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Stockpiling Cold Central Plant Recycling Mixtures

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Final Report VTRC 19-R32

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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 19-R32	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Stockpiling Cold Central Plant Recycling Mixtures		5. Report Date: May 2019 6. Performing Organization Code:
7. Author(s): Benjamin F. Bowers, Ph.D., P.E., Brian K. Diefenderfer, Ph.D., P.E., and Syed Kazmi		8. Performing Organization Report No.: VTRC 19-R32
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 112108
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report.		

16. 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.

17 Key Words: Pavement Recycling, Cold Central Plant Recycling		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 42	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2019
VTRC 19-R32

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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.

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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/ft^3, 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.

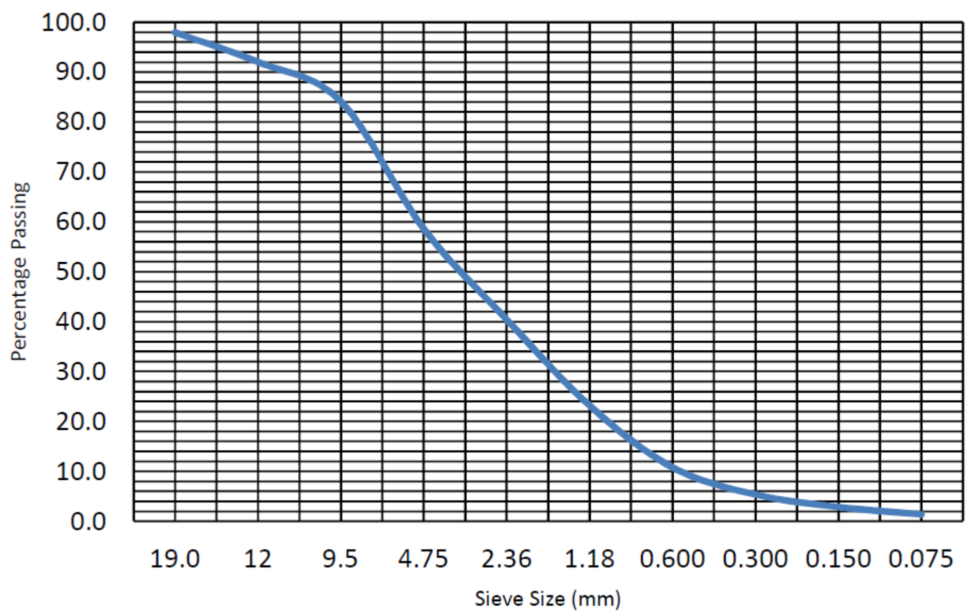


Figure 3. CCPR "Black Rock" Gradation. CCPR = cold central plant recycling.

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/ft^3 (2082.4 kg/m^3). 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/ft^3. 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/ft^3 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.

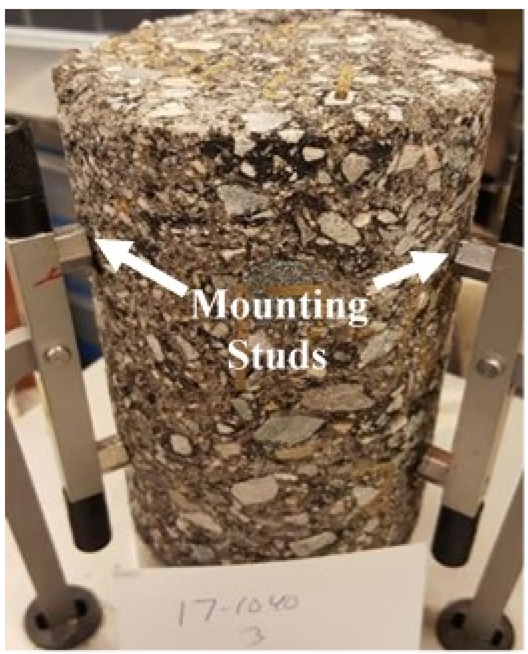


Figure 11. Mounting Studs Affixed to Dynamic Modulus Test Specimen

Table 1. Dynamic Modulus Temperature and Equilibrium Time

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

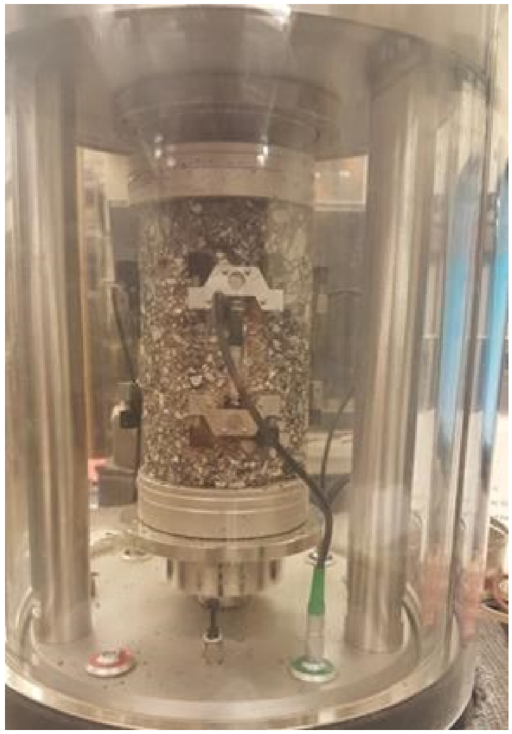


Figure 12. Dynamic Modulus Test Specimen in Asphalt Mixture Performance Tester

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 the 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.

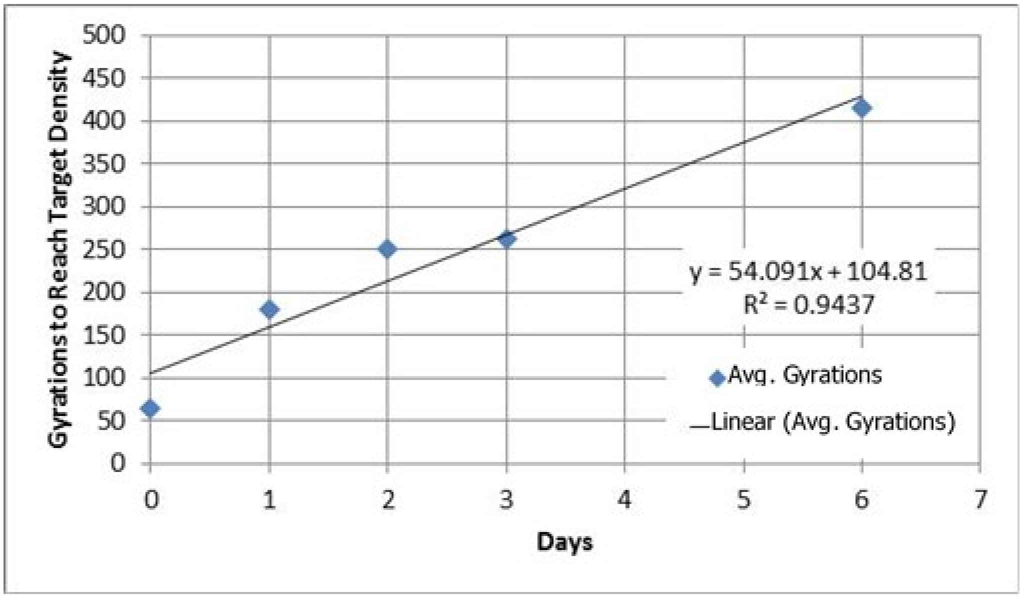


Figure 13. Number of Gyrations to Meet Target Specimen Density

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/in^2 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/ft^3 to 127 lb/ft^3 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.

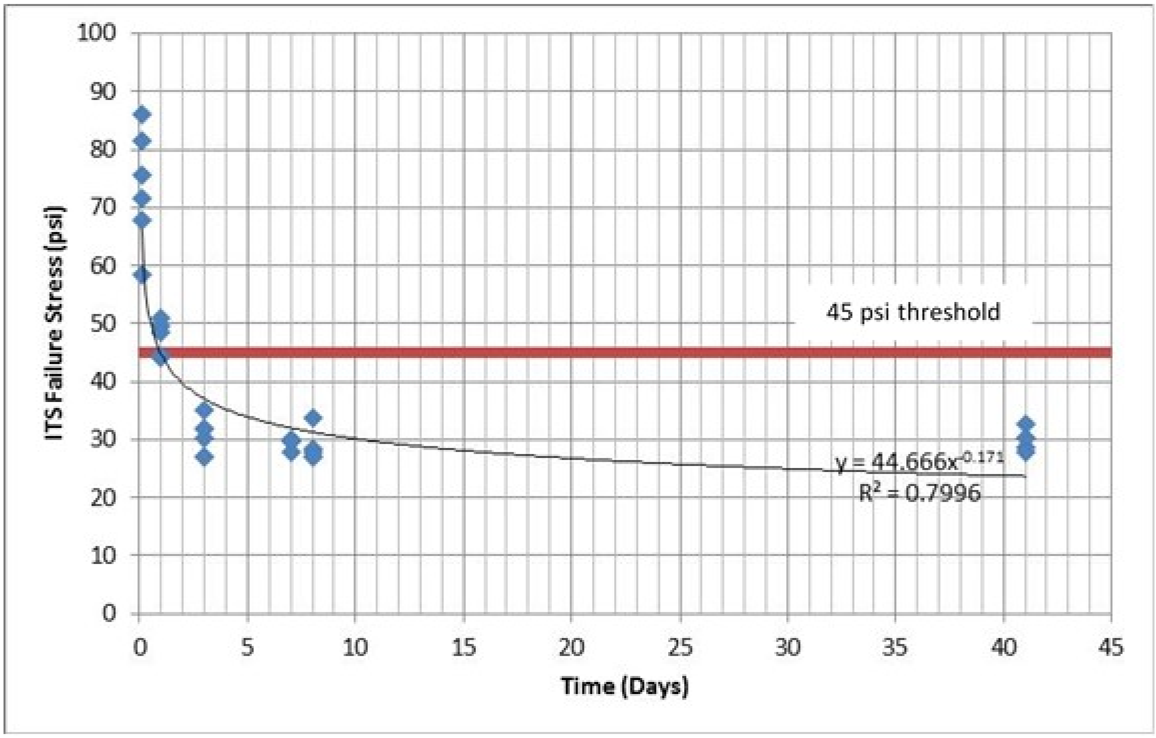


Figure 14. ITS Test Results. ITS = indirect tensile strength.

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.

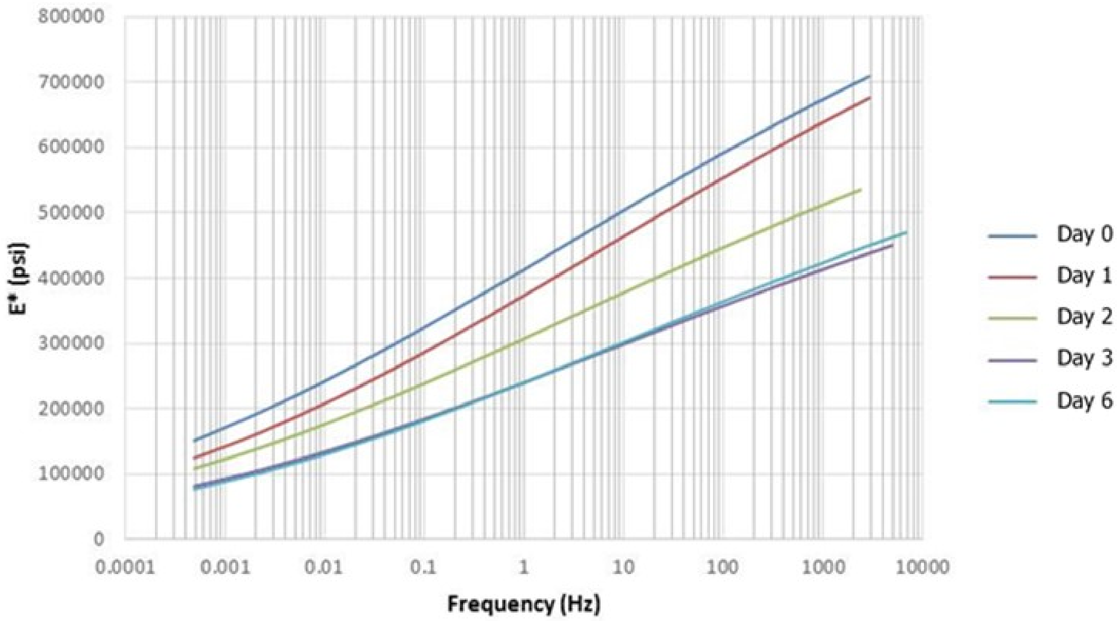


Figure 15. Dynamic Modulus Results

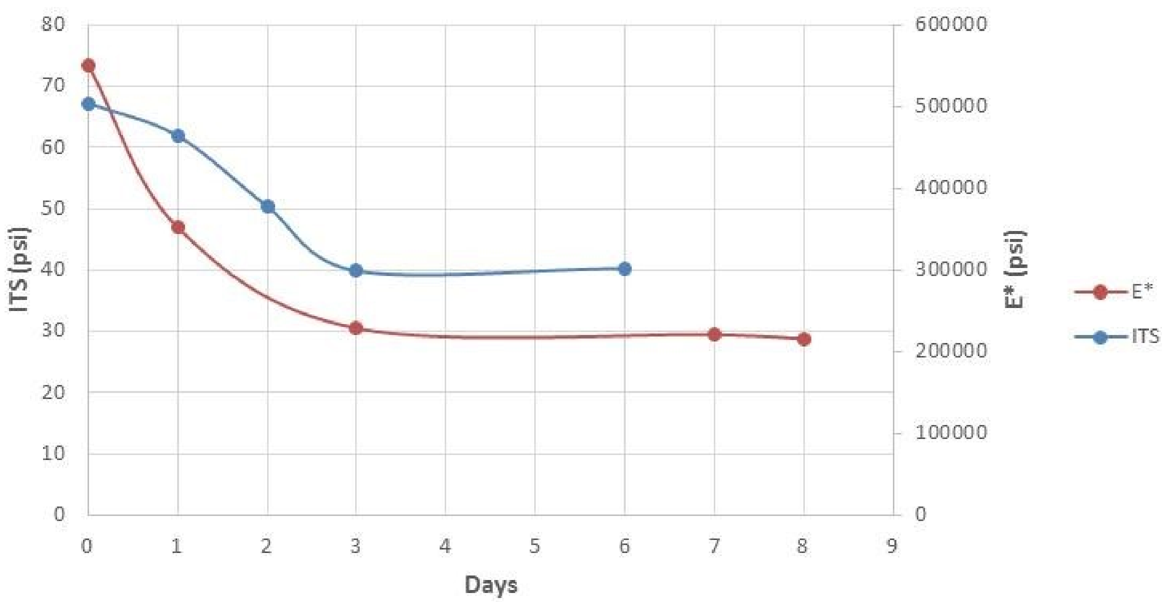


Figure 16. Average ITS and E* at 21.1°C and 10 Hz. ITS = indirect tensile strength.

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/in^2 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/in^2 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

The authors acknowledge the assistance of Nick Schwear, Rob Schwear, and Travis Cable (Allan Myers); Mike Marshall (Wirtgen America); Stephanie Drain (S. Drain Engineering of Illinois); and Steve Cross (Asphalt Recycling and Reclaiming Association). The authors acknowledge Linda Evans, VTRC, for assistance with the editorial process.

Affan Habib, Girum Merine, Thomas Tate, and Mike Wells (VDOT) and Trenton Clark (Virginia Asphalt Association) served as the technical review panel for this study.

REFERENCES

Diefenderfer, B.K., Bowers, B.F., and Apeagyei, A.K. Initial Performance of Virginia's Interstate 81 In-Place Pavement Recycling Project. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2524, 2015, pp. 152-159.

Diefenderfer, B.K., Bowers, B.F., Schwartz, C.W., Farzaneh A., and Zhang, Z. Dynamic Modulus of Recycled Pavement Mixtures. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2575, 2016, pp. 19-26.

Diefenderfer, B.K., Sanchez, M.D., Timm, D.H., and Bowers, B.F. *Structural Study of Cold Central Plant Recycling Sections at the National Center for Asphalt Technology (NCAT) Test Track*. VTRC 17-R9. Virginia Transportation Research Council, Charlottesville, 2017.

Kim, Y., Im, S., and Lee, H. 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*, Vol. 23, 2011, pp. 542-553.

Schwartz, C., Diefenderfer, B., and Bowers, B. *NCHRP Report 863: Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete*. Transportation Research Board, Washington, DC, 2017.

Stroup-Gardiner, M. *NCHRP Synthesis 495: Use of Reclaimed Asphalt Pavement and Recycled Asphalt Shingles in Asphalt Mixtures*. Transportation Research Board, Washington, DC, 2016.

Virginia Department of Transportation. *Special Provision for Cold Central Plant Recycling Material Placement*. Richmond, 2015a.

Virginia Department of Transportation. *Special Provision for Cold Central Plant Recycling Material*. Richmond, 2015b.

Virginia Department of Transportation. I-64 Widening—Segment II. 2019. http://i64widening.org/learn_more/segment_2.asp. Accessed March 22, 2019.

Wirtgen GmbH. *Cold Recycling Manual*. Windhagen, Rhineland-Palatinate, Germany, 2012.

Xu, J., Huang, S.-C., Qin, Y.-C., and Li, F. The Impact of Cement Contents on the Properties of Asphalt Emulsion Stabilized Cold Recycling Mixtures. *International Journal of Pavement Research and Technology*, Vol. 4, No. 1, 2011, pp. 48-55.

Zhou, F., Das, G., Scullion, T., and Hu, S. *RAP Stockpile Management and Processing in Texas: State of the Practice and Proposed Guidelines*. FHWA/TX-10/0-6092-1. Texas Transportation Institute, Austin, 2010.

APPENDIX A

CCPR MIX DESIGN REPORT

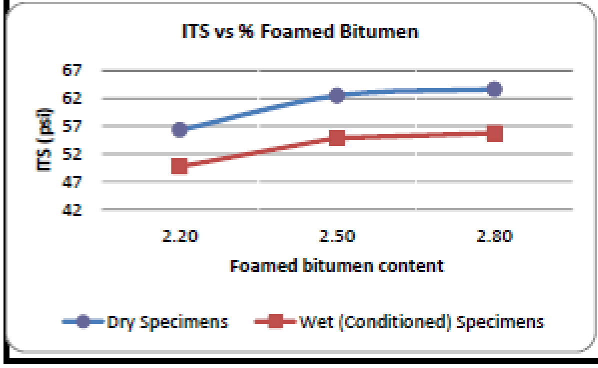
Client:	Allan Myers - New Kent Plant West Point, VA			
Project:	I-64 CCPR		Date Tested:	7/20/2017
Sample Number:	RAP (85%) and #10 Screenings (15%) Blend		Date Reported	7/20/2017

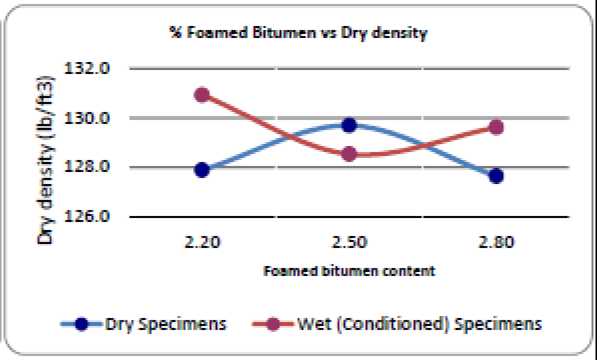
FOAMED BITUMEN MIX DESIGN REPORT

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

			Preparation		After Curing	
		Hygroscopic	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

			Preparation		After Curing	
		Hygroscopic	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

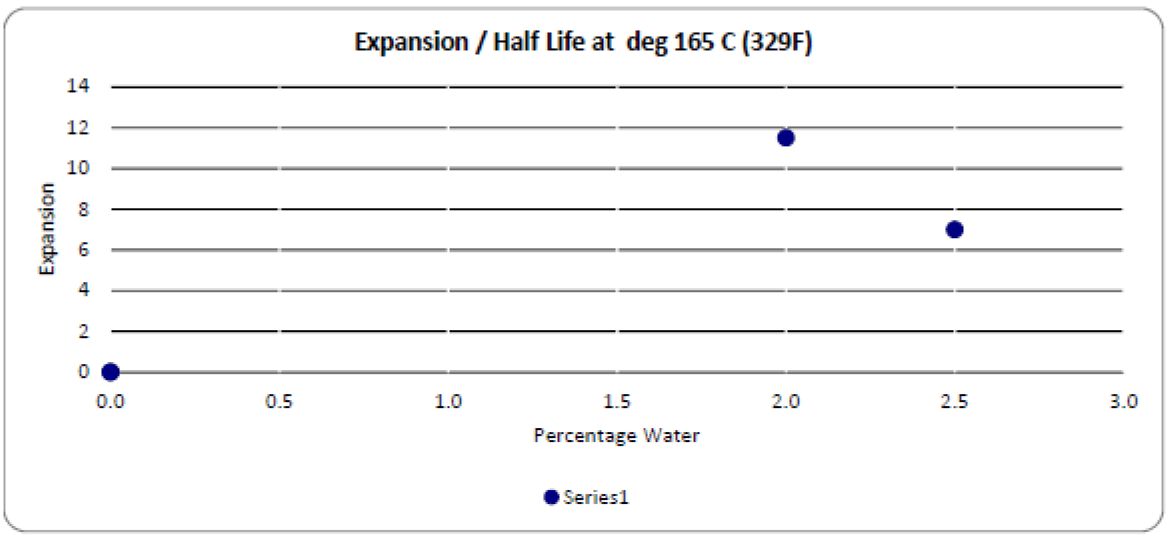
Setting

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

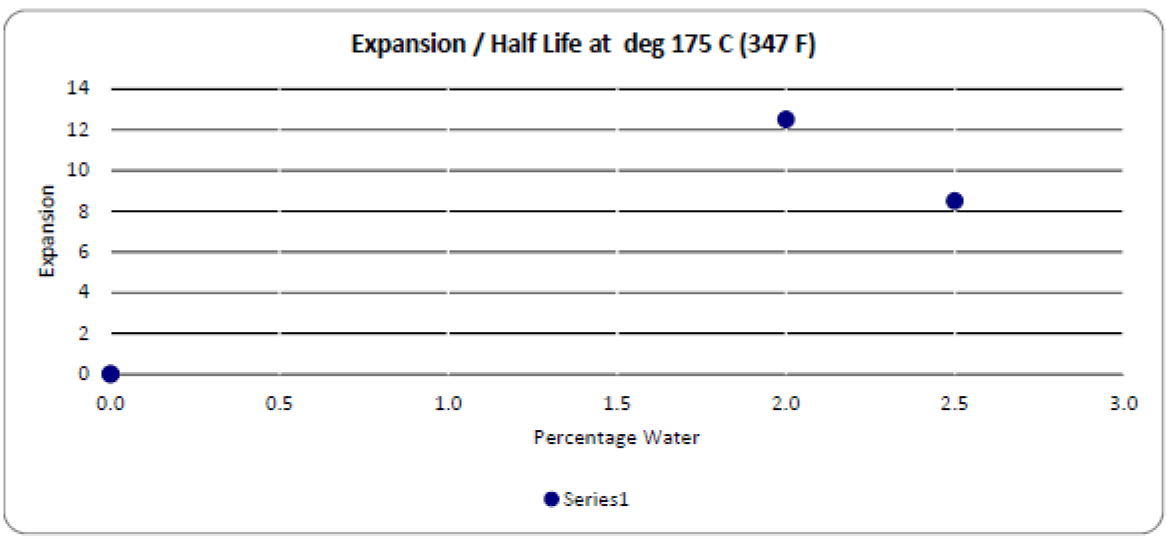
Setting

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

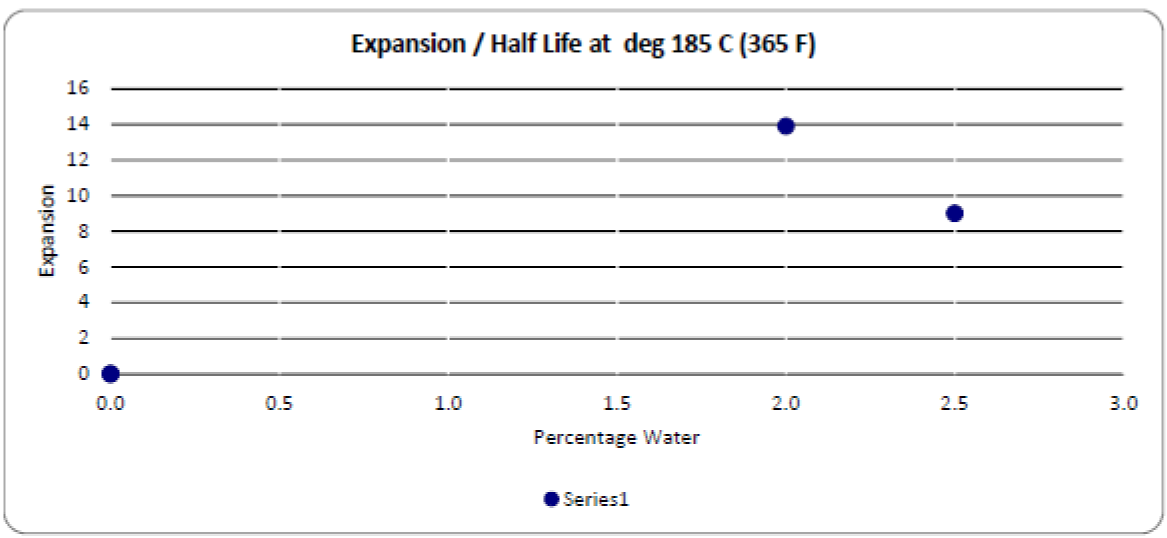
Setting

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

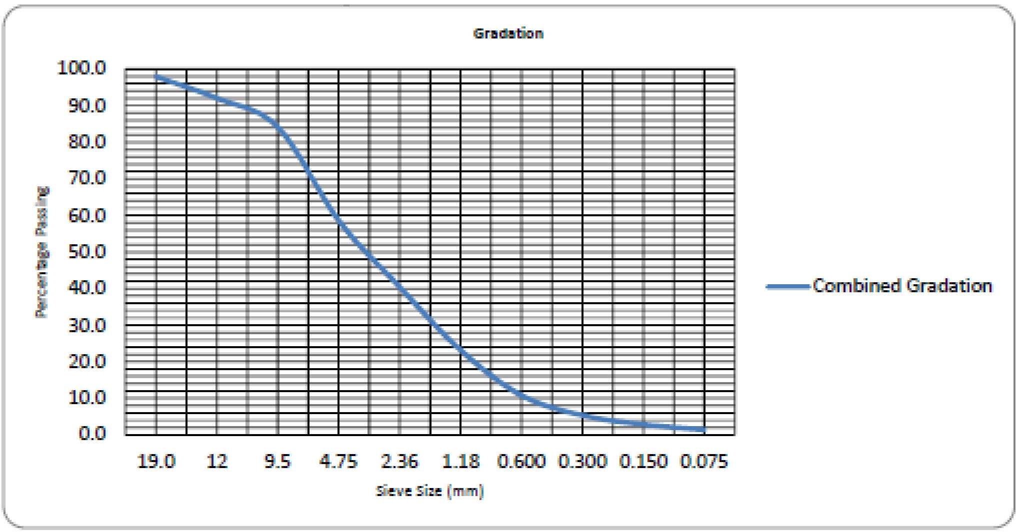


OPTIMUM FOAM MOISTURE CONTENT	**2.0%**

FOAMED BITUMEN SIEVE ANALYSIS	AASHTO T 27 (Dry)

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

		1		2		3		
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						Flat & Elongated		
	Bulk Dry	SSD	Apparent	Absorption	Unit Weight	Voids Coarse Agg	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.

LUCK STONE

Gradation Report

Location: Boscobel

Product: VDOT #10

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

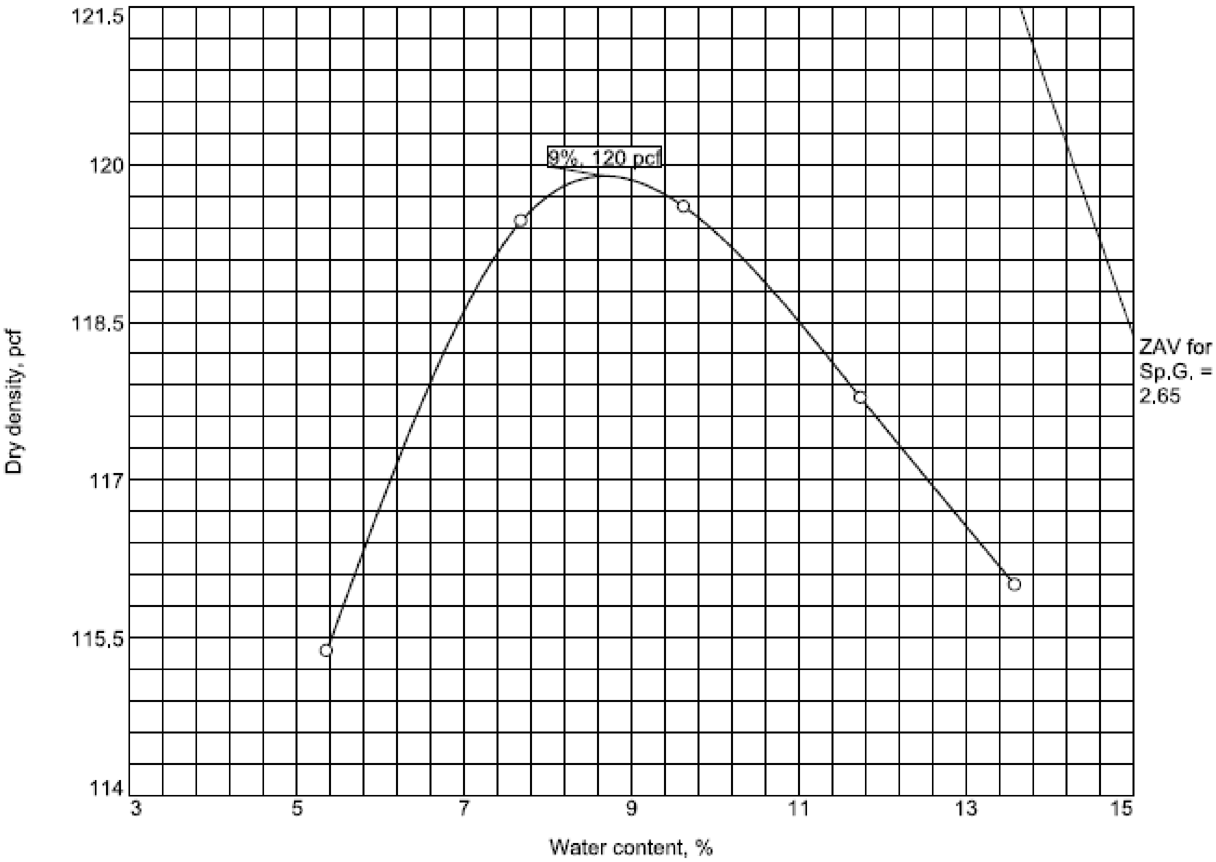
Voice of the Customer

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

Maximum dry density = 120 pcf

Optimum moisture = 9 %

MATERIAL DESCRIPTION

(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

Remarks:

Tested in accordance with AASHTO T-180

WET DENSITY- 130.8

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

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

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
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