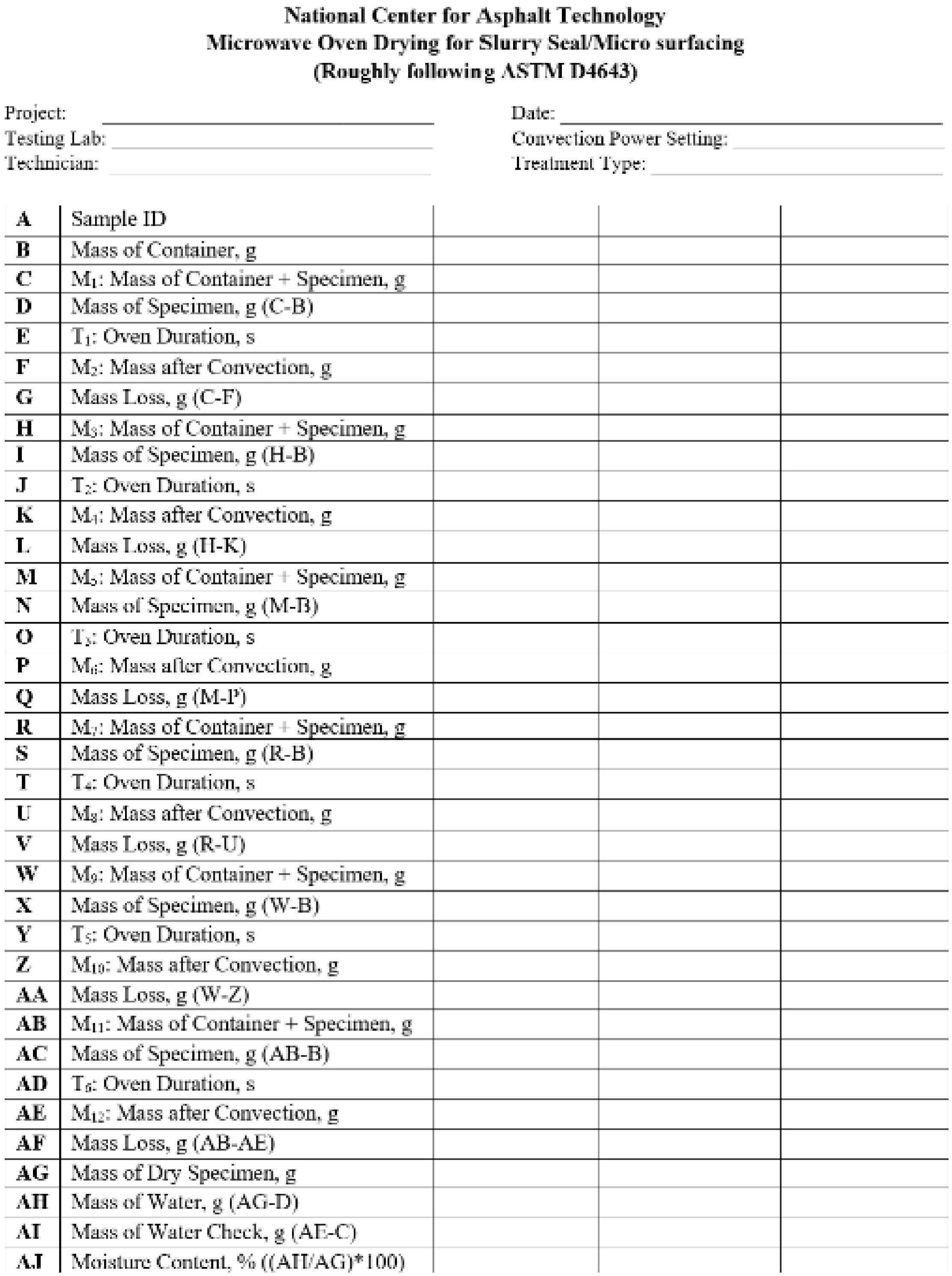
Roadway	Emulsion Residual Difference (Tested - Ticket)	Absolute Difference
15	0.00%	0.00%
15	-0.42%	0.42%
15	0.15%	0.15%
15	0.04%	0.04%
11	0.20%	0.20%
11	-0.05%	0.05%
11	-0.14%	0.14%
11	0.13%	0.13%
11	0.01%	0.01%
16	-0.25%	0.25%
16	0.36%	0.36%
15	1.13%	1.13%
15	0.84%	0.84%
15	2.14%	2.14%
15	2.33%	2.33%
11	-0.66%	0.66%
11	0.64%	0.64%
15	1.16%	1.16%
5	0.84%	0.84%
5	1.58%	1.58%
5	1.19%	1.19%
5	0.09%	0.09%
5	-0.16%	0.16%
5	-0.09%	0.09%
5	0.19%	0.19%
5	-0.42%	0.42%
5	-0.50%	0.50%
5	0.47%	0.47%
5	-1.10%	1.10%
5	-0.52%	0.52%
18	-0.31%	0.31%
18	0.15%	0.15%
18	-2.17%	2.17%
18	0.05%	0.05%
18	0.57%	0.57%
18	1.34%	1.34%
18	-1.15%	1.15%
18	0.16%	0.16%
18	-1.29%	1.29%
18	-0.74%	0.74%
18	-0.56%	0.56%
18	-2.75%	2.75%
18	-1.20%	1.20%
18	-0.32%	0.32%
4	-1.22%	1.22%
4	-1.22%	1.22%
14	2.28%	2.28%
14	1.95%	1.95%
6	2.33%	2.33%
6	2.61%	2.61%
6	2.48%	2.48%
6	2.73%	2.73%
14	2.28%	2.28%
14	2.10%	2.10%
14	1.95%	1.95%
14	2.07%	2.07%
14	2.64%	2.64%
14	2.73%	2.73%
14	2.73%	2.73%
14	2.46%	2.46%
14	2.25%	2.25%
14	2.13%	2.13%
14	2.18%	2.18%
14	1.95%	1.95%
14	1.45%	1.45%
14	1.51%	1.51%
14	1.60%	1.60%
14	1.70%	1.70%
14	1.62%	1.62%
14	1.53%	1.53%
19	0.61%	0.61%
19	0.34%	0.34%
10	0.13%	0.13%
10	0.13%	0.13%
10	0.19%	0.19%
10	0.13%	0.13%
10	0.10%	0.10%
10	0.10%	0.10%
10	0.42%	0.42%
10	-0.47%	0.47%

Table 40: Field Samples Method B Database Part E (Continued)

Roadway	Emulsion Residual Difference (Tested - Ticket)	Absolute Difference
10	-0.11%	0.11%
10	-0.04%	0.04%
10	-0.46%	0.46%
10	-0.02%	0.02%
10	0.16%	0.16%
10	0.21%	0.21%
10	0.29%	0.29%
10	0.06%	0.06%
10	0.16%	0.16%
2	1.72%	1.72%
2	1.87%	1.87%
2	1.91%	1.91%
2	1.82%	1.82%
2	2.31%	2.31%
2	2.19%	2.19%
17	0.53%	0.53%
17	0.36%	0.36%
17	1.18%	1.18%
17	0.93%	0.93%
17	0.67%	0.67%
17	0.72%	0.72%
17	0.67%	0.67%
17	0.65%	0.65%
17	0.51%	0.51%
17	0.58%	0.58%
17	0.59%	0.59%
12	-0.15%	0.15%
12	-0.27%	0.27%
12	-0.81%	0.81%
12	-0.42%	0.42%
12	0.81%	0.81%
12	1.05%	1.05%
12	0.37%	0.37%
12	0.35%	0.35%
3	2.93%	2.93%
20	3.60%	3.60%
20	3.10%	3.10%
20	3.48%	3.48%
20	3.17%	3.17%
13	-1.87%	1.87%
13	-1.89%	1.89%
13	-1.92%	1.92%
13	-2.21%	2.21%
20	0.08%	0.08%
20	0.10%	0.10%
7	2.91%	2.91%
7	3.35%	3.35%
7	2.09%	2.09%
7	1.64%	1.64%
1	-0.14%	0.14%
1	-0.08%	0.08%
1	0.06%	0.06%
1	-0.24%	0.24%
1	1.39%	1.39%
1	1.24%	1.24%
1	1.27%	1.27%
1	1.47%	1.47%
8	0.03%	0.03%
8	0.10%	0.10%
8	0.13%	0.13%
8	0.06%	0.06%
8	0.36%	0.36%
8	0.31%	0.31%
8	0.34%	0.34%
8	0.33%	0.33%

APPENDIX D: INTERLABORATORY STUDY INSTRUCTIONS & DATA COLLECTION

Table 41: Microwave Drying Data Sheet



National Center for Asphalt Technology
Microwave Oven Drying for Slurry Seal/Micro surfacing
(Roughly following ASTM D4643)

Project: ______________________ Date: ______________________
Testing Lab: ______________________ Convection Power Setting: ______________________
Technician: ______________________ Treatment Type: ______________________

A	Sample ID			
B	Mass of Container, g			
C	M_1: Mass of Container + Specimen, g			
D	Mass of Specimen, g (C-B)			
E	T_1: Oven Duration, s			
F	M_2: Mass after Convection, g			
G	Mass Loss, g (C-F)			
H	M_3: Mass of Container + Specimen, g			
I	Mass of Specimen, g (H-B)			
J	T_2: Oven Duration, s			
K	M_4: Mass after Convection, g			
L	Mass Loss, g (H-K)			
M	M_5: Mass of Container + Specimen, g			
N	Mass of Specimen, g (M-B)			
O	T_3: Oven Duration, s			
P	M_6: Mass after Convection, g			
Q	Mass Loss, g (M-P)			
R	M_7: Mass of Container + Specimen, g			
S	Mass of Specimen, g (R-B)			
T	T_4: Oven Duration, s			
U	M_8: Mass after Convection, g			
V	Mass Loss, g (R-U)			
W	M_9: Mass of Container + Specimen, g			
X	Mass of Specimen, g (W-B)			
Y	T_5: Oven Duration, s			
Z	M_{10}: Mass after Convection, g			
AA	Mass Loss, g (W-Z)			
AB	M_{11}: Mass of Container + Specimen, g			
AC	Mass of Specimen, g (AB-B)			
AD	T_6: Oven Duration, s			
AE	M_{12}: Mass after Convection, g			
AF	Mass Loss, g (AB-AE)			
AG	Mass of Dry Specimen, g			
AH	Mass of Water, g (AG-D)			
AI	Mass of Water Check, g (AE-C)			
AJ	Moisture Content, % ((AH/AG)*100)			

Table 42: Instructions to Participating Laboratories

Thank you for participating in our study. The Round Robin is intended to verify a testing method for slurry surfacing systems to be used for quality assurance. Specifically, the testing determines the binder content of a mix. Follow the instructions below to condition and test the specimens provided. Datasheets are attached for recording the necessary information.

Apparatus

1. Oven capable of maintaining 125°C ± 5°C
2. Balance, 7-kg or greater capacity, capable of measuring to the nearest 0.1 g.
3. Microwave oven
4. Microwave safe container
5. Stirring tools (spatulas, spoons, etc.)
6. Heat sink (a small glass beaker or another microwave safe container partially filled with a non-flammable liquid with a building point above water (i.e., cooking oil))
7. Ignition furnace

Conditioning

1. Remove packaging from sample and preheat in the disposable aluminum pan in a conventional oven at 125°C for approximately 20 minutes.
2. Determine and record the mass of the microwave safe container.
3. Transfer the warm sample to the microwave safe container and crumble it so it is well-spread across the surface. Determine and record the mass.
4. Place the container with the specimen in a microwave oven with the heat sink and microwave for 360 seconds.

    Note – the initial time and power setting may be modified as needed. A setting of "high" should be satisfactory; however, it may be adjusted depending on experience with a particular oven.

5. Remove the container with the specimen from the oven and mix with a spatula. Allow the specimen to cool sufficiently to allow handling and to prevent damage to the balance. Determine and record the mass.
6. Return the container with the specimen to the oven and continue microwaving until the change between two consecutive mass determinations is 0.1% or less. It is recommended to dry the sample for the following cycles as needed:
    i. 360 seconds (from step 4)
    ii. 300 seconds
    iii. 240 seconds
    iv. 180 seconds
    v. 120 seconds
    vi. 60 seconds
    vii. Continue drying for rounds of 60 seconds if needed.

7. Once the specimen has reached constant mass, proceed with testing to determine the residual asphalt content.

Testing Procedure

1. Place the dry sample in the ignition furnace and burn it to a constant mass using the appropriate test procedure for bituminous mixtures.
    a. Preheat the ignition furnace to 538 ± 5°C.
    b. Determine and record the weight of the sample basket assembly.
    c. Evenly distribute the sample in the sample basket assembly, taking care to keep material away from the edges of the basket.
    d. Determine and record the weight of the sample and basket assembly in the furnace. Calculate the initial weight of the sample (Mi = total weight – weight of basket assembly)
    e. Input the initial weight of the sample (Mi) into the ignition furnace controller. Do not input a correction factor.
    f. Open the chamber door and place the sample basket assembly in the furnace Close the chamber door and verify that the total weight displayed is correct.
    g. Initiate the test by pressing the start/stop button.
    h. Allow the test to continue until the stable light and audible stable indicator indicate that the change in mass does not exceed 0.01 percent for three consecutive minutes.
    i. Open the chamber door, remove the sample basket assembly, and allow to cool to room temperature.
    j. Determine and record the total weight after ignition. Calculate the weight of the sample after ignition (Mf = total weight after ignition – weight the basket assembly).
    k. Calculate the asphalt content:

$$Measured\ AC = \frac{M_i - M_f}{M_f}$$

    l. Record the asphalt content given by the printed ticket.

Report

2. Use the attached forms to report the required values. If you have any questions, contact Dr. Adriana Vargas at adriana.vargas@auburn.edu or (334) 844-7303.

APPENDIX E: INTERLABORATOY STUDY IGNITION INDIVIDUAL TEST RESULTS

Table 43: Mixture 1 Interlaboratory Study Results

Sample ID	Mix Type	Aggregate type	Emulsion Grade	Theor.% Binder	AC Test	Measured Bitumen Ratio from Furnace Ticket	Percent Difference	Absolute Difference
1-MS-1-A	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.94	-0.66	0.66
1-MS-1-C	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.84	-0.57	0.57
1-MS-2-B	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.84	-0.57	0.57
1-MS-2-D	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.77	-0.49	0.49
1-MS-3-A	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.51	-1.23	1.23
1-MS-3-C	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.51	-1.23	1.23
1-MS-4-A	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.62	-0.34	0.34
1-MS-4-C	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.76	-0.48	0.48
1-MS-5-B	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.76	-0.48	0.48
1-MS-5-D	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.65	-0.37	0.37
1-MS-6-A	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.95	-0.67	0.67
1-MS-6-B	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.53	-1.25	1.25
1-MS-6-C	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.02	-0.74	0.74
1-MS-6-D	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.42	-1.14	1.14
1-MS-8-B	MS Type II	Limestone	CSS-1HP	6.28	Ignition	7.24	-0.96	0.96
1-MS-8-D	MS Type II	Limestone	CSS-1HP	6.28	Ignition	6.84	-0.56	0.56

Table 44: Mixture 4 Interlaboratory Study Results

Sample ID	Mix Type	Aggregate type	Emulsion Grade	Theor. % Binder	AC Test	Measured Bitumen Ratio from Furnace Ticket	Percent Difference	Absolute Difference
4-SS-1-B	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.45	0.54	0.54
4-SS-1-D	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.65	0.34	0.34
4-SS-2-A	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.65	0.34	0.34
4-SS-2-B	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.40	-0.41	0.41
4-SS-2-C	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.74	0.25	0.25
4-SS-2-D	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.40	-0.41	0.41
4-SS-4-B	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.79	-0.80	0.80
4-SS-4-D	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.93	-0.94	0.94
4-SS-7-A	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.62	0.37	0.37
4-SS-7-B	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.05	-0.06	0.06
4-SS-7-C	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.72	0.27	0.27
4-SS-7-D	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	9.09	-0.10	0.10
4-SS-8-B	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.51	0.48	0.48
4-SS-8-D	Slurry Seal Type II	Olivine Basalt	CQS-1HP	8.99	Ignition	8.46	0.53	0.53

Table 45: Mixture 3 Interlaboratory Study Results

Sample ID	Mix Type	Aggregate type	Emulsion Grade	Theor. % Binder	AC Test	Measured Bitumen Ratio from Furnace Ticket	Percent Difference	Absolute Difference
3-MS-1-A	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.37	0.43	0.43
3-MS-1-C	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.41	0.39	0.39
3-MS-2-A	MS Type III	Granite	CQS-1HP	7.81	Ignition	7.81	0.00	0.00
3-MS-2-B	MS Type III	Granite	CQS-1HP	7.81	Ignition	7.38	0.43	0.43
3-MS-2-C	MS Type III	Granite	CQS-1HP	7.81	Ignition	7.53	0.28	0.28
3-MS-2-D	MS Type III	Granite	CQS-1HP	7.81	Ignition	7.29	0.53	0.53
3-MS-5-A	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.96	-0.16	0.16
3-MS-5-C	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.87	-0.07	0.07
3-MS-7-A	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.82	-0.02	0.02
3-MS-7-B	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.33	0.47	0.47
3-MS-7-C	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.80	0.00	0.00
3-MS-7-D	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.05	0.75	0.75
3-MS-8-A	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.04	0.76	0.76
3-MS-8-C	MS Type III	Granite	CQS-1HP	7.80	Ignition	7.21	0.59	0.59

Table 46: Mixture 2 Interlaboratory Study Results

Sample ID	Mix Type	Aggregate type	Emulsion Grade	Theor. % Binder	AC Test	Measured Bitumen Ratio from Furnace Ticket	Percent Difference	Absolute Difference
2-SS-1-A	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.63	0.37	0.37
2-SS-1-C	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.37	0.63	0.63
2-SS-3-A	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	8.20	-0.20	0.20
2-SS-3-B	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.59	0.41	0.41
2-SS-3-C	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	8.32	-0.32	0.32
2-SS-3-D	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.60	0.40	0.40
2-SS-4-A	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.20	0.80	0.80
2-SS-4-C	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.38	0.62	0.62
2-SS-5-B	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.25	0.75	0.75
2-SS-5-D	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.46	0.54	0.54
2-SS-6-B	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	8.01	-0.01	0.01
2-SS-6-D	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.85	0.15	0.15
2-SS-7-A	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.20	0.80	0.80
2-SS-7-C	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.59	0.41	0.41
2-SS-8-B	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.45	0.55	0.55
2-SS-8-D	Slurry Seal Type B	Granite	CQS-1H	8.00	Ignition	7.54	0.46	0.46

Table 47: Interlaboratory Study Asphalt Content Raw Data for Precision & Bias

Raw Data - Asphalt Content				
Lab/Mix	1	2	3	4
1	6.76	7.49	7.36	8.83
	6.77	7.71	7.33	8.91
2	7.24	7.63	7.81	9.05
	6.84	7.37	7.53	9.09
3	7.51	8.01	7.82	9.4
	7.52	7.85	7.80	9.4
4	6.62	7.25	7.04	8.45
	6.76	7.46	7.21	8.65
5	6.84	7.2	7.38	8.62
	6.77	7.59	7.29	8.72
6	6.94	7.45	7.48	8.53
	6.84	7.54	7.23	8.73
7	6.95	7.59	7.33	8.65
	7.02	7.6	7.05	8.74
8	7.53	8.2	7.96	9.79
	7.42	8.32	7.87	9.93
9	6.76	7.2	7.37	8.51
	6.65	7.38	7.41	8.46

Table 48: Mixture 1-4 Raw Data for Precision & Bias

Lab	**Test Results - Mixture 1**		**Test Results - Mixture 2**		**Test Results - Mixture 3**		**Test Results - Mixture 4**	
1	6.76	6.77	7.49	7.71	7.36	7.33	8.83	8.91
2	7.24	6.84	7.63	7.37	7.81	7.53	9.05	9.09
3	7.51	7.51	8.01	7.85	7.82	7.8	9.4	9.4
4	6.62	6.76	7.25	7.46	7.04	7.21	8.45	8.65
5	6.84	6.77	7.2	7.59	7.38	7.29	8.62	8.72
6	6.94	6.84	7.45	7.54	7.48	7.23	8.53	8.73
7	6.95	7.02	7.59	7.6	7.33	7.05	8.65	8.74
8	7.53	7.42	8.2	8.32	7.96	7.87	9.79	9.93
9	6.76	6.65	7.2	7.38	7.37	7.41	8.51	8.46

APPENDIX F: INTERLABORATORY STUDY PRECISION & BIAS INTERMEDIATE CALCULATIONS

Table 49: Intermediate Cell Averages for Precision & Bias

Lab	Mixture 1	Mixture 2	Mixture 3	Mixture 4
1	6.77	7.60	7.35	8.87
2	7.04	7.50	7.67	9.07
3	7.51	7.93	7.81	9.40
4	6.69	7.36	7.13	8.55
5	6.81	7.40	7.34	8.67
6	6.89	7.50	7.36	8.63
7	6.99	7.60	7.19	8.70
8	7.48	8.26	7.92	9.86
9	6.71	7.29	7.39	8.49
AVG	6.99	7.60	7.46	8.91
ST DEV	0.31	0.31	0.27	0.46

Table 50: Intermediate Calculations Cell Standard Deviation for Precision & Bias

Lab	Mixture 1	Mixture 2	Mixture 3	Mixture 4
1	0.007	0.156	0.021	0.057
2	0.283	0.184	0.198	0.028
3	0.000	0.113	0.014	0.000
4	0.099	0.148	0.120	0.141
5	0.049	0.276	0.064	0.071
6	0.071	0.064	0.177	0.141
7	0.049	0.007	0.071	0.064
8	0.078	0.085	0.643	0.099
9	0.078	0.127	0.354	0.035
Sr	0.111	0.148	0.265	0.084

Table 51: Intermediate Calculations Cell Deviations for Precision & Bias

Lab	Mixture 1	Mixture 2	Mixture 3	Mixture 4
1	-0.220	-0.002	-0.114	-0.044
2	0.055	-0.102	0.211	0.156
3	0.525	0.328	0.351	0.486
4	-0.295	-0.247	-0.334	-0.364
5	-0.180	-0.207	-0.124	-0.244
6	-0.095	-0.107	-0.104	-0.284
7	0.000	-0.007	-0.269	-0.219
8	0.490	0.658	0.456	0.946
9	-0.280	-0.312	-0.069	-0.429