Effect of Cold Central Plant Recycled Stockpiling on Mixture Performance

A Thesis

Presented to

the faculty of the School of Engineering and Applied Science

University of Virginia

in partial fulfillment
of the requirements for the degree

Master of Science

by

Syed Kazmi

August 2018

APPROVAL SHEET

This Thesis
is submitted in partial fulfillment of the requirements
for the degree of
Master of Science

Author Signature: ____________________

This Thesis has been read and approved by the examining committee:

Advisor: Jose Gomez

Committee Member: Ben Bowers

Committee Member: Lindsay Burden

Committee Member: Steve Chase

Committee Member: ____________________

Committee Member: ____________________

Accepted for the School of Engineering and Applied Science:

Craig H. Benson, School of Engineering and Applied Science

August 2018

Acknowledgements

This work would not have been possible without the funding and research facilities of the Virginia Department of Transportation (VDOT) and its research branch, the Virginia Transportation Research Council (VTRC), both of which are greatly appreciated.

I would like to thank the following individuals for their contributions to the success of this research:

- Ben Bowers (thesis advisor), for seeing this project through with me from start to finish guiding me along every step of the way.
- Jose Gomez (thesis advisor), for helping me from undergraduate to my graduate studies with all the issues and concerns that came up
- Lindsay Burden (thesis chair), for advising me through the process of completing my thesis as well as serving on the committee
- Steve Chase for his participation in my committee along with the commentary provided
- Brian Diefenderfer for his expertise in the subject matter as well as the comic relief he provided through the entirety of the study.
- VTRC lab technicians, Troy Deeds, Donald Dodds, Jenny Samuels, John Burch, Zack Robb for teaching me lab methodology and assisting with the testing that made this study possible
- Nick Schwear and the folks at the Alan Myers Plant for providing the materials used as well as their knowledge to push the study forward
- My family and friends for all their support and motivation for the past few years to allow this study to be completed. They provided the proper encouragement as well as the much needed breaks throughout the development of the study

ABSTRACT

Paving roads in the traditional manner using hot mix asphalt is a very intensive process that requires a lot of energy and virgin material. Meanwhile, there are many piles of reclaimed asphalt pavement (RAP) available to use which reduces the need for virgin material. As of now, this usage is limited to about 30% by the Virginia Department of Transportation (VDOT), which is higher than most state DOTs allow. One of the methods that reuses a large quantity of RAP is cold central plant recycling (CCPR), a type of cold recycling. For this method, RAP is taken to a cold recycling asphalt plant, and after being graded and sorted is mixed with binder, water, and other aggregates to create a new mix for paving. Although this method has been around for a while, there is currently been interest by contractors to try and stockpile this mix, however, the effects of this on cold recycled asphalt are unknown. The purpose of this study was to understand the behavior of CCPR asphalt after it has been stockpiled with varying times between creating the mix and compacting specimens to the required density. For this study, the asphalt mix was processed at the plant and stored in plastic 5-gallon buckets that were lined with a large plastic bag to simulate a stockpile and keep moisture loss to a minimum. Specimens were created at varying time intervals and, after properly curing, were tested for characteristics such as indirect tensile strength and dynamic modulus. In addition to the strength characteristics of the CR mix, information about fabrication, such as moisture content and number of gyrations, was also recorded. This study found that even after 24 hours, the strength properties of the asphalt drop significantly and reach a plateau after 72 hours. If mix is stored properly, it is possible to maintain the moisture content over a long period of time however the number of gyrations required to create the specimens as well as its stiffness

increase the longer the mix is stored. When running the dynamic modulus test to determine the overall stiffness of the specimen, this study found that the material became stiffer as time went on for three days after which it remained constant. However, plugging in the values for the dynamic modulus into a mechanistic empirical program, PavementME, suggested that this loss of stiffness has little effect on pavement performance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

AMPT: asphalt mixture performance tester used to determine dynamic modulus

Chemical stabilizing agents: materials such as cement, lime, and fly ash added to asphalt mix with the purpose of increasing the early strength of the reclaimed materials and enhancing foamed binder dispersion throughout the mixture

Cold central plant recycling: recycling asphalt at a central location using a stationary configuration without the addition of heat

Cold in-place recycling: recycling asphalt within the roadway without the addition of heat by cold milling the pavement surface and remixing with recycling agents followed by compacting the mix

Cold recycling: process of recycling asphalt pavement without the addition of heat

Dynamic modulus (E*): determines the relationship between stress and strain under elastic sinusoidal loading

Emulsified asphalt: mixture of asphalt binder, water, and emulsifying agent with the purpose of properly dispersing the asphalt binder within water to allow for pumping, storing and mixing

Foamed asphalt: mixture of air, water, and hot asphalt with the purpose of reducing viscosity and increasing the surface area of the binder to allow for proper dispersion within the mix

Indirect tensile test: a test to determine the tensile strength of an asphalt specimen by applying a force at a rate of 2in/min to a cylindrical specimen

International roughness index: Smoothness of a pavement determined by measuring roughness of a longitudinal profile of the surface

Reclaimed asphalt pavement (RAP): asphalt pavement or paving mixture removed from its original location to be used reused in future pavements

Total rut depth: longitudinal surface depression in the while path due to permanent deformation of the pavement surface

INTRODUCTION

Cold Recycling

Cold recycling (CR) is the method of recycling asphalt pavement without the application of heat using reclaimed asphalt pavement (RAP) combined with binder, water, and other additives (BARM 2015). This mixture can then be used as layers of a new pavement, typically very deep in the structure and not for surface paving. The two main methodologies of cold recycling are cold in place recycling (CIR) and cold central plant recycling (CCPR). CIR uses all the RAP created during the process and treats generally the top 3 to 4 inches of a pavement (BARM). Depending on the equipment, the surface can be removed with a cold planing drum or a full lane cold planing machine used for single-unit and multi-unit CIR trains respectively (BARM 2015). CCPR, the method which this study explores, collects the RAP from older pavements and takes it to a CCPR plant where it is processed and then immediately ready for use (BARM). These plants can use the RAP immediately or store it at the plant in stockpiles until needed after which it is processed and combined with the water, binder, and other additives such as cement or fibers to create a new mix. This mix can then be transported on site to create a new pavement. These cold recycling methods allow new pavement layers to be made by recycling pavements and using up to 82% less energy in the process making them very important in efforts to be more sustainable (Bloom 2016).

CCPR Stockpiling

Sometimes, the materials may be ready but the conditions just are not ideal to process the mix. This can be due to unexpected weather conditions or issues with the CR plant functioning properly. In these cases, it may be necessary to stockpile the processed materials, a combination of RAP, binder, and chemical additives, and use them when the setting is more appropriate. It can also be necessary to stockpile mix when a project requires more mix than a plant is capable of producing at one time. In these instances, it would be useful to stockpile the completely processed mix, to ensure the job can be completed on time. Stockpiling certain component materials, such as RAP, is not an issue and is done in many instances. However, there are various opinions on the circumstances of stockpiling. For example, in the past, recycled asphalt pavement (RAP) has been collected and stockpiled for nearly two years before it was transported to the site where it was processed to create mix to be used (Diefenderfer 2014). But there is a preference suggested by the National Academies of Sciences, Engineering, and Medicine the states to use it within a year (NASEM 2016). There are suggestions on the proper methods to store RAP and the conditions in which it should be kept, including the shape of the pile, the type of land it is stored on, the type of covering, if any, is required (Zhou 2010, West 2010).

Curing

To understand how these types of pavements perform without having to run full scale field tests, it is important to be able to simulate field conditions within a laboratory setting. For this reason, laboratory curing is a crucial step when testing cold recycled asphalt mix for strength properties. Curing considers how long and under what conditions the CR asphalt specimens should be kept in order to gain strength in manners similar to how it would on site. By understanding how to cure CR asphalt properly, it is possible to simulate real world conditions within the laboratory setting. If the asphalt is not allowed enough time to cure, it will not perform up to its proper strength and will therefore be a poor representation of how this material behaves in the field. Recommendations for curing times and methods for recycled pavements have been suggested since the early 1970s. The proposed method of curing the mix was to keep it at 60C for 3 days. This method was chosen to stimulate the loss of mixing water while the mix is strengthened, as is what happens during construction (Bowering 1970, Muthen 1999). Since then there have also been suggestions for curing trying to simulate short term and long term conditions, curing it for 1 day at 40°C and just for 3 days at 46°C respectively (Jenkins and Van de Ven 1999). There are also studies suggesting letting the mixture cure in a mold for certain periods of time and then removing the specimen from the mold to cure further (Sebaaly et al. 2004). There are many studies and variations in technique for curing CR asphalt. Yet, with all these ideas, there is still no definitive method established for curing any type of CR mix.

Aside from curing, there are many other factors that determine the effectiveness of a CR mix design including, but not limited to, moisture content, compaction method, variety of materials, and volumetrics. With all these factors, it is very difficult to create one set of guidelines that could be applicable to multiple cases. Therefore, depending on the various factors mentioned, different steps are suggested to be taken to effectively process and store CR mix. These guidelines are still just suggestions meaning that there is more work to be done in the field of stockpiling CR asphalt mix and materials.

PURPOSE AND SCOPE

The purpose of this project is to determine the impact of stockpiling time on the mechanical properties of CCPR mixture. For this study, the stockpiling time was defined as the time period between production of the CCPR material and fabrication of the test specimen in the laboratory. The goal of the study is to quantify the changes that take place in the mix to advise future contractors on the feasibility of stockpiling processed asphalt mix and, in stockpiling, the expected level of performance. The literature review was performed to find if there were any standards or guides on how to properly stockpile cold recycled asphalt mix. Upon finding none, the literature review was conducted on best practices for stockpiling RAP, curing methods, and various mix designs employed by different agencies. Based on the findings from the literature review, as well as the knowledge of the VTRC research scientists, a laboratory method was set up to simulate a stockpile. After determining the most effective method to stockpile the asphalt mix, various test standards were consulted to create specimens at different intervals of time.

LITERATURE REVIEW

Stockpiling

This study looks at how time affects strength and stiffness properties of asphalt mix while in a stockpile. However, within the asphalt industry, stockpiling material, especially RAP, is something that is done often. An asphalt plant may need to hold on to RAP collected from one project until another appropriate project is presented that requires its use. Within Virginia, only 30% of the RAP collected can be reused in new pavement, meaning that with each project to recycle a roadway, there is at least 70% of RAP that goes unused in the repaving of that road. This happens frequently enough that there are recommended guidelines for the proper methods with which the RAP should be stored. Some of the concerns that come up with improperly stored RAP include variability in properties such as the aggregate gradation, asphalt content, and the volumetric properties. This variability is caused by reasons including, but not limited to, mixing sources of RAP, piles containing non-asphalt materials such as concrete or wood, and mixing the various layers of the pavement (Zhou 2010).

To avoid these causes and others, there are certain practices that have been recommended by various organizations. One important factor is to keep material from different sources in different stockpiles thereby reducing the chance of inconsistent gradation and keeping the pile more homogeneous (Karlsson 2017). Another method to ensure homogeneity within piles is fractionating which is to screen, crush, size, and separate the RAP into stockpiles based on size and composition to ensure uniform conditions (Zhou 2010).

Along with the proper sorting and crushing of the RAP that must take place, the conditions of its storage are important as well. It has been suggested that RAP intended for cold recycling be kept in dry weather and temperatures no colder than 10C (50F) (Kearney 1997). Dry conditions being important for RAP because often times it is the moisture content of RAP that may limit how much of it can be used. This was supported by Kim (2011) who found a relationship where a decrease in moisture content would lead to an increase in tensile strength. In areas that are not very dry, it is beneficial to store the rap on a paved, sloped surface to allow the rain water to drain away. A final measure can be taken to minimize moisture content by covering the RAP stockpile, ideally under the roof of an open-sided building to allow air to pass through but keep the pile safe from precipitation (Zhou 2010). The shape of the stockpile plays a role in the how well it functions as well. In the case that the stockpile cannot be covered, a conical shape is the most effective to protect the RAP from precipitation. However, the stockpile cannot be made too high and large vehicles should also not travel close to the top to avoid any compaction of the RAP (Stroup-Gardiner 2016).

Curing Methods

CR asphalt mixture must be allowed to cure properly after it has been placed in order to gain strength. This can happen typically on a construction site where the CR asphalt will be stronger even after a few hours, although for the mix to gain close to full strength can take days to weeks (Xu 2014). Within a laboratory setting, a lot of the factors can be controlled, such as the temperature, the humidity, the packaging of the sample, etc., to allow the CR mix to gain strength quickly. There is currently no specified method that is considered ideal for curing but many researchers have set up practices that fit best for their specific conditions to be simulated.

Depending on the type of curing, wet curing or dry curing, a suggested curing temperature of 20+/-2C at a relative humidity of 50+/-5% has been recommended where the former sample is sealed to keep prevent free water evaporation and the latter is left unsealed (Graziani, 2017). However, curing at 60C has been used by many researchers, at various times ranging from 6 hours to 30 days (Bowering 1970, Maccarrone et al. 1994, Lee et al. 2003, Van Wijk 1983, Murphy 2014, Sebaaly et al. 2004). One reason for this has been suggested to be that 3 days at 60C is the ideal condition to simulate the initial water loss that takes place for the CR asphalt to reach its strength during construction (Bowering 1970). To go even beyond the 3 day curing onto 30 days should do well to simulate the long term curing of the asphalt (Sebaaly et al. 2004). Long term curing is also suggested for foamed-asphalt pavements since they continue to gain significant strength and stability over long periods of time (Ruckel et al. 1983). Meanwhile, curing for 6 hours at 60C is suggested because it represents the typical value of the pavements temperature on a hot summer day, where the temperature ranges from 26 to 30C (Lee et al. 2003, Brayton et al. 2001).

Curing conditions performed in a laboratory setting are often done to mimic the results found out in the field after CR asphalt has been placed. Depending on what part of the world the testing is being done, different conditions for curing will be used. When looking at the standard curing methods used in Great Britain and Ireland, there are conditions put in place to model the frequent rains that take place. The authors suggest sealing the specimen for 28 days at 40C in conditions of 90-100% humidity (Valenová 2015). Table 1 some of the standard methods of curing used in different parts of the world as presented by Valenová (2015).

Table 1: Standard curing methods as summarized by Valenová (Valenová 2015)

Country	Curing Method
Czech Republic	90-100% humidity @ 20 +-2C for 2 days then stored at 40-70% humidity at the same temperature until testing
Great Brit and Ireland	Sealed for 28 days at 40C at 90-100% humidity
France	Stored at 18C at 40-70% humidity for at least 7 days and then until testing
Australia	40C for 3 days without impermeable covers, then at 20+-2C until testing
South Africa	40C for 3 days in impermeable cover, followed by 20+-2C without cover until testing
Portugal	1 day at 40-70% humidity at 20+-2C, then transfer to temperature chamber at 50C and then stored at 20+-2C until testing

Mix Designs

An important factor that needs to be considered and contributes to the variability in performance of a CR mix is the mix design that is used to create it. The procedure is also dependent on the chemical additives and recycling agents being introduced into the mix, whether it is foamed asphalt or emulsified asphalt. To categorize some of the factors influencing the mix design, they can be broken up into a few categories: the compaction method, the type of bitumen, curing times, temperatures, and curing conditions.

The Wirtgen manual states that cold recycled mixes should be compacted using a Marshall compaction hammer with 75 blows for foamed bitumen. Then to simulate dry curing, the specimen should be kept at 40C until constant mass is achieved for a minimum of 72 hours. To simulate field curing conditions, the specimen should be kept at 30C for 20 hours, then placed in a sealed bag at 40C for 48 hours after which it should be cooled at 25C (Wirtgen 2012).

For testing on CR asphalt mix that has been treated with cement as a chemical additive, a mix design has been described as follows by Grilli (2012). Before compaction, the mix is kept sealed in a plastic bag for 12 hours. After this period, a shear gyratory compactor (SGC) applies 600 kPa (87 psi) of pressure at 30 rpm for 180 gyrations at an angle of 1.25 degrees. After extruding the specimen, they are stored at 20C and 70% humidity until it is time for testing (Grilli 2012). Although this guideline is not used in this study, it is important to note the various methods of specimen fabrication.

The Asphalt Academy has a suggested mix design for creating specimen depending on what type of recycling mechanism is being used, whether it be foam or emulsion. If the goal is to check the indirect tensile strength of a mix, either a vibratory compaction or Marshall hammer is used to create a specimen of 100mm. It is cured for 72 hours unsealed at 40C. For further testing, such as to determine the moisture content for emulsified asphalt, the asphalt academy suggests to use a vibratory compactor to create a specimen that is 150mm in diameter and 127mm in height. To cure, the specimen is left unsealed for 26 hours at 30C and then sealed for 48 hours at 40C. The third mix design is recommended for triaxial testing of foamed asphalt where the vibratory compactor is used to create a specimen 150mm in diameter and 300mm in height. To allow for proper curing, the specimen is left unsealed for 30 hours at 30C and then sealed for 48 hours at 40C (Asphalt Academy 2009).

PavementME

PavementME is a software developed based on mechanistic-empirical principles using data from climate, traffic, construction, and material properties to predict the performance of a roadway design (MEPDG 2008).

Prior to the mechanistic-empirical methodology, the pavement design process was purely an empirical method. Early in the 20th century, the main factor determining strength of a pavement was the thickness. For example, every section of highway could have the same thickness even if the soils encountered varied greatly. After the late 1920s, agencies started within the United States started using strength tests for soils when developing a pavement design. Even then, the designs were based more on experience and trial and error as opposed to the mechanistic methods that came after them (Huang 2004). Further attempts to predict pavement performance relied on statistical analysis of data collected from road tests conducted in Illinois between 1955 and 1960. Using the results from this testing, pavement design began focusing on serviceability and reliability. As research into the design process continued, more mechanistic components had been added over the years leading to a design guide by AASTHO in 1993.

Following road tests, AASTHO developed the present serviceability index (PSI) which related traffic to pavement thickness. The design guide developed an equation for the number of equivalent single axle loads (ESALs) to predict the failure of the pavement. This equation required inputs for resilient modulus, reliability levels, and a structural number which was based on layer structural coefficients and layer drainage coefficients (Mallick et al. 2009).

As opposed to the previous methods used for pavement design, the mechanistic-empirical methodology relies on several inputs to more accurately predict performance. These inputs include the expected traffic loading, the climate for the region the pavement is designed for, and many properties for the asphalt layers used. The software has categories for the different types of layers including subgrades and flexible pavements. Within each pavement layer, there are default properties set in place based on the type of soil expected to be used. These default values are based on data that has been collected from extensive road tests conducted in the past, hence the empirical part. The values include volumetrics, such as unit weight, binder content, and air voids, as well as mechanical properties including dynamic modulus, types of binder, indirect tensile strength, and creep compliance.

For the inputs of values including dynamic modulus and creep compliance, which will be explained further in the manuscript, there are 3 different levels. Level 1 requires the greatest knowledge about the material and uses parameters that have been measured directly. This level leads to the best performance predictions but also requires greater cost and time to collect the data. Level 2 inputs estimated from correlation or regression equations. These can be based on other site-specific data and represents regional measured values, but not project-specific values. Input level 3 is the default value based on global or regional averages, depending on how much data may be available for a specific region. This level of input requires the least knowledge about the parameter and uses median values from groups of data with similar characteristics. Depending on the time and cost limitations of a project, different levels of input may be used (MPEDG 2008).

The outputs from PavementME include total rut depth (TRD), international roughness index(IRI), and various types of cracking. TRD is the longitudinal surface depression in the wheel path due to permanent deformation (MEPDG 2008). IRI is defined as the standardized roughness measurement characterizing the longitudinal profile of a pavement surface. It explains a vehicles suspension motion when traveling for certain duration denoted in inches and miles respectively. The standard range for a new pavement's IRI is between 95 in/mi to 222 in/mi (Sayers et al. 1986). To calculate the TRD, PavementME uses the following equation for the permanent deformation for HMA mixtures:

$$\Delta_p = \varepsilon_p h = \beta_{1r} k_z \varepsilon_r 10^{k_{1r}} n^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}}$$

Δ_p = plastic vertical deformation

ε_p = plastic strain

ε_r = elastic strain at mid-depth

h = thickness of layer

n = number of axle-load repetitions

T = mix or pavement temperature

k_z = depth confinement factor

$k_{1r,2r,3r}$ = global field calibration factors

$\beta_{1r,}\beta_{2r,}\beta_{3r}$ = local field calibration factors

For the permanent deformation in unbound pavement sublayers and the foundations or embankment soil, the following equation is used:

$$\Delta_p = \beta_{s1} k_{s1} \varepsilon_v h \left(\frac{e_0}{e_r}\right) e^{-\left(\frac{\rho}{n}\right)^{\beta}}$$

Δ_p = plastic vertical deformation

ε_0 = intercept determined from repeated load permanent deformation test

ε_r = resilient strain imposed to obtain material properties

ε_v = average vertical elastic strain calculated by structural response model

h = thickness of layer

n = number of axle-load applications

k_{s1} = global calibration coefficient

ε_{s1} = local calibration constant for rutting in unbound layers

To determine the IRI value over time, or the smoothness degradation, the following equations are used for flexible pavements and rigid pavements respectively.

$$IRI = IRI_0 + 0.0150(SF) + 0.400(FC_{total}) + 0.0080(TC) + 40.0(RD)$$

$$IRI = IRI_0 + 0.00825(SF) + 0.575(FC_{total}) + 0.0014(TC) + 40.8(RD)$$

IRI_0 = initial IRI after construction

SF = site factor

FC_{total} = area of fatigue cracking, percent of total lane

TC = length of transverse cracking

RD = average rut depth

Although the manual provides a methodology to guide pavement design, it is not calibrated for regional or local levels of design and therefore must be adapted to the proper area in which the guide is being used. Adjusting the calibration factors for the PavementME software in accordance with local conditions, along with using the measured values for the material properties, have shown to reduce bias and increase accuracy of the predicted results when compared with experimental data (El-Badawy 2012). With disregard to local calibration, the design guide is set up for the broader areas where data was available, however due to the variability in testing and materials, the design guide produces a better representation of conditions when adjusted properly. PavementME takes this into account with its outputs providing two sets of values, one where the reliability of the input data is set to a level of 95% and a second set where it is 50%. To determine how well the data fits or if further calibration is needed, the results need to be validated using an independent data set (Tran 2017).

Dynamic Modulus

The dynamic modulus test is used to determine the relationship between stress and strain under a sinusoidal loading (Schwartz et al. 2017). The dynamic modulus describes the stiffness of a material and is important for pavements because it can be an indication of field performance. To properly determine this property, it is suggested to allow the specimen to properly harden by waiting at least 14 days from fabrication till testing (Zeinali et al. 2014). The dynamic modulus has been used to define design criteria for CIR pavements as well as to determine what levels of rehabilitation may be required (Islam 2018). The values acquired from this testing have been used with mechanistic-empirical software to determine pavement performance (Diefenderfer et al. 2015, Islam 2018). This study will also be using a mechanistic-empirical approach which is why the dynamic modulus testing is important, to provide the inputs so that the performance of different pavements can be compared. Factors affecting the dynamic modulus values include temperature and frequency of loading whereas the confining pressure is not shown to have significant effects (Yan 2014). For the purpose of this study the test is conducted by applying a compressive load but a tension-compression test is a better representation of loading conditions met in the field (Witczak 1974).

VDOT Specification

The tests run in this study will be done so based on the specifications used by VDOT. The specifications used for the specimen fabrication and for the tests conducted are summarized below in Table 2.

Table 2: Standards and specifications used

Method	Specification
Preparation of Asphalt Mixture Specimens Using Marshall Apparatus	ASTM D6926-16
Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)	AASHTO R83-17
Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage	AASHTO T283-14
Standard Practice for Developing Dynamic Modulus Master Curves for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)	AASHTO R84-17
Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying	ASTM C566-13
Developing Dynamic Modulus Master Curves for Asphalt Mixtures	AASHTO R62-13

According the VDOT Special Provision for Cold Central Plant Recycling Material, the dry indirect tensile test must meet at a minimum of 45 psi. This is to be done using at least 3 specimen produced with 75 blows per side in accordance with ASTM D6926-16. After being produced, they must be oven dried for 72 hours at 40C and allowed to cool at ambient temperature for 24 hours. As a quality check, contractors must test the mix in a random manner to determine ITS and if less than 90% of the produced specimens fail to meet the required criteria, production must cease until the issues can be addressed.

VDOT Special Provision for Cold Central Plant Recycling Material Placement explains the required conditions to place CCPR material. The recycling operations should only be completed when the temperature is at a minimum of 10C (50F) and there should not be a forecast of freezing temperatures within 48 hours of placement of the CCPR mix. If the placement of CCPR mix will be done during night time and opened to traffic the next morning, then emulsions shall not be used.

METHODS

Mix Design

The CR mix design used for this study consisted of a blend of 85% RAP and 15% #10 aggregate The CR mix had 2.5% foamed binder, PG 64-22, as well as 1% Portland cement by weight. The target wet density for the CR mix was 130.8pcf and the target moisture content was 4.8%. The gradation for the aggregates is shown below in Figure 1. The mix design for this study was done by the contractor and is provided in Appendix A.

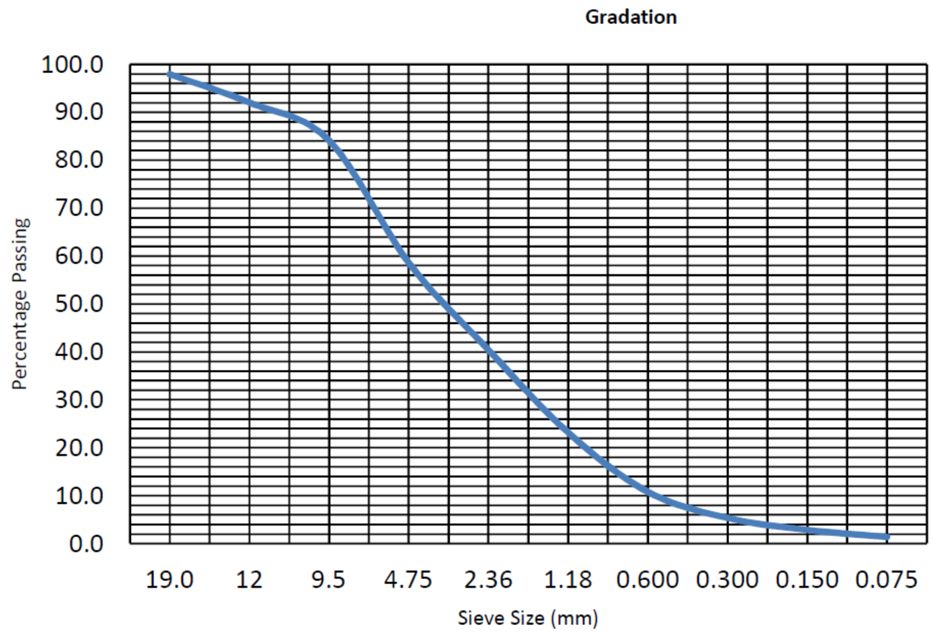


Figure 1: Gradation

Sample Collection

On December 4th, 2017, a visit was made to the Allen Myers asphalt plant in Williamsburg VA to collect the CR mix that would be used throughout the experiment. While on site, all the components of the CR mix the aggregates, binder, water, and Portland cement, were processed through a CCPR plant and collected by a front loader which was used to create a small stockpile from which to sample. The top surface of the pile was scraped off to provide a flat plane for collection. This process is shown below in Figure 2.

Figure 2: Processed mix pile

Stockpile Simulation

The CR mix was shoveled into 5-gallon buckets that were lined with a large plastic bag used to ensure minimal moisture loss. Since a real stockpile was not available to compare the results of this study to, it was important to keep conditions as similar to a proper stockpile. While in contact with the contractor, it was learned that they would be covering and misting the stockpile to make sure the mix did not dry out. For this reason, it was critical to make sure the moisture content was affected as little as possible, hence, the emphasis on keeping moisture loss to a minimum. Once filled, the mix was topped with 2 damp rags, 8x8in wrung out. The bag tied shut with the lid closing the air tight bucket. A total of 13 buckets of mix were collected. These steps are displayed in Figure 3.

Figure 3: Collecting mix into buckets

After determining that further testing would need to take place and would require more mix, a second trip was made to the asphalt plant on April 3^{rd} to collect an additional 9 buckets of mix.

Specimen Fabrication

For the purpose of this study, there were 2 types of specimens that were created. For the indirect tensile test, specimens 4 inches in diameter and 2.5 inches in height (100mm diameter and 63.5mm height) were produced. These specimens were made in accordance with ASTM D6926-16 Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus With a target density of 130pcf (20.4 kN/m^3), using the known volume of the specimen based on the dimensions stated earlier, it was calculated that 2.425lbs (1100g) of mix would be needed for a single specimen. To create these specimens, a compaction mold was filled and rodded 25 times: 15 times in the center and 10 times around the perimeter (Figures 4a and 4b).

(a) (b)

Figure 4: Preparing the mold for Marshall hammer

(a) Mold for Marshall specimen (b) Filled mold for Marshall specimen

After the mold was filled, it is placed into the Marshall hammer device as show in Figure 5a below. The mold is locked into place using the O shaped clamp and the hammer is placed in the appropriate position shown in Figure 5b and set up for 75 blows with a weight of 10lbs (4.536kg). Once started, the hammer drops from a height of 18 inches for 75 blows after which the mold is flipped and the process repeated to apply the same compaction force to both sides of the specimen. The final specimens should have a diameter of 4 inches and a height of 63.5 ± 2.5 mm to be within the specifications. After being extruded from the mold, the samples were allowed to cure unsealed at 40C for 72 hours followed by 21C to 24 hours after which the test was conducted in accordance with AASHTO T 283-14.

(a) (b)

Figure 5: Setting mold into Marshall hammer

(a) Loading mold into apparatus (b) Setting up Marshall hammer

The second type of specimens fabricated was for the dynamic modulus testing. These specimens were made in accordance with AASHTO R83-17. With a target density of 130pcf (20.4 kN/m^3) established by the mix design, 15.07lbs (6853g) of mix was used to create specimens with the height of 7in (180mm) and diameter of 6 in (152.4mm). After weighing out the required amount of mix, about half of it was placed in the mold and prodded 25 times. The second half is added in as well and rodded again 25 times (Figure 6).

(a) (b) (c)

Figure 6: Preparing the mold for SGC

(a) Pouring CR mix to mold, (b) Rodding mix after filling mold half way, (c)Rodding mix after filling mold completely

After the mix has been placed, the mold was set into the Superpave gyratory compactor set to compact until the desired height of 180mm was reached. After the specimen had been compacted adequately and the number of gyrations recorded, it was extruded out of the mold and allowed to cure for 3 days at 40C and for at least 2 weeks at approximately 21C following. A sample specimen that was cured is shown below in Figure 7.

Figure 7: Superpave Gyratory Specimen 180mm

After the 180mm specimens were cured, they were cored down to a diameter of 4in (100 mm) and each face was cut to leave a specimen with a height of 6in (150mm). These smaller specimens, shown in Figure 8, are then used to run the dynamic modulus test.

Figure 8: 150mm specimen for the dynamic modulus test

ITS Test

There were 6 specimens created for each stockpiling time increment including an initial value when the mix was first produced. The specimens were not compacting to the desired height after 7 days of simulated stockpiling. For this reason, the density was recalculated to be 127 pcf and the mass of mix being used was reduced from 2.425lbs to 2.293lbs (1100g to 1040g).

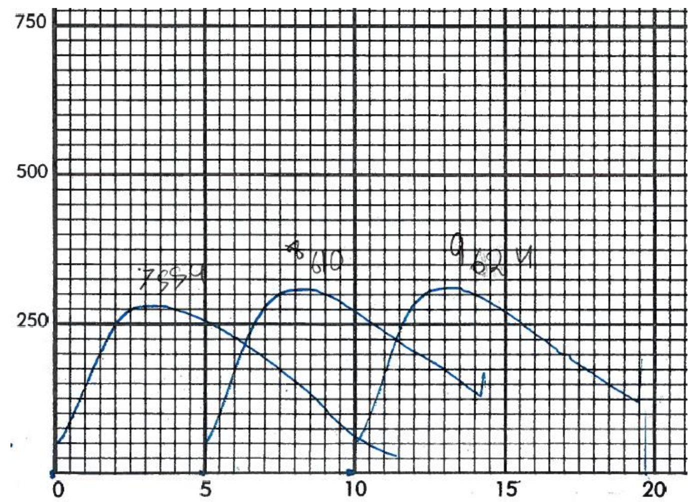
These specimens were tested as stated in AASHTO T 283-14 with the exception of the subset being conditioned in the soaking cycle. For the purposes of this study, all specimens were tested in dry conditions. Although there were 6 specimens tested for each time period, due to user error, only 5 results were found from the 7, 8, and 41-day testing. A test specimen, as well as the apparatus in which the test is conducted, are shown in Figures 9a and 9b respectively. It is important to note that the ITS specimens exceeded the required height by a few millimeters which is why the amount of mix used was reduced, to keep the specimens within specifications.

(a) (b)

Figure 9: ITS testing

(a) ITS specimen (b) ITS apparatus

To conduct the test, the specimen was placed in the ITS apparatus which applies a compressive force at a rate of 2in/min. This force resulted in the specimen cracking in half while the tensile strength is recorded by the machine. Broken specimens are show in Figure 10a along with a sample of the results in Figure 10b.



(a) (b)

Figure 10: Breaking ITS specimen

(b) Broken specimen (b) Sample ITS results

Dynamic Modulus Test

The dynamic modulus test was conducted in accordance with AASHTO R84-17. The dynamic modulus test applies a cyclical load to the specimen while measuring the strain at three locations around the middle of the cylindrical face. This applied stress only causes elastic deformation and is applied at 6 different frequencies, 25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz and 0.1 Hz over 3 different temperatures. This is a deviation from the AASHTO standard suggestions of four temperatures. The standard temperatures are typically conducted for testing HMA. When using CR mix, there was concern about the highest temperature causing permanent deformation. To avoid this, the highest temperature of 54.4C was not used. By collecting the data from the different temperatures and frequencies, the plot can be fit to a master-curve using time-temperature superposition. The results from this test quantify the stiffness of the material and can be used as an input to analysis software.

To prepare the specimen for the dynamic modulus test using the AMPT, mounting studs for strain gauges are attached using a mixture of super glue and baking powder at a 1 to 1 ratio. These mounting studs are small hexagonal prisms attached to the specimen that allow the strain gauges to measure the strain when the load is applied. These mounting studs are shown in Figure 11.

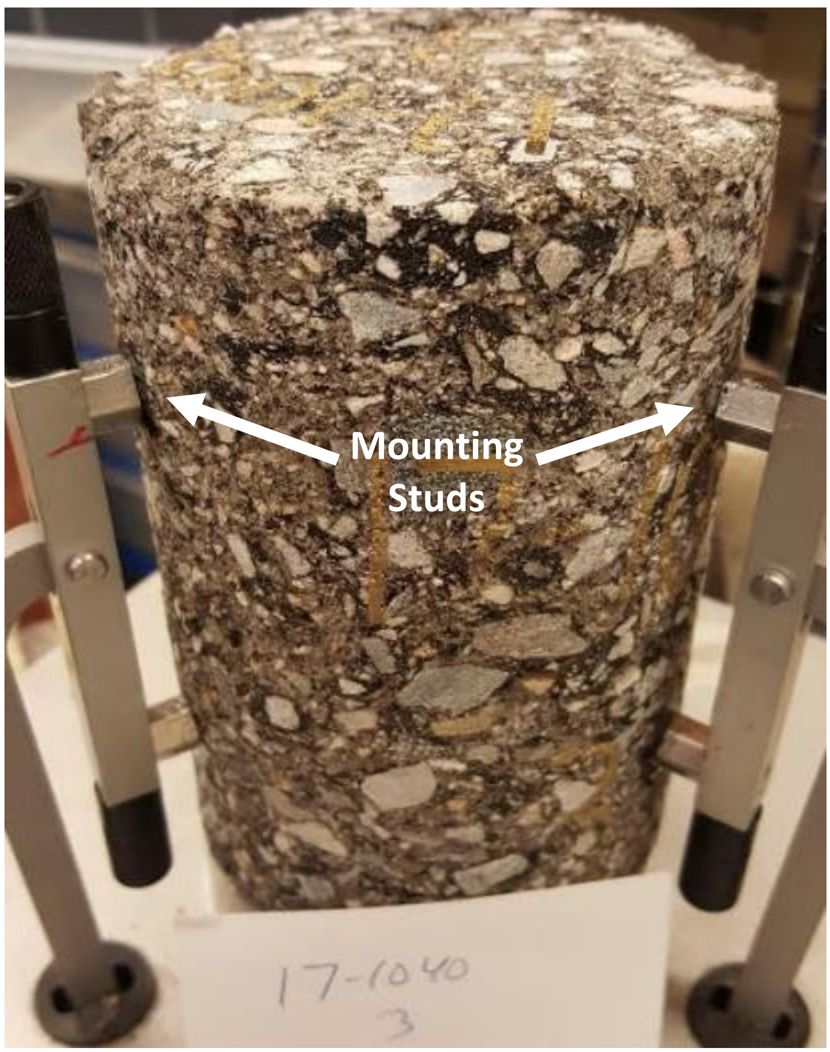


Figure 11: Mounting studs

Following the mounting studs, the test specimens are held in an environmental chamber to bring the internal temperature to the appropriate testing temperatures for the required times, which are described in Table 3.

Table 3: Dynamic Modulus Temperature and Equilibrium Time

Temperature C	Equilibrium Time
4.4	Overnight
21.1	4 hours
37.8	2 hours

Once the specimens reached the required temperature, they were placed in the asphalt mixture performance tester (AMPT) and the strain gauges were attached. After waiting for the temperature chamber to reach the proper temperature, the dynamic modulus test was started. This process was repeated with 3 specimens from each time interval while the specimens were. Examples of the set up for both cases are shown below in Figure 12.

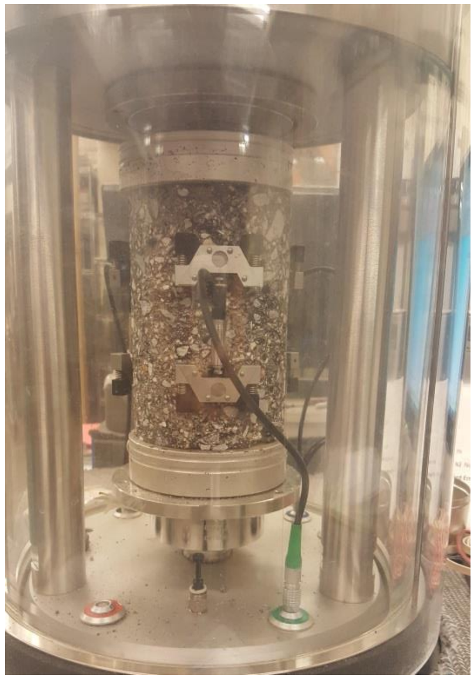


Figure 12: Set up for dynamic modulus test

Dynamic modulus master curve generation

The dynamic modulus master curve was developed in accordance with AASHTO R63-13. The data of the dynamic modulus values was averaged and fit to a master curve using time-temperature superposition. The equation used to perform this shift is

$$log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta+\gamma log f_r}}$$

$\|E^*\|$	=	dynamic modulus, psi
α, β, δ, and γ	=	fitting parameters
f_r	=	reduced frequency, Hz

An example of the shift factors is shown below displaying stress strain curves before and after curve fitting at a reference temperature of 70F (21.1C).

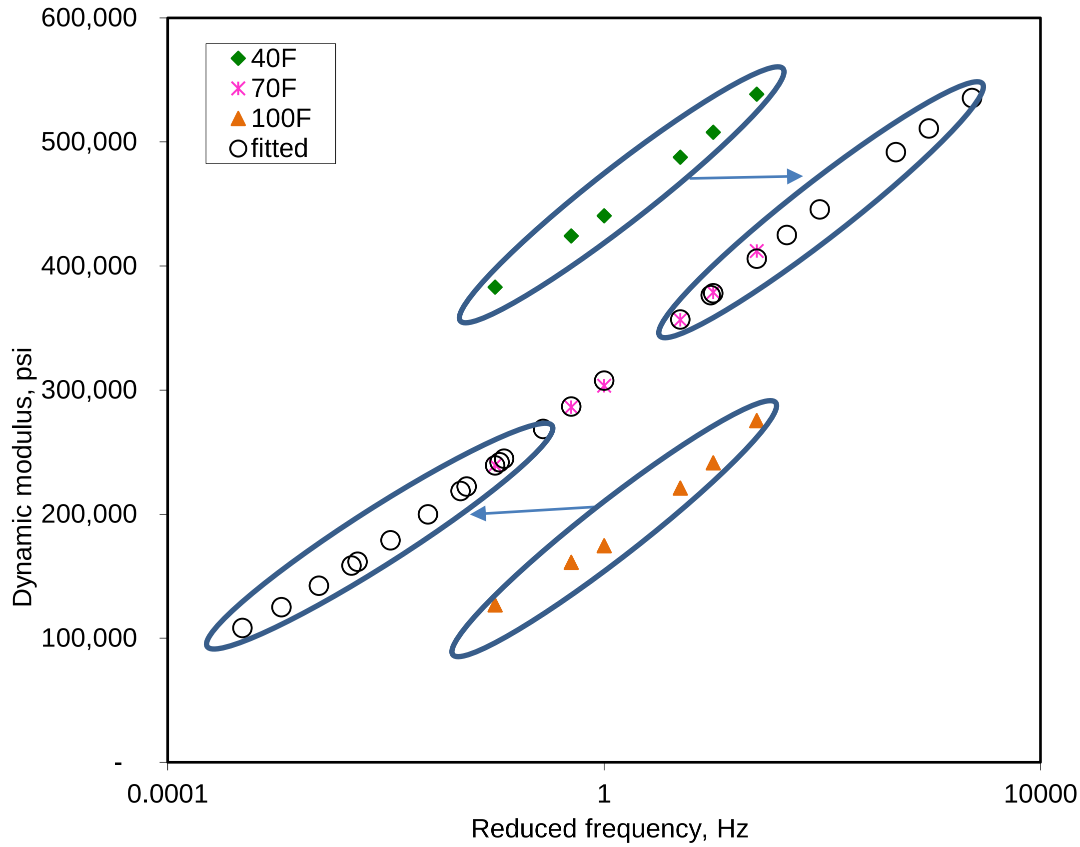


Figure 13: Master curve fitting

PavementME

The PavementME software uses mechanistic-empirical principles that have been validated with performance data from a variety of road tests that have been conducted. For this software, the cross-section of the pavement is modeled based on the different layers and their properties. Figure 14 shows a sample of the inputs required for this software below.

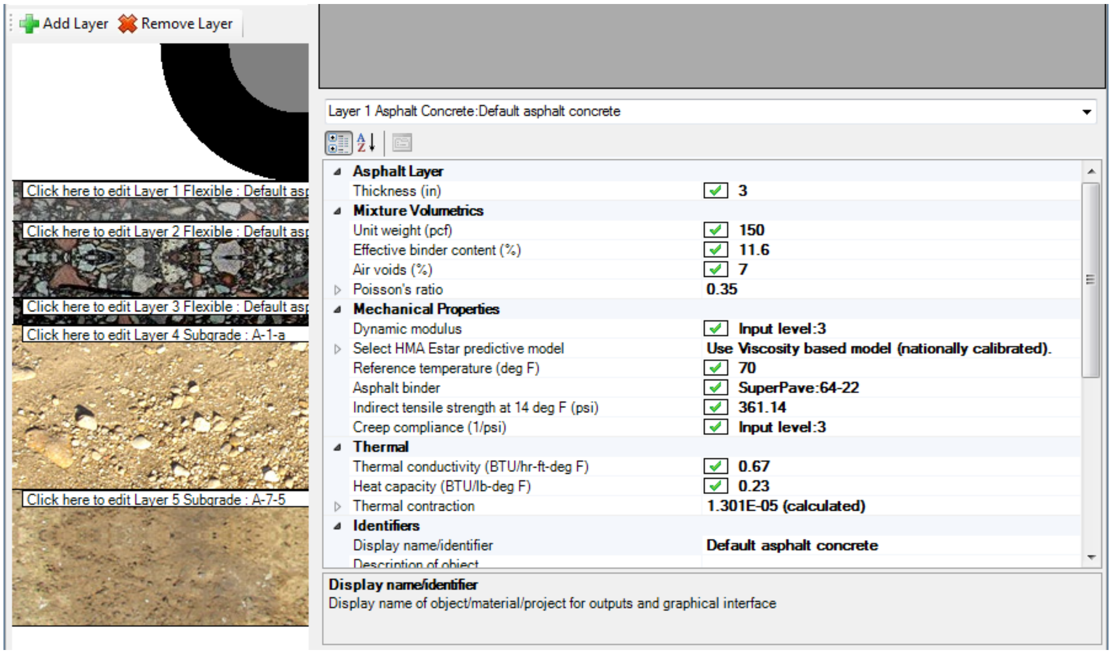


Figure 14: PavementME cross-section

The PavementME software, using the dynamic modulus data collected from the CR specimens, models the performance of a pavement over a lifespan of 20 years. The default values have been used for all aspects of each layer except for the second layer which were measured values for CCPR. For that layer, the dynamic modulus data was used to determine how it affects performance. A sample of this input is shown in Figure 15.

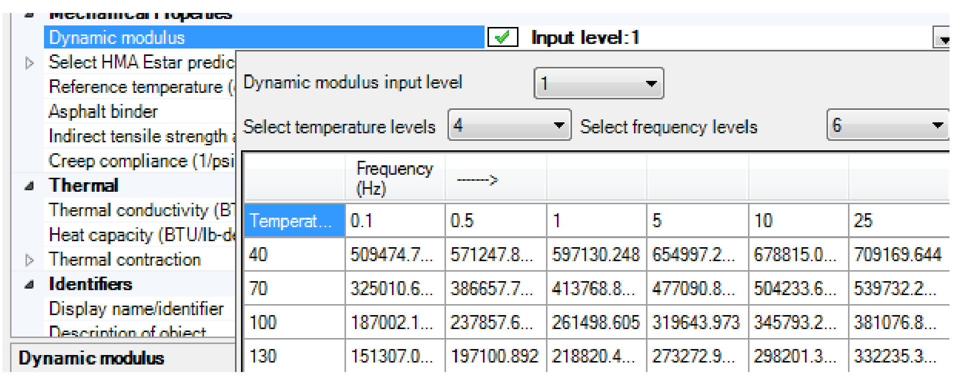


Figure 15: Dynamic modulus input for PavementME

Since the dynamic modulus is the only value being changed, the key assumptions being made are for the effective binder content, air voids, and properties for creep. For the CR asphalt layer, the effective binder content was assumed to be 11.6%, the air voids 7%, and the creep compliance was determined by the software based on the dynamic modulus values. These assumptions are the defaults for PavementME and are based on the global and regional median values the have been found with similar pavement layers. The final input required for the software is the climate. For the purpose of this study, the Charlottesville climate station has been selected since it is where the mix was being stored and the inputs from that data are shown in Figure 16.

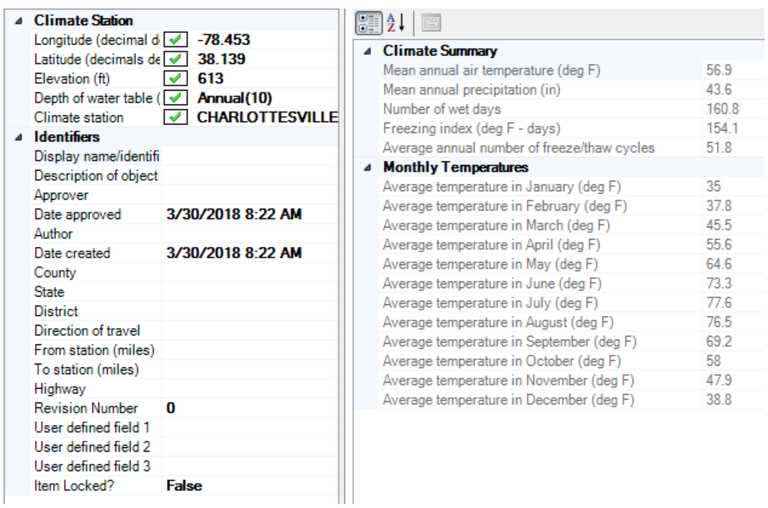


Figure 16: Climate inputs for PavementME

Using this provided data, PavementME outputs the expected performance of the pavement. For this study, the influence of the change in dynamic modulus values on pavement performance is discussed.

ANALYSIS AND DISCUSSION

Moisture Content

As the mix was stored in the buckets to simulate a stockpile, one of the major concerns was the retention of moisture within the mix. As the testing continued and each new bucket was used, the moisture content of a sample of mix was determined using ASTM C566-13. The results of the moisture content are shown in Table 4 along with the percent difference from the initial value.

Table 4: Moisture content

Days	Moisture %	% Difference from initial
Initial	6.00	0
1	5.98	0.33
2	6.28	-4.66
3	6.03	-0.50
6	6.03	-0.50

The target moisture content that was determined from the mix design was 6.00%, and was achieved at the plant as seen from the initial day value. The average moisture content while the mix was stockpiled was 6.08% with a standard deviation of 0.14. The average percent difference from the target moisture content was 1.33% where the largest value of 6.28 was 4.60%. The other values differed no more than 0.50% suggesting minimal variability in the moisture content. Due to this lack of variability, the methodology used to stockpile the CR mix was an effective means to minimize moisture loss.

Compaction Effort

The other issue with stockpiling the mix that may arise is that of compactability. While using the specimen gyratory compactor to create the 180mm specimen, after each day there was an increase in the number of gyrations required to create the specimen. Figure 17 below shows the average number of gyrations required to create a specimen with respect to the number of days it had been stored.

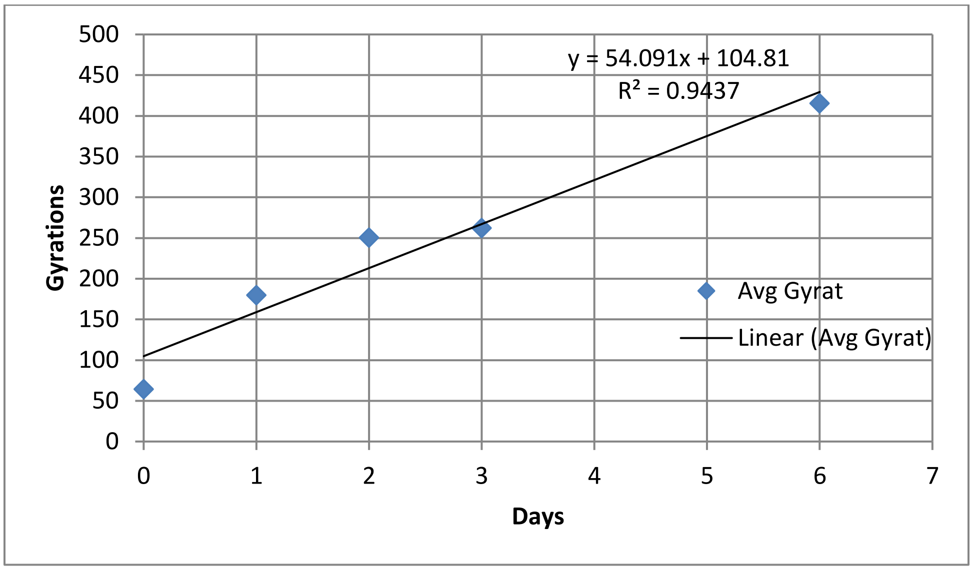


Figure 17: Number of gyrations

The number of gyrations required to compact the material increases linearly for 6 days. This increase in compactive effort suggests the mix is less workable if it is stockpiled for an extended period of time. If the number of passes increases in a similar manner to the number of gyrations, stockpiling even for a couple of days can double the amount of time required to compact the pavement. This can especially be as issue because if the pavement is not compacted quickly enough, a crust can form on the mixture making compaction even more difficult (BARM 2015).

ITS Results

As stated before, there were 6 specimens tested for the first three sets and 5 tested for the last three and the mean results, as well as the standard deviation for the testing are shown below in table 5 while the raw data is available in Appendix B.

Table 5: Mean results from ITS testing

Days	Mean ITS result(psi)	St. Dev.
Initial	73.48	123.99
1	46.98	38.85
3	30.50	38.82
7	29.48	12.68
8	28.79	35.37
41	29.92	23.02

The results from this testing could be described using an exponential relationship with a coefficient of determination (R^2) term of 0.79 as shown in the Figure 21. These results suggest that there is a sharp drop in tensile strength for the asphalt mix even after just 1 day of being stored losing about 36% of its strength and at 3 days about 59% of the initial strength after which the data reaches a stable value. The data in Figure 18 are also shown with a 45psi threshold for what is acceptable as suggested by VDOT CCPR specifications.

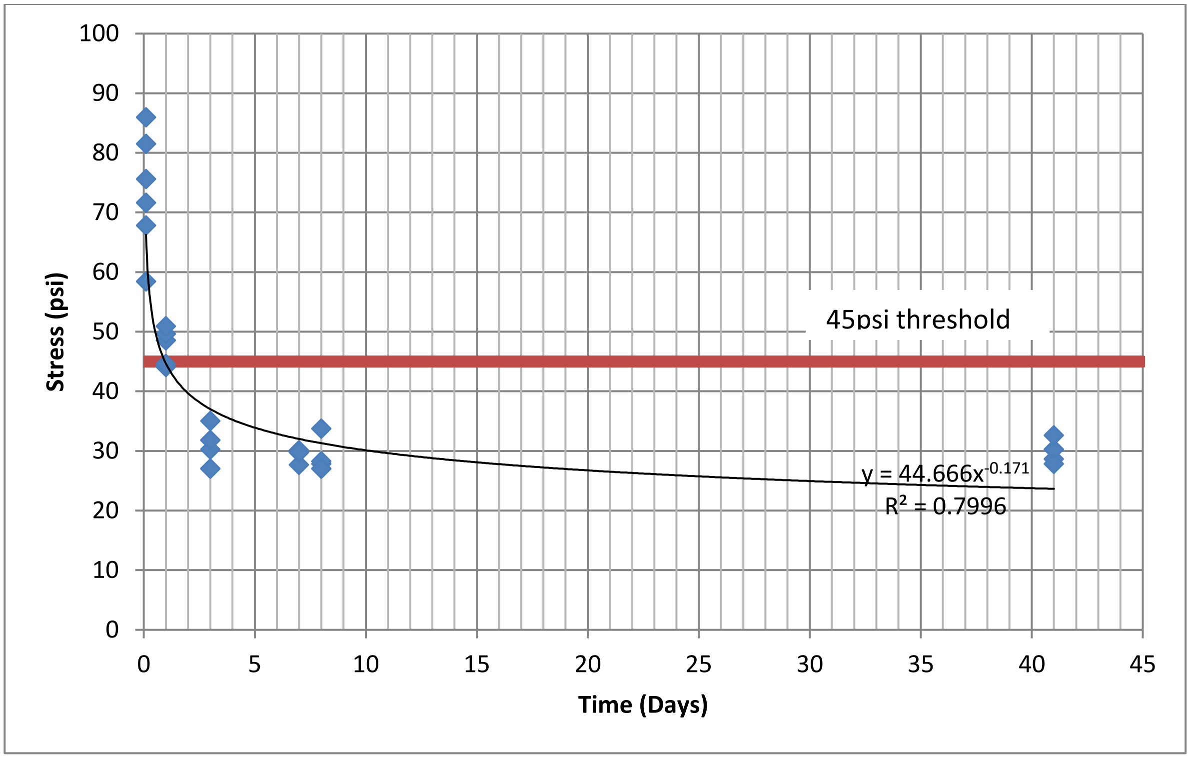


Figure 18: ITS test results

In addition to testing for regression a series of student t-tests were run to compare consecutive sets of tests to determine if the differences in stockpiling times are statistically significant. An f-test was conducted to determine equal or unequal variance. Depending on the results from the f-test, the appropriate t-test was conducted. The summary of these results is presented below in table 6.

Table 6: T-test results

	Variance	P Value	Result
Initial vs. 1	Equal	0.00	Difference is significant
1 vs. 3	Unequal	0.00	Difference is significant
3 vs. 7	Equal	0.50	Difference is not significant
7 vs. 8	Equal	0.62	Difference is not significant
8 vs. 41	Unequal	0.48	Difference is not significant

The results from the t-test suggest that after 3 days, the differences in the mean indirect tensile strength of CR asphalt are not statistically significant. This suggests that after 3 days, the CR asphalt has reached its potential lowest strength and storing it longer will have little to no effect. For the tensile tests, after the 7 day tests, the test specimens' height was reduced due to difficulties in compacting the test specimens to the desired height; the amount of mix used was reduced from 1100 grams to 1040 grams. The results of the t-test validate that the change in density had little or no significance on the tensile strength.

Dynamic Modulus Results

The dynamic modulus test was conducted on specimen created at the initial time of collection, and at 1, 2, 3, and 6 days after the mix had been collected. For each set, three specimens were fabricated and tested. The average E* results of those specimens is shown in Table 7.The final master curve was made in accordance with AASHTO R62-13 using an excel spreadsheet. The results from the dynamic modulus curves are shown in Appendix C.

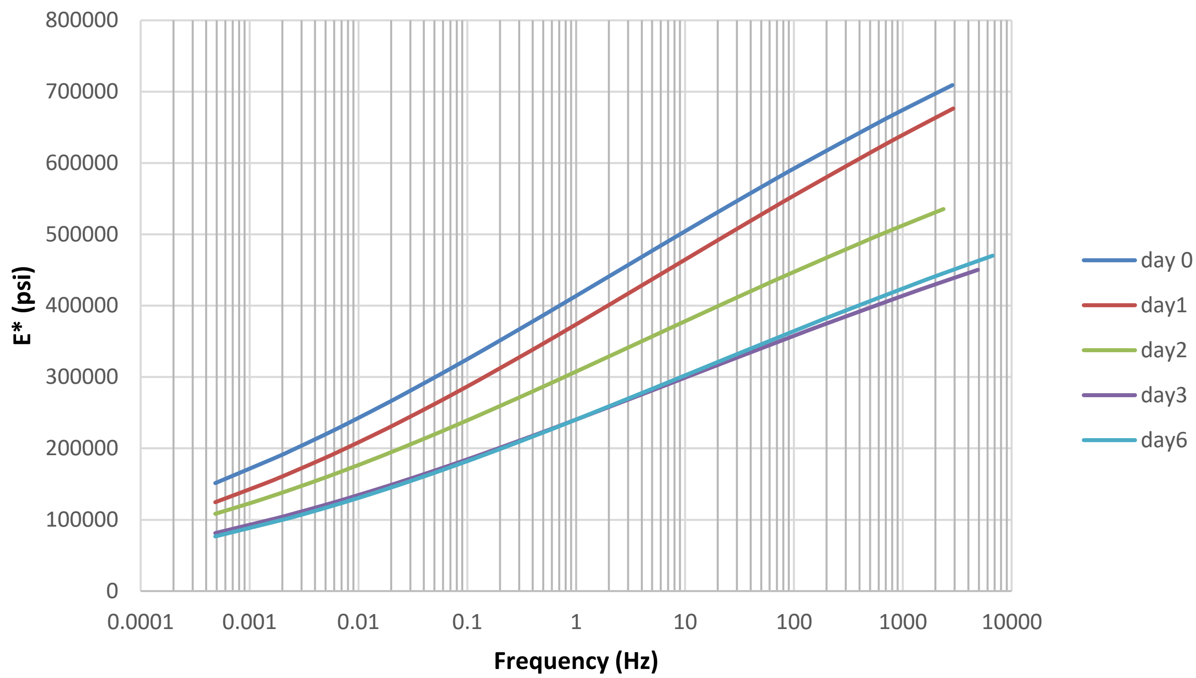


Figure 19: Dynamic modulus results

Figure 19 shows a decrease in the dynamic modulus between 7 and 20 percent with each consecutive day from the initial until the third day for the frequency of 10Hz using the fitted curve with a reference temperature of 21.1C (70F). However, between the third and sixth day, the difference is only 1 percent for the initial frequency and the final result is an increase by about 4 percent. This suggests that stiffness, like the indirect tensile strength, is lost very quickly within the first few days of stockpiling but remains constant after the third day. Figure 20 below compares the trends observed for the average ITS values and the dynamic modulus values at 21.1C and 10 Hz. The correlation coefficient between these two trends is 0.89 suggesting that the results of testing are likely related to a high degree.

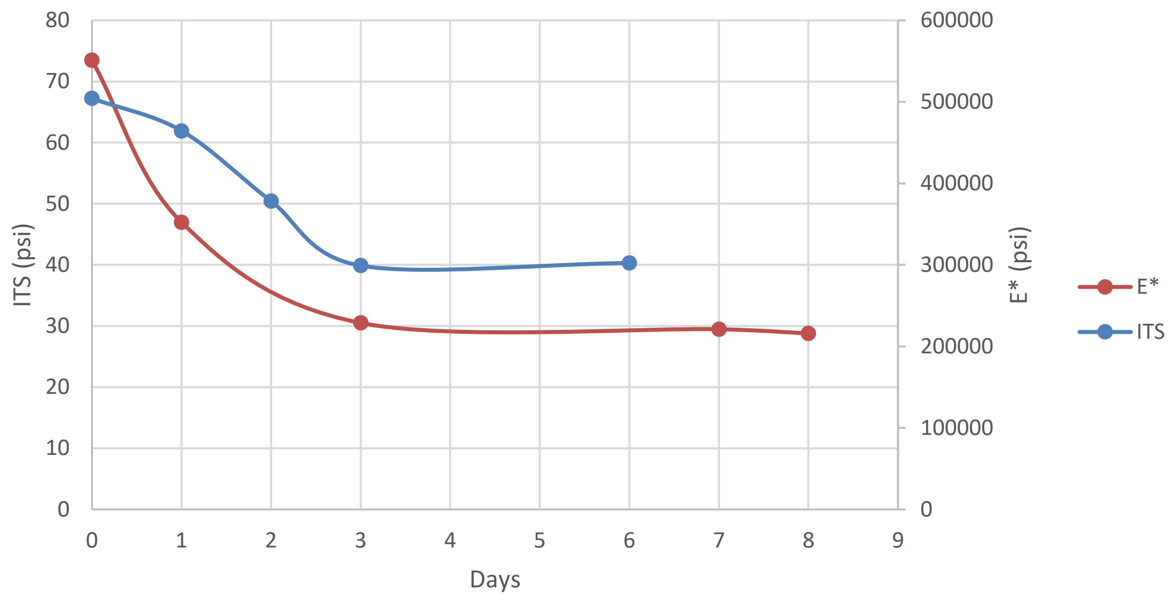


Figure 20: Average ITS and E* at 21.1C and 10Hz

This relationship may suggest that the factors causing the decrease in tensile strength are also cause the decrease in stiffness over time while the CR mix is stockpiled. A study conducted by Xu (2011) suggested that tensile strength increases linearly with cement content and those specimens with 1.5% cement performed better in testing for rut resistance. These findings suggest that cement plays a role in these factors and could explain why the dynamic modulus and the ITS values follow a similar trend. Cement begins to hydrate as soon as the mix is processed which is why the specimens made the same day have the highest values for stiffness and tensile strength. As the mix is stockpiled and the cement hydrates further, the bonds that increase the strength of the mix are not as well established and can be broken since the mix is not compacted, this being after 3 days according to the results from this study.

Mechanistic-Empirical Pavement Design

AASHTO has created a software, PavementME, that provides a set of procedures to design and analyze the performance of flexible pavements. It takes into account a variety of factors including the type of pavements, the various levels of traffic, and the climate to predict how well a pavement will behave along with the levels of destress it will be in for the lifespan of the road. PavementME was used for this report in order to predict how the property changes caused by stockpiling would potentially affect the performance of the pavement.

To assess the effects of stockpiling, the pavement cross section, acquired from NCHRP research report 863, shown below in Figure 21 was modelled in PavementME (Schwartz et al. 2017).

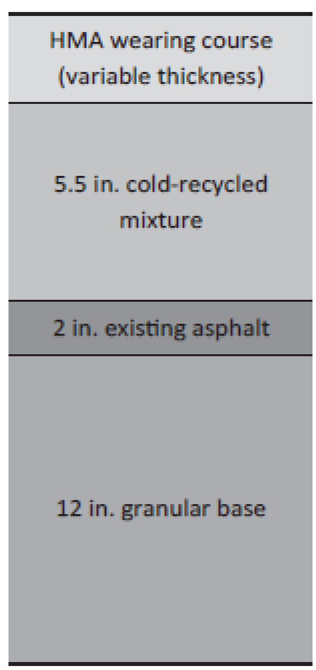


Figure 21: Pavement cross-section

Using this cross section as a typical CIR pavement, the values collected from the dynamic modulus testing were input into the software. The outputs report values for IRI (smoothness) and total rut depth (TRD). The results for these values are presented below in Figures 22 and 23.

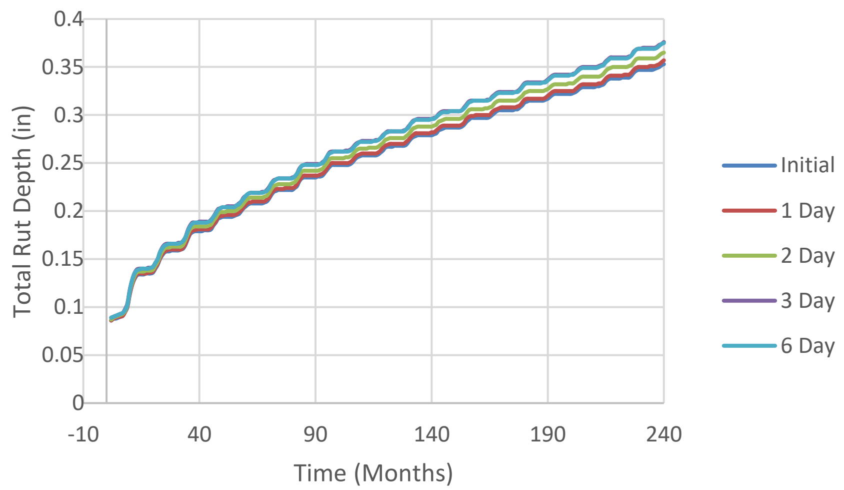


Figure 22: Total Rut Depth (TRD)

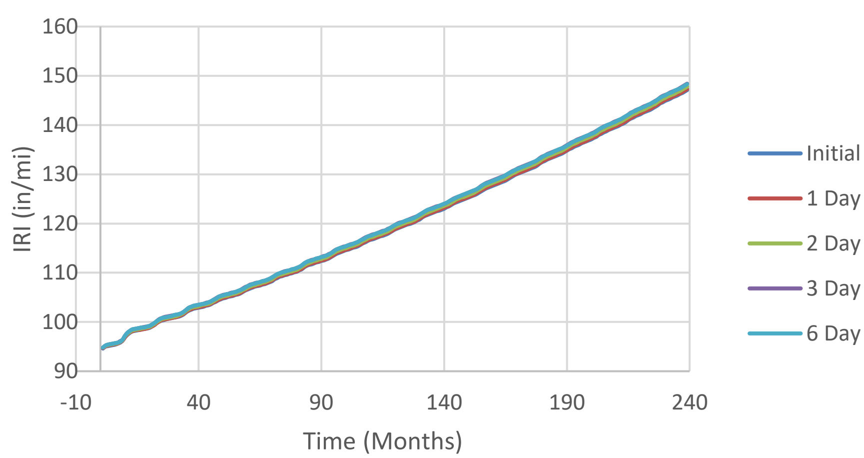


Figure 23: (International Roughness Index) IRI

After a period of 20 years, PavementME suggests that stockpiling the mix for 6 days increases the total rut depth (TRD) by 6% and the IRI by 0.8%, both of these being negligible. These values are higher than the recommended thresholds of 0.26in for TRD and 140in/mi for IRI after 20 years however the concerns for the purposes of this study, the effects of the change in performance are more relevant than whether the pavement can perform for a 20 year life. These results are to be expected based on the E* values that were found from the stockpiled CR mix. Just as the E* values for days 3 and 6 are similar, the TRD and IRI values for those days are very close as well. This data makes sense for understanding the effect that the varying E* values have on pavement performance however more inputs would need to be found to properly determine the full effect that stockpiling has on performance.

SUMMARY

The purpose of this study was to evaluate the effect of stockpiling CR mix on its material properties and predicted performance. Since there was not a proper stockpile to compare the results with, one method to determine if the storage method was sufficient was to test the moisture content. Throughout this study, the moisture content did not vary more than 0.3% from the initial conditions that were recorded at the plant. This suggests that the methodology used of placing the mix in a bucket layered with a plastic bag and stored with damp rags may be an effective way to minimize moisture loss, similar to what is expected of a properly managed CCPR stockpile. However, to confirm this, a future study should be conducted to compare this method of a simulated stockpile to that of a real stockpile.

The compaction effort required to create the specimens increases the longer the CR mix is stockpiled. This would be an issue in the field because if the material is not workable enough then the amount of time it would take to place the mix would be greatly increased. With higher levels of compaction required, it may take significantly more time to compact the pavement which may be a disadvantage to the contractors working on the job. The compaction effort here is stated in terms of the number of gyrations, which increases more than 100% within the first 2 days. Relating the number of gyrations to the average time it takes to compact pavement to a certain density using a roller, this would mean that each mile of pavement would take twice as long to compact on site.

The ITS data gathered from this report demonstrated a very sharp decline in strength followed by a constant minimum after 3 days of being stockpiled. It is important to note the mean strength dropped to about 47psi after just one day of stockpiling. This is a key finding considering the acceptable ITS strength suggested by VDOT specifications is 45psi. Taking into account that these specimens were created under ideal laboratory conditions, one may expect more discrepancies when creating these specimens in the field.

The results from PavementME suggest that stockpiling the mix has little effect on overall performance however these results cannot be definite. PavementME is a program made to model pavements that are not made of cold recycled materials, such as HMA and concrete, and was used with values pertaining to cold recycled material. For this reason, there were a few assumptions made to properly model the pavement layers. These include values for the binder properties and for the specimen itself since air voids and effective binder content could not be found. These results could mean either that the pavement would experience little change in quality from stockpiling or that PavementME needs to be developed further to properly model the behavior of cold recycled mix. To properly determine which case is valid, the software would have to be calibrated for using CR mix.

FINDINGS AND CONCLUSIONS

Stockpiling CIR mix is a method that currently is practiced by some contractors in order to have an efficient plan for making and placing mix. For example, when projects need to be completed but due to weather conditions, the plant cannot construct the pavement, it may be appropriate to stockpile the CR mix overnight. For these instances, the mix is misted to ensure moisture retention and may be placed on a plastic tarp to prevent contamination. However, based on the results from this study, stockpiling mix for even one day has a large impact on the strength properties of the pavement and needs to be studied even further before being used. The results from this study suggest that even after one day, the CIR mix quickly loses about 36% of its initial strength. Considering these specimens were created and tested under ideal laboratory conditions, it is possible that the reduction in strength would be even greater when tested in the field. Keeping the CR mix in a bucket as opposed to a proper stockpile also decreases the likelihood of contamination. If the CR mix had to be stockpiled for less than a day as was the case with this study, it may meet the requirements for strength set by VDOT. Any time longer than a day and the mix would need to be created with a higher initial strength to ensure the CR mix meets the criteria after the reduction of strength. Since the loss of strength is not continuous and plateaus after the third day of being stockpiled, it may be possible to keep the strength within specifications for an extended period of time for this sample of CR mix, however, as stated, the initial strength would have to be higher.

The dynamic modulus testing suggests the mix exhibited a stiffness reduction as it is stockpiled but as with the ITS data, after three days it is constant. The results from PavementME suggest the change in stiffness does not play a significant role in the outputs of the software being considered for this study, those being IRI and rut depth. However, there would need to be further studies to determine how well the software can be applied to cold recycled pavements.

The methodology used to simulate a proved to be effective in keeping the moisture content in check. With minimal moisture loss, the mix was still workable enough to create specimen and any reduction in workability could be attributed to other factors such as the hydrating of the cement. In other studies, CR mix that has cement additives stiffens over time and is attributed to the curing of the cement (Diefenderfer 2016). Since the greatest increase in strength for cement happens in the first few days, it is possible that leaving the mix in a stockpile for a few days leads to the final product gaining less strength from the cement. This may be the cause of the decrease in stiffness over time for the CR mix. For a real stockpile, the moisture would be kept under check using a scheduled misting but as the results here demonstrate, damp rags and a sealed container do well to contain the moisture in the mix.

In summary

- The laboratory stockpiling methodology used works well to prevent moisture loss
- The compactive effort increases after laboratory stockpiling
- Change in density to keep CR mix within spec had no significant change on tensile strength

- Tensile strength decreased more than 50% after 3 days of stockpiling and then remained constant
- Dynamic modulus decreased within the first 3 days of stockpiling and then remained constant
- PavementME suggests stockpiling has little effect on performance

FUTURE WORK

Quantifying how CR mix properties change after being stockpiled is an important step in being making better use of the resources that are available for pavements. However, with the limited scope of this study, there are still many steps that can be taken in order to advance this area on knowledge further. The first step would be to conduct a study with mix using a real stockpile and a simulated lab stockpile to determine how well this methodology can mimic the conditions of a stockpile. Depending on how well one compares to the other, there would be further steps needed to improve the technique to simulate stockpiling. This could involve looking at different sized containers and seeing how the quantity of each set impacts the material properties, as well as looking at different types of containers and conditions to contain the CR mix. Perhaps the key difference may be to cover the samples in a way that is not air tight and would require misting, which may be a better representation of a proper stockpile. There are just a few ways that this study could be advanced further.

There are different additives used in CR mix that may impact the material properties differently. This study looked at cement stabilized bitumen and one suggestion was that the

Portland cement played a large role in how the material lost strength and stiffness. It would be an important study to repeat this experiment with a CR mix that contains no cement and observing if that plays a large role in the behavior of the material. That could be taken even further by stockpiling mix with different quantities of cement to see if there is a point where the quantity of cement has little to no effect. Aside from cement, there are other additives that can be used for CR mix such as fibers, lime, or fly ash. It would be good to observe how CR mixes with different additives behave when being stockpiled.

In addition to quantifying how CR mix is affected due to stockpiling, it would be an important step to develop the calibration factors needed for PavementME to more thoroughly model the pavement performance instead of relying on the default values based on global and regional medians. This step would require that date be collected from as many types of CR projects that have been conducted to go through an iterative process for properly calibrating the software. As it currently stands, and as it has been stated in this study, PavementME is set up to predict performances of HMA and other materials, but not CR mixes. To create a catalog of different types of CR mix, as there is of HMA, and their long term performance would be an important step in improving the design process as well as making it more efficient.

BIBLIOGRAPHY

AASHTO. (2008). *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice.* AASHTO.

Asphalt Academy, TG2. (2009). Bitumen Stabilised Materials: A Guideline for the Design and Construction of Bituem Emulsion and Foamed Bitumed Stabilised Materials.

Association, A. R. (2015). *Basic Asphalt Recycling Manual.*

Bowering, R. H. (1970). Properties and Behavior of Foamed Bitumen Mixtures for Road Building. *Proceedings of the 5th Australian Road Research Board Conference* (pp. 38-57). Australia: ARRB.

Brayton, T., Wayne, L., Harington, J., & Kearny, E. (2001). Characterization of Cold In-Place Recylcing Asphalt Mixtures. *Construction and Materials Issues*, 193-205.

Chen, X. (2015). *Evaluation of Cold Recycled Asphalt Mixtures Modified with Conventional and Polymner Modified Emulsions.*

Diefenderfer, B., & Link, S. (2014). Temperature and Confinement Effects on the Stiffness of a Cold Central-Plant Recycled Mixture. *Proceedings of the 12th International Society for Asphalt Pavements Conference on Asphalt Pavements*, 1641-1650.

El-Badawy, S., Bayomy, F., & Awed, A. (2012). Performance of MEPDG Dynamic Modulus Predictive Models for Asphalt Concrete Mixtures: Local Calibration for Idaho. *Journal of Materials in Civil Engineering V 24*.

Graziani, A., Godenzoni, C., Cardone, F., & Bocci, M. (2016). Effect of Curing on the Physical and Mechanical Properties of Cold-Recycled Bituminous Mixtures. *Materials and Design V96*, 358-369.

Graziani, A., Godenzoni, C., Cardone, F., & Bocci, M. (2017). An Application of hte Michaelis-Menten Model to Analyse the Curing Process of Cold Recycled Bituminous Mixtures. *International Journal of Pavement Research and Technology, V 10*, 62-74.

Grilli, A., Graziani, A., & Bocci, M. (2012). Compatibility and Thermal Sensitivity of Cement-Bitumen-Treated Materials. *Road Maetrials and Pavement Design, V.13*, 599-617.

Harvey, J. T., & Tsa, B.-W. (1996). Effects of Asphalt Content and Air Void Content on Mix Fatigue and Stiffness. *Transportation Research Record: Journal of the Transporation Research Board 143*, 38-45.

Huang, Y. (2004). *Pavement Analysis and Design.* Upper Saddle River, NJ: Pearson Prentice Hall.

Islam, R., Kalevela, S., & Rivera, J. (2018). *Dynamic Modulus of Cold-in-Place Recycling (CIR) Material.* Denver, Colorado.

Jacques, C., Daniel, J., Bennert, T., Reinke, G., Norouzi, A., Ericson, C., et al. (2016). Effect of Silo Storage Time on The Characteristics of Virgin and Reclaimed Asphalt Mixtures. *Transportation Research Record: Journal of the Transportation Research Board, V2753*, 76-85.

Jenkins, K. J., & Van de Van, M. F. (1999). Mix Design Considerations for Foamed Bitumen Mixtures. *Proceedings of the 7th Conference on Asphalt Pavements for Southern Africa.*

Karlsson, R., & Isacsson, U. (2006). Material-Related Aspects of Asphalt Recycling- State-of-the-art. *Journal of Materials in Civil Engineering*, 81-92.

Kim, Y., & Lee, H. (2006). Development of Mix Design Procedure for Cold In-Place. *Journal of Maeterials in Civil Engineering*, 116-124.

Kim, Y., Im, S., & Lee, D. (2011). Impacts of Curing Time and Moisture Content on Engineering Properties of Cold In-Place Recycling Mixtures Using Foamed or Emulsified Asphalt. *Journal of Materials in Civil Engineering V 23 Issue 5*, 542-553.

Kim, Y., Im, S., & Lee, H. (2011). Impacts of Curing Time and Mositure Content on Engineering Properties of Cold In-Place Recycling Mixtures Using Foamed or Emulsified Asphalt. *Journal of Materials in Civil Engineering V 23*, 542-553.

Kim, Y., Lee, H., & Heitzman, M. (2009). Dynamic Modulus and Repeated Load Tests of cold In-Place Recycling Mixtures Using Foamed Asphatl. *Journal of Materials in Civil Engineering V 21*, 279-285.

Lee, H., & Kim, Y. (2007). Manual of Laboratory Mix Design Procedure for Cold In-Place recycling using Foamed Asphalt (CIR-foam). *IRHB Report TR 474*.

Lee, W., Brayton, T., & Harrington, J. (2003). New mix-design procedure of cold in-place recycling for pavement rehabilitation. *TRB 82nd Annual Meeting.* Washington, DC.

Maccarrone, S., Holleran, G. D., & Hey, S. (1994). Pavement Recycling unsing Foamed Bitumen. *17th ARRB Conference*, (pp. 349-365). Gold Coast, Queensland.

Mallick, R., & El-Korchi, T. (2009). *Pavement Engineering: Principles and Practice.* CRC Press.

(1994). *Method of Test for Preperation of Marshall Specimen for Cold In-Place Recycled Mixtures, LS-300.* Ontario Ministry of Transportation: Laboratory Testing Manual, Engineering Materials Office.

Murphy, D., & Emery, J. (2014). Modified Cold In-Place Asphalt Recylcing. *Transportation Research Record: Journal of the Transporation Research Board, V154*, 143-150.

Muthen, K. M. (1999). *Foamed Asphalt Mixes.* Transportation Research Record 898.

Performance of MEPDG Dynamic Modulus Predictive Models for Asphalt Concrete Mixtures: Local Calibration for Idaho. (2012). *Journal of Materials in Civil Engineering V 24*, 1412-1421.

Ruckel, P., Acott, S. M., & Bowering, R. H. (1983). Foamed-Asphalt Paving Mixtures: Prepreration of Design Mixes and Treatment of Test Specimens. *Transportation Research Record 911*.

Sayers, M. W., Gillespie, T. D., & Queiroz, C. A. (1986). The International Road Roughness Experiment: A Basis for Establishing a Standard Scale for Road Roughness Measurements. *Transportation Research Record 1084*, 76-85.

Schwartz, C., Diefenderfer, B., & Bowers, B. (2017). *NCHRP Research Report 863: MAterial Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt concrete.*

Sebaaly, P., Bazi, G., Hitti, E., Weitzel, D., & Bemanian, S. (2004). Performance of Cold In-Place Recycling in Nevada. *Transportation Research Record: Journal of the Transportation Research Board*, 162-169.

Tran, N., Robbins, M., Rodezno, C., & Timm, D. (2017). *Pavement ME Design- Impact of Local Calibration, Foundation Support, and Design and Reliability Thresholds.* National Center for Asphalt Technology.

Valentová, T., Cížková, Z., Valentin, J., Simnofske, D., & Mollenhauer, K. (2015). Influence of the Specimens Curing Procedure on the Final Cold Recycled Mix Properties. *Conference on Asphalt Pavements for Southern Africa.* Sun City, South Africa.

VDOT. (2015). *Special Provision for Cold Central Plant Recycling Material Placement.* VDOT.

VDOT. (2015). *Special Provision for Cold Central Plant Reycling Material.* VDOT.

West, R. (2010). Reclaimed Asphalt Pavement Management: Best Practices. *National Center for Asphalt Technology*.

Wijk, A., & Wood, L. (1983). Use of Foamed Asphalt in Recycling of an Asphalt Pavement. *Transportation Research Record 911*, 96-103.

Wirtgen Cold Recycling Manual. Wirtgen GmbH. (2012). Windhagen, Germany.

Witczak, M. W., & root, R. E. (1974). Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness KIc of Metallic Materials. *Fatigue and Dynamic Testing of Bituminous Mixtures, ASTM STP 561, American Society for Testing and Material*, 67-94.

Xu, J., Huang, S.-C., Qin, Y.-C., & Li, F. (2011). The Impact of Cement Contents on the Properties of Asphalt Emulsion Stabilized Cold Recycling Mixtures . *International Journal of Pavement Research and Technology*, 48-55.

Yan, J., Zhang, Z., Charmot, S., & Ding, W. (2015). Investigation and Prediction Model for the Dynamic Modulus of Asphalt Emulsion Cold Recycled Mixtures. *Journal of Materials in Civil Engineering V 27*.

Zeinali, A., Blankenship, P., & Mahboub, K. (2014). Effect of Long-term Ambient Storage of Compacted Asphalt Mixtures on Laboratory -Measured Dynamic Modulus and Flow Number. *Transportation Research Record: Journal of the Transportation Research Board V 2447*, 109-116.

Zhang, W., Drescher, A., & NEwcomb, D. E. (1997). Viscoelastic Behavior of Asphalt Concrete in Diametral Compression. *Journal of Transportation Engineering*, 495-502.

Zhou, F., Das, G., Scullion, T., & Hu, S. (2009). *RAP Stockpile Management and Processing in Texas: State of the Practice and Proposed Guidelines.* Austin, Texas.

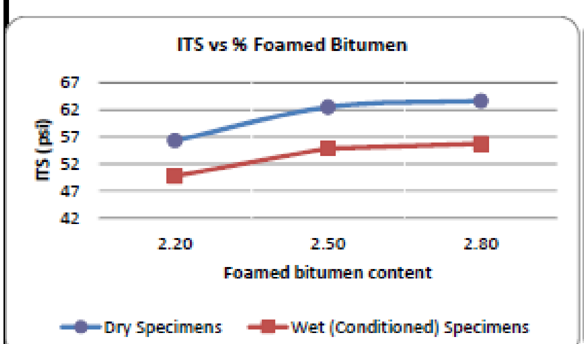
APPENDICES

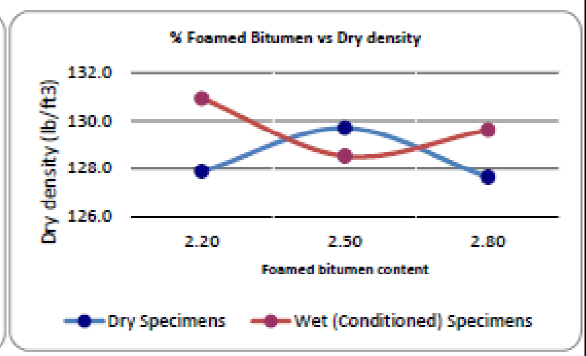
Appendix A: Plant Mix Design

Client:	Allan Myers - New Kent Plant West Point, VA			
Project:	I-64 CCPR		Date Tested:	7/20/2017
Sample Number:	RAP (85%) and #10 Screenings (15%) Blend		Date Reported	7/20/2017

FOAMED BITUMEN MIX DESIGN REPORT

MATERIAL TO BE STABILISED	Aggregates		Bitumen	Filler
Location / Source:	Allan Myers Plant		Associated Asphalt	Giant Cement
Description	RAP material blended with 15% Screenings		PG 64-22	1% Portland Cement
Maximum dry density :	**144.6 lb/ft^3 (2317 kg/m^3)**	Optimum moisture content (%):	4.1	*AASHTO T-180 Method D*
Target wet density for CCPR:	**130.8 lb/ft^3**	Target Dry Indirect Tensile Strength	**45 psi**	
BITUMEN FOAMING CONDITIONS				
Foaming water added (%)	**2.0**		Bitumen temperature (°C)	**165°C (329°F)**
FOAMED BITUMEN STABILISED MATERIAL CHARACTERISTICS				***Test Method***
Compactive effort	**Marshall Hammer - 75 blows**		**100mm diameter**	**ASTM D6926**
Date moulded	7/16/2017			*After compaction, specimens were placed in a 40 °C force draft oven for 72 hours for curing.*
Foamed bitumen added (%)	2.20	*2.50*	2.80	
Type and percent filler added (%)	1% Cement	*1% Cement*	1% Cement	
Moulding moisture content (%)	4.9	*4.8*	4.1	
TEST RESULTS		*Optimum*		
ITS dry (psi)	56	*63*	64	*AASHTO T-283 (77 °F)*
Moisture content at break (%)	0.0	*0.0*	0.0	*Dry density values for each content was calculated with the volumetrics of each set of specimens*
Dry Density (lb/ft3)	127.9	*129.7*	127.6	
Temperature at break (oF)	78	*78*	78	*77 ± 3.6 °F (25 ± 2°C)*
ITS wet (psi)	50	*55*	56	*AASHTO T-283 (77 °F)*
Moisture content at break (%)	3.9	*3.8*	3.5	*Cured specimens were placed in 77F water bath for 24 hrs prior to testing*
Dry Density (lb/ft3)	130.9	*128.5*	129.6	
Temperature at break (oF)	78	*78*	78	*77 ± 3.6 °F (25 ± 2°C)*
Retained ITS (%)	88	*88*	88	*70% (Min)*





FOAMED BITUMEN MIX DESIGN - WORKSHEET

Sheet 1

Project : I-64 CCPR

Date 7/20/2017

Description : Unprocessed RAP (85%) combined with #10 Screenings (15%)

Bitumen Source: Allan Myers | Bitumen grade: PG 64-22

MOISTURE DETERMINATION

		Hygroscopic	Preparation Moulding		After Curing Dry	After Curing Soaked
Pan No.						
Mass wet sample + pan	m1		1190.9		3223.5	3357.6
Mass dry sample + pan	m2		1140		3223.5	3231.6
Mass pan	mp		108.7			
Mass moisture	m1-m2 = Mm		50.9		0	126
Mass dry sample	m2-mp= Md		1031.3		3223.5	3231.6
Moisture content	Mm/Mdx100=Mh		4.9		0.0	3.9

Percentage of water added to sample for mixing:	2.0	Amount of water added :	450mL
Percentage water added to sample for compaction	0.0	Amount of water added :	0
Total percentage water added:	2.0	Total water added:	450mL
Percentage foamed bitumen added :	2.2	Additive and percentage	1% Cement

SPECIMEN DETAILS

Sample ID	N	P	R	O	Q	S
Date Moulded	7/16/2017					
Date placed in oven	7/16/2017					
	Dry			Soaked		
Date tested	7/20/2017			07/20/147		
Diameter (inch)	4	4	4	4	4	4
Individual Thickness Readings (inch)	64	65	65	64	63	63
Avg. Thickness (inch)	2.52	2.56	2.56	2.52	2.48	2.48
Mass after curing (lb)	1062.1	1078.9	1082.5	1081.8	1068.2	1081.6
Bulk density (lb/ft3)	127.7	127.8	128.2	130.1	130.5	132.1
Dry density (lb/ft3)	127.7	127.8	128.2	130.1	130.5	132.1

Cure specimens for 72 hours @ 104°F thereafter cool to ± 77°F.

INDIRECT TENSILE STRENGTH TEST

Condition	Dry (± 77°F)			Soaked (± 77°F)		
Maximum load (lb)	1100.0	600.0	1000.0	900.0	800.0	640.0
Tensile strength (psi)	69.45	37.30	62.17	56.83	51.31	41.05
Mean ten. strength (psi)	56			50		
Tensile strength ratio	88					

FOAMED BITUMEN MIX DESIGN - WORKSHEET

Project : I-64 CCPR **Sheet 2**

Sample No.: Date 7/20/2017

Description : Unprocessed RAP (85%) combined with #10 Screenings (15%)

Bitumen Source Allan Myers Bitumen grade PG 64-22

MOISTURE DETERMINATION

		Hygroscopic	Preparation: Moulding		After Curing: Dry	After Curing: Soaked
Pan No.						
Mass wet sample + pan	m1		1301.5		3235.1	3343.6
Mass dry sample + pan	m2		1247		3235.1	3222.7
Mass pan	mp		122.2			
Mass moisture	m1-m2 = Mm		54.5		0.0	120.9
Mass dry sample	m2-mp= Md		1124.8		3235.1	3222.7
Moisture content	Mm/Mdx100=Mh		4.8		0.0	3.8

Percentage of water added to sample for mixing:	2.0	Amount of water added :	450mL
Percentage water added to sample for compaction	0.0	Amount of water added :	0
Total percentage water added:	2.0	Total water added:	450mL
Percentage foamed bitumen added :	2.50	Additive and percentage	1% Cement

SPECIMEN DETAILS

Sample ID	H	J	L	I	K	M
Date Moulded	7/16/2017					
Date placed in oven	7/16/2017					
	Dry			Soaked		
Date tested	7/20/2017			7/20/2017		
Diameter (inch)	4	4	4	4	4	4
Individual Thickness Readings (inch)	64	64	64	64	65	64
Avg. Thickness (inch)	2.52	2.52	2.52	2.52	2.56	2.52
Mass after curing (lb)	1080.5	1074.5	1080.1	1077.3	1068.2	1077.2
Bulk density (lb/ft3)	129.9	129.2	129.9	129.6	126.5	129.5
Dry density (lb/ft3)	129.9	129.2	129.9	129.6	126.5	129.5

Cure specimens for 72 hours @ 104°F thereafter cool to ± 77°F.

INDIRECT TENSILE STRENGTH TEST

Condition	Dry (± 77°F)			Soaked (± 77°F)		
Maximum load (lb)	1100.0	980.0	890.0	980.0	840.0	800.0
Tensile strength (psi)	69.45	61.88	56.19	61.88	52.22	50.51
Mean ten. strength (psi)	63			55		
Tensile strength ratio	88					

FOAMED BITUMEN MIX DESIGN - WORKSHEET

Sheet 3

Project : I-64 CCPR

Sample No.:

Date 7/20/2017

Description : Unprocessed RAP (85%) combined with #10 Screenings (15%)

Bitumen Source: Allan Myers

Bitumen grade: PG 64-22

MOISTURE DETERMINATION		Hygroscopic	Preparation Moulding		After Curing Dry	After Curing Soaked
Pan No.						
Mass wet sample + pan	m1		1306.2		3265.5	3362.6
Mass dry sample + pan	m2		1258.8		3265.5	3250
Mass pan	mp		109.1			
Mass moisture	m1-m2 = Mm		47.4		0.0	112.6
Mass dry sample	m2-mp= Md		1149.7		3265.5	3250
Moisture content	Mm/Mdx100=Mh		4.1		0.0	3.5

Percentage of water added to sample for mixing:	2.0	Amount of water added :	450mL
Percentage water added to sample for compaction	0.0	Amount of water added :	0
Total percentage water added:	2.0	Total water added:	450mL
Percentage foamed bitumen added :	2.8	Additive and percentage	1% Cement

SPECIMEN DETAILS

Sample ID	A	C	E	B	D	F
Date Moulded	7/16/2017					
Date placed in oven	7/16/2017					
	Dry			Soaked		
Date tested	7/20/2017			7/20/2017		
Diameter (inch)	4	4	4	4	4	4
Individual Thickness Readings (inch)	64	65	68	64	65	64
Avg. Thickness (inch)	2.52	2.56	2.68	2.52	2.56	2.52
Mass after curing (lb)	1079.0	1086.0	1100.5	1081.8	1090.9	1077.3
Bulk density (lb/ft3)	129.8	128.6	124.6	130.1	129.2	129.6
Dry density (lb/ft3)	129.8	128.6	124.6	130.1	129.2	129.6

Cure specimens for 72 hours @ 104°F thereafter cool to ± 77°F.

INDIRECT TENSILE STRENGTH TEST

Condition	Dry (± 77°F)			Soaked (± 77°F)		
Maximum load (lb)	980.0	1140.0	980.0	1080.0	780.0	800.0
Tensile strength (psi)	61.88	70.87	58.24	68.19	48.49	50.51
Mean ten. strength (psi)	64			56		
Tensile strength ratio	88					

		BITUMEN CALIBRATION	Test Method: Wirtgen Cold Recycling Manual

BITUMEN

Source :	Allan Myers	Type:	PG 64-22
Test temperature:	165C (329F)		

MACHINE SETTINGS
Pump calibration

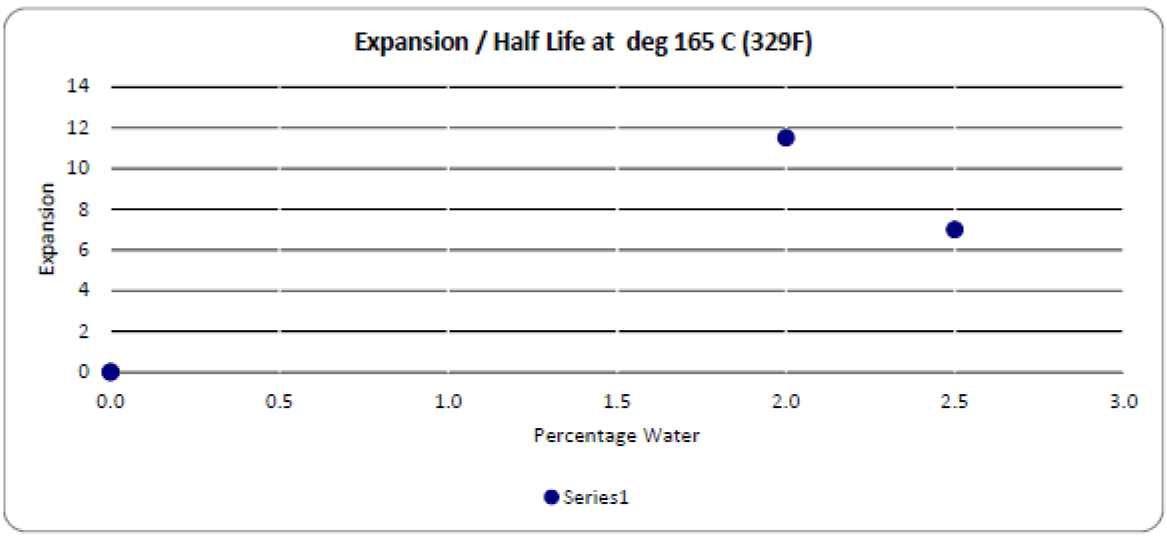
Setting

Quantity required (g):	500
Quantity sprayed (g):	500.00

Water

Quantity required (%):	2	3	4	5
Flow meter setting (l/h):	7.2	10.8	14.4	18

% Water	Expansion	Half Life
2.0	11.5	15.6
2.5	7.0	15.8



OPTIMUM FOAM MOISTURE CONTENT **2.0%**

		BITUMEN CALIBRATION	Test Method: Wirtgen Cold Recycling Manual

BITUMEN

Source :	Allan Myers	Type:	PG 64-22
Test temperature:	175C (347F)		

MACHINE SETTINGS
Pump calibration

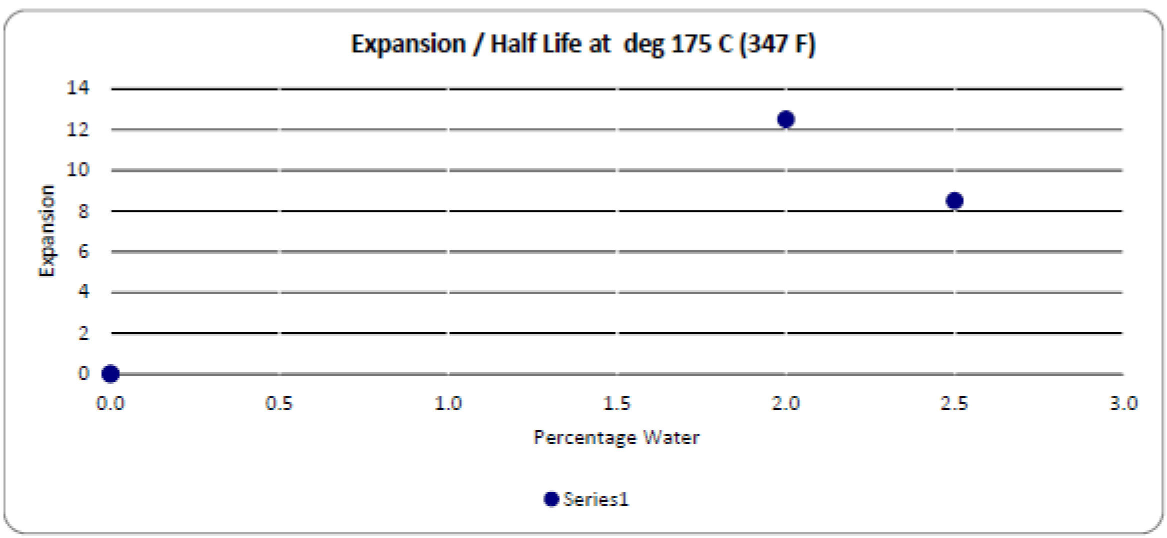
Setting

Quantity required (g):	500
Quantity sprayed (g):	500.00

Water

Quantity required (%):	2	3	4	5
Flow meter setting (l/h):	7.2	10.8	14.4	18

% Water	Expansion	Half Life
2.0	12.5	16.3
2.5	8.5	16.5



OPTIMUM FOAM MOISTURE CONTENT	**2.0%**

		BITUMEN CALIBRATION	Test Method: Wirtgen Cold Recycling Manual

BITUMEN

Source :	Allan Myers	Type:	PG 64-22
Test temperature:	185C (365F)		

MACHINE SETTINGS

Pump calibration

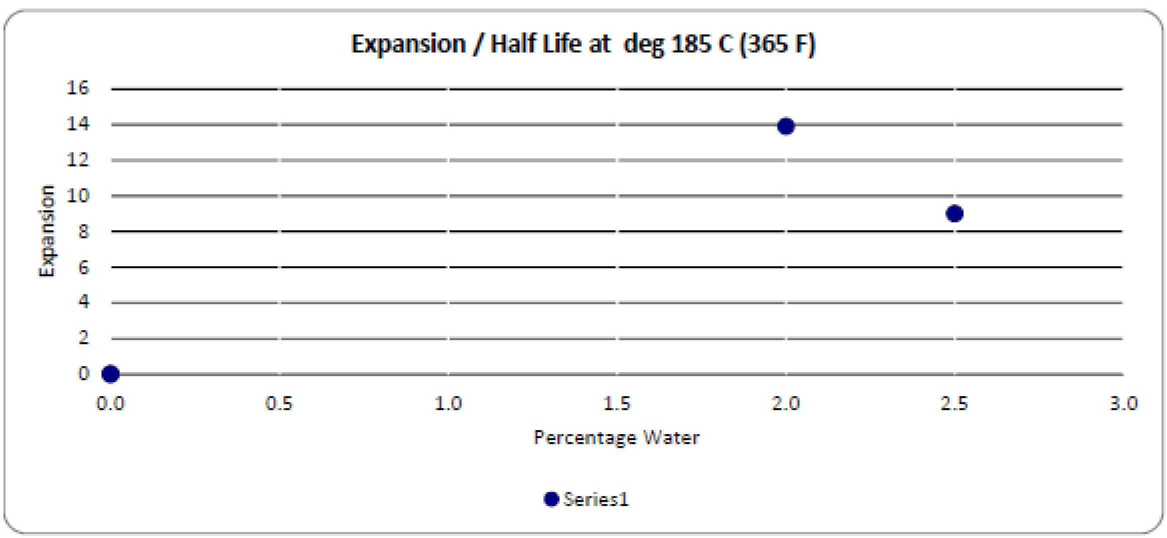
Setting

Quantity required (g):	500
Quantity sprayed (g):	500.00

Water

Quantity required (%):	2	3	4	5
Flow meter setting (l/h):	7.2	10.8	14.4	18

% Water	Expansion	Half Life
2.0	13.9	17.2
2.5	9.0	17.4

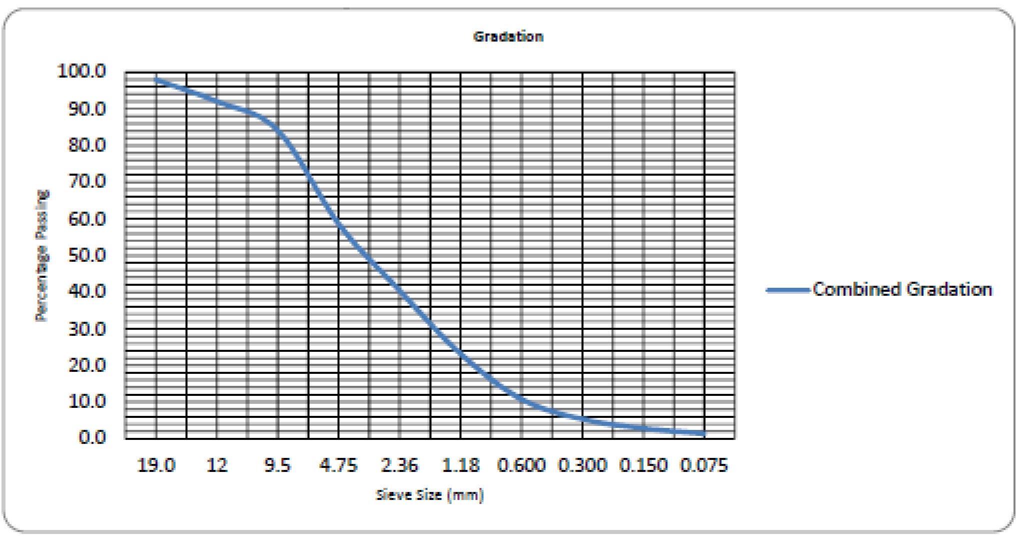


OPTIMUM FOAM MOISTURE CONTENT	**2.0%**

FOAMED BITUMEN SIEVE ANALYSIS	AASHTO T 27 (Dry)

Client	Allan Myers - New Kent Plant West Point, VA
Project	I-64 CCPR

		1		2		3		
Location:								Total percentage in Blend
Description:		Unprocessed RAP		#10 Screenings				
Sample No.:								
Date sampled:		8/28/2017		8/28/2017				
Percentage in Blend		85.0		15.0				100
Mass of sample (g)		1661.4		525.6				
Sieve size		Weight Retained	% Pass.	Weight Retained	% Pass.	Weight Retained	% Pass.	Combined Grading
mm	inch							
37.5	1 1/2	0	100.0	0	100.0			100.0
25	1	0	100.0	0	100.0			100.0
19.0	3/4	40.2	97.6	0	100.0			97.9
12	1/2	155.4	90.6	0	100.0			92.0
9.5	3/8	310.1	81.3	0	100.0			84.1
4.75	#4	807.3	51.4	3.2	99.4			58.6
2.36	#8	1111.1	33.1	95.3	81.9			40.4
1.18	#16	1377.7	17.1	222.2	57.7			23.2
0.600	#30	1564.9	5.8	320.9	38.9			10.8
0.300	#50	1635.8	1.5	384.3	26.9			5.3
0.150	#100	1654.3	0.4	438.5	16.6			2.8
0.075	# 200	1660.1	0.1	480.3	8.6			1.4



Note: Sampled RAP and aggregate materials, provided by contactor Allan Myers was combined and split to the reported sample size using AASHTO T 248 (Method A). RAP and aggregate samples were taken

LUCK STONE

Physical Properties Report

Location: Boscobel

Coarse Aggregates

Product	Specific Gravity				Unit Weight	Voids Coarse Agg	Flat & Elongated		
	Bulk Dry	SSD	Apparent	Absorption			5:1	3:1	2:1
VDOT #56	2.599	2.615	2.642	0.63	97	40	0.0	13.4	53.3
VDOT #57	2.597	2.612	2.636	0.56	94	42	0.9	11.6	49.7
VDOT #68	2.588	2.605	2.633	0.67	93	43	2.2	11.5	49.8
VDOT #78	2.597	2.617	2.650	0.77	92	43	3.8	24.8	67.5
VDOT #8	2.582	2.606	2.646	0.93	91	43	1.6	15.2	52.4
VDOT #9	2.582	2.606	2.646	0.93	88	46			

Fine Aggregates

Product	Specific Gravity				Fine Aggregate Angularity		Sand Equivalent	Compaction Weight (lb / ft^3) (Volume estimation only)
	Bulk Dry	SSD	Apparent	Absorption	1252-A	VTM-5		
VDOT #10	2.578	2.607	2.655	1.12	50.5	55.6	52	116.4 @ 2.4 % Moisture
VDOT Grading B Sand	2.672	2.693	2.728	0.76	49.6	55.9	79	109.1 @ 2.3 % Moisture

Source Properties

Coarse Aggregates

Soundness (MgSO4)	L.A. Abrasion A	L.A. Abrasion B	L.A. Abrasion C	Moh's Hardness	Clay Lumps / Friable Particles
7.3	34	33	35	6.0	0.0

Fine Aggregates

Soundness (MgSO4)	Organic Impurities	Clay Lumps / Friable Particles
20.3	Color Plate 1	0.0

LUCK STONE

Gradation Report

Location: Boscobel

Product: VDOT #10

For Period: 04/01/2017 - 09/07/2017

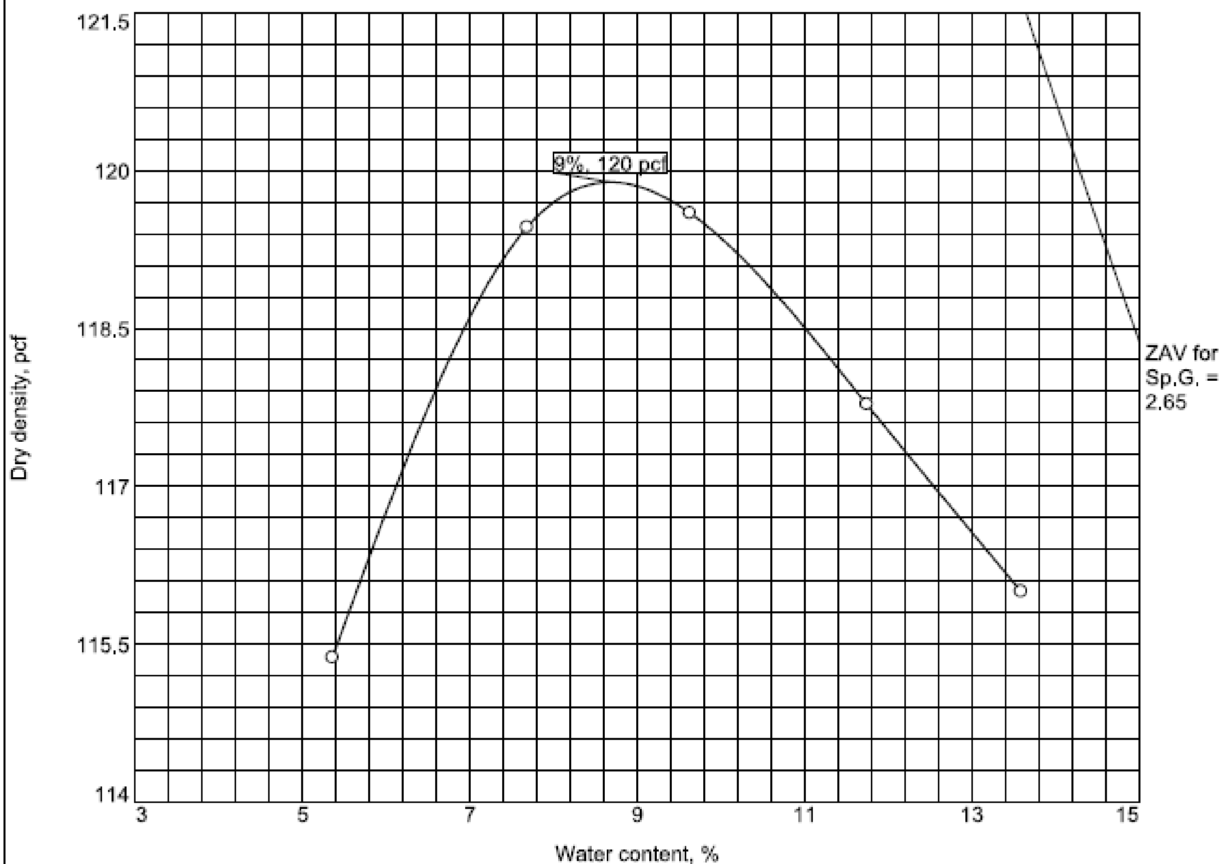
Voice of the Customer

Sieve Size	3/8	#4	#8	#16	#30	#50	#100	#200
Specification	100-100	85-100	Opt	Opt	Opt	Opt	10-30	Opt
Target	100	92.5					20	
Tolerance		7.5					10	

Voice of the Process

Avg % Passing	100.0	99.5	78.6	54.1	37.1	25.7	17.5	11.9
Avg Ind % Retained	0.0	0.5	20.9	24.5	17.0	11.4	8.2	5.6
Number of Samples	25							

Fm
2.9



Test specification: AASHTO T 180-15 Method D Modified

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in.	% < No.200
	USCS	AASHTO						
0.00-0.01	SW	A-1-a		2.65	NP	NP	3.4	1.1

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 120 pcf Optimum moisture = 9 %	(SW) Black, Fine to Coarse Recycled Asphalt Product

Project No. 13786-A **Client:** Allan Myers
Project: I-64 Capacity Improvements Segment II Sub Base Mix Design
Date: 8/24/2017
○ **Source of Sample:** Allan Myers- RAP **Sample Number:** CCPRM #2

ECS MID-ATLANTIC, LLC
108 Ingram Road, Suite 1
Williamsburg, VA 23188
Phone: (757) 229-6677
Fax: (757) 229-9978

Remarks:
Tested in accordance with AASHTO T-180

WET DENSITY- 130.8

Figure

Tested By: MK **Checked By:** SDP

ECS Mid-Atlantic, LLC
1643 Merrimac Trail, Suite A
Williamsburg, Virginia 23185
Office (757) 229-6677
Fax (757) 229-9978

AASHTO T-112
Standard Test Method for Clay Lumps and Friable Particles in Aggregate

ECS Project No.:	13876-A	Principal Engineer	L. Ward, P.E.
Project Name:	I-64 Segment II Sub Base Mix Designs	Project Engineer	S. Phillips
Report Date:	9/13/2017	Tested By	S. Priest

Sample Location	Sample	Percentage Clay Lumps/Friable Particles 1.5" Sieve	Percentage Clay Lumps/Friable Particles 3/4" Sieve	Percentage Clay Lumps/Friable Particles 3/8" Sieve	Percentage Clay Lumps/Friable Particles #4 Sieve	Percentage Clay Lumps/Friable Particles #16 Sieve	Maximum Allowable Percentage Per Sieve Size
Allan Myers New Kent- RAP	2	0	0	0	0	0	0.20

Appendix B: ITS Values (psi)

Initial	**1 Day**	**3 Day**	**7 Day**	**8 Day**	**41 Day**
81.48733	44.08592	35.01409	29.76197	27.85212	28.64789
58.40986	48.54226	30.23944	30.08028	27.05634	30.23944
67.80001	49.65634	27.05634	30.08028	33.74085	30.23944
71.61972	44.08592	27.05634	27.69296	28.25	32.62676
85.94367	50.92958	31.83099	29.76197	27.05634	27.85212
75.5986	44.56338	31.83099			

Appendix C: E* Values (psi)

Initial						
Temp.	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
4ºC	711,893	677,133	652,138	592,382	569,998	515,174
20ºC	544,230	504,344	476,594	410,215	385,994	326,286
38ºC	386,525	346,157	318,793	257,249	236,605	188,984
1 Day						
Temp.	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
4ºC	679,840	642,565	616,555	554,914	532,337	476,255
20ºC	505,021	464,266	436,418	370,040	346,882	288,190
38ºC	339,630	299,213	272,864	214,462	196,139	152,995
2 Day						
Temp.	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
4ºC	538,428	507,777	487,665	440,576	424,284	382,948
20ºC	412,052	378,887	356,599	303,516	286,353	239,699
38ºC	275,330	241,536	221,037	174,577	161,137	126,947
3 Day						
Temp.	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
4ºC	454,355	426,072	408,958	369,701	356,599	322,080
20ºC	330,057	298,778	279,778	236,218	222,294	186,083
38ºC	225,582	197,783	180,282	142,263	131,225	103,658
6 Day						
Temp.	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
4ºC	476,956	447,224	428,586	385,438	371,297	332,426
20ºC	328,510	299,793	281,083	236,484	222,995	185,938
38ºC	232,786	202,908	183,473	143,167	131,216	102,701