

Stockpiling Cold Central Plant Recycling Mixtures

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FINAL REPORT

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ABSTRACT

The Virginia Department of Transportation (VDOT) contracted to reconstruct and add new lanes to a portion of Interstate 64 near Williamsburg. As the work progressed, the contractor requested permission to produce and stockpile the cold central plant recycling (CCPR) mixture that was being used on the project. Since VDOT's specifications did not address this issue, VDOT asked the Virginia Transportation Research Council to investigate whether stockpiling a CCPR mixture had any negative consequences with respect to the mechanical properties of the mixture.

The purpose of this study was to assess the mechanical properties of a CCPR mixture subjected to a laboratory stockpiling procedure. The mechanical properties assessed included the indirect tensile strength and dynamic modulus of the CCPR mixture.

The study found that the laboratory stockpiling procedure was effective at retaining moisture within the mixture over a period of 41 days. The study also found that the CCPR mixture became less workable, as defined by the number of gyrations required to compact a CCPR test specimen in a gyratory compactor, as curing time progressed. The study showed that the indirect tensile strength and dynamic modulus decreased exponentially within the first 3 days of stockpiling and then reached a steady value.

The study recommends that VDOT consider allowing stockpiling of a CCPR mixture produced using foamed asphalt as the recycling agent and cement as the active filler for up to 24 hours, following verification of these findings from a future study that examines field stockpiling from additional projects. Further, the Virginia Transportation Research Council should conduct a follow-up study investigating the stockpiling of CCPR mixtures having different recycling agents and/or active fillers and investigate the ability to store produced CCPR material in a field stockpile.

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INTRODUCTION

Cold central plant recycling (CCPR) is a cold recycling process that uses reclaimed asphalt pavement (RAP) millings to produce new structural layers. Over the last decade, the Virginia Department of Transportation (VDOT) has performed extensive work that identified CCPR as a viable technology for use in shoulders, lane widening, and deep reconstruction of interstate pavements (Diefenderfer et al., 2015; Diefenderfer et al., 2017). Typically, a CCPR mixture is produced at a mobile plant using RAP from the current project or from an existing RAP stockpile. A small amount of emulsified or foamed asphalt binder (typically 1% to 3%) is added at the plant as a recycling agent, and an active filler (portland cement, lime, fly ash, etc.) is added as a dispersing agent and to help with early strength. In addition, recent research has shown that the chemical additive may also have a positive long-term impact on strength (Diefenderfer et al., 2016; Schwartz et al., 2017).

The ability to stockpile CCPR after production prior to paving on a project could help manage construction logistics. Constraints can result if the CCPR plant production rate is less than the rate at which the CCPR material can be placed (especially for thicker layers). However, it is unknown if or for how long the mixture can be produced and stockpiled without sacrificing the as-produced material properties. Current VDOT specifications do not prohibit this practice, and experienced pavement recycling contractors claim that it has been done elsewhere with success. However, observations by Diefenderfer et al. (2016) raise some concerns about the impact on long-term strength. The concern is that any chemical or physical bonds formed within the material in a stockpile would be permanently broken when the material is loaded, transported, placed, and compacted in the field. Although there is existing literature with regard to laboratory curing, there is no information in the literature regarding the impact of stockpiling on the mechanical properties of a CCPR mixture prior to placement. This study sought to address these concerns with respect to mixture performance and to investigate a potential laboratory conditioning method that will simulate stockpiling for future studies.

PURPOSE AND SCOPE

The purpose of this study was to investigate the impact of stockpiling on the mechanical properties of a CCPR mixture. A plant-produced CCPR mixture was sampled, a laboratory stockpiling method was developed, test specimens from the laboratory-stockpiled mixture were fabricated, and the change in mixture properties over time was determined. Mixture properties were assessed at 0, 1, 3, 6, 7, 8, and 41 days after production. The mixture sampled was the CCPR mixture produced for Segment II of the I-64 Widening/ Reconstruction Project (VDOT, 2019).

METHODS

The following tasks were performed to achieve the study objectives:

1. A literature review was conducted.
2. The CCPR mixture was collected from the contractor.
3. A laboratory stockpiling method was developed.
4. Specimens from the CCPR mixture stockpiled in a laboratory in accordance with the developed stockpiling method were prepared and tested in the laboratory.

Literature Review

Literature related to CCPR mixtures was identified by searching various databases related to transportation engineering such as the Transport Research International Documentation (TRID) database. The identified literature was then reviewed to summarize the findings from the relevant previous work.

Collection and Storage of CCPR Mixture Collected From the Contractor

On December 4, 2017, and April 3, 2018, CCPR material was sampled from the Allan Myers asphalt plant in West Point, Virginia. While on-site, all the components of the CCPR mixture (processed RAP, No. 10 aggregates, asphalt binder, water, and portland cement) were processed through a CCPR plant and collected by a front loader. The loader was used to create a small stockpile of processed CCPR material from which to sample. The top surface of the pile was removed to provide a flat plane for collection. The photographs in Figure 1 show the key steps in the process.



Figure 1. Processed CCPR Mixture: (Left) loader collecting the processed mixture; (Right) the processed mixture pile. CCPR = cold central plant recycling.

Development of Laboratory Stockpiling Method

Since the contractor decided not to produce a field stockpile of processed CCPR mixture, the research team had to develop a way to simulate a stockpile in the laboratory. The contractor's initial plan was to cover and mist the stabilized CCPR stockpile to ensure that the mixture did not lose much of the internal moisture present during mixing. Thus, for the simulated stockpile in the laboratory, retaining the mixing moisture was considered to be a good indicator of simulation quality. The researchers developed methods to ensure that the moisture content of the laboratory-stockpiled mixture did not change greatly throughout the study. This was accomplished by storing the processed CCPR mixture in 5-gal buckets.

The sampled CCPR mixture was placed into 5-gal buckets lined with a large plastic bag. Once the buckets were filled, the CCPR mixture was topped with two damp rags, 8 by 8 in, both of which were rung out to remove excess water. The bag was then tied and the lid was closed to create an airtight seal. Steps in that process are shown in Figure 2. A total of 13 buckets of CCPR mixture was collected on the first trip, with an additional 9 buckets on the second trip. Simulated stockpile materials were tested for moisture content and mechanical properties at 1, 3, 6, 7, 8, and 41 days after production.



Figure 2. Sampled CCPR Mixture: (Left) mixture placed into plastic bag lining the bucket; (Middle) damp rags placed on top of mixture; (Right) plastic bag tied around mixture. CCPR = cold central plant recycling.

Preparation and Testing of Specimens From Laboratory-Stockpiled CCPR Mixture

Mix Design

The CCPR mix design used for this study consisted of a blend of 85% RAP and 15% No. 10 aggregate. The CCPR mixture used 2.5% foamed asphalt with a performance grade (PG) of 64S-22 and 1% portland cement by dry weight of the mixture. The target (wet) density for the CCPR mixture was 130.8 lb/ft³, and the target moisture content was 4.8%. The “black rock” gradation (i.e., the gradation of the CCPR mixture including any aged binder coating on the RAP) is shown in Figure 3. This test was conducted in accordance with AASHTO T 27 using a dry sieve analysis. The mix design for this study was performed by the contractor and is provided in Appendix A.

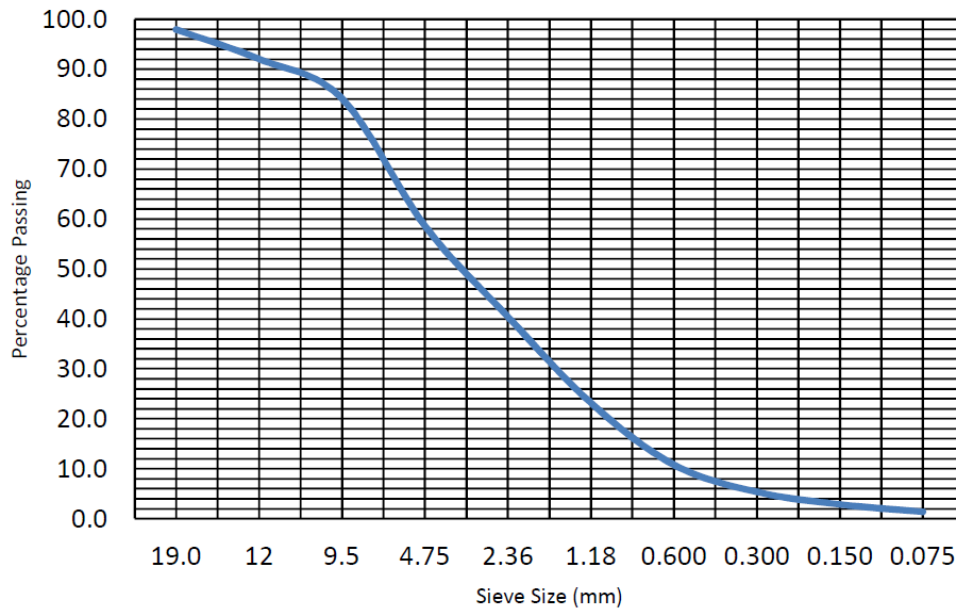


Figure 3. CCPR “Black Rock” Gradation. CCPR = cold central plant recycling.

Specimen Fabrication

Two types of specimens were fabricated from the stockpiled buckets for testing during this study: specimens for indirect tensile strength (ITS) and dynamic modulus tests. For the ITS testing, six specimens having a 4-in diameter and a 2.5-in height (100-mm diameter and 63.5-mm height) were produced. The 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 130 lb/ft³ (2082.4 kg/m³). Using the known volume of the specimen based on the specified dimensions, it was calculated that 2.425 lb (1,100 g) of CCPR mixture would be needed for a single specimen. To create these specimens, a compaction mold (shown in Figure 4) was filled and rodded 25 times: 15 times in the center and 10 times around the perimeter.



Figure 4. Preparing Mold for Marshall Compaction: (Left) mold for Marshall specimen; (Right) filled mold for Marshall specimen

After the mold was filled, it was placed into the Marshall hammer device, as shown in Figures 5 and 6. The specimen was compacted for 75 blows per face/side and had a compacted height of 63.5 ± 2.5 mm. After being extruded from the mold, the samples were cured in a forced draft oven at 40°C for 72 hours followed by 21°C for 24 hours after which the test was conducted in accordance with AASHTO T 283-14.



Figure 5. Setting Mold Into Marshall Hammer: (Left) loading mold into apparatus; (Right) setting up Marshall hammer.



Figure 6. Preparing Mold for Dynamic Modulus Specimens: (Left) placing CCPR mixture into mold; (Middle) rodding mixture after filling bottom half; (Right) rodding mixture after filling top half. CCPR = cold central plant recycling.

After the mixture was placed in the mold, the mold was set into the Superpave gyratory compactor and set to compact until the desired height of 7 in (177.8 mm) was reached. After the specimen was compacted to the desired height and the number of gyrations was recorded, the specimen was extruded from the mold and allowed to cure in a forced draft oven for 3 days at 40°C and for at least 2 weeks at 21°C. An example of a cured specimen is shown in Figure 7.



Figure 7. Cured CCPR Specimen for Dynamic Modulus Testing. CCPR = cold central plant recycling.

After the 7-in (177.8-mm) specimens were cured, they were cored and trimmed to produce a test specimen having a diameter of 4 in (100 mm) and a final height of 6 in (150 mm). These smaller specimens, shown in Figure 8, were then used in the dynamic modulus test.



Figure 8. 150-mm Specimen for Dynamic Modulus Test

Indirect Tensile Strength

Six specimens were created for each stockpiling time increment. For stockpiling times of 0, 1, 3, and 6 days, the specimens were fabricated to a density of 130.0 lb/ft³. At 7 days of simulated stockpiling, the material was too stiff to compact to the original target unit weight and thus a reduced density of 127 lb/ft³ was used for specimens fabricated at 7, 8, and 41 days of stockpiling. For these later ages, the mass of mixture used in each specimen was reduced from 2.425 lb to 2.293 lb (1.100 kg to 1.040 kg).

ITS specimens were tested in accordance with AASHTO T 283-14 with the exception that the soaking cycle was not included (i.e., all specimens were tested in the dry condition). Although six specimens were prepared for each time period, the results for only five are reported for testing at 7, 8, and 41 days. The other specimens at these times were damaged during preparation. A test specimen and the Marshall press apparatus in which the test was conducted are shown in Figure 9.

To conduct the test, the specimen was placed in the ITS apparatus, which applies a compressive force at a rate of 2 in/min. This force results in an indirect tensile failure. Broken specimens and sample results are shown in Figure 10.



Figure 9. ITS Testing: (Left) ITS specimen; (Right) ITS apparatus. ITS = indirect tensile strength.



Figure 10. ITS Specimens After Breaking. ITS = indirect tensile strength.

Dynamic Modulus

The dynamic modulus test was generally conducted in accordance with AASHTO TP 79-15 at stockpiling times of 1, 2, 3, and 6 days. The dynamic modulus test applies a cyclical load

to the specimen while measuring the strain at three locations around the perimeter of the cylinder. This applied stress causes only elastic deformation and was applied at six different frequencies, 25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz, and 0.1 Hz, over three different temperatures, 4.4°C, 21.1°C, and 37.8°C. This was a deviation from the AASHTO standard testing regime of four test temperatures. By collecting the data from the different temperatures and frequencies, a master curve showing the material stiffness at different reduced frequencies was prepared in accordance with AASHTO R 62-13.

To prepare the specimen for testing, strain gauges were attached to mounting studs, which were affixed 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. They are shown in Figure 11.

Following application of the mounting studs, the test specimens were held in an environmental chamber to bring the internal specimen temperature to the appropriate testing temperatures for the required times, which are described in Table 1. Once the specimens reached the required temperature, they were placed in the asphalt mixture performance tester and the strain gauges were attached as shown in Figure 12. After waiting for the environmental chamber in the tester to reach the test temperature, the dynamic modulus test was started. This process was repeated with three specimens from each time interval.



Figure 11. Mounting Studs Affixed to Dynamic Modulus Test Specimen

Table 1. Dynamic Modulus Temperature and Equilibrium Time

| Temperature, °C | Equilibrium Time |
|-----------------|------------------|
| 4.4 | Overnight |
| 21.1 | 4 hr |
| 37.8 | 2 hr |



Figure 12. Dynamic Modulus Test Specimen in Asphalt Mixture Performance Tester

RESULTS AND DISCUSSION

Literature Review

Stockpiling

The literature review identified few sources directly discussing stockpiling of a CCPR mixture. However, much study has been devoted to stockpiling RAP, and some of this relevant information is included here.

Improperly stockpiled RAP or CCPR can increase variability in properties such as aggregate gradation, asphalt content, and moisture content (Kim et al., 2011; Zhou et al., 2010). Kim et al. (2011) found a relationship where a decrease in moisture content led to an increase in tensile strength. In areas that receive significant precipitation, it is beneficial to store the RAP on a paved, sloped surface to allow rainwater to drain away. Variations in moisture content of stockpiled materials can also be reduced by covering the stockpile, ideally under the roof of an open-sided building, to allow air to pass through but keep the pile safe from precipitation (Zhou et al., 2010). The shape of the stockpile also plays a role in how well it functions. In the case that the stockpile cannot be covered, a conical stockpile shape is the most effective to protect the RAP from precipitation. In addition, the stockpile should not be made too high, and to avoid any compaction of the RAP, large vehicles should not travel on the top (Stroup-Gardiner, 2016).

Curing Methods

To gain strength, CCPR mixtures must be allowed to cure properly after they have been produced and placed. This has been shown to happen on a construction site where the CCPR mixture will be stronger after even a few hours, although gaining near-full strength can take days to weeks (Xu et al., 2011). To accelerate this process in the laboratory, Wirtgen GmbH (2012) recommended curing laboratory-fabricated specimens in a forced draft oven for 72 hours at 40°C or 60°C for CCPR mixtures using foamed asphalt or emulsified asphalt, respectively.

Mechanical Testing

Because a foamed CCPR mixture was used in this study, the ITS test was used for mix design and for quality control and acceptance (VDOT, 2015a; VDOT, 2015b; Wirtgen GmbH, 2012). Dynamic modulus testing of CCPR was conducted by Diefenderfer et al. (2016) and expanded further with additional mixture types by Schwartz et al. (2017). Schwartz et al. (2017) found that the dynamic modulus test captured the time-temperature dependency of the CCPR mixtures and the influence of active fillers (lime and cement) on stiffness.

Storage of Collected CCPR Mixture in the Laboratory

The CCPR mixture collected from the contractor was stored in their 5-gal buckets until the material was used to fabricate test specimens. The buckets were stored in the laboratory at the Virginia Transportation Research Council (VTRC) under ambient laboratory conditions. To determine if the laboratory simulation adequately represented a field stockpile, the research team assessed the moisture content of the mixture. The contractor had originally planned to use a series of water misters in the field stockpile to keep the produced CCPR at the mixing moisture content. If the produced CCPR mixture was allowed to dry (i.e., have a moisture content less than the mixing moisture content), it was thought that the material would be too stiff to place and achieve the desired density.

Developed Laboratory Stockpiling Method

Moisture Content

One major concern during stockpile simulation was ensuring adequate retention of moisture within the mixture. During specimen preparation, a sample was taken from one bucket at each laboratory stockpiling time interval and the moisture content was determined in accordance with ASTM C566-13. The moisture contents and the percent differences from the initial value are shown in Table 2.

The initial moisture content determined at the time of sampling was 6.00% and was achieved at the plant, as seen from the initial day value in Table 3. The average moisture content across all stockpiling times was 6.08%, with a standard deviation of 0.14. The average percent difference from the initial value of 6.00% was 1.33% where the largest average percent difference from the initial value was 4.66%. The other values differed no more than 0.50%,

suggesting minimal variability in moisture content. Because of the lack of variability, the method used to stockpile the CCPR mixture in the laboratory was deemed an effective means of minimizing moisture loss.

Table 2. Moisture Content

| Day | Moisture Content (%) | Percent Difference From Initial Value |
|---------|----------------------|---------------------------------------|
| Initial | 6.00 | 0 |
| 1 | 5.98 | -0.33 |
| 2 | 6.28 | 4.66 |
| 3 | 6.03 | 0.50 |
| 6 | 6.03 | 0.50 |

Table 3. Mean Results From ITS Testing

| Day | Mean ITS Result (psi) | Standard Deviation | Coefficient of Variability (%) |
|---------|-----------------------|--------------------|--------------------------------|
| Initial | 73.5 | 9.9 | 13.4 |
| 1 | 47.0 | 3.1 | 6.6 |
| 3 | 30.5 | 3.1 | 10.1 |
| 7 | 29.5 | 1.0 | 3.4 |
| 8 | 28.8 | 2.8 | 9.8 |
| 41 | 29.9 | 1.8 | 6.1 |

ITS = indirect tensile strength.

Test Results for Laboratory-Prepared Specimens

Compaction Effort

In addition to moisture retention, the other concern with stockpiling a CCPR mixture that may arise is that of compaction effort. The study found that the number of gyrations required to reach the same specimen density increased for each day of stockpiling. The gyratory specimens used in this analysis were those that were used for the dynamic modulus test. Figure 13 shows the average number of gyrations required to create a specimen with respect to the number of days the mixture had been stockpiled.

The number of gyrations required to compact the material increased linearly for 6 days. This increase in compaction effort suggests that the mixture was less workable and therefore might be more difficult to compact in the field if it is stockpiled in the field for an extended period of time. It is suggested here that the cement begins hydrating when the mixture is produced and these bonds cause the mixture to be less workable. By extension, if these bonds are broken when the loose mixture is compacted, they are not likely to be reestablished. No specimens were compacted after 6 days because of the effort required by the gyratory compactor to meet the density requirements for the specimens.

ITS Results

As previously stated, six specimens were tested for the first three stockpiling periods (initial, 1 day, 3 days) and five were tested for the last three (7 days, 8 days, 41 days). The mean and standard deviation for the tests are shown in Table 3. The raw data are provided in Appendix B.

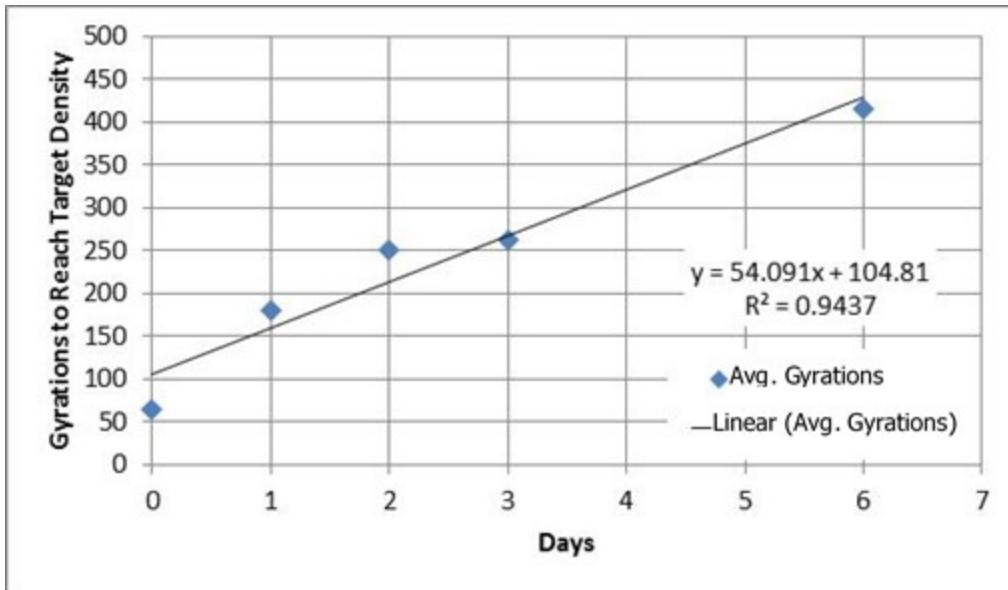
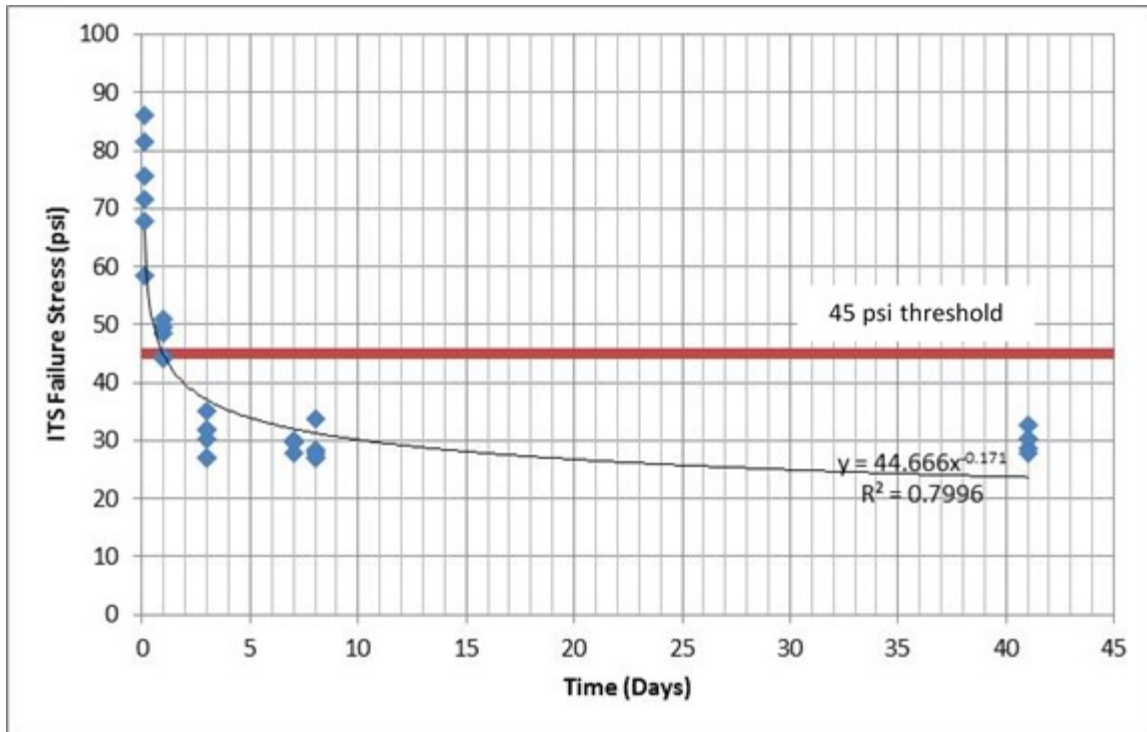


Figure 13. Number of Gyration to Meet Target Specimen Density

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 Figure 14. These results suggest that there is a sharp drop in tensile strength for the CCPR mixture even after just 1 day of laboratory stockpiling, with a 36% reduction of its initial tensile strength. At 3 days, there is a reduction of approximately 59% of the initial strength, after which the strength achieves a stable value. The data in Figure 14 are also shown with a 45 lb/in² threshold for what is acceptable as defined by VDOT's CCPR specifications.

A series of Student's *t*-tests were used to compare consecutive sets of tests to determine if the differences in ITS values at different stockpiling times were 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 in Table 4.

The results from the *t*-test showed that after 3 days, the differences in the mean ITS values of this CCPR mixture were not statistically significant. This suggests that after 3 days the CCPR mixture reaches its lowest strength and storing it longer would have little to no effect on the ITS values. Further, after the 7-day tests, the density of the prepared test specimens had decreased from 130 lb/ft³ to 127 lb/ft³ because they could no longer be compacted to the higher density. This change in density did not cause a statistical difference in the ITS result.



Figure

14. ITS Test Results. ITS = indirect tensile strength.

Table 4. *t*-Test Results

| Comparison | 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 |

Dynamic Modulus Results

Figure 15 shows the dynamic modulus master curves for the initial, 1-, 2-, 3-, and 6-day specimens. The tabulated results for the dynamic modulus curves are provided in Appendix C. There was a decrease in the dynamic modulus of between 7% and 20% with each consecutive day from the initial until the third day at a frequency of 10 Hz using the fitted curve with a reference temperature of 70°F (21.1°C). However, between the third and sixth day, the difference was only 1% for the initial frequency and the final result was an increase by about 4%. This suggests that stiffness, as with ITS, is lost very quickly within the first few days of stockpiling but remains constant after the third day. Figure 16 compares the trends observed for the average ITS values and the dynamic modulus values at 21.1°C and 10 Hz. The correlation coefficient between these two trends was 0.89, suggesting that the results of testing are correlated to a high degree.

The identified relationship between ITS and dynamic modulus may suggest that the factors causing the decrease in tensile strength also cause the decrease in stiffness over time while the CCPR mixture is stockpiled. Xu et al. (2011) suggested that tensile strength increases

linearly with cement content; this increase suggests that cement plays a key role and could explain why the dynamic modulus and ITS values follow a similar trend. Cement begins to hydrate as soon as the mixture is produced, which is why the test specimens made the same day the mixture was produced had the highest values for stiffness and tensile strength. As the mixture is stockpiled and the cement continues to hydrate, the bonds that increase the strength of the mixture may be broken upon compaction at later ages.

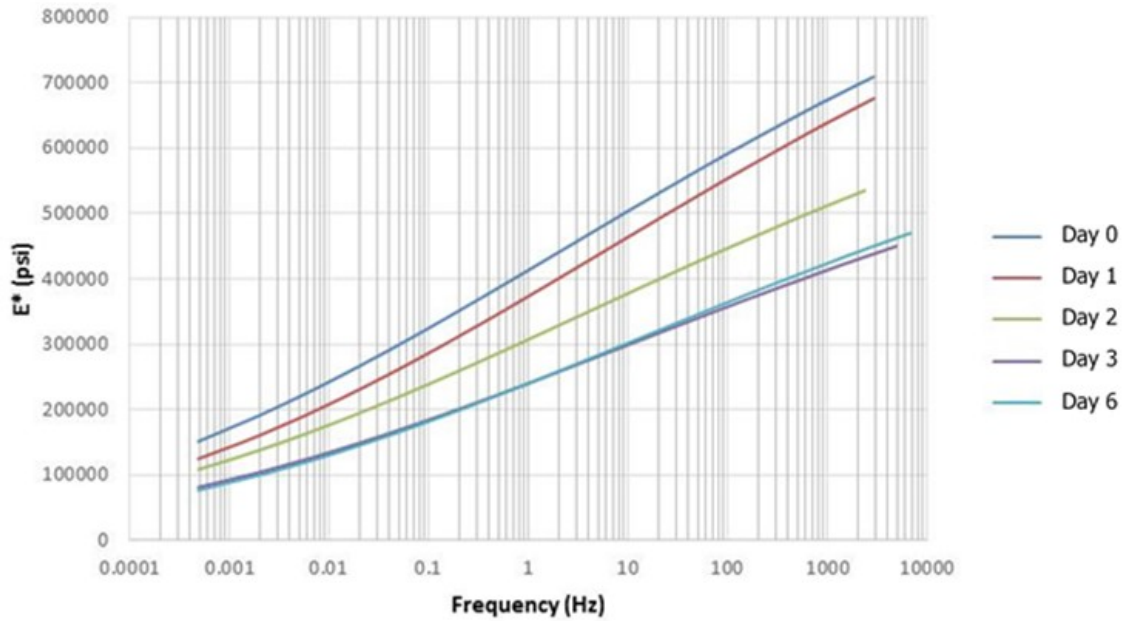


Figure 15. Dynamic Modulus Results

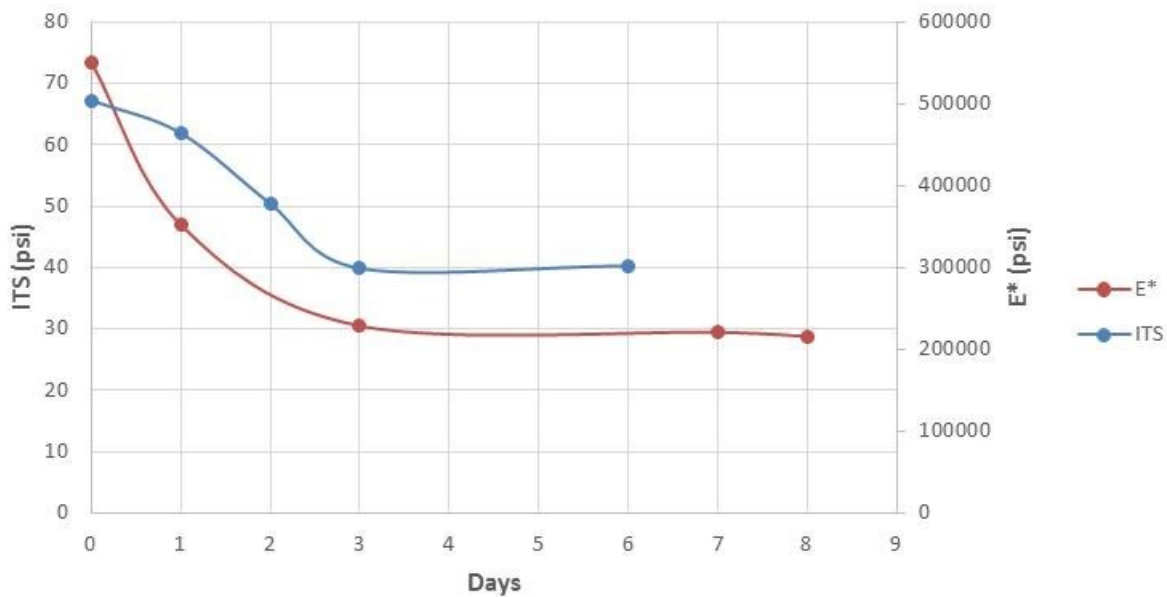


Figure 16. Average ITS and E* at 21.1°C and 10 Hz. ITS = indirect tensile strength.

SUMMARY OF FINDINGS

- The moisture content did not vary practically regardless of the number of days the mixture was stockpiled in a laboratory stockpiling environment, validating the laboratory stockpiling process.
- Laboratory stockpiling increased the compactive effort required to create a specimen for each additional time increment tested.
- After 3 days of stockpiling, the ITS test specimen was produced to a lower density in order to meet the specimen geometry requirements outlined in the ITS specification. This did not appear to affect the ITS of the CCPR mixture.
- The tensile strength after 1 day of laboratory stockpiling was just above VDOT's 45 lb/in² minimum, but it had decreased by 36% compared to the strength of the day-of-production specimens.
- The tensile strength decreased more than 50% within the first 3 days of stockpiling, falling below the VDOT-required 45 lb/in² minimum, after which it remained constant.
- The dynamic modulus decreased by 7% to 20% within the first 3 days of stockpiling and then remained constant.

CONCLUSIONS

- *The increase in required compactive effort in the laboratory for CCPR mixtures likely portends an increase in compactive effort required in the field.*
- *As a CCPR mixture is stockpiled and the cement continues to hydrate, the bonds that increase the potential strength of the mixture may be broken upon compaction at later ages.*
- *All testing was conducted on a CCPR mixture using foamed asphalt as the recycling agent and cement as the active filler; therefore, the recommendations in this report apply only to CCPR mixtures using these same additives.*

RECOMMENDATIONS

1. *VDOT's Materials Division should consider allowing a contractor to stockpile a CCPR mixture produced using foamed asphalt as the recycling agent and cement as the active filler for up to 24 hours following verification of these findings from a future study that examines field stockpiling from additional projects.*

2. *VTRC should conduct a follow-up study investigating the stockpiling of CCPR mixtures having different recycling agents and/or active fillers and study the ability to store produced CCPR material in a field stockpile.*

IMPLEMENTATION AND BENEFITS

Implementation

Recommendation 1 will be considered by VTRC and the VDOT Materials Division's Pavement Recycling Committee in discussing future modifications to VDOT's CCPR specification. It is anticipated that this recommendation will be considered during the 2019 construction season.

Recommendation 2 will be implemented by VTRC in a forthcoming study. It is anticipated that this study will begin during the 2019 construction season depending on availability of projects and contractor assistance.

Benefits

With regard to implementing Recommendation 1, allowing a contractor to stockpile a CCPR mixture for a short time period after production could allow for increased production by accommodating the difference between plant production rates and construction time. In this study, it was found that the tensile strength of the material decreased rapidly after production. Therefore, the ability to pass all required quality tests should be assessed prior to placing the material in the field. This phenomenon should be understood when modifying the existing VDOT CCPR placement specification to allow limited stockpiling as approved by the project engineer.

With regard to implementing Recommendation 2, conducting tests on materials from additional projects will give VDOT the added information required to make a change to existing specifications.

ACKNOWLEDGMENTS

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APPENDIX A
CCPR MIX DESIGN REPORT

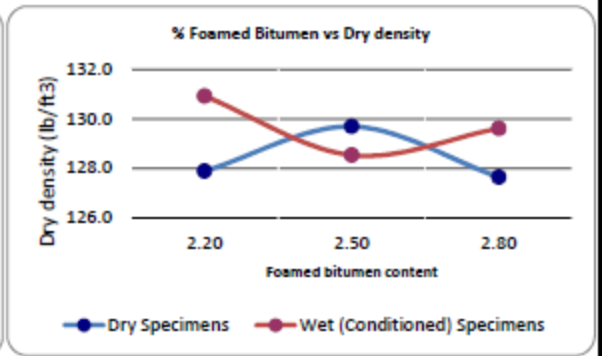
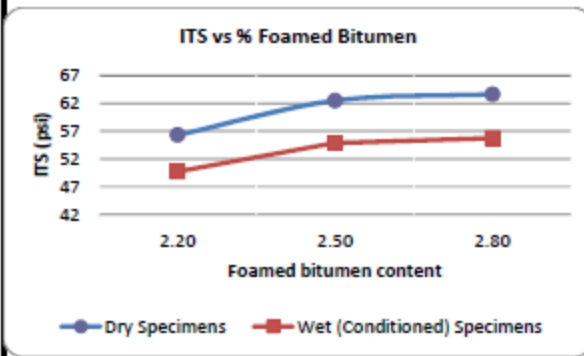
Client: Allan Myers - New Kent Plant West Point, VA
 Project: I-64 CCPR Date Tested: 7/20/2017
 Sample Number: RAP (85%) and #10 Screenings (15%) Blend Date Reported: 7/20/2017

FOAMED BITUMEN MIX DESIGN REPORT

| <u>MATERIAL TO BE STABILISED</u> | | 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 | |

| <u>BITUMEN FOAMING CONDITIONS</u> | | | |
|-----------------------------------|-----|--------------------------|---------------|
| Foaming water added (%) | 2.0 | Bitumen temperature (°C) | 165°C (329°F) |

| <u>FOAMED BITUMEN STABILISED MATERIAL CHARACTERISTICS</u> | | | | 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 | | |
| <i>Optimum</i> | | | | | |
| 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

Project : I-64 CCPR Sheet 1
 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 | | After Curing | |
|------------------------|--------------|-------------|-------------|--|--------------|--------|
| | | | Moulding | | Dry | 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

Sheet 2

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 | | After Curing | |
|-----------------------|--------------|-------------|--|--------------|--------|
| | | Moulding | | Dry | 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

Project : I-64 CCPR Sheet 3
 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 | | After Curing | |
|------------------------|--------------|-------------|-------------|--|--------------|--------|
| | | | Moulding | | Dry | 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

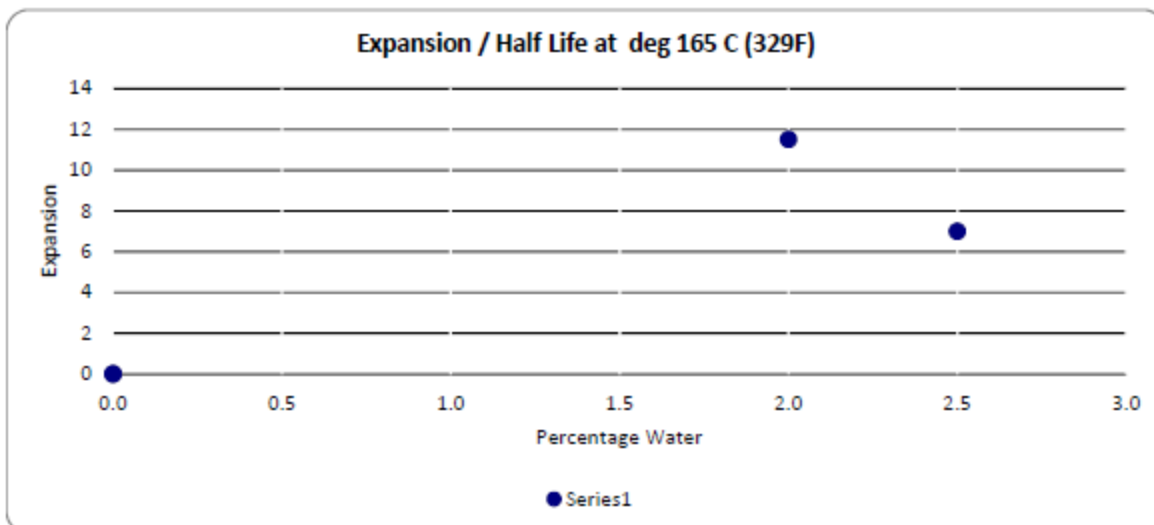
Setting

| | |
|------------------------|--------|
| 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

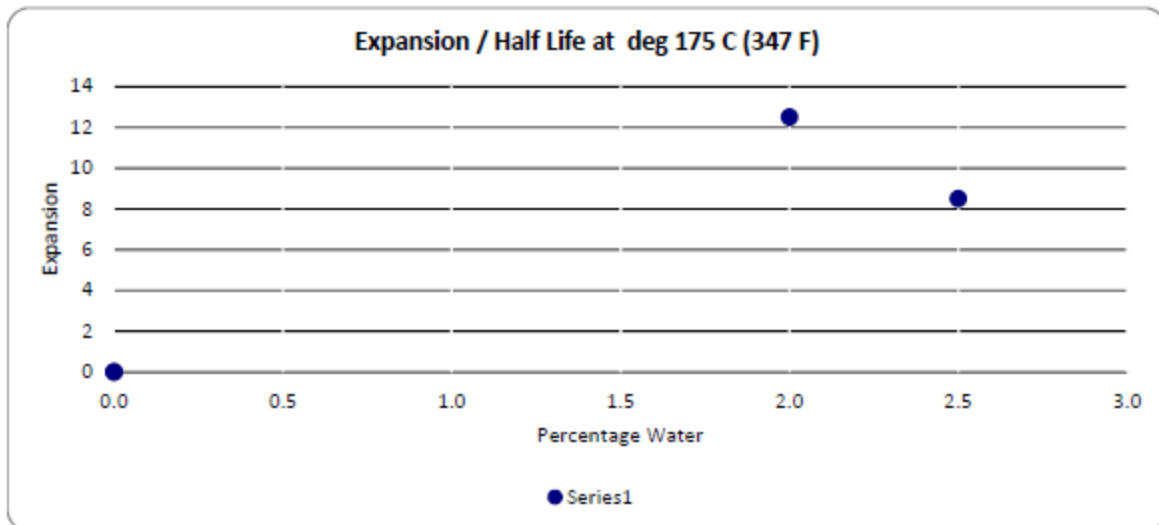
Quantity required (%):

| | | | |
|---|---|---|---|
| 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 |
|-----|

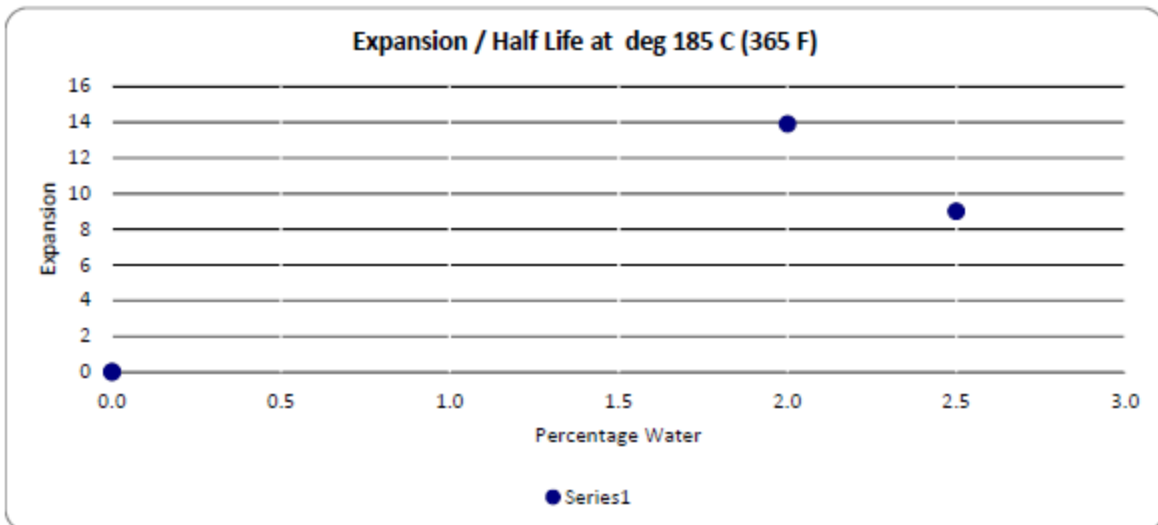
 Quantity sprayed (g):

| |
|--------|
| 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 |



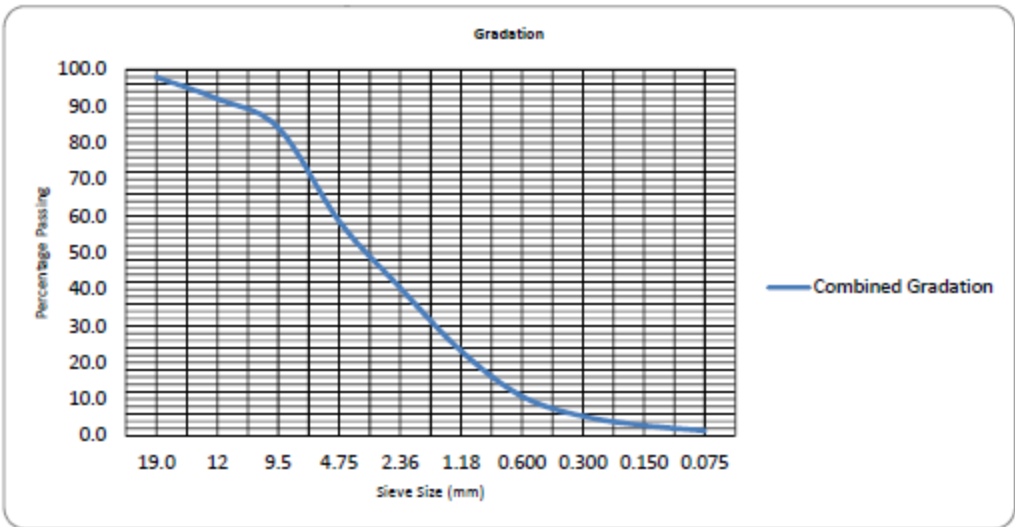
OPTIMUM FOAM MOISTURE CONTENT

| |
|-------------|
| 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 | | Total percentage in Blend |
|---------------------|-------|-----------------|-------|----------------|-------|----------|-------|------------------------------------|
| Location: | | Unprocessed RAP | | #10 Screenings | | | | |
| Description: | | | | | | | | |
| Sample No.: | | | | | | | | |
| Date sampled: | | 8/28/2017 | | 8/28/2017 | | | | |
| Percentage in Blend | | 85.0 | | 15.0 | | | | |
| Mass of sample (g) | | 1661.4 | | 525.6 | | | | |
| Sieve size | | Weight | % | Weight | % | Weight | % | Combined Grading |
| mm | inch | Retained | Pass. | Retained | Pass. | Retained | Pass. | |
| 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 contractor Allan Myers was combined and split to the reported sample size using AASHTO T 248 (Method A). RAP and aggregate samples were taken



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 |

The information contained in this bulletin follows accepted AASHTO or ASTM testing protocols and is considered accurate, but are made without guarantee. Luck Stone Corp. disclaims any liability incurred in connection with the use of this data.



Gradation Report

Location: Boscobel

Product: VDOT #10

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

Voice of the Customer

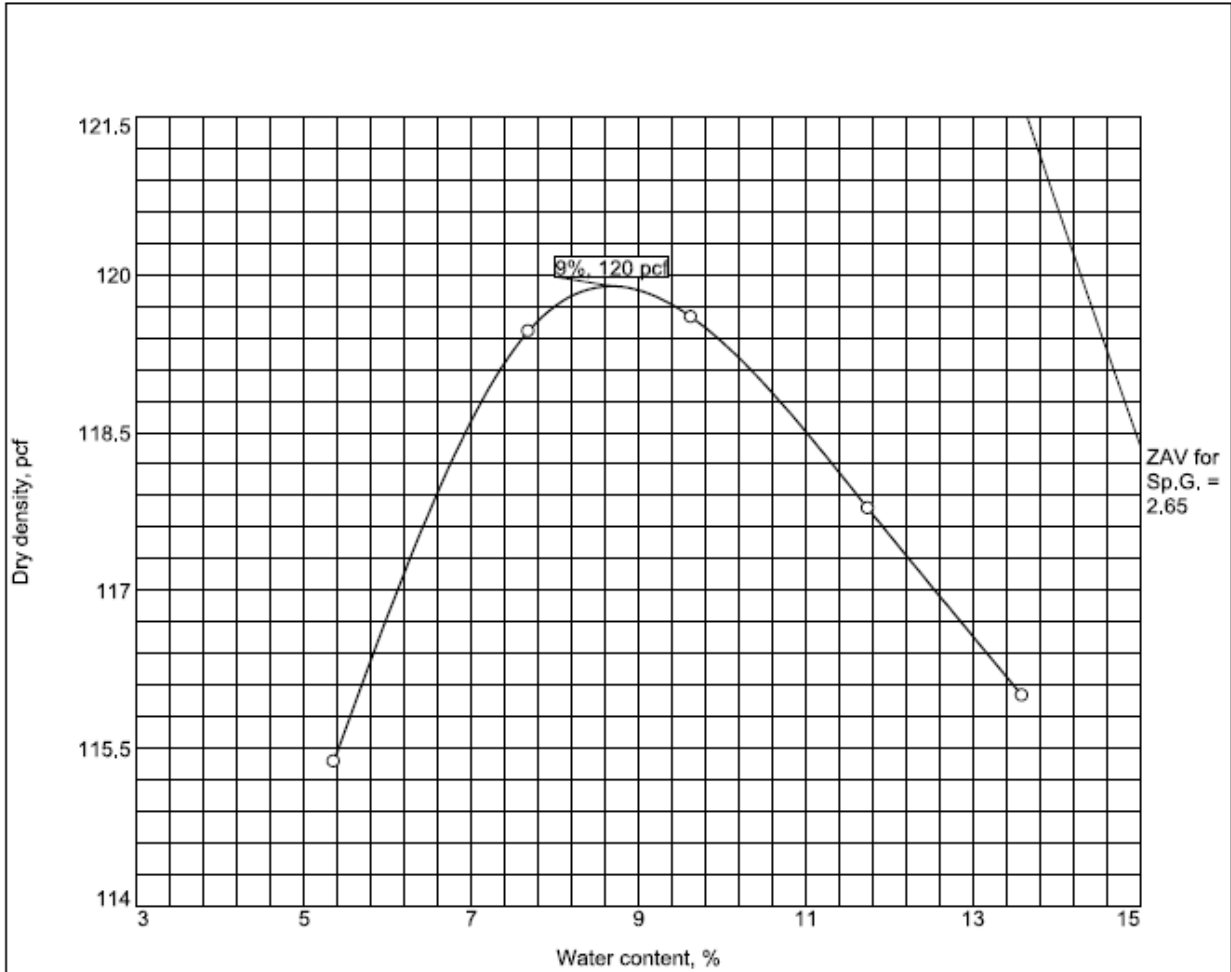
| Sieve Size | 3/8 | #4 | #8 | #16 | #30 | #50 | #100 | #200 |
|---------------|---------|--------|-----|-----|-----|-----|-------|------|
| Specification | 100-100 | 85-100 | Opt | Opt | Opt | Opt | 10-30 | Opt |
| Target | 100 | 92.5 | | | | | 20 | |
| Tolerance | | 7.5 | | | | | 10 | |

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 <input type="checkbox"/> Source of Sample: Allan Myers- RAP Sample Number: CCPRM #2 | Remarks: Tested in accordance with AASHTO T-180 WET DENSITY- 130.8 |
| | |

Figure

Tested By: MK Checked By: SDP



ECS Mid-Atlantic, LLC
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 Office (757) 229-6677
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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 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |

APPENDIX B

INDIRECT TENSILE STRENGTH DATA

Table B1. ITS Values (psi)

| Initial | 1 Day | 3 Day | 7 Day | 8 Day | 41 Day |
|----------------|--------------|--------------|--------------|--------------|---------------|
| 81.5 | 44.1 | 35.0 | 29.8 | 27.9 | 28.6 |
| 58.4 | 48.5 | 30.2 | 30.1 | 27.1 | 30.2 |
| 67.8 | 49.7 | 27.1 | 30.1 | 33.7 | 30.2 |
| 71.6 | 44.1 | 27.1 | 27.7 | 28.3 | 32.6 |
| 85.9 | 50.9 | 31.8 | 29.8 | 27.1 | 27.9 |
| 75.6 | 44.6 | 31.8 | | | |

APPENDIX C
DYNAMIC MODULUS TEST RESULTS

Table C1. Dynamic Modulus Values (psi)

| Initial | | | | | | |
|----------------|---------|---------|---------|---------|---------|---------|
| Temp. | 25 Hz | 10 Hz | 5 Hz | 1 Hz | 0.5 Hz | 0.1 Hz |
| 4°C | 711,893 | 677,133 | 652,138 | 592,382 | 569,998 | 515,174 |
| 20°C | 544,230 | 504,344 | 476,594 | 410,215 | 385,994 | 326,286 |
| 38°C | 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 |
| 4°C | 679,840 | 642,565 | 616,555 | 554,914 | 532,337 | 476,255 |
| 20°C | 505,021 | 464,266 | 436,418 | 370,040 | 346,882 | 288,190 |
| 38°C | 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 |
| 4°C | 538,428 | 507,777 | 487,665 | 440,576 | 424,284 | 382,948 |
| 20°C | 412,052 | 378,887 | 356,599 | 303,516 | 286,353 | 239,699 |
| 38°C | 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 |
| 4°C | 454,355 | 426,072 | 408,958 | 369,701 | 356,599 | 322,080 |
| 20°C | 330,057 | 298,778 | 279,778 | 236,218 | 222,294 | 186,083 |
| 38°C | 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 |
| 4°C | 476,956 | 447,224 | 428,586 | 385,438 | 371,297 | 332,426 |
| 20°C | 328,510 | 299,793 | 281,083 | 236,484 | 222,995 | 185,938 |
| 38°C | 232,786 | 202,908 | 183,473 | 143,167 | 131,216 | 102,701 |