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Improvements to Dry-Back Procedure of AASHTO T 209

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CHAPTER 1 INTRODUCTION AND RESEARCH APPROACH

1.1 Introduction and Background

AASHTO T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt [1], is the basis for asphalt mixture compaction specifications, which specify a percentage of the maximum specific gravity obtained with this test procedure. Maximum specific gravity (Gmm) is required to be determined on regular basis for design of the mixtures and to assure that the required level of compaction is being achieved in the field. T 209 requires measurement of the mass and volume of representative loose asphalt mixture samples. Prior to determining the sample volume, any pockets of air in the voids between particles must be removed. To accomplish this, air is forced out of the voids through a vacuum suction process and the voids are backfilled with water.

During the vacuum suction process, if the surfaces of aggregates in the mixture are not completely coated with asphalt (due, for example, to the presence of RAP in mixture and/or insufficient asphalt content), water can be absorbed into aggregate particles and under the asphalt film. For the mixtures containing high absorptive aggregates and slags, the amount of water absorbed into the pores can be significant.

In case of asphalt mixtures with well coated aggregate particles, the volume of the mixture is determined by weighing the mixture when submerged in water and then subtracting it from the original dry mass. However, for a mixture in which water has been absorbed into aggregate pores, the Saturated Surface Dry (SSD) mass of the mixture, in place of the original dry mass, is used for determining the volume.

To obtain the SSD mass, AASTHO T 209 includes supplemental procedures for porous aggregates. The supplemental (Dry-back) procedure accounts for the water absorption by the aggregate during testing. The procedure requires that after the mixture is weighed in water, excess water is drained and the mixture is dried back on a flat surface in front of a fan. The dry back process involves measuring the mass of the mixture every 15 minutes until the SSD condition, which is defined as when the loss in mass is less than 0.05% for an interval, is reached. Theoretically, the Dry-back procedure provides a more accurate value with which to measure compaction in the field. AASHTO currently recommends using the Dry-back Procedure when the water absorption of the individual aggregate is greater than 1.5%.

1.2 Problem Statement

The dry-back procedure has several challenges. First, it is not certain if 1.5% water absorption is the appropriate trigger value for performing a dry-back procedure. It has been observed that the dry-back procedure run on mixes with aggregates with 1.5% water absorption resulted in a difference between the two procedures that is insignificant in relation to the effect on compaction. Second, the dry back method produces Gmm values with higher variability than the conventional AASHTO T 209 method due to the possible loss of particles during the process. Third, the dry-back procedure includes steps that are very subjective in determining when the mix has reached the SSD condition, possibly increasing the variability of the results. Fourth, the procedure is time consuming. It typically takes about 2 hours to reach the SSD mass.

1.3 Project Objectives

The objectives of this research were several fold. First, to determine the appropriate trigger measure and to identify the appropriate trigger value, which necessitates use of dry-back procedure. Second, to determine improvements that can be made to the dry-back procedure to make it less subjective and to produce more repeatable and reliable test results. Third, to explore various methods to accelerate the dry-back process to make it less time consuming. Fourth, to explore various criteria for determining the SSD condition and select the most reliable and straightforward criterion. The results of the research can be used to modify and improve the current AASHTO T 209 test procedure.

1.4 Project Scope

Accomplishment of the project objectives required the following tasks:

- Task 1. Perform a literature review including recent research on AASHTO T 209 and the impacts highly absorptive aggregates may have on laboratory testing and pavement performance. Include agencies' modifications to AASHTO T 209 and interview these agencies' material experts on the purpose of the modifications.
- Task 2. Analyze NCHRP 9-26 (Phase 4) data, including conventional and dry-back Gmm of asphalt mixtures with highly absorptive aggregates, to determine the correct trigger measure and trigger value that necessitates use of dry-back procedure.
- Task 3. Perform a laboratory investigation of the significance of the water absorption of the aggregate and RAP materials on the dry-back procedure. Include mixtures with various RAP contents and aggregate sources with different levels of absorption from various locations.
- Task 4. Perform a laboratory investigation to improve methods to ensure proper dry back of field and laboratory mixtures.
- Task 5. Determine if modifications can be made to the procedure to reduce effort and/or time of the dry back process.
- Task 6. Determine a reliable criterion for determining Saturated Surface Dry (SSD) condition for a reduced effort and/or time of the dry-back procedure.
- Task 7. Recommend revisions to AASHTO T 209 to include in the supplemental (Dry-back) procedure.

CHAPTER 2 LITERATURE REVIEW

For the first task of the project, a literature review was performed, which included a review of recent research projects on the dry-back procedure of AASHTO T 209 and a review of state highway agency test methods. The results of a survey of the state DOTs, performed to inquire about their experience with the dry-back procedure, was studied. The results of the NCHRP 9-26 (Phase 4) [2] study involving measurements of maximum specific gravity of mixtures with absorptive aggregates were reexamined. The applicability of the dry-back data in the NCHRP 9-26 study for evaluating various trigger measures was investigated. The results of the literature search, the states DOT survey, and review of NCHRP 9-26 study are discussed in the following sections.

2.1 Review of Research Projects

In a study performed by NCAT in 1992 [3], it was found that by using a minimum residual pressure of 30 mm Hg (in combination with 15 min vacuum time at 77°F), the need for running the supplementary procedure (Section11 of ASTM 2041) can generally be avoided when testing a thoroughly coated mix. At the time of the study, ASTM D2041 did not specify restriction on the lower limit of the residual pressure and a residual pressure of 30 mm of Hg or less could be used. The authors stated that setting the lower limit of residual pressure is especially important while testing mixtures with highly absorptive aggregates since such aggregates can absorb water during the vacuuming phase of the Rice method, which necessitates the use of a supplementary (dry-back) procedure that is time-consuming and prone to testing errors. This finding was based on testing of two mixtures, one with aggregate water absorption of 1.68% and another with aggregate water absorption of 0.38% tested using combinations of three residual pressure of 16, 23, and 30 mm Hg and three vacuuming time of 5, 10, and 15 min at three temperatures of 69, 77, and 85°F. In search for the best combination of test variables, the researchers aimed at maximizing the value of the theoretical maximum specific gravity (Gmm) before running the supplementary (dry-back) procedure or reducing the difference between the Gmm values before and after running the supplementary procedure.

To avoid performing the time-consuming dry back procedure, the Asphalt Institute suggests fully coating the exposed aggregates in recycled asphalt pavement (RAP) and in mixtures broken from field cores by adding 1 to 2% asphalt binder [4]. To remove the effect of the additional binder on Gmm calculation, the mass and volume of the added asphalt is subtracted in the mass-volume equation. While this method could ensure sealing of the exposed aggregate; heating of the original field mixture and curing of the mixture after addition of asphalt could impose the possibility of changing the Gmm of the original mixture.

To prevent water absorption into the pores of aggregates, the Corelok method [5] was examined for measuring the Gmm of mixtures with absorptive aggregates in a number of research studies. In this method, mixture is vacuumed dry inside a plastic bag which avoids absorption of water into aggregate pores. Florida DOT has compared the Gmm measured from Corelok with those from Rice and dry back in a study involving eight mixtures with aggregates of various absorption levels [6]. They found that Corelok results are significantly higher than the dry-back results for mixtures with aggregates with high water absorption level. Therefore, they did not recommend replacing the dry-back with Corelok.

In a similar study at the University of Cincinnati, a range of mix types and aggregate sources, including slag aggregate, resulting in 33 samples was used to compare Corelok and T 209 [7].

The results indicated that for mixtures with low absorptive aggregates, Corelok Gmm is lower than the T 209 Gmm and for mixtures with high absorptive aggregates Corelok provides higher Gmm than T 209.
West Virginia DOT also compared Corelok, Rice, and dry-back methods [8]. In addition, they investigated the effects of residual moisture in aggregates, conditioning duration, and increasing asphalt content by 0.5%. Gmm values measured by Corelok were statistically compared with the conventional Rice and dry-back results for mixtures with different percentages of slag (12%, 27%, and 42%), two conditioning durations (0 and 2 hrs.), two levels of aggregate residual moisture (0 and 2%), and two levels of asphalt content (design and design+0.5%). The results of the study indicated that Corelok provided the same Gmm as the conventional Rice but significantly different Gmm from dry-back. The Corelok Gmm were consistently higher than dry-back Gmm. The effect of residual moisture was found insignificant, while the effect of conditioning was found significant. The 2-hr conditioning provided significantly higher Gmm than no conditioning. The additional 0.5% asphalt was not found effective in reducing the difference between Rice and dry-back Gmm values, which may have to do with the high void content in slag aggregates.

2.2 Consequence of Not Using Dry-Back Gmm

For determination of maximum specific gravity of asphalt mixtures, the original dry mass of the mixture is divided by its volume. The volume of the mixture is equivalent to the volume of water displaced when mixture is submerged in water. For water kept at 25ºC, specific gravity of water is 1g/cm^3 and volume of water is equal to the mass of the water displaced. The mass of water displaced is the difference between the dry mass of the mixture and its mass in water. Therefore, the volume in the denominator is determined by subtracting the mass of mixture in water from the mass of the mixture in air.
During the vacuum saturation of an asphalt mixture, if the aggregate surfaces in the mixture are not completely covered with asphalt (due to RAP in the mixture and/or insufficient asphalt), water could be absorbed into the pores of the aggregates. For mixtures containing highly absorptive aggregates and slag aggregates, the amount of water seeping into the pores could be significant.
When such a mixture, with water in its pores, is placed in the water bath, due to the larger mass of the mixture than the original dry weight, a greater volume of water would be displaced. To capture the larger volume, the Saturated Surface Dry (SSD) mass of the mixture is used in place of the original dry mass in the denominator of the Gmm formula. As a result, a lower maximum specific gravity will be measured.
Failing to use the SSD mass when the difference between conventional and regular Gmm is significant, would have impacts on both laboratory testing and pavement performance. In the laboratory, higher Gmm means using higher binder content than may actually needed to achieve the required 4% air voids. The laboratory mechanical test results of such mixture would then underestimate the rutting performance and overestimate the cracking performance in the field. With the increased use of RAP in mixtures, this might be problematic.
In the field, failing to use dry-back Gmm (if significantly different from conventional Gmm) could result in over compaction of the pavement. A higher level of compaction would be required to achieve the desired density in the field, e.g., 93% of the maximum specific gravity. If Gmm is off by more than 0.01, density will be off by approximately 4%. In this case, the

contractor would over compact to 97% density in order to achieve 93% density. This means extra cost to the contractors and eventually to the state DOT.

2.3 Review of State Agency Test Methods

The state agencies' test procedures were reviewed to identify their approaches to the use of the dry-back procedure. Any supplementary information or modifications to AASHTO T 209 regarding the dry-back procedure in the states' test methods were identified and are discussed below.

North Carolina DOT performs the dry-back procedure on the first four Rice tests for any job mix formula. The average of the differences between conventional and dry-back procedure is used as a correction factor. For all the Rice tests thereafter, the established correction factor is subtracted from the Gmm values obtained without the dry-back procedure. After that, the dry-back procedure will be repeated on every eighth Rice test and a new correction factor will be computed [9].

Caltrans uses the supplemental dry-back procedure of AASHTO T 209 for reclaimed asphalt pavement (RAP) and for asphalt mixtures where the combined virgin aggregate water absorption is 2.0 % or more [10].

Arizona uses the dry-back procedure (referred as fan drying method) for the first four samples taken at the beginning of production on a project [11]. The maximum specific gravity is determined without fan drying (conventional procedure) and on fan dried samples. If the difference in resultant air voids, when determined as described in Arizona Test Method 416 Section 9, is greater than 0.2%, subsequent samples will be subjected to fan drying. During the course of the project comparisons are made on approximate 10-sample intervals to determine a need for fan drying. In case of dispute, fan drying is used.

Ohio DOT uses the dry-back procedure referred to as the SSD method if a 12.5-mm surface course contains air-cooled blast furnace slag (No. 8 or larger) or a 19-mm or Type 2 intermediate course contains dolomite, air-cooled blast furnace slag, or limestone virgin coarse aggregate (No. 8 or larger). They require the contractor to perform the 'Supplemental Procedure for Mixtures Containing Porous Aggregate' (SSD) to determine the amount of retained water. If the retained water in the JMF is greater than 0.18 percent based on the dry mass of mix, then the SSD procedure should be applied for both the JMF testing and in quality control testing [12].

City of Columbus, Ohio requires performing the dry-back procedure for determining Gmm for every mix design. However, use of an alternate forced air system is allowed in place of an electric fan as long as (1) the 15-minute interval mass measurement shows less than 0.05 percent mass loss from the preceding mass for at least 1 hour and (2) forced air flow over the sample(s) is constant during a test and over multiple tests [13].

Several states have modified the setup for fan drying the mixture. In Supplement 1036 of Ohio DOT, use of a 12 inch (305 mm) diameter 'full height' sieve meeting the requirements of ASTM E11 is specified for the SSD procedure instead of a pan as specified in T 209. The fan axis must be perpendicular to the sieve mesh with air flowing thru the sieve. This setup would ensure that the air flow can readily escape the sieve bottom [12].

West Virginia uses a drying rack fabricated from two No. 30 sieves held at an angle for each test replicate. A fan is placed behind each of the sieves to blow air up through the bottom of the sieves (Figure 2-1) [8].

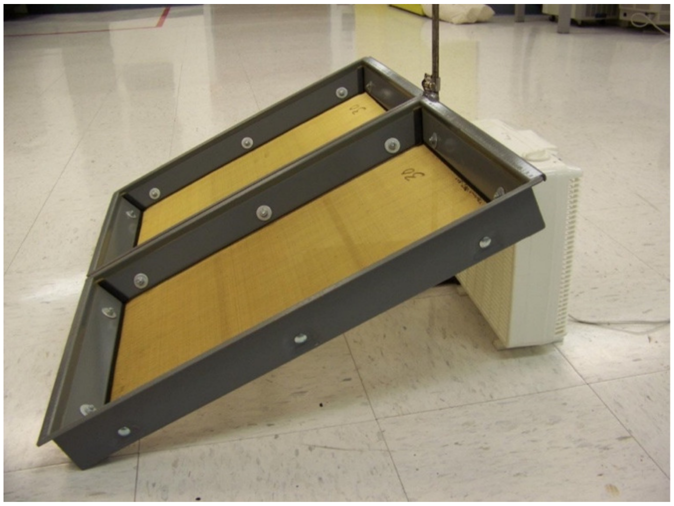

Figure 2-1- WV drying rack and fan setup

Several state DOTs perform additional steps to improve the accuracy of the dry-back procedure. Colorado DOT uses a filter paper for draining the water and obtaining the mixture. Filter paper is first oven dried and its mass is recorded. The filter paper is then placed into a filter paper cone holder. Water is drained from the specimen through the filter paper cone with care not to lose any of the specimen. After allowing the specimen to drain completely, the specimen is emptied from the filter paper into a weighed pan and placed before an electric fan. The filter paper with any mixture remained on it is dried in the oven at 110 °C ± 5 for more than 30 min. The mass of filter paper before draining and after drying in the oven provides the mass of the mixture remaining on the filter paper. This mass is then added to the SSD mass of the sample [14]. Texas DOT requires performing the instructions in Sections 10.18–10.26 (dry-back procedure) of the state test method if the aggregate is expected to absorb water during the test, i.e., when the surfaces of any absorptive aggregate are not completely coated or are coated very thinly with asphalt. This problem may increase when highly effective vacuum pumps are used and if the samples remain exposed to this vacuum for an excessive time. Very porous aggregates, such as light-mass aggregates, are listed as particularly prone to absorbing water during this test. Texas DOT follows a similar procedure to the T 209 supplemental procedure; however, they suggest verifying the validity of the end-point by drying for an additional 30-minute period when practical. If a loss greater than 0.5 g occurs after 30 min, drying should be continued until a new constant endpoint is reached. The test method notes that Gmm from conventional and dry-back methods are rarely equal, even when no water absorption occurs, and that in some instances, the determination of the SSD condition is inaccurate because of the moisture commonly contained inside fine aggregate conglomerates. Therefore, some values will tend to indicate more correction than is justified. The decision on accepting the correction factor is based on several factors such as if mixture is lean, if high vacuum is used on mixture with high absorptive aggregates, if there are fractured aggregates in the mix, and if the difference between conventional and dry-back Gmm is more than 1% [15].

2.4 Results of State DOT Survey

A survey of the state DOTs was performed to determine the applicability of the dry-back procedure for the mixtures used in different states. The survey results are summarized in Appendix A.

2.4.1 Questions in the Survey

14 questions were asked in the survey. Key questions are as follows:

1. How often do you run the dry-back procedure?
    a. Conventionally
    b. Not on a conventional basis
    c. Never

2. Under what conditions do you decide to run the dry-back procedure?
    a. When mixtures have absorptive aggregates
    b. If broken aggregates in the mixture show sign of water absorption
    c. If aggregates are not well coated with asphalt

3. What trigger values (i.e., specific values of water or asphalt absorption) do you use to determine if the dry-back procedure is to be used (e.g., 1.5 % aggregate water absorption, etc.)?

4. What steps do you take in achieving the SSD condition as part of the dry-back procedure?
    a. Steps specified in AASHTO T 209 or ASTM D2041
    b. Your agency's specification. Please explain.

5. How do you determine if the mix has reached SSD condition?
    a. Criteria used in AASHTO T 209 or ASTM D2041
    b. Your agency's criteria. Please explain.

6. Have you made any modifications to AASHTO T 209 or used any specific device for reducing the subjectivity of SSD determination and/or shortening the time specified for the dry-back procedure? Please explain.

In the survey, a question was also asked regarding the use of field cores for Gmm measurements. The responses to this question will be applicable to the next phase of the project.

2.4.2 Responses to the Survey Questions

Responses were received from 29 states. The responses are summarized in Appendix A. Below is the highlight of the responses:

1. 20 states follow AASHTO T 209, 1 state follow ASTM D2041, and 8 states follow either a local test procedure or a modified T 209.
2. 13 states do not run the dry-back procedure, 10 states run dry-back but not on a conventional basis, and 6 states use dry-back conventionally. SDDOT prefers to run the maximum specific gravity test at a higher asphalt content and coat the aggregate so the dry-back procedure is not needed during the mix design testing.
3. 9 states use the dry-back if mixtures have absorptive aggregates, 7 states use dry-back if aggregates are not well coated with asphalt, and 2 states use dry-back if there are broken aggregates in the mixtures. Other responses included performing dry back on every eighth QC sample; when aggregate water absorption is above 1.5%; for pavement cores; at the initial mix design stage; if the difference between mixture dry air mass and fan dried mass is more than 0.2%; when the mixture includes slag and Plum Run dolomite; for forensic and investigational purposes only; or when using RAP mixtures.
4. Different states use different trigger values for use of the dry-back procedure. Some states use 1.5% water absorption (same as AASHTO T 209). Other states use 1.2% or 2% water absorption as the trigger value. Another trigger measure in using dry back is the difference between dry mass and fan-dried mass; if the difference is more than 0.2 %, then the dry-back method will be used.
5. In achieving SSD condition, some states use CoreDry at low heat and dry at 125°F similar to AASHTO T 166 (section 6.1). Some other states allow the use of newspaper or wax-coated paper to speed up moisture removal.

2.5 Review of NCHRP 9-26 Phase 4 Study

The NCHRP Project 9-26 Phase 4 study was conducted to determine precision estimates of volumetric properties including maximum specific gravity (Gmm) of asphalt mixtures with high absorptive aggregates. Additionally, the effect of short-term conditioning duration on the volumetric properties of the same mixtures was investigated. Two gradations of two sources of absorptive aggregates were used to prepare four asphalt mixtures. To develop precision estimates, loose mixtures were sent out to laboratories participating in the interlaboratory study (ILS); the participants were asked to perform the dry-back procedure on 3 replicates of each of the 4 mixtures and provide the data for analysis. To investigate the effect of conditioning duration on the volumetric properties, 2 replicates of each of the four mixtures were conditioned in the oven for various durations and the change in their volumetric properties including dry-back Gmm was investigated. The dry-back results indicated an increase in Gmm of the mixtures with increase in conditioning duration, which might be caused by both stiffening of the asphalt binder and continued absorption of asphalt into the aggregate pores [2].

The statistical and physical significance of the differences between conventional and dry-back Gmm of the mixtures with highly absorptive aggregates from the NCHRP Project 9-26 Phase 4 study were reanalyzed for the evaluation of the trigger measures and trigger values used by the state DOTs. The results of the reanalysis will be discussed in Chapter 3.

CHAPTER 3 INVESTIGATION INTO NCHRP PROJECT 9-26 PHASE 4 DRY-BACK DATA

Prior to performing a laboratory investigation, the dry-back data from the NCHRP Project 9-26 Phase 4 study are analyzed to investigate conditions when performing dry-back is necessary. As discussed in Chapter 2, several physical trigger measures are being used by the state DOTs for deciding if dry back should be performed. In addition, these data can be used to investigate the effects of several mixture variables such as aggregate gradation, aggregates absorption, and effective asphalt content on the significance of the difference between conventional and dry-back Gmm.

The mass/volume data from the dry-back Gmm measurements were used for this investigation. The data correspond to four mixtures from two sources of absorptive aggregates and two gradations 9.5-mm and 19.0-mm NMAS. Source 1 aggregate has water absorption of about 5% and Source 2 aggregate has water absorption of about 4%. Both the ILS data and the conditioning time study data were reanalyzed. In the ILS, each of the four mixtures was tested by more than 20 laboratories; however, not all laboratories provided the complete set of raw dry-back data. Therefore, not all of the results collected in the ILS could be reanalyzed for this study. For the conditioning time study, the data from four mixtures conditioned for 2, 4, 6, 8, 16, and 32 hours were reanalyzed. Since G_{mm} was increased with increase in conditioning time, it could also be assumed that the mixtures after each conditioning duration are independent of each other and their dry-back data could be treated as separate sets of data.

For the investigation in this chapter, the dry-back and conventional G_{mm} data were compared and the significance of their differences are examined both statistically and from a practical view point using the state DOTs' trigger measures. The relationships between the decisions made based on the statistical and physical criteria were evaluated to determine the applicability of the DOTs' trigger measures and the trigger values for performing dry-back.

3.1 State DOTs' Trigger Measures for Performing Dry-back

As discussed in Chapter 2, several state DOTs use different trigger measures and values in place of aggregate absorption level (specified in AASHTO T 209) to decide if dry back should be performed. A summary of the criteria and their threshold values are as follows:

1. The single-operator d2s of AASHTO T 209. The within-laboratory precision estimate of AASHTO T 209 is used to decide when dry-back should be performed. If the difference between dry-back and conventional Gmm is larger than the single operator d2s of 0.011, then the states require performing the dry-back procedure. This trigger measure is referred to as "Gmm difference."

2. The allowable percent difference of 1% between the conventional and dry-back Gmm values. If the difference between dry-back and conventional Gmm is larger than 1%, dry-back is required. This is similar to trigger #1, but is expressed in terms of percent. This trigger is referred to as "percent Gmm difference."

3. A maximum difference of 0.17%, 0.18%, or 0.2% (different values used by different states) between the final dry-back mass and the original dry mass. If the difference in dry

and dry-back mass is larger than the 0.17%, 0.18%, or 0.2% then dry back should be performed. This trigger is referred to as "percent mass difference."

4. The maximum difference of 5 g between the original dry mass and the final dry-back mass. This is similar to trigger # 3, but is expressed in terms of absolute mass. This trigger is referred to as "mass difference."

5. The allowable difference of 0.2% between air voids computed from the conventional and dry-back Gmm for a specific G_{mb}. If the difference exceeds 0.2%, dry back is required. This trigger is referred to as "percent air void difference."

3.2 Evaluation of Trigger Measures and Trigger Values by Analysis of NCHRP Project 9-26 Phase 4 Data

The Gmm data from the interlaboratory and conditioning studies of Phase 4 of NCHRP Project 9-26 were used to evaluate the trigger measures and their values by examining the significance of the difference between the dry-back and conventional G_{mm} both physically and statistically. The results of the analysis could determine the reliability of each trigger measure and its corresponding value.
The statistical significance of the difference between conventional and dry-back G_{mm} was investigated using a two-sample t-test. The computed t-value was compared with the critical t-value at a 5% level of significance corresponding to a one-tail t-distribution. The one-tailed t distribution was used since the dry-back Gmm is always smaller than the conventional Gmm.

3.2.1 Comparison of Conventional and Dry-Back Gmm of NCHRP 9-26 Phase 4 ILS

Four groups of data are available from testing of the four mixtures with absorptive aggregates (2 sources of aggregates x 2 gradations). Only the data sets with complete raw data could be used for this analysis. The number of data sets after eliminating the incomplete sets are as follows:

- 15 sets of data for the mixture with 9.5-mm NMAS gradation of Source 1 aggregate (S1-9.5),
- 14 seta of data for the mixture with 19.0 mm NMAS gradation of Source 1 aggregate (S1-19),
- 17 sets of data for the mixture with 9.5-mm NMAS gradation of Source 2 aggregate (S2-9.5),
- 15 sets of data for the mixture with 19.0-mm NMAS gradation of Source 2 aggregate (S2-19).

The conventional and dry-back data and the significance of their differences from physical (i.e., the differences exceed the trigger values of the five criteria discussed in Section 3.1) and statistical stand points are shown in the tables of Appendix C. A summary of the percentages of cases where the difference between conventional and dry-back Gmm is significant (statistically or physically) are summarized in **Error! Reference source not found.**. The sample IDs represent aggregate source (Source 1=1 or Source 2=2) and aggregate gradation (9.5-mm=9.5 or 19.0 mm= 19). The observations are discussed as follows:

Table 3-1- Percentages of significant differences between conventional and dry-back Gmm in NCHRP Project 9-26 ILS based on statistical and physical criteria

	Mix ID	# of Labs	Statistically Significant Difference	Physically Significant Difference				
				Mass Diff, Threshold 5 g	% Mass Diff, Threshold 0.17%	Gmm Diff, Threshold 0.011	% Gmm Diff, Threshold 1%	% AV Diff, Threshold 0.2%
Number of Significant Differences	S1-9.5	15	11	1	8	6	0	15
	S1-19	14	10	8	13	11	0	14
	S2-9.5	17	11	7	11	8	1	14
	S2-19	15	11	4	5	3	1	15
Percentages of Significant Differences	S1-9.5		73%	7%	53%	40%	0%	100%
	S1-19		71%	57%	93%	79%	0%	100%
	S2-9.5		65%	41%	65%	47%	6%	82%
	S2-19		73%	27%	33%	20%	7%	100%
Average			**71%**	**33%**	**61%**	**46%**	**3%**	**96%**

S1-9.5 Mixture

For the S1-9.5 mixture, the results of statistical analysis indicate that in 11 out of 15 laboratories, the difference between conventional and dry-back Gmm is significant. The trigger measures and their values indicated different decisions regarding the significance of the difference between conventional and dry-back data:

- The “mass difference” trigger indicated that the difference between dry and dry-back masses was significant in only laboratory # 4.
- The “percent mass difference” exceeds the threshold of 0.17% in 8 out of 15 laboratories. Out of the 8 cases, there are 6 agreements with the statistical results. There are also 2 cases of agreement with statistical results where the differences between conventional and dry-back data are not practically significant. Therefore, there are a total of 8 cases where “percent mass difference” and statistical testing provide the same decisions. For this mixture, the threshold values of 0.18% and 0.2% provide a 7 and 6 cases of agreements with the statistical results, respectively.
- The “Gmm difference” exceeds the threshold of 0.011 in 6 laboratories. Out of the 6 cases, 4 agree with the statistical results. There are also 2 cases of agreements with statistical results where the differences between conventional and dry-back data are not practically significant. This totals to 6 agreements

between statistical results and decisions based on Gmm difference. If the trigger value is decreased to 0.010, the number of agreements with the statistical results would increase to 7 cases.

- None of the laboratories exceeded the “percent Gmm difference” of 1%. However, there are 2 cases of agreements with statistical results where the differences between conventional and dry-back data are not practically significant. The threshold value of 1% could be lowered to obtain a greater number of agreements with the decisions based on other physical trigger measures and the statistical criteria. A lower threshold value of 0.4% provides 6 agreements with the statistical results.
- The “percent air void difference” exceeds the threshold value of 0.2% in all 15 laboratories. Out of the 15 cases of a significant difference, there are 11 agreements with the statistical results. By using a larger threshold value of 0.4%, the number of agreements with statistical results decreases from 11 to 7.

S1-19 Mixture

For S1-19 mixture, statistical results show that the difference between conventional and dry-back Gmm is significant for 10 out of the 14 laboratories. The trigger measures indicated different decisions regarding the significance of the differences:

- The “mass difference” trigger indicated that in 8 out of 14 laboratories the difference between dry and dry-back mass is more than 5 g. Out of the 8 cases, 6 agree with the statistical results. There are also 2 cases of agreements with the statistical results when the the differences are insignificant. This totals to 8 agreements between “mass difference” criteria and statistical results.
- The “percent mass difference” is more than 0.17% in 13 out of 14 laboratories. Out of the 13 cases of significance, 9 agree with the statistical results. For the cases where the differences between conventional and dry-back are not significant, the percent mass difference and statistical criteria do not agree. Therefore, there are total of 9 cases where “percent mass difference” and statistical results provide the same decisions. If the threshold value changes to 0.2%, there would be the 8 cases of agreements with the statistical results.
- The “Gmm difference” trigger exceeds 0.011 in 11 laboratories. In 7 cases, decisions agree with the decisions based on statistical results. There is no case of agreement with statistical results when the differences are not significant. By using the threshold value to 0.010, the number of agreements with the statistical results increases to 9.
- The “percent Gmm difference” shows that in none of the laboratories, the percent difference exceeds 1%. This threshold could be lowered to obtain better agreements with the decisions based on other trigger measures and statistical criteria. A threshold value of 0.4% provides 9 agreements with the statistical results.
- The “percent air void difference” exceeds the threshold value of 0.2% in all 14 laboratories. Among these cases, there are 10 agreements with the statistical

decisions. The fact that a larger number of significant differences are determined by the "percent air void difference" criteria than by other trigger measures might indicate that the threshold value of 0.2% is too low and can be increased. A threshold value of 0.4 % provides 9 agreements with the statistical results.

S2-9.5 Mixture

For S2-9.5 mixture, statistical results show that the difference between conventional and dry-back Gmm is significant for 11 out of the 17 laboratories. Different physical criteria indicated different decisions regarding the significance of the differences:

- The "mass difference" trigger measure indicates that in 7 out of 17 laboratories, the difference between dry and dry-back mass is more than 5 g. Out of the 7 significant cases, 6 agree with the statistical results. There are also 5 cases of agreement when the differences between conventional and dry-back Gmm are not significant. This totals to 11 cases of agreements.
- The "percent mass difference" indicates that in 11 out of 17 laboratories, the difference between dry and dry-back mass is more than 0.17%. Out of the 11 cases, 8 agree with the statistical results. There are also 3 cases of agreements where the differences are not significant. Therefore, there are total of 11 agreements between the decisions based on "percent mass difference" measure and statistical criteria. For this mixture, the threshold value of 0.18% provide 10 agreements with the statistical results.
- The "Gmm difference" shows that in 8 laboratories the difference between conventional and dry-back Gmm is more than 0.011. In 6 of the 8 cases, the decisions agree with the statistical results. There are also 4 cases of agreement with statistical results when the differences are not significant. This totals to 10 agreements between statistical results and physical criteria of "Gmm difference." By using the threshold value of 0.010, the number of agreements with the statistical results does not change.
- The percent Gmm difference shows that in only 1 laboratory, the percent difference exceeds 1%. By decreasing the threshold to 0.4%, the number of agreements increases to 11.
- The percent air void differences indicate that in 14 out of 17 laboratories, the difference in air voids exceeds the 0.2% threshold. Out of the 14 cases, 11 agree with the statistical results. There are also 3 cases of agreement with statistical results when the differences are not significant. This totals to 14 cases of agreement between the decisions based on air void difference and statistical analysis. By using the threshold of 0.4%, the number of agreements would decrease to 10 cases.

S2-19 Mixture

For S2-19 mixture, statistical results show that the difference between conventional and dry-back Gmm is significant for 11 out of the 15 laboratories. The physical criteria indicated different decisions regarding the significance of the differences:

- The “mass difference” trigger indicates that in 4 out of 15 laboratories, the difference between dry and dry-back mass is more than 5 g. All 4 cases agree with the statistical results. There are also agreements with the statistical results in 4 cases when the differences between conventional and dry-back Gmm are not significant. Therefore, there is a total of 8 agreements between the decisions based on “mass difference” criteria and statistical analysis.
- The “percent mass difference” indicate that in 5 out of 15 laboratories, the difference is more than 0.17%. All 5 cases agree with the statistical results. The percent mass difference and statistical results agree in 4 cases where the differences are not significant. Therefore, there are total of 9 out of 15 agreements between the decisions based on statistical and percent mass difference criteria. If the threshold value changes to 0.18%, there would be 8 cases of agreements with the statistical results.
- The “Gmm difference” shows that in 3 laboratories the difference is more than 0.011. In all three cases, the decisions agree with the statistical results. There are also 4 cases of agreement with statistical results when the differences are not significant. Therefore, there are total of 7 agreements between the decisions made based on statistical measure and “Gmm difference” criteria. By using the threshold value to 0.010, the number of agreements with the statistical results does not change.
- The “percent Gmm difference” shows that in only 1 laboratory the percent Gmm difference exceeds 1%. By decreasing the trigger value to 0.4%, there would be 9 agreements with the statistical decisions.
- The “percent air void differences” indicate that in all 15 laboratories, the difference in air voids exceeds the 0.2% threshold. Out of the 15 case, there are 11 cases of agreement with statistical results. There are no cases of agreement when the differences are not significant. If the threshold value is increased to 0.4%, the number of agreements would decrease to to 8.

3.2.2 Explanation of ILS Results

The following explanations can be provided based on the above observations from the analysis of the ILS data:

1. Discrepancies between the decisions based on the physical and statistical criteria could be due to very small or very large differences in replicate values of either conventional or dry-back data groups. If the difference between replicates of one group is very small compared to the difference between the two groups, statistical analysis could determine that the difference between the two groups is significant, where it might not be a meaningful significance from physical standpoint. Conversely, if the differences between the replicates in one group are very large compared to the difference between the two groups, statistical analysis could determine that the difference between the two groups (conventional and dry-back Gmm) is not significant, where it might be significant from physical standpoint.

2. In the cases where the decisions based on the physical and statistical criteria are different and the values of the physical criteria are not close to the threshold value, it makes sense to make the decision based on the physical criteria.
3. In the cases where the decisions based on physical and statistical criteria are different but the values of the physical criteria are close to their threshold values, the threshold values are adjusted to obtain the same decision based on both physical and statistical criteria.
4. The trigger measure of "mass difference" and its threshold value do not appear reliable in detecting the dry-back condition. The trigger detected only a few significant differences between conventional and dry-back data. Moreover, using an absolute mass as a trigger measure might not be appropriate considering that the mass requirement is different for mixtures with different NMAS.
5. The trigger measure of "percent mass difference" provides the second best agreement with the statistical results (after the air void difference trigger). It seems that the threshold value of 0.17% provides more agreements with the statistical results than the threshold value of 0.18% and 0.20%.
6. The trigger value of 0.010 for the trigger measure of "Gmm difference" indicated better agreement with the decisions from other trigger measures and those from statistical criteria than the trigger value of 0.011.
7. The trigger measure of "air void difference" with threshold value of 0.2% provide the most number of agreements with the statistical results. However, a threshold value of 0.4% provides the best agreement with the other trigger measures (percent mass difference and Gmm difference). Considering that the allowable difference between replicate air voids is 1% (±0.5% from the design air voids), the threshold of 0.2% seems rather small from practical stand point.
8. In summary, the following trigger values provide the best agreements between the decisions made based on the selected trigger measures: 0.17% for "percent mass difference,"0.010 for the "Gmm difference," and 0.4% for the "air void difference". Table 3-2 shows that by adjusting the threshold values for the "Gmm difference" and "% air voids difference," the average percentages of physical significance become in better agreement with each other and with the average percentage of statistical significance.

Table 3-2- Percentages of significant differences between conventional and dry-back Gmm in NCHRP Project 9-26 ILS based on statistical and selected physical criteria with adjusted threshold values

	Mixture ID	# of Labs	Statistically Significant Difference	Physically Significant Difference		
				% Mass Diff, Threshold 0.17%	Gmm Diff, Threshold 0.010	% AV Diff, Threshold 0.4%
Number of Significant Difference	S1-9.5	15	11	8	7	7
	S1-19	14	10	13	13	13
	S2-9.5	17	11	11	10	10
	S2-19	15	11	5	3	4
Percentages of Significant Difference	S1-9.5		73%	53%	47%	47%
	S1-19		71%	93%	93%	93%
	S2-9.5		65%	65%	59%	59%
	S2-19		73%	33%	20%	27%
Average			**71%**	**61%**	**55%**	**56%**

3.3 Analysis of NCHRP 9-26-Phase 4 Conditioning Time Data

From the conditioning study, there are mass and volume data corresponding to the conventional and dry-back G_{mm} of 20 mixtures: 2 aggregate sources x 2 aggregate NMAS x 5 conditioning durations. The significance of the difference between conventional and dry-back data of the conditioning study were evaluated statistically and using the three trigger measures selected based on the analysis of the NCHRP 9-26 (Phase 4) ILS data: “percent mass difference” (trigger value=0.17%), “Gmm difference” (trigger value=0.010), and “air void difference” (trigger value=0.4%). The decisions based on these trigger measures showed the best agreement with each other and with the statistical decisions. The results of the comparisons are shown in Table 3-3 through Table 3-6. The values of the trigger measures are provided in Columns 4, 7, and 10 of each table. The P-values for the statistical significance are provided in Column 11. A P-value smaller than 0.05 would indicate a statistically significant difference between conventional and dry-back Gmm values. In the table, the numbers in the sample IDs represent aggregate source (1 or 2), aggregate gradation (1=9.5-mm, 2=19.0 mm), replicate (1 or 2), aging duration (2=2 hr., 4= 4 hr., 8=8 hr., 16=16 hr., 32=32 hr.), respectively. The cases of significant difference are shaded grey.

Table 3-3 shows the results of comparisons of conventional and dry-back Gmm data for the mixture with 9.5-mm NMAS of Source 1 aggregate. The shaded values of the trigger measures indicate that the differences between the dry-back and conventional Gmm are significant for 2-hr., 16-hr., and 32-hr. conditioned mixtures. The statistical analysis agreed on the significance of the differences for 2-hr. and 32-hr. conditioned mixtures.

Table 3-3- Evaluation of significance of difference between conventional and dry-back Gmm values from physical and statistical standpoints for mixtures with 9.5 mm NMAS of Source 1 aggregates

1 Sample ID	2 Air Dry Wt.	3 Dry-back Wt.	4 %Diff. Dry and Dry-back Mass (Threshold=0.17%)	5 Dry-back Gmm	6 Conventional Gmm	7 Diff. Dry-back & Conventional Gmm (Allowable= 0.010)	8 Gmb Conventional	9 %Air Void-Dry-back	10 Diff. Dry-back & Conventional Air Voids (Allowable=0.4%)	11 P-value Two-Sample t-test
1-1-1-2	2049.6	2053.1	0.17	2.273	2.282	0.009	2.191	3.6	0.37	0.022
1-1-2-2	2039.2	2045.2	0.29	2.268	2.284	0.015	2.192	3.4	0.65	
1-1-1-4	2024.1	2025.1	0.05	2.299	2.302	0.003	2.210	3.9	0.11	0.400
1-1-2-4	2005.5	2008.4	0.14	2.272	2.279	0.007	2.188	3.7	0.32	
1-1-1-8	2038.3	2040.5	0.11	2.293	2.299	0.006	2.207	3.8	0.24	0.283
1-1-2-8	2041.8	2043.4	0.08	2.304	2.308	0.004	2.216	3.8	0.17	
1-1-1-16	2083.3	2085.3	0.10	2.289	2.294	0.005	2.203	3.8	0.21	0.288
1-1-2-16	2052.9	2056.8	0.19	2.303	2.313	0.010	2.220	3.6	0.42	
1-1-1-32	2044.3	2053.2	0.44	2.324	2.348	0.024	2.254	3.0	0.98	0.038
1-1-2-32	2043.1	2055.3	0.60	2.309	2.341	0.032	2.247	2.7	1.34	

Table 3-4 provides the results of comparisons for the mixture with 19-mm NMAS of Source 1 aggregate. The shaded values of the trigger measures indicate that the differences between the dry-back and conventional Gmm are significant for 2-hr., 8-hr., and 32-hr. conditioned mixtures. However, the statistical analysis shows a significant difference only for the 2-hr. conditioned mixture.

Table 3-4- Evaluation of the significance of difference between conventional and dry-back Gmm values from physical and statistical standpoints for mixtures with 19 mm NMAS of Source 1 aggregates

1 Sample ID	2 Air Dry Wt.	3 Dry-back Wt.	4 %Diff. Dry and Dry-back Mass (Threshold=0.17%)	5 Dry-back Gmm	6 Conventional Gmm	7 Diff. Dry-back & Conventional Gmm (Allowable= 0.010)	8 Gmb Conventional	9 %Air Void-Dry-back	10 Diff. Dry-back & Conventional Air Voids (Allowable=0.4%)	11 P-value Two-Sample t-test
1-2-1-2	2070.4	2073.7	0.16	2.280	2.289	0.008	2.197	3.6	0.35	0.007
1-2-2-2	2081.4	2085.5	0.20	2.281	2.291	0.010	2.199	3.6	0.43	
1-2-1-4	2081.8	2084.1	0.11	2.295	2.300	0.006	2.208	3.8	0.24	0.320
1-2-2-4	2071.0	2074.4	0.16	2.275	2.283	0.009	2.192	3.6	0.36	
1-2-1-8	2028.3	2035.4	0.35	2.300	2.319	0.019	2.226	3.2	0.78	0.154
1-2-2-8	2082.6	2085.1	0.12	2.295	2.301	0.006	2.209	3.7	0.27	
1-2-1-16	2077.4	2079.4	0.10	2.300	2.305	0.005	2.213	3.8	0.21	0.389
1-2-2-16	2065.0	2066.4	0.07	2.320	2.324	0.004	2.231	3.8	0.15	
1-2-1-32	2188.6	2196.4	0.36	2.327	2.346	0.019	2.252	3.2	0.80	0.072
1-2-2-32	2187.3	2196.6	0.43	2.338	2.361	0.023	2.267	3.0	0.96	

Table 3-5 provides the results of comparisons of the conventional and dry-back Gmm for the mixture with 9.5- NMAS of Source 2 aggregates. The differences between conventional and dry-back Gmm are significant for all conditioning durations based on both physical and statistical criteria.

Table 3-5- Evaluation of the significance of difference between conventional and Gmm values from physical and statistical standpoints for mixtures with 9.5 mm NMAS of Source 2 aggregates

1 Sample ID	2 Air Dry Wt.	3 Dry-back Wt.	4 %Diff. Dry and Dry-back Mass (Threshold=0.17%)	5 Dry-back Gmm	6 Conventional Gmm	7 Diff. Dry-back & Conventional Gmm (Allowable= 0.010)	8 Gmb Conventional	9 %Air Void- Dry-back	10 Diff. Dry-back & Conventional Air Voids (Allowable=0.4%)	11 P-value Two-Sample t-test
2-1-1-2	2168.4	2178.8	0.480	2.289	2.314	0.025	2.222	2.9	1.07	0.008
2-1-2-2	2178.7	2186.3	0.349	2.290	2.309	0.018	2.217	3.2	0.77	
2-1-1-4	2168.5	2174.5	0.277	2.305	2.320	0.015	2.227	3.4	0.62	0.003
2-1-2-4	2166.4	2172.6	0.286	2.303	2.319	0.015	2.226	3.4	0.64	
2-1-1-8	2158.0	2165.9	0.366	2.317	2.337	0.020	2.243	3.2	0.82	0.021
2-1-2-8	2163.9	2168.2	0.199	2.322	2.333	0.011	2.239	3.6	0.44	
2-1-1-16	2174.3	2181.3	0.322	2.330	2.348	0.018	2.254	3.3	0.73	0.003
2-1-2-16	2149.7	2155.6	0.274	2.333	2.348	0.015	2.254	3.4	0.62	
2-1-1-32	2183.8	2187.6	0.174	2.357	2.367	0.010	2.272	3.6	0.40	0.002
2-1-2-32	2176.9	2180.4	0.161	2.357	2.366	0.009	2.271	3.6	0.37	

Table 3-6 provides the comparison of conventional and dry-back data for the mixture with 19-mm NMAS of Source 2 aggregates. As indicated, based on the values of the trigger measures, the differences between conventional and dry-back Gmm are significant for all but 32-hr conditioned mixtures. The results of the statistical analysis indicate that the differences are significant for all but 2-hr and 32-hr conditioned mixtures.

Table 3-6- Evaluation of the significance of difference between conventional and Gmm values from physical and statistical standpoints for mixtures with 19 mm NMAS of Source 2 aggregates

1 Sample ID	2 Air Dry Wt.	3 Dry-back Wt.	4 %Diff. Dry and Dry-back Mass (Threshold=0.17%)	5 Dry-back Gmm	6 Conventional Gmm	7 Diff. Dry-back & Conventional Gmm (Allowable= 0.010)	8 Gmb Conventional	9 %Air Void-Dry-back	10 Diff. Dry-back & Conventional Air Voids (Allowable=0.4%)	11 P-value Two-Sample t-test
2-2-1-2	2492.8	2502.6	0.393	2.295	2.316	0.021	2.224	3.1	0.87	0.061
2-2-2-2	2471.3	2477.0	0.231	2.308	2.320	0.012	2.227	3.5	0.51	
2-2-1-4	2500.2	2506.0	0.232	2.321	2.333	0.013	2.240	3.5	0.52	0.036
2-2-2-4	2494.1	2496.8	0.108	2.326	2.331	0.006	2.238	3.8	0.24	
2-2-1-8	2474.0	2480.0	0.243	2.325	2.338	0.013	2.244	3.5	0.54	0.003
2-2-2-8	2496.3	2502.4	0.244	2.326	2.339	0.013	2.246	3.5	0.55	
2-2-1-16	2486.2	2489.9	0.149	2.342	2.350	0.008	2.256	3.7	0.34	0.025
2-2-2-16	2473.1	2477.6	0.182	2.338	2.348	0.010	2.254	3.6	0.41	
2-2-1-32	2499.5	2503.7	0.168	2.353	2.363	0.009	2.268	3.6	0.38	0.125
2-2-2-32	2497.4	2501.6	0.168	2.362	2.371	0.009	2.276	3.6	0.38	

Thus, the trigger measures and statistical results agree in the majority but not all cases. As mentioned before, the reason for the discrepancy could be that the differences between the replicates of each group (conventional and/or dry-back) are either too large or too small relative to the difference between averages of the two groups.

3.4 Selected Trigger Measures and Trigger Values

The analysis of NCHRP 9-26 (Phase 4) conditioning time study data confirmed the applicability of the three trigger measures that were selected as the most reliable measures from the analysis of NCHRP 9-26 (Phase 4) ILS data. The selections of the trigger measures were made based on obtaining the best agreements between their corresponding decisions and the decision from statistical analysis regarding the significance of the difference between conventional and dry-back data. Below is a summary of the selected trigger measures and trigger values.

- The trigger measure of percent difference between dry and dry-back mass with the trigger value of 0.17%. A percent difference between dry and dry-back mass of more than the threshold value of 0.17% is considered significant, which requires performing of the dry-back procedure.

- The allowable difference between conventional and dry-back Gmm. The trigger value of 0.010 which is slightly smaller than the AASHTO T 209 single-operator d2s (0.011) is selected as the trigger value.

- The maximum allowable difference in air voids has a meaningful and practical application for acceptance and quality assurance of asphalt mixtures. A maximum difference of 0.4% in air voids computed using conventional and dry-back Gmm (assuming constant Gmb) is found to be an appropriate threshold value for deciding if dry-back is required. This threshold value is less than half of the allowable difference between replicate air void values (±0.5% from design).

3.5 Investigating Effect of Various Mixture Properties on the Differences between Conventional and Dry-back Data Using NCHRP 9-26 (Phase 4) Conditioning Time Study Data

In previous section, it was found that the difference between conventional and dry-back air voids is a reliable physical criterion for deciding if the difference between conventional and dry-back Gmm are significant. Examining the difference between air voids computed from conventional and dry-back Gmm measured after various conditioning times could reveal some information regarding the effect of aggregate absorption, gradation, and effective binder content on both conventional and dry-back Gmm measurements.

Figure 3-1 shows the effect of aggregate source and gradation on the differences between air voids calculated from conventional (without dry-back=w/o DB) and dry-back (with dry-back=w/ DB) Gmm for different conditioning durations. A dash red line in the graph represents the allowable tolerance of 0.4% in air voids difference (established in previous section). Any value exceeding 0.4%, would indicate that the difference between conventional and dry-back data is significant. Several observations can be made from the graphs.

- The top graph of Figure 3-1 indicates that for the mixtures with 9.5-mm NMAS, the differences between conventional and dry-back air voids are more significant for the mixtures with Source 2 aggregates than for the mixtures with Source 1 aggregates. This is contrary to the expectation that the conventional and dry-back air voids should be more different for mixtures with more absorptive aggregates. An investigation into this indicated that although Source 1 aggregates were more absorptive than Source 2 aggregates, the mixtures with Source 1 aggregate have more effective asphalt binder than the mixtures with Source 2 aggregate (Figure 3-2). Higher effective binder indicates better coating of aggregates and therefore, less difference between conventional and dry-back results. This could indicate that adequate effective asphalt content could reduce the effects on Gmm caused by high level of absorption of the aggregates.

- Comparison of the differences between conventional and dry-back air voids of mixtures with 9.5-mm and 19.0-mm NMAS mixtures of Source 2 aggregate in the top and bottom graphs of Figure 3-1 shows that more number of differences are significant (exceeding 0.4% threshold) for the mixtures with 9.5-mm NMAS than for the mixtures with 19.0-mm NMAS. This could indicate that mixtures with finer gradation retain more moisture than the mixtures with coarser gradation. This moisture might be mistakenly considered as the moisture in aggregate pores, which would increase the difference between conventional and dry-back air voids. A longer drying time might be considered for mixtures with finer gradation to ensure SSD has been achieved.

- For the 9.5-mm mixture with Source 1 aggregate (top graph in Figure 3-1), there is a trend of decrease in air void differences with increase in conditioning time from 2 to 8 hours of conditioning. Nevertheless, with further increase in conditioning, the difference in air voids start to increase and reaching a maximum for the 32-hour conditioned mixture. This might indicate that with up to 8 hours of conditioning more asphalt have been absorbed into the pores which have caused less water being absorbed during vacuum suction. However, conditioning in excess of 8 hours might have caused brittleness and cracking of asphalt film resulting in seepage of moisture into aggregate pores during vacuum suction.

- For the 9.5-mm mixture with Source 2 aggregate (top graph in Figure 3-1), there is a similar trend of decrease in air voids differences with the increase in conditioning time up to 8 hours, which is then followed by an increase in air voids differences for the 16-hr. conditioned mixture. However, the increase in air voids differences is not seen for the 32-hr. conditioned mixture. This is probably due to significant stripping and loss of binder films during vacuum suction, which would affect conventional Gmm as well as the dry-back Gmm. The lower effective binder of the mixture with Source 2 aggregates is speculated to be the cause of stripping when mixture is conditioned for 32 hours.

- There is no specific trend in the differences between the air voids computed from conventional and dry-back Gmm of the mixtures with 19.0-mm gradation of either Source 1or Source 2 aggregates conditioned for various durations (bottom graph of

Figure 3-1). This might indicate that mixtures with coarser gradation are less affected by the changes in the level of water absorption as a function of conditioning time than mixtures with finer gradation.

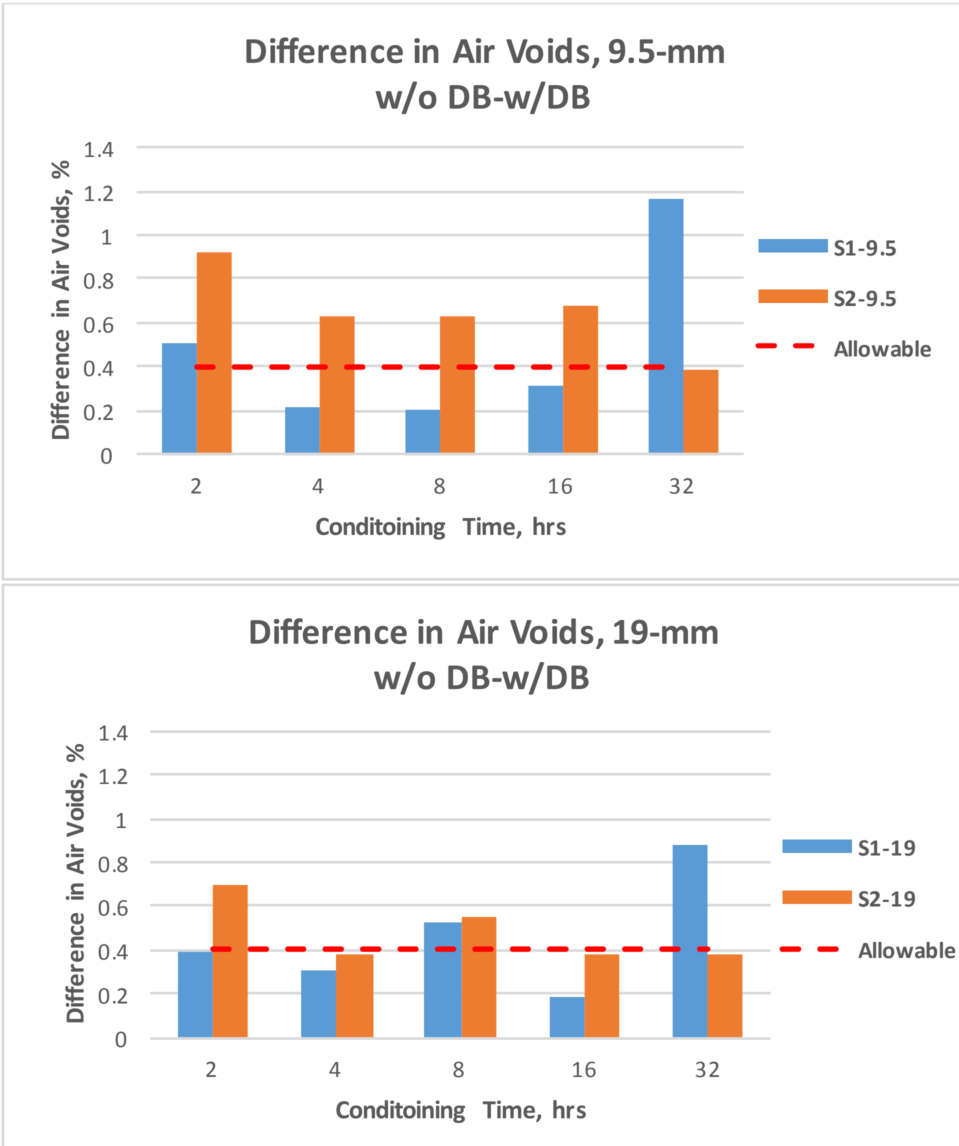

Figure 3-1-Effect of aggregate source (absorption level) and aggregate gradation on differences in air voids calculated from conventional (without dry-back= w/o DB) and dry-back (with dry-back=w/ DB) Gmm for different conditioning durations

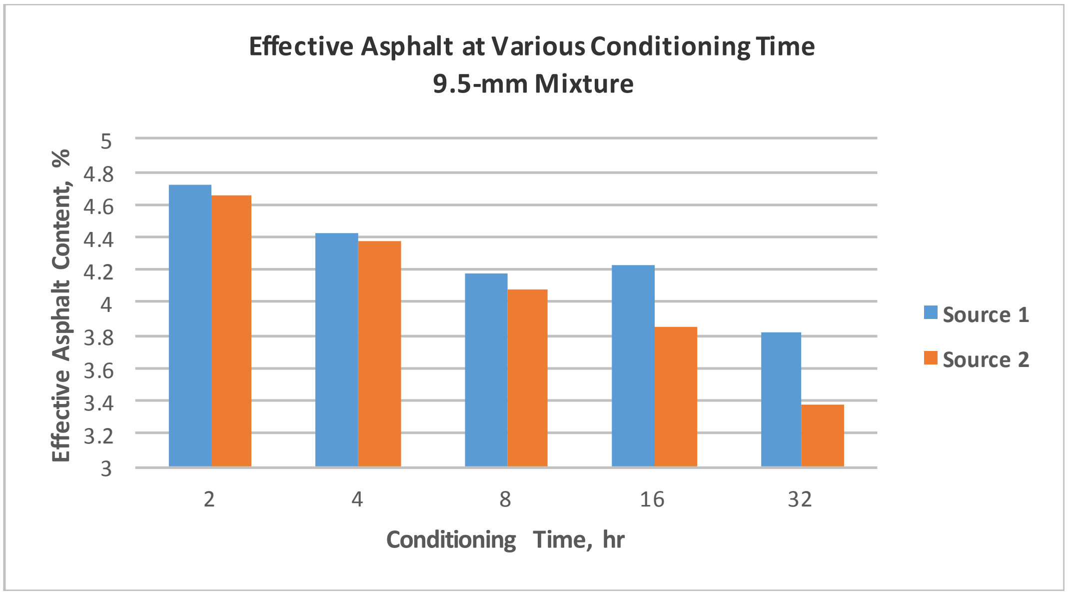

Figure 3-2-Change in effective asphalt content with increase in conditioning time for 9.5-mm mixtures

CHAPTER 4 LABORATORY INVESTIGATION

The laboratory investigation aimed to explore methods to improve the dry-back procedure by testing mixtures with components such as absorptive aggregates, slag aggregates, and recycled pavement, which are known to contribute to the use of the dry-back procedure. The mixtures were tested according to the AASHTO T 209 dry-back procedure and two alternative procedures with potential for reducing the subjectivity of the process and accelerating the procedure. A new criterion is introduced to reduce the efforts involved during the T 209 dry-back process. The selected mixtures, the performed tests, and the modified criterion are discussed in this chapter.

4.1 Selection of Materials

Error! Reference source not found. presents the materials used in this study. The materials were selected based on the results of the survey of the state DOTs (Chapter 2). The mixtures that are typically subjected to dry-back procedure due to having absorptive aggregates, RAP materials, and slag aggregates were obtained from the states who participated in the survey. A total of 11 mixtures were received from 8 state DOTs for the study. Additionally, one mixture was obtained from the 2015 ALF Fatigue experiment. **Error! Reference source not found.** also presents the five categories to which each mixture would correspond. The variables of the 12 mixtures are shown in Table 4-2; the mixtures cover a wide range of variables: aggregate gradation, aggregate absorption, binder grade, slag content, and RAP content.

Table 4-1 Material types and mixture IDs

Materials Type	Mixtures
Control Mixture- Aggregate absorption below 1.5	UT-3
	CO
Mixture with Aggregate Absorption >2% and <3%	MO-6
Mixture with Aggregate Absorption >3 %	NC
Mixture with Slag Aggregate	WV-2
	WV-2B
	MO-6B
Mixture with RAP	UT-4
	ALF
	NE
	MS
	FL

Table 4-2- Properties of the mixtures tested in this study

ID	State	Mix. ID	NMAS, mm	Binder PG	Agg. Abs. %	RAP, %	Slag %
1	NC	RSF9.5A	9.5	-	5.6	0%	-
2	WV	1426497	9.5	70-22	-	15%	59%
2B	WV	1398971	9.5	64-22	-	15%	15%
3	UT w/o RAP	US 6	12.5	76-34	0.4	0%	-
4	UT w/RAP	SR-191	12.5	64-34	1.6	20%	-
5	ALF	Lane 9	12.5	64-22	-	20%	-
6	MO	SP 125 15-68	12.5	70-22	2.7	20%	9%
6B	MO	SP 125 14-3	12.5	64-22	2.0	15%	-
7	CO	FBR0704-230	12.5	76-28	0.7	0%	-
8	FL	SP 14-12461B (TL-C)	12.5	67-22	2.1	15%	-
9	NE	NH-80-9(80)	12.5	64-34	-	30%	-
10	MS	ST 019.15029	19	67-22	1.6	30%	-

4.2 Testing of Mixtures

The 12 mixtures were tested according to three methods. First, they were tested according to Section 15 of AASHTO T 209, "Supplemental Procedure for Mixtures Containing Porous Aggregates." Second, the mixtures were dried back using the CoreDry device, which is used by several state DOTs for rapid drying of aggregates. Third, the mixtures were dried back using a rotating tumbler to accelerate the drying process. Two replicates of each mixture were prepared for each test according to Section of 9 of AASHTO T 209.

Testing of the mixtures according to the dry-back procedure of AASHTO T 209 was performed at Specialized Engineering's facility in Hanover, Maryland. Testing of the mixtures using the CoreDry and rotating tumbler methods was performed at Pavement Systems' laboratory.

A summary of each method is given below.

4.2.1 AASHTO T 209 Dry-Back Procedure

The complete set of steps for measuring maximum specific gravity of the 12 asphalt mixtures according to the dry-back procedure of AASHTO T 209 is provided in Appendix B. The dry-back procedure involves first draining the water from the sample. The sample is then spread on a flat surface in front of a fan to remove the surface moisture. The mass of the sample is then determined at 15-min intervals. The sample is occasionally stirred between the measurement intervals for consistent drying. When the loss in mass is less than 0.05% for an interval, the sample is considered surface dry. This procedure requires about 2 hr.

4.2.2 Accelerated Methods

With the increased use of recycled pavements in the design of asphalt mixtures, the possibility of having exposed aggregate surfaces makes performing the dry-back procedure inevitable. During the busy schedule of the state DOTS during the construction season, spending 2 hours or more on performing the dry-back procedure could be overwhelming. Therefore, it is desirable to explore if the dry-back procedure can be accelerated and if the accelerated method could serve as a reliable alternative to AASHTO T 209 dry-back procedure. Two different methods are explored here for possible reduction of the drying time: a method involving CoreDry device and a method involving a rotating tumbler [5].

CoreDry for Rapid Drying Back

Several state DOTs use CoreDry to speed the dry-back process of Gmm mixtures. Setting 1 of the device, which is the same setting used for drying field cores and compacted mixtures with a vacuum level of 10 mmHg and low heat level of 120ºF is used by the states and also explored in this study for drying back of Gmm mixtures. Mixture samples are placed inside a cylindrical basket that is placed inside the incubator of the CoreDry device. The mixture is subjected to several drying intervals. Each interval includes ten 1.7-min cycles of vacuum, accompanied by low level heat. The mass of the wet mixture before and after each drying interval is measured to determine the Saturated Surface Dry (SSD) mass of the mixture.

Accelerated Method using Rotating Tumbler

A set up including a rotating tumbler and a conventional air blower was used for the accelerated drying back of the Gmm samples. The rotating tumbler, also known as aggregate washer, holds a cylindrical bucket that rotates at a speed of 30 revolutions per minute and uniformly tumbles its content. The aggregate washer was examined as part of the NCHRP 10-87 [16] study and is currently used by several state DOTs for conventional Gmm measurements. NCHRP 10-87 showed that the aggregate washer was effective for releasing the entrapped air during the vacuum suction process due to constant agitation.

Figure 4-1 shows the rotating tumbler setup for the accelerated dry-back process. The following explains the steps for performing the accelerated drying back process:

After the mixture is weighed in water, it is drained over a #200 sieve. Care is taken not to lose any particles of the mixture. The mixture is then transferred to the tumbler bucket (this step is avoided if aggregate washer was also used for vacuum suction). The mass of the bucket and the wet mixture is recorded and the bucket is placed in the tumbler to be rotated. An air blower, such as a conventional hair dryer, positioned on a stand, blows room temperature air to the mixture inside the rotating bucket. The tumbler is stopped at various intervals and the mass of bucket and its contents is measured and recorded. The first mass measurement is after a 15-min drying interval. The subsequent measurements are performed at 5-min intervals until SSD condition is reached.

To determine the SSD condition, a criterion in addition to the AASHTO T 209 criterion is utilized. The percent mass difference of 0.17 %, which was selected as a reliable trigger measure for deciding if dry-back is necessary in Chapter 3, can also serve as a criterion for determining if SSD condition has been reached.

After the first drying interval, which is 15 min., the dry-back mass is checked against the original dry mass by calculating "percent mass difference." If the difference of dry-back and dry mass is 0.17% or less, the final mass is considered the SSD mass. If the difference of dry-back and dry mass is more than 0.17%, the drying continues in 5-min intervals and the mass is checked after each interval. When the change in mass for an interval is 0.05% or less (the same criterion as T 209), the SSD condition has been reached and the final mass at that point is considered the SSD mass.

4.3 Modified SSD Criteria for Reducing Dry-back Time and Effort of AASHTO T 209

Use of "percent mass difference" in combination with the T 209 criterion provides a major advantage in reducing the time and effort of the current T 209 dry-back procedure. Since at the initial stages of drying, only the surface water is being lost, knowing the rate at which the moisture is being dried is not necessarily important. Therefore, frequent mass measurements for an initial period can be eliminated. Consequently, the first drying interval can be lengthened, e.g., to 60 min without any mass measurements. The percent difference between the dry-back mass and dry mass after the 60-min drying period will provide an assessment of the amount of remaining moisture. At this stage the majority of the surface moisture is dried and the remaining moisture is in either fine conglomerates or inside aggregate pores. A percent mass difference of less than 0.17% would indicate that the remaining moisture is not significant and the drying process can be stopped. A percent mass difference of greater than 0.17% would indicate that drying back should be continued, but at smaller time intervals, e.g., 15 min. At this stage the application of the T 209 criterion is important for identifying the SSD condition. A percent mass loss in an interval that is less than 0.05% (as specified in AASHTO T 209) would indicate the SSD condition has been reached.

Figure 4-1- Rotating tumbler (also known as Aggregate Washer) for accelerated dry-back

CHAPTER 5 RESEARCH RESULTS

In this chapter the results of testing the 12 mixtures according to the AASHTO T 209 dry-back method, and with the CoreDry device and the accelerated rotational tumbler device, are discussed. The factors affecting the time to reach SSD are investigated. Moreover, the correlations between the dry-back data corresponding to AASHTO T 209 and the accelerated tumbler method are explored.

5.1 Results According to AASHTO T 209 Dry-Back

Table 5-1 provides the replicate values of the conventional and dry-back Gmm of the 12 mixtures tested according to AASHTO T 209. The differences of the conventional and dry-back Gmm are provided in the last column of the table. The table indicate that the differences between dry-back and conventional Gmm of one or both replicates of five of the mixtures are physically significant; i.e., the difference exceeds the threshold of 0.010 (established in Chapter 3). The samples with significant difference between their conventional and dry-back Gmm are highlighted grey in Table 5-1 and correspond to the following mixtures: two mixtures from Utah, the ALF mixture, the two mixtures from MO, and the mixtures from CO and MS. Four of the five mixtures that showed significant difference between the dry-back and dry Gmm have different percentages of RAP and aggregates with absorption level of above 1.5%. However, contrary to the expectation, UT#3 and CO mixtures with no RAP or absorptive aggregates, which served as control mixtures, exhibited a significant difference between the conventional and the dry-back Gmm values. On the other hand, the NC mixture with highly absorptive aggregates (5.6%), WV mixtures with 59% and 15% of slag, and the NE mixture with 30% RAP did not indicate a significant difference between the conventional and dry-back Gmm values. This suggests that the percentage of RAP, level of aggregate absorption, and percentage of slag content, are not by themselves defining factors for use of dry-back. The effect of these factors most probably have been offset by adequate effective asphalt, which has covered any exposed aggregates surfaces.

Table 5-1 Gmm results according to T 209 dry-back method

ID	State	NMAS, mm	Binder PG	Agg. Abs. %	Slags %	RAP, %	Average Dryback Gmm	Average Conventional Gmm	Difference (Dryback-Conventional)
1	NC	9.5	-	5.6	-	-	2.376	2.383	0.008
							2.379	2.384	0.005
2	WV w/slag	9.5	PG 70-22	-	59	15%	2.500	2.509	0.009
							2.506	2.514	0.008
2B	WV w/slag	9.5	PG 64-22	-	15	15%	2.474	2.483	0.009
							2.477	2.484	0.006
3	UT w/o RAP	12.5	76-34	0.4	-	0%	2.418	2.431	0.012
							2.420	2.431	0.011
4	UT w/RAP	12.5	64-34	1.6	-	20%	2.401	2.415	0.013
							2.410	2.427	0.017
5	ALF	12.5	64-22	-	-	20%	2.721	2.730	0.009
							2.728	2.741	0.013
6	MO	12.5	70-22	2.7	-	20%	2.435	2.441	0.006
							2.424	2.443	0.019
6B	MO	12.5	64-22	2.0	9	15%	2.428	2.439	0.011
							2.433	2.442	0.009
7	CO	12.5	76-28	0.7	-	0%	2.446	2.456	0.010
							2.455	2.459	0.004
8	FL	12.5	67-22	-	-	15%	2.371	2.373	0.002
							2.366	2.372	0.006
9	NE	12.5	64-34	-	-	30%	2.466	2.475	0.009
							2.460	2.464	0.005
10	MS	19	67-22	2.5	-	30%	2.428	2.438	0.010
							2.431	2.442	0.011

The importance of aggregate absorption and RAP content on Gmm differences of the 12 mixtures is also examined graphically. The relationship between the differences and the aggregates absorption level and between differences and percent RAP content for the 12 mixtures are shown in Figure 5-1. As seen from the figures, the R^2 values for both relationships are very small, indicating that aggregate absorption and RAP content have no effect on the differences between the conventional and dry-back Gmm values of the mixtures in this study.

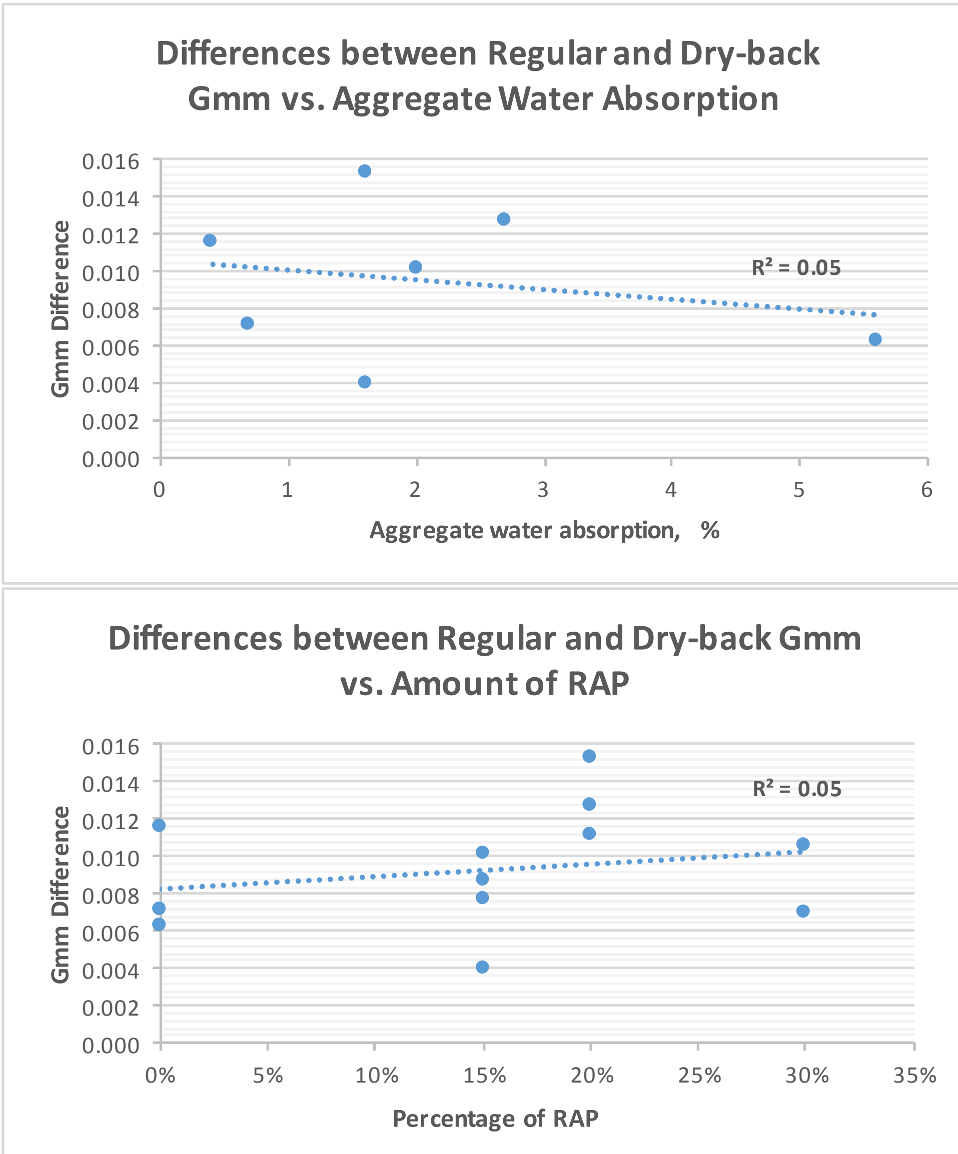

Figure 5-1-Relationship of the difference between conventional and dry-back Gmm with the level of aggregate absorption (Top graph) and amount of RAP (bottom graph)

5.1.1 Dry-Back at Mixture Design

Use of the dry-back procedure requires a lot more care and effort than performing conventional Gmm measurements. It takes an extra 2 hrs. of the technician time and the results are generally more variable than the Gmm values from conventional method. Therefore, it is preferable to avoid using dry-back when it is not absolutely necessary to perform it.

The literature suggests that the effects from aggregates with high level of absorption, slags, and RAP on maximum specific gravity measurements could be offset by using adequate binder to fill the pores and to cover the exposed surfaces of the aggregates [4]. Therefore, if the amount of asphalt is optimized in a mix design, conventional and dry-back procedures of AASHTO T 209 likely would not provide significantly different Gmm values.

For mixtures containing aggregates with known absorption level, optimizing the design for adequate effective binder is a straightforward task. The binder content can be adjusted until the difference between conventional and dry-back Gmm values are not significant.

However, for mixtures with RAP, due to uncertainty with the quality of RAP materials, optimizing the mix design does not provide the certainty that the surface of aggregates would not be exposed during production. For these mixtures performing the dry-back procedure on a regular basis cannot be avoided.

5.1.2 Relationship between Time to SSD Condition and Mixture Variables

The supplemental procedure of T 209 infers that a mixture has reached SSD condition when the change in the retained moisture, between the 15-min interval measurements, is 0.05% or less. The procedure states that this process takes about 2 hours. Although the majority of the mixtures in this study reached the SSD condition, the time it took for each mixture to exhibit 0.05% or less mass change in consecutive measurements was different. For some mixtures the SSD condition was reached before 2 hours and for other mixtures the SSD condition was not reached after 3 hours of drying.

Relationship between Time to SSD and Aggregate Absorption

To explore the possible reasons for the prolonged drying of some of the mixtures, the relationships between time of drying (to 0.05% mass change) and aggregate absorption level and percent RAP in the mixture were explored. Figure 5-2 shows a graphical representation of the relationships. As shown from the figure, there are no relationships between SSD time and aggregate absorption level and between SSD time and mixtures RAP amount. This suggests that aggregate absorption and RAP content are not necessarily the determining factor for the length of the drying process.

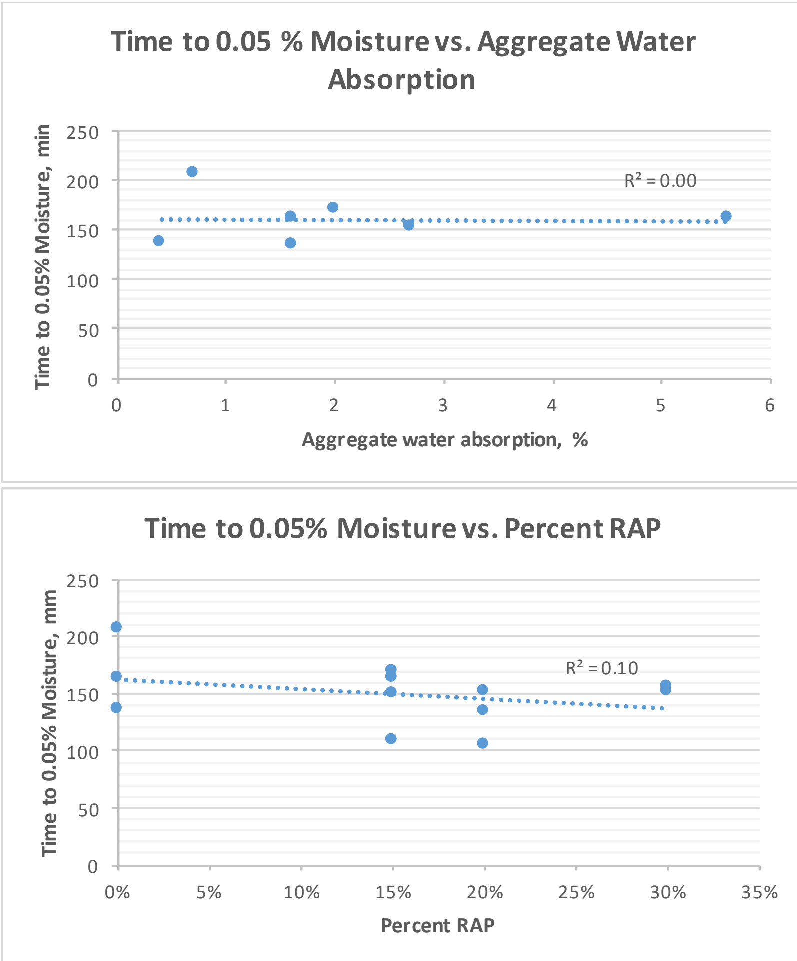

Figure 5-2- Relationships between Time to SSD and level of aggregate absorption and the amount of RAP

Relationship between Time to SSD and Aggregate Gradation

In a continued search for the possible causes of various SSD times, the effect of aggregate gradation was investigated. Figure 5-3 shows the relationship between SSD time and various aggregate gradation variables such as nominal maximum aggregate size (NMAS) and percent passing of different sieve sizes. As indicated from the figure, other than the small relationship between SSD time and percent passing #100 (R^2= 0.30), the relationships between SSD time and aggregate gradation parameters are not significant.

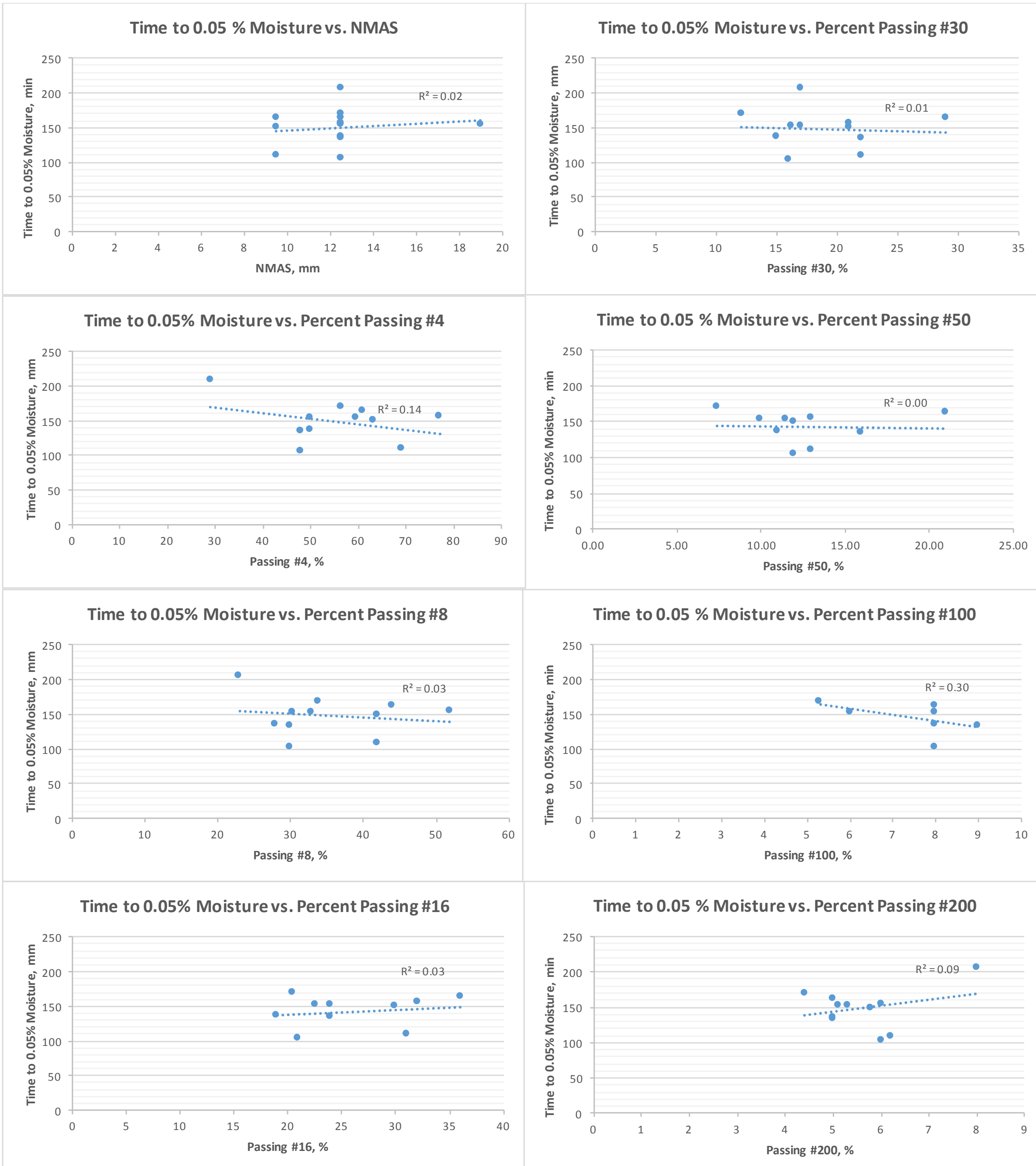

Figure 5-3- Relationship between time to SSD condition and various variables of aggregate gradation

Relationship between Time to SSD and Mixture Gradation

Although gradation of aggregates did not show significant correlation with the time to SSD, the laboratory observations suggested that mixture gradation could be a factor affecting the time to SSD condition. The effect on moisture retained in fine conglomerates of mixture has been also stated in the TX DOT specification [15]. To investigate the effect of mixture gradation, loose mixtures of the 12 mixtures were sieved over # 8 sieve.

The average percent passing #8 sieve and the average time to 0.05% change in moisture are provided in Table 5-2 and shown in Figure 5-4. As indicated from the figure, there is a high correlation ($R^2 = 0.70$) between the time of drying and percent of mixture passing the # 8 sieve, meaning that it would take a longer time for mixtures with more fine particles to reach the SSD condition. For example, for the Colorado mixture with 23.9% passing #8 sieve, it takes 206. 5 min to reach SSD condition while for the ALF Lane 9 mixture with 1.9% passing #8 sieve it only takes 104 min to reach SSD condition.

Table 5-2-Mixture percent passing #8 sieve and time to AASHTO T 209 saturated surface Dry time for the 12 mixtures in this study

Mixture Source	Mixture % Passing #8	AASHTO T 209 Time to 0.05% Consecutive Moisture Loss, min
NC	25.2	162.5
WV	1.65	109
WV	9	149
UT w/o RAP	5.75	136
UT w/RAP	4.95	133.5
ALF	1.9	104
MO	10	152.5
MO	10.1	169.5
CO	23.85	206.5
FL	19.85	162.5
NE	14.45	155
MS	10.3	152.5

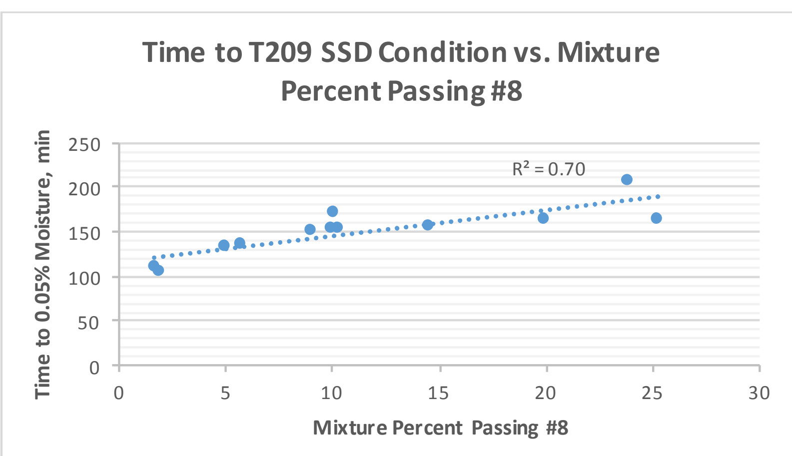

Figure 5-4-Relationship between time to T 209 SSD condition and percent of mixture passing #8 sieve

The above observations suggest that a prolonged drying time may not be always associated with moisture seeping into the pores. Rather, the moisture within fine agglomerates and the moisture surrounding the fine particles could be causing a prolonged drying time. However, unlike the moisture that seeped into the pores, the moisture on the surface of fine aggregates would be dried out within a practical drying time, i.e., 2 to 3 hours by means of air flow and agitation. For this reason, it is important to allow sufficient drying time to reach the SSD conditions so that the persistent moisture between fine particles is not misinterpreted as moisture in the aggregate pores.

Relationship between Mixture Gradation and Aggregate Gradation

To evaluate if aggregate class sizes correspond to the percent mixture passing # 8 sieve, the relationships between the percent passing #8 sieve of the 12 mixtures with the percent of aggregates passing #4 and smaller sieve sizes were explored. Figure 5-5 provides the correlations. As shown from the figure, all correlations are rather small. The largest correlation is with aggregate percent passing #16 (R^2=0.30), which could be a random effect. The low correlation between the finer portion of aggregate and mixture gradations is reasonable since the finer particles of a mixture are random coagulation of various size fine aggregates.

Figure 5-5-Correlations of mixture percent passing #8 sieve with the aggregate percent passing #4 and smaller sieve sizes

5.1.3 Modified SSD Criteria

It is possible to reduce the effort and time involved in drying back the mixture according to the AASHTO T 209 supplemental procedure using modified criteria. In Chapter 3, "percent mass difference" as well as "percent air voids difference" and "Gmm difference" were found to be effective trigger measures for determining if dry-back is needed. Since any of these measures determine the significance of the effect of the retained moisture from a practical stand point, they can also serve as criteria in determining if the amount of moisture left during the dry-back process is significant.

The "percent mass difference," in particular, is effective in determining the SSD condition since it can be readily calculated at the time of drying by subtracting the dry-back mass from the original dry mass. It was also shown in Chapter 3 that a decision on the significance of the difference between dry-back and original dry mass was in good agreement with the decision regarding the significance of the difference between conventional and dry-back air voids, which serves as an important quality control and acceptance parameter.

In this respect, "percent mass difference" is selected as a criterion for determining the SSD condition. If a mixture, during the dry-back process, reaches within 0.17% or less of its original dry mass, it can be stated that the SSD mass would not be significantly different from the original dry mass and, therefore, the dry-back process can be stopped. The final mass is used as the SSD mass. However, if the difference between the dry-back mass and original mass remains more than 0.17% of the original mass for several subsequent mass measurements, the SSD condition is determined using the T 209 criterion. When the change in mass is less than 0.05% for an interval, SSD is reached. In a case, where the mass loss in the interval is less than 0.05%, but the "percent mass difference" is more than 0.17%, the resulting dry-back Gmm would be significantly different from the conventional Gmm.

Use of "percent mass difference" as a SSD criterion may reduce the effort during the dry-back process. To find out if the dry-back mass is less than or more than the threshold value (0.17% of the original mass), the mass measurements do not have to be performed as frequently as after each 15-min interval. There can be longer intervals and less frequent measurements. For example, an initial time interval of 60 min followed by several 15-min. intervals can be used. The percent mass difference is calculated after each drying interval. If the difference is 0.17% or less, the process can be stopped and the final mass is taken as the SSD mass. If the difference is more than 0.17%, then additional 15-min drying intervals are performed until the change in mass is 0.05% or less for an interval.

To investigate the applicability of the "percent mass difference" trigger measure and its threshold value as a SSD criterion, the time to percent mass difference of 0.17% was correlated to the T 209 time to SSD (time to 0.05% consecutive mass loss) for the 12 mixtures. Figure 5-6 shows the relationship. The figure shows that the correlation between the two sets of drying times is good (R^2=0.81). For the majority of the mixtures, 0.17% criterion provides a shorter time to SSD than the T 209 criterion (0.05%). This suggests that the dry-back process could be stopped earlier and that the dry-back mass would not be significantly different from the original dry mass.

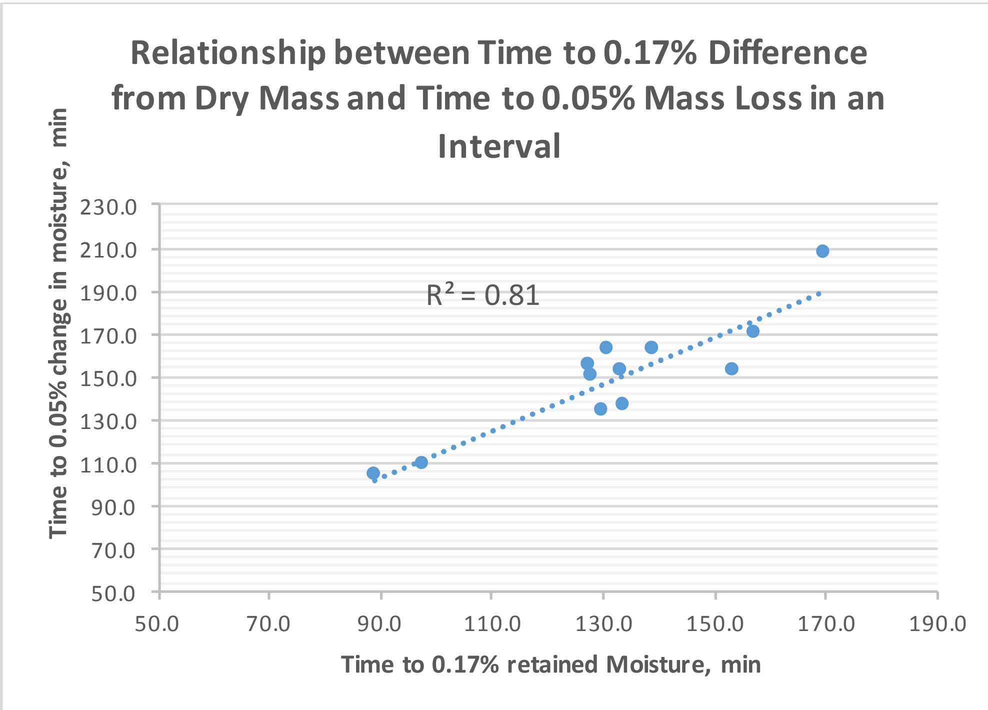

Figure 5-6-Relationship between AASHTO T 209 SSD time based on the threshold of 0.05% mass loss in an interval and time to reach 0.17% difference between original and final mass

5.2 Results of CoreDry

The 12 mixtures in this study were dried back using the CoreDry device to explore if the device can be considered for reducing the time and effort of the dry-back process. CoreDry applies a 10 mm Hg vacuum at 120ºF, which is typically used to rapidly dry the compacted samples after bulk specific gravity measurements. The percent moisture loss per 10-cycle interval (equivalent to 17 min.) for the 12 mixtures are shown in Figure 5-7. It is important to note that in each operation, about half of each mixture was dried back (approximately 1000 g). Figure 5-7 shows that the drying time of the samples using CoreDry are approximately half of the time reported for the mixtures tested according to AASHTO T 209 dry-back procedure (Table 5-3). For example, the dry-back time of AASHTO T 209 procedure for the NC mixture is 162.5 min. and the CoreDry drying time for the half-sized sample of the same mixture is 78.2 min. (46 cycles x 1.7 min./cycle). Considering the size of the samples tested using CoreDry, it can be stated that CoreDry does not provide saving in the time of the drying back process.
The drying patterns of the mixtures using CoreDry are also shown in Figure 5-7. A decreasing exponential trend for loss of moisture with time (or cycle), similar to the trend observed for the dry-back process of AASHTO T 209, can be seen from the graphs. However, note that for some mixtures, the percent moisture loss does not consistently follow the exponential trend and there is occasional reduction of percent loss during one or more drying intervals. For example, for the NE mixture, the percent moisture loss shows a consistent decrease during the first two 10-cycle intervals; however, during the third 10-cycle interval the percent moisture loss is considerably smaller than the percent loss in previous intervals. In the fourth 10-cycle interval, the percent moisture loss increases and follows the exponential trend.

This observation might be explained by the CoreDry mechanism. The CoreDry vacuum may be more effective in drying moisture in the outer edge of the samples than in the inner core. The drying of the inner core would take place at a slower rate than the outer edge. The rate of drying in the inner core increases when there is considerable loss of moisture in the outer core. Therefore, the rate reductions observed for some mixtures are probably due to transition of vacuum from outer edge to the inner core after the outer edge has considerably dried out. This mechanism would work well for the compacted mixtures since moisture does not penetrate into the core of the samples. However, for the un-compacted mixtures moisture needs to be dried consistently throughout the sample.

Another limitation of the CoreDry is possibility of missing the SSD point. Due to the high vacuum, after the surface moisture is removed, the moisture in the pores are exposed to vacuum. The mixture could pass the SSD condition within a relatively short period of time due to suction of moisture out of the pores. This is not desired since the purpose of drying back is to determine the mass at the SSD point.

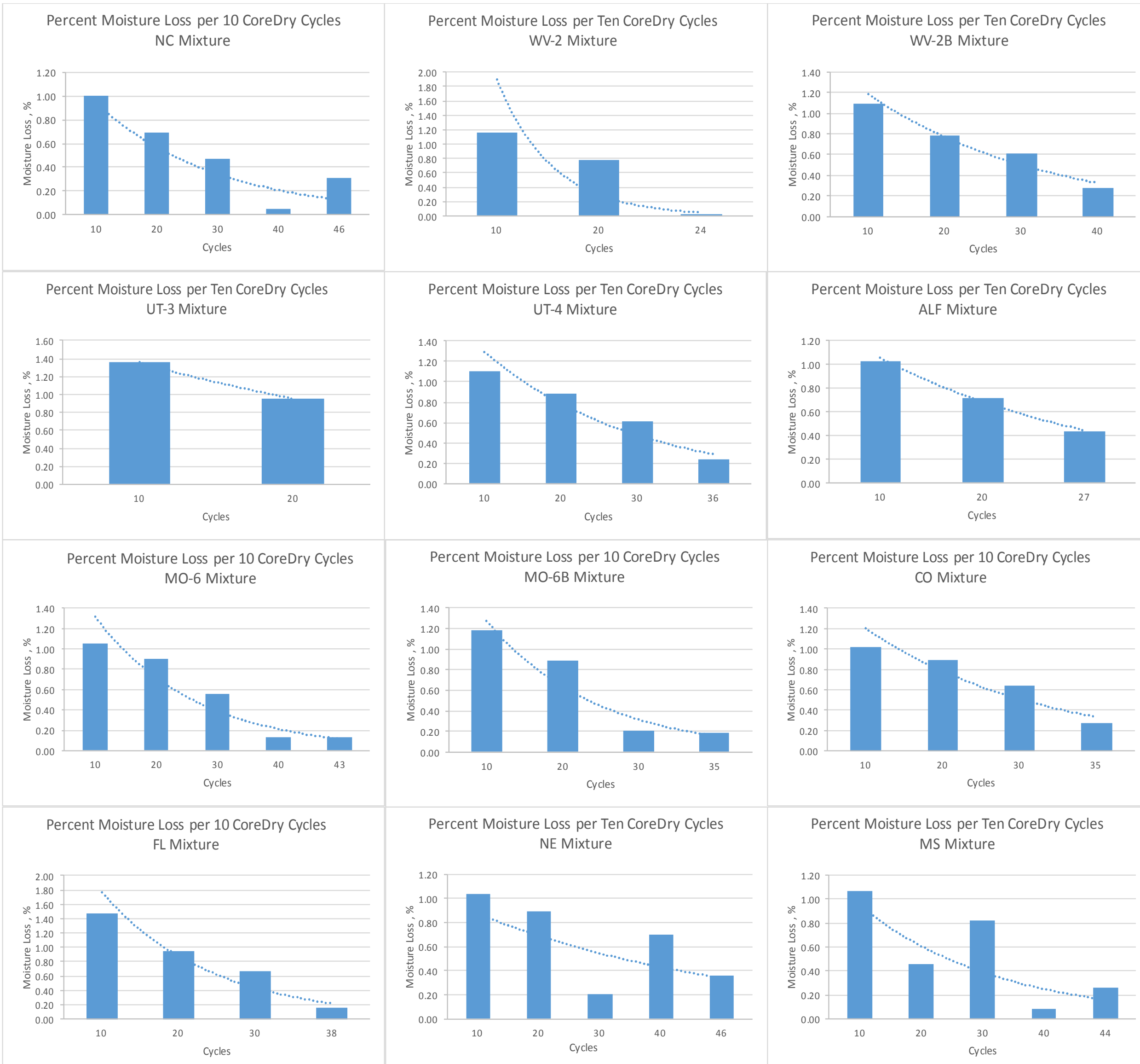

Figure 5-7-Percent loss of Moisture in 12 mixtures dried back using CoreDry; mass measurements were performed every 10 drying cycles equivalent to 17 min.

5.3 Results of Accelerated Rotating Tumbler Dry-back Method

Table 5-3 provides the Gmm values and times to SSD from testing the 12 mixtures according to the accelerated tumbler method. The SSD condition is determined based on the criterion of percent difference between the dry-back mass and the original dry mass using the threshold value of 0.17%. For the comparison, the time to SSD following the T 209 dry-back method using both the 0.05% criterion (consecutive mass loss) and the 0.17% criterion (percent difference of dry-back mass and original dry mass) are also included in the table. As indicated from the table, the accelerated SSD time ranges from 10 min. to 26 min., T 209 SSD time using 0.05% threshold ranges from 104 min. to 206.5 min., and T 209 SSD time using 0.17% threshold ranges from 89 min. to 170 min.

Table 5-3- SSD time of the 12 mixtures tested according to T 209 dry-back procedure and accelerated dry-back method; Two criteria used for the T 209 dry-back time: mass loss of 0.05% between consecutive measurements and mass difference of 0.17% between dry-back mass and the original dry mass; the criterion for the accelerated dry-back time is mass difference of 0.17% from the original dry mass

Mixture source	Mixture % Passing #8	Aggregate % Passing #16	Accelerated Dry-back Gmm	Accelerated Time to 0.17% Mass Difference (from Original Dry Mass)	AASHTO T 209 Time to 0.05% Consecutive Mass Loss	AASHTO T 209 Time to 0.17 % Mass Difference (from Original Dry Mass)
NC	25.2	-	2.377	21.7	162.5	139.0
WV	1.7	31.0	2.503	14.7	109.0	97.8
WV(2B)	9.0	30.0	2.489	19.8	149.0	128.0
UT w/o RAP	5.8	19.0	2.431	15.3	136.0	134.0
UT w/RAP	5.0	24.0	2.406	13.8	133.5	130.0
ALF	1.9	21.0	2.709	10.0	104.0	89.0
MO	10.0	22.6	2.433	17.0	152.5	153.5
MO(2)	10.1	20.5	2.448	17.7	169.5	157.5
CO	23.9	-	2.448	26.0	206.5	170.0
FL	19.9	36.0	2.371	19.3	162.5	131.0
NE	14.5	32.0	2.446	18.5	155.0	127.5
MS	10.3	24.0	2.418	17.0	152.5	133.5

Figure 5-8 shows the relationship between T 209 SSD time based on the 0.05% criteria and the accelerated SSD time based on 0.17% criteria. The figure shows that for the 12 mixtures in this study, the accelerated SSD time has a very good correlation (R^2=0.83) with the T 209 SSD time.

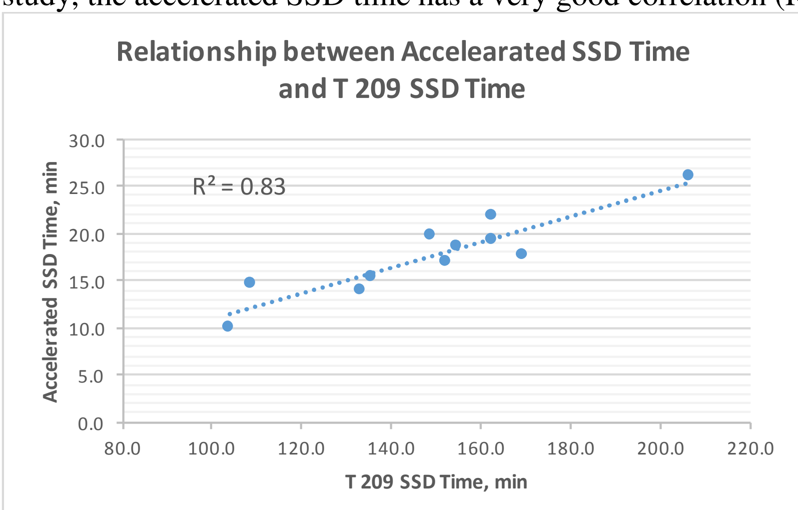

Figure 5-8-Relationship between the T 209 SSD time and the accelerated SSD time

Error! Reference source not found. shows the relationship between T 209 dry-back Gmm values with those using the accelerated method. As shown from the figure, there is a very good agreement between the Gmm values from the two methods. This suggests that the same dry-back Gmm values can be measured with the accelerated tumbler method in one-fourth of the time required to perform the T 209 dry-back measurements.

The good correlation between the accelerated tumbler method and the AASHTO T 209 procedure is expected because of the similarities in the fundamental mechanisms underlying the two methods. In both processes, mixtures are subjected to agitation. In addition, in both methods, room temperature air is blown over the mixtures by a fan. This distinguishes the tumbler method from the CoreDry method, where the sample is stationary inside the incubator and vacuum is used for drying.

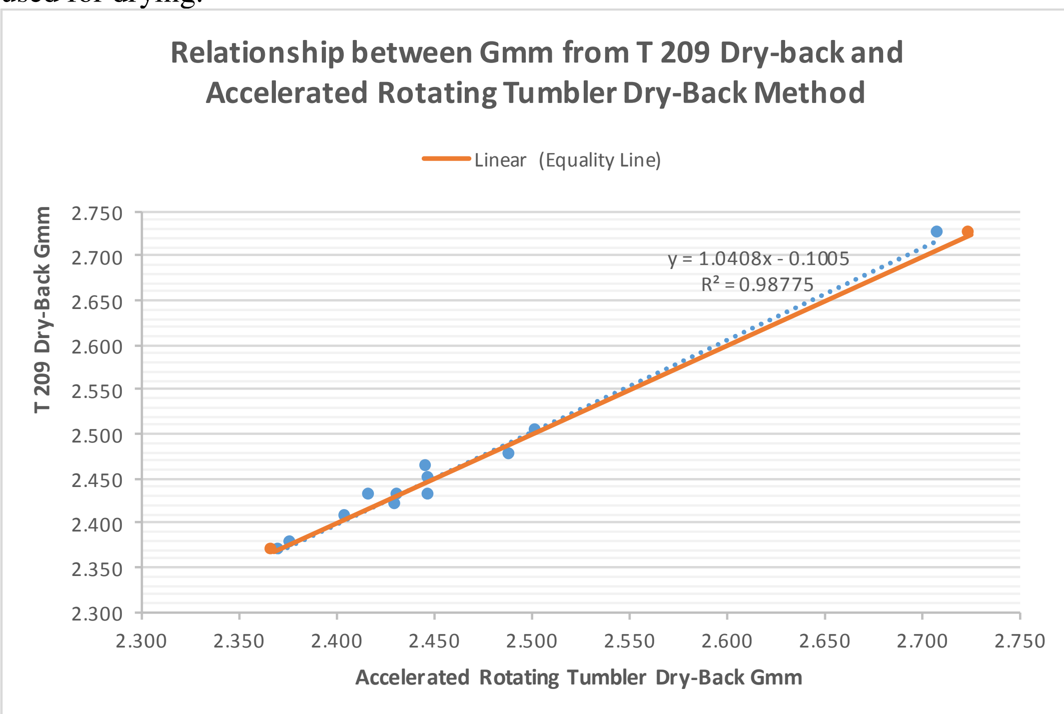

Figure 5-9-The relationship between T 209 dry-back Gmm and the accelerated rotating tumbler dry-back Gmm

Table 5-4 provides the results of a t-test for statistical comparison of the Gmm values from the accelerated rotating tumbler method and those from the T 209 dry-back method. The p-values smaller than 0.05 indicate a significant difference between the Gmm of the two methods and are shaded gray in the table. As indicated from the table, only for two out of the 12 mixtures, the Gmm values from the two methods are significantly different.

Table 5-4- Results of t-test for comparison of Gmm from T 209 dry-back procedure and accelerated dry-back method; shaded P-values indicate statistically significant differences

Mixture ID	T 209 Dry-Back Gmm	Accelerated Dry-Back	Difference	P-value
NC	2.376	2.372	0.004	0.990
NC	2.379	2.383	-0.004	
WV	2.500	2.503	-0.003	0.817
WV	2.506	2.504	0.002	
WV(2)	2.474	2.493	-0.019	0.070
WV(2)	2.477	2.486	-0.009	
UT w/o RAP	2.418	2.433	-0.015	0.028
UT w/o RAP	2.420	2.430	-0.009	
UT w/RAP	2.401	2.406	-0.005	0.981
UT w/RAP	2.410	2.405	0.005	
ALF	2.721	2.705	0.016	0.122
ALF	2.728	2.714	0.014	
MO	2.435	2.446	-0.011	0.852
MO	2.424	2.419	0.005	
MO(2)	2.428	2.446	-0.018	0.038
MO(2)	2.433	2.451	-0.018	
CO	2.446	2.453	-0.007	0.774
CO	2.455	2.444	0.011	
FL	2.371	2.375	-0.005	0.627
FL	2.366	2.367	-0.001	
NE	2.466	2.451	0.015	0.091
NE	2.460	2.442	0.018	
MS	2.428	2.421	0.007	0.064
MS	2.431	2.415	0.016	

5.3.1 Effect of Mixture Gradation on Accelerated Dry-back Time

Figure 5-10 shows the relationship between the accelerated dry-back time and the mixture percent passing # 8 sieve. Similar to the relationship between T 209 dry-back time and the mixture percent passing #8 sieve, the correlation is relatively high. This suggests that the time it will take for the mixture to reach to the SSD condition is more determined by the moisture covering the surface and retained within agglomerates of the fine particles than the moisture in the aggregate pores.

This relationship between time to SSD and mixture fineness could be helpful for predicting the time to SSD. If time to SSD is estimated, it is possible to decide when to make the first weight measurement; that is the point when the sample has lost most of its surface moisture. From that point, shorter drying increments can be applied to identify the SSD point. The 0.17% criterion in combination of 0.05% criteria can be used for the SSD determination.

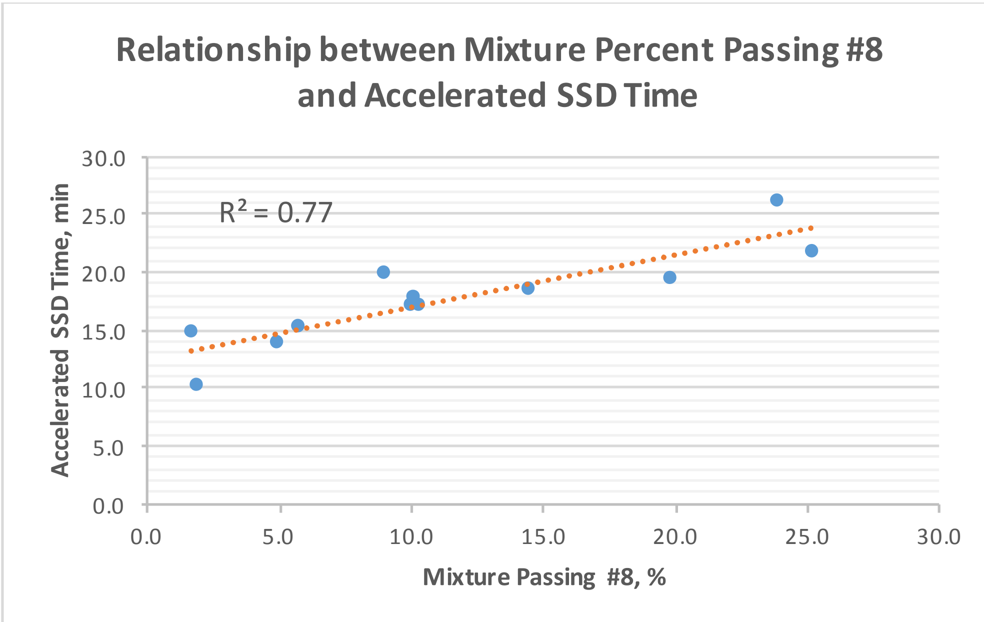

Figure 5-10-Relationship between the accelerated dry-back time and mixture percent passing #8 sieve

CHAPTER 6 FINDINGS AND CONCLUSIONS

The objectives of this research are the following: first, to determine the appropriate trigger measure and trigger value that requires performing the dry-back procedure when it is absolutely necessary in relation to the effect on compaction; second, to determine improvements that can be made to the dry-back procedure to make it less subjective and to produce more repeatable and reliable test results; third, to explore various methods to accelerate the dry-back process to make it less time consuming; and fourth, to explore various criteria for determining the condition of Saturated Surface Dry (SSD) and select the most reliable, straightforward criterion. A summary of findings of the study are discussed below.

6.1 Summary

6.1.1 Literature Review

A comprehensive literature review of the most recent research on the AASHTO T 209 Dry-Back procedure was performed. In addition, the state DOTs were surveyed to ask about the techniques they use for improvement of the dry-back procedure. Furthermore, phone conversations with several state DOTs were conducted and their concerns regarding the dry-back method was queried.

A summary of the literature review, survey, and the phone conversations are provided in Chapter 2. The findings are grouped into the following categories:

1) alterations to the dry-back method practiced by DOTs
2) techniques to accelerate the dry-back procedure
3) use of different triggers to reduce frequency of performing dry-back and to avoid performing dry-back unnecessarily

6.1.2 Analysis of NCHRP 9-26 (Phase 4) Data

In NCHRP Project 9-26 Phase 4 precision estimates were developed for volumetric properties, including Gmm, of asphalt mixtures with highly absorptive aggregates. The study also looked at the effect of laboratory conditioning time on volumetric properties, including Gmm. The raw data from the dry-back procedure performed on the asphalt mixtures in the NCHRP 9-26 Phase 4 study were analyzed to evaluate five trigger measures and their corresponding values used by the state DOTs for determining the conditions when dry-back is necessary. The evaluation of the trigger measures was performed statistically and from a practical point of view, i.e., physical significance with respect to laboratory testing and field performance.

The data from the NCHRP Project 9-26 (Phase 4) study were also used to investigate the effect of aggregate absorption, aggregate gradation, and effective asphalt content on the significance of the difference between conventional and dry-back Gmm. The results of this investigation and the evaluation of the trigger measures are provided in Chapter 3.

6.1.3 Laboratory Investigation

For the laboratory investigation, 12 field mixtures were selected based on the results of the literature review and responses to the survey. Eleven mixtures were obtained from 9 state DOTs and one mixture was obtained from the FHWA ALF facility. Two of the mixtures served as controls; they contained no RAP, slag, or absorptive aggregates. The other 10 mixtures included RAP, slag, absorptive aggregates, or combinations of the three and have been subjected to the dry-back procedure on a regular basis by the state DOTs. These 10 mixtures covered a wide range of aggregate sources with varying levels of water absorption, different percentages of slag, different percentages of RAP, and variety of different NMAS.

The 12 mixtures were tested according to three different methods: the supplemental dry-back procedure of AASHTO T 209; the CoreDry method for rapid mixture dry-back; and a rotating tumbler, also known as aggregate washer, along with a small air blower, to accelerate the dry-back process.

6.2 Findings

6.2.1 Literature Review

A summary of findings of the literature review and the survey of the state DOTs are as follows:

1. The decision on performing the dry-back procedure should not be made based on the level of aggregate water absorption alone. Other factors, such as low level of effective asphalt content, high vacuum level, fractured aggregates in the mix, RAP content, or materials from pavement cores, could cause a significant difference between conventional and dry-back Gmm.
2. Several trigger measures, other than the level of aggregate absorption, are used by the DOTs for deciding if dry-back is necessary. The trigger measures have physical meanings in laboratory testing and pavement performance. They include allowable difference between conventional and dry-back Gmm based on AASHTO T 209 single operator d2s, allowable difference between dry and dry-back air voids, and the percent difference between original dry mass and the dry-back mass. Various threshold values for these trigger measures are being used.
3. States are also applying different modifications to T 209 to expedite the dry-back process. Examples of these are use of a meshed angled surface in place of solid flat surface or use of different devices such as Corelok and CoreDry.
4. To reduce variability of the dry-back Gmm, states are practicing methods to prevent loss of fine particles when draining excess water, such as use of filter paper to collect fine particles and drying them separately in the oven. The mass of the dried particles is then added to the SSD mass.
5. To avoid performing dry-back on a regular basis during construction season, DOTs determine an adjustment factor from performing dry-back during the mix design process. During production, the adjustment factor is applied to the Gmm values determined using conventional method. Different state DOTs reevaluate the adjustment factor at different frequencies, e.g., every eighth QC Gmm measurement.

6.2.2 Analysis of NCHRP Project 9-26 (Phase 4) Data

The NCHRP Project 9-26 (Phase 4) data revealed the applicability of the trigger measures and their corresponding trigger values for determining when dry-back is needed. The effect of aggregate absorption level, aggregate gradation, and effective asphalt content on the significance of the difference between conventional and dry-back Gmm was also investigated. The findings are as follows:

1. Among the five trigger measures used by the state DOTs, three were selected and their trigger values were adjusted. The selection of trigger measures and trigger values was based on obtaining the best agreements with the statistical results and with each other.
2. The three trigger measures and their values are 1) difference between air voids computed using conventional and dry-back Gmm with the trigger value of 0.4%, 2) allowable difference between Gmm values (single laboratory d2s value) with the trigger value of 0.010, and 3) the percent difference between the dry-back mass and the original dry mass with the trigger value of 0.17%.
3. Analysis of data from the conditioning time study of NCHRP Project 9-26 Phase 4 data indicated that differences between the conventional and dry-back Gmm are more significant for mixtures with finer gradation than for mixtures with coarser gradation.
4. Contrary to the expectation, the difference between the air voids computed from the conventional and dry-back Gmm was shown to be less significant for the mixture with higher absorptive aggregate than for the mixture with lower absorptive aggregate. An investigation into this indicated that the mixture with higher absorptive aggregate had higher effective asphalt content than the mixture with lower absorptive aggregate. Therefore, sufficient effective asphalt could offset the effect of aggregate absorption on Gmm measurement.

6.2.3 Laboratory Investigations

1. In this study, several of the mixtures with high percentages of RAP and/or highly absorptive aggregates exhibited dry-back Gmm that were not significantly different from the conventional Gmm. The mixtures might have been produced with adequate effective asphalt content. It may be concluded that despite the level of aggregate absorption, amount of slag, and the percentages of RAP, use of dry-back seems unnecessary if pores of aggregates are filled and surfaces of aggregates are covered with asphalt.
2. For mixtures with absorptive aggregates, dry-back may only be necessary during the mix design process to ensure the amount of binder is adequate. A mixture optimized for asphalt content should meet the following criteria: the difference between the Gmm values from the conventional and dry-back methods is 0.010 or less; the difference in the original dry and dry-back mass is 0.17% or less; the difference in the air voids computed using the conventional and dry-back Gmm is 0.4% or less. Optimizing the mixture for asphalt content eliminates the need for performing dry-back on regular basis.
3. For mixtures with RAP, due to uncertainty in RAP qualities, optimizing the mix design would not be enough for reducing the number of dry-back procedures. For these mixtures, use of dry-back on regular basis seems necessary. With the increased use of RAP in asphalt mixtures, frequent conduct of dry-back could be very time consuming, which could become a burden during the construction season. It is therefore desirable to reduce the technician effort and/or accelerate the dry-back process.
4. Three types of moisture may be retained in asphalt mixtures: The first type is the moisture on the surface of individual particles. The drying time at this stage depends on

the amount of fine particles in the mixture. The second type is the moisture that has trapped in fine conglomerates of a mixture. It takes longer for this moisture to be dried. The third type is the moisture that has seeped inside the pores of aggregates due to uncoated or cut aggregate surfaces. This moisture takes the longest to dry. The first two types of moisture can be dried using blowing air and occasional agitation within a reasonable time period; however, the moisture that is in the pores of aggregate can only be removed using vacuum suction or by blowing air for a relatively long time.

5. The time to SSD condition was found to have direct relationship with the percentage of mixture passing the # 8 sieve (finer portion). For the 12 mixtures in this study, a relatively high correlation was observed between percentage of mixture passing #8 sieve and the time to SSD condition (R^2=0.70). The higher the finer portion of a mixture, the longer it took for the mixture to reach the SSD condition.

6. Modified criteria for determining SSD condition were utilized. The modified criteria are a combination of "percent difference between the dry and dry-back mass" with a threshold value of 0.17% and "percent mass loss in an interval with a threshold value of 0.05% (specified in T 209). As a SSD criterion, any difference of 0.17% or less between the dry-back mass and the original dry mass would be insignificant from practical point of view and the drying process can be stopped. If the difference is larger than 0.17%, the drying continuous and the change in mass in an interval will be compared with 0.05%. threshold value (as specified in T 209). A change of less than 0.05% for two consecutive intervals would indicate SSD condition.

7. The effort involved with the dry-back process of T 209 can be reduced by using the modified criteria. The first mass measurement is performed after 60 min. of drying when the moisture that is being dried is mainly on the surface of the particles. The measured mass is used to determine percent difference with the original dry mass. If the difference is 0.17% or less, the mass is the SSD mass. If the difference is more than 0.17%, the drying continues in 15-min interval following T 209 dry-back process to determine the amount of moisture in the pores. After each 15-min interval, mass is measured and the change in mass for that interval is determined. A change of less than 0.05% in two consecutive intervals would indicate the SSD condition.

8. The dry-back procedure can be significantly accelerated by using a rotating tumbler device. Asphalt mixture is tumbled inside a bucket while being blown by an air blower.

9. The time to SSD condition using the rotating tumbler method is approximately one-fourth of the time to SSD condition using the T 209 dry-back procedure, yet a very good correlation exists between the Gmm values from the accelerated tumbler procedure and from the T 209 dry-back procedure.

10. To determine the condition of SSD with the accelerated method, the modified criteria, suggested for reducing effort of T 209 dry-back procedure in #6, is used. The only difference is that the time intervals are considerably shorter due to constant agitation of the mixture in the tumbler. The first mass measurement is performed after the first 15-min drying interval, when water at the surface of aggregates are dried out. If percent difference between this mass and the original dry mass is less than 0.17%, this mass is considered SSD mass. If the difference is more than 0.17%, drying continuous in 5-min intervals. Depending on the amount of fine particles in the mixture, one or more 5-min

intervals are required to dry the moisture in the fine conglomerates. A percent change of 0.05% or less in a 5-min interval would indicate the SSD condition.

11. The vacuum suction of the CoreDry could pull moisture out of the particle pores. In this case, the condition of SSD could be missed within a short period of time.
12. Lack of agitation during the drying back process in a CoreDry might cause inconsistent drying of the mixture, where the outer edge of a sample could get more dried than the inner core. Occasional reduction in the drying rate was observed for some mixtures during the drying process, which could indicate that the moisture in the inner core of the sample is less accessible to vacuum than the moisture in the outer edge.

6.3 Recommendations

Based on the the findings of this study, the following recommendations are made:

1. AASHTO T 209 indicates aggregate water absorption as the trigger measure to decide performing the dry-back procedure. While aggregate water absorption could be a significant factor, it is not the only factor that could lead to dry-back. There are other conditions such as testing mixture with RAP or testing pavement cores, which may require use of dry-back. These conditions should be included in AASHTO T 209, in addition to aggregate absorption, as the factors that could lead to the use of dry-back.
2. The test method specifies that the dry-back procedure should be performed if water absorption of the aggregates in the mixture is as small as 1.5%. The results of this study indicated that mixture with higher absorptive aggregates could produce dry-back Gmm that is not significantly different from conventional Gmm. It is recommended to remove the 1.5% absorption as a trigger measure for the dry-back procedure.
3. The results of testing the mixtures in this study as well as the review of the literature and the survey of State DOTs indicated that adequate effective binder could eliminate the need for preforming the dry-back procedure even if mixtures include highly absorptive aggregates and RAP. Therefore, it is recommended that trigger measure of 1.5% water absorption in AASHTO T 209 to be replaced by the trigger measure and trigger value of percent difference of 0.17% between the dry-back and the original dry mass. If this value exceeds, the mixture is required to be dried back.
4. It was shown in this study that it is possible to have mixtures with absorptive aggregates and the dry-back mass not to be significantly different from the original dry mass. This can be accomplished by optimizing mixtures for asphalt content to ensure there are adequate asphalt to coat the aggregates regardless of the level of aggregate absorption. In this respect, dry-back can be performed mainly at the time of mix design and less frequently during the production. It is recommended to use the trigger measure of percent difference between dry-back and dry mass of 0.17% when optimizing the design and adjusting the binder content. It is also recommended that after adjusting the binder content, in addition to the volumetric properties, mechanical performance of the optimized mixture to be evaluated to ensure the resistance of the mixture to rutting and fatigue is balanced.
5. For mixtures with RAP, due to uncertainty in the RAP quality, performing of dry-back on regular basis seems necessary. Since performing dry-back is labor intensive and time

consuming it could create a burden during the construction season. It is recommended to either modify the T 209 dry-back process to make it less labor intensive or to accelerate the dry-back process by adopting the rotating tumbler.

6. It is recommended to use the modified criterion for deciding on the condition of SSD. A criterion of 0.17% or less for the difference between the dry-back and the original dry mass in combination with the T 209 criterion of less than 0.05% in mass change for an interval could be used to reduce the effort and or the time needed for the dry-back procedure.
7. it is recommended to make AASHTO T 209 dry-back procedure less labor intensive by reducing the frequency of the mass measurements. The mass measurements can be eliminated for the first 60 min of drying since during this time only surface moisture is being dried. After 60 min. of drying, the mass is measured and the percent difference of the mass with the original dry mass is calculated. A value of less than 0.17% indicates the SSD condition has been reached. A value of greater than 0.17% necessitate continuation of the drying following the AASHTO T 209 dry-back process until SSD is reached. The condition of SSD is recognized when the change is mass in the interval is less than 0.05%.
8. It is recommended to use the rotating tumbler set up to accelerate the drying back process. The tumbler method produces not significantly different Gmm from the T 209 in one-fourth of the time needed for the T 209 dry-back process. The drying back process includes a 15-min initial interval followed by one or more 5-min intervals. The modified criteria suggested in #6 for determining SSD condition of T 209 also applies for the accelerated method: difference of less than 0.17 % between the dry-back mass and the original dry mass after the first 15-min interval and mass change of less than 0.05% for a 5-min interval.
9. It is recommended to explore the application of the findings in this study for the pavement cores with cut surfaces. These include use of the accelerated rotating tumbler method, the recommended trigger measure and trigger value for determining if dry-back is needed, and the recommended criteria and threshold values for determining if SSD condition has been reached.
10. It is recommended to further investigate the relationship between mixture fineness and time to SSD. This information can be used in predicting how long is the initial stage of drying when only surface moisture is being dried. Knowing this information eliminates the need for frequent mass measurements during this period.

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APPENDIX A- SURVEY RESULTS AND ANALYSIS

Survey Results
& Analysis

for

SOM 2015-02 Questionnaire - TS 2c Improvements to AASHTO T 209 Dry Back Procedure

Tuesday, September 29, 2015
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Executive Summary

This report contains a detailed statistical analysis of the results to the survey titled *SOM 2015-02 Questionnaire - TS 2c Improvements to AASHTO T 209 Dry-back Procedure.* The results analysis includes answers from all respondents who took the survey in the 29 day period from Monday, August 31, 2015 to Tuesday, September 29, 2015. 29 completed responses were received to the survey during this time.

Survey Results & Analysis

Survey: SOM 2015-02 Questionnaire - TS 2c Improvements to AASHTO T 209 Dry-back Procedure
Author: Henry Lacinak
Filter:
Responses Received: 29

TS 2c Improvements to AASHTO T 209 Dry-back Procedure (2015 Survey Summary)

	Standard	Dry-back: Frequency	Conditions to run Dry-back procedure:	Trigger Values:	Steps taken to achieve SSD Condition:	Determine if SSD is reached:	Used asphalt field cores for Gmm determination	Sample offered
AZ	ARIZ 417 (T 209 modified)	Conventionally	>0.2% Difference b/w Air v. Fan Drying	Dry-back (fan dry) and Air dry are performed on the first four samples at the beginning of production. If the difference in resultant air voids is >0.2%, we continue to perform fan drying.	ARIZ 417 steps are similar to T 209	ARIZ 417 steps are similar to T 209	Yes	No
CA	T 209	Never						
CT	T 209	Never - Water absorption is typically <1.5%					Yes	

DE	T 209	Not Conventionally	If aggregates are not well coated with asphalt	We run dry-backs only when testing rap.	T 209 or D2041	T 209 or D2041	Yes	Yes
FL	FM 1-T 209	Not Conventionally	At the initial mix design stage.		T 209 or D2041	Mass loss <0.5g in 15 min.	Yes	Yes
GA	T 209	Never	Aggregate water absorption. All aggregates in our state have absorption in the range between 0.38% and 0.73%, which is <1.5%, the absorption required in Section 15 of T-209.			T 209 or D2041		
ID	T 209	Not Conventionally	When Mixtures have absorptive aggregates If broken aggregates in the mixture show sign of water absorption If aggregates are not well coated with asphalt	Note 12 AASHTO T 209	T 209 or D2041	T 209 or D2041	No	No
KS	KT-39: local test procedure for Gmm	Never						
KY	T 209	Not Conventionally	When Mixtures have absorptive aggregates	Type of aggregate used (by experience)	T 209 or D2041	T 209 or D2041	No	Not Sure

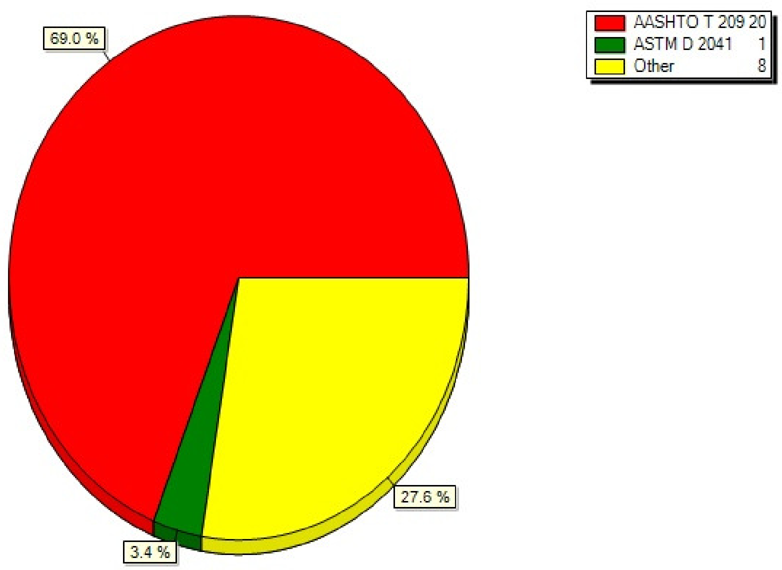
			blast furnace slag or plum run dolomite					
ME	T 209	Never					No	
MI	D2041	Never					No	
MN	T 209	Never					Yes	No
MO	T 209	Conventionally	When Mixtures have absorptive aggregates If aggregates are not well coated with asphalt	Water absorption over 2.0%.	T 209 or D2041	T 209 or D2041	Yes	Yes
MS	T 209	Conventionally	Every 8th QC sample	Every mix	T 209 or D2041	T 209 or D2041	Yes	Yes
MT	T 209	Never					No	No
NC	NCDOT-T 209 (modified version of T 209)	Conventionally	Absorptive aggregates	>1.5 % aggregate water absorption. Specific quarries identified with these absorption values and any asphalt containing these aggregates require Dryback.	T 209 or D2041	T 209 or D2041	Yes	Yes
NH	T 209	Conventionally	If aggregates are not well coated with asphalt				Yes	No
NJ	T 209	Never					Yes	No
NM	T 209	Never	For investigative work only	We don't use dry-back procedure at our lab.	T 209 or D2041	T 209 or D2041	No	Not Sure

NY	T 209	Never					Yes	Not Sure
OR	T 209	Conventionally	Absorptive aggregates	Absorption > 1.2%	Drain water from sample over a #40 sieve	< 0.5g loss after 15 min	No	Not Sure
PA	T 209 (modified)	Not Conventionally	If pavement cores & aggregates are not well coated	None	T 209 or D2041	T 209 or D2041	Yes	No
SC	T 209	Not Conventionally	If aggregates are not well coated with asphalt	We have low absorption materials like granite, but if we have cut or uncoated aggregate, we will run the dry-back procedure. Not typically ≥2.0% either way.	T 209 or D2041	T 209 or D2041 (syringes to remove visible water)	Yes	Not Sure
SD	SD 312	Not Conventionally	When Mixtures have absorptive aggregates If broken aggregates in the mixture show sign of water absorption If aggregates are not well coated with asphalt	Prefer to run the maximum specific gravity test at a higher asphalt content and not use the dry-back procedure.	T 209 or D2041	T 209 or D2041	Yes	Not Sure
TN	T 209	Never					Yes	No

VA	T 209	Not Conventionally	When Mixtures have absorptive aggregates	The majority of our aggregate sources have lower absorption values. Therefore, we don't explore the dry-back procedure.	T 209 or D2041	T 209 or D2041	Yes	No
WA	WAQTC FOP for AASHTO T 209	Never					Yes	
WV	T 209	Not Conventionally	When Mixtures have absorptive aggregates	1.5% absorption in the aggregate	T 209 or D2041	T 209 or D2041	Yes	Not Sure
MTO Ontario	MTO LS264	Not Conventionally	When Mixtures have absorptive aggregates If aggregates are not well coated with asphalt	We have a limit for absorption of 2% so unless it is a non-standard mix, there would not be an aggregate considered porous in our mixes.		ASTM D2041-95, Section 11	Yes	Not Sure

2) What standard do you follow for measuring maximum specific gravity of asphalt mixtures?

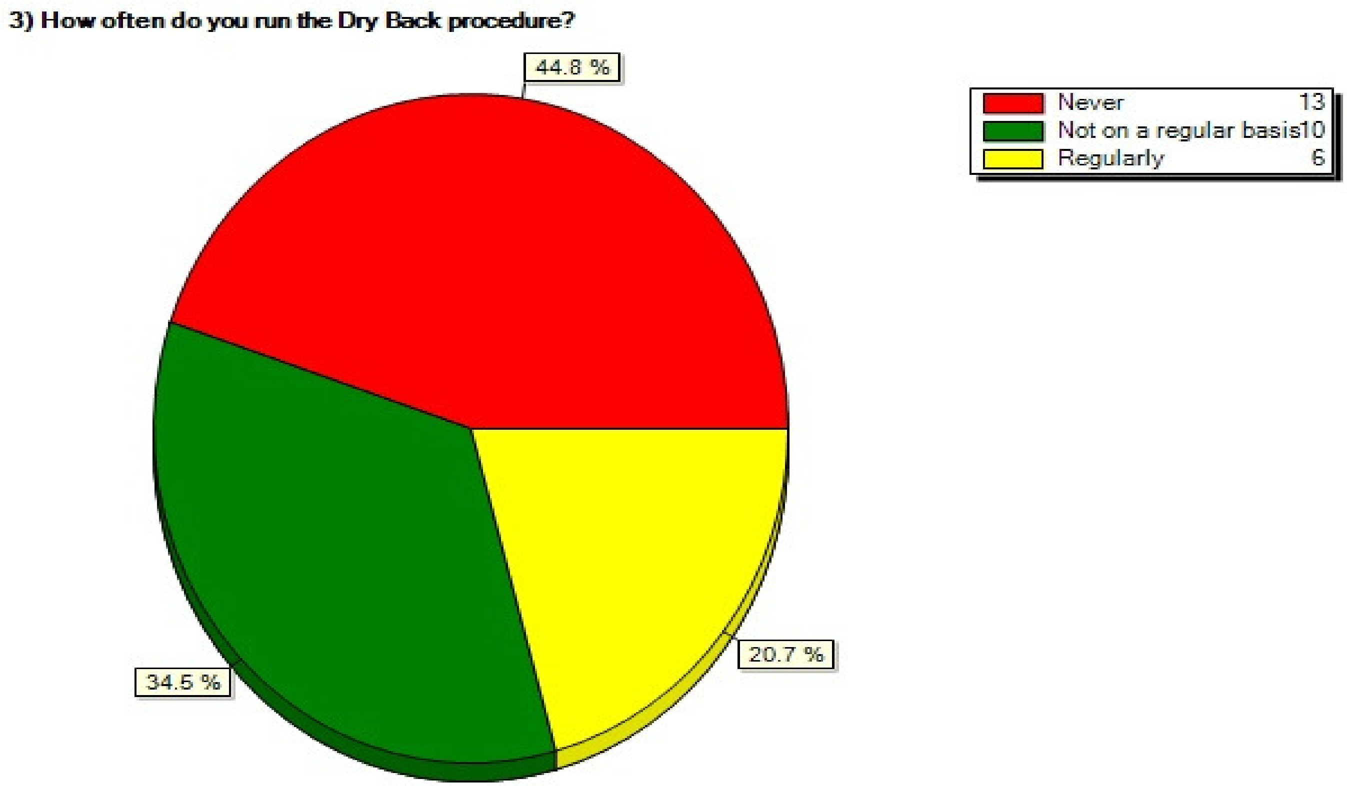
2) What standard do you follow for measuring maximum specific gravity of asphalt mixtures?



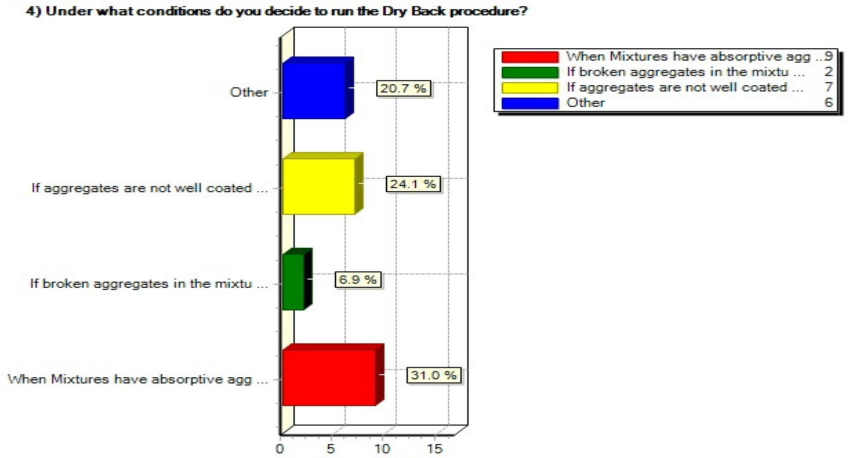
Other Responses:

KT-39: local test procedure for Gmm
NCDOT-T-209 (modified version of T 209)
AASHTO T 209 Modified
WAQTC FOP for AASHTO T 209
We use FM 1-T 209
ARIZ 417 (A Modification of T209)
SD 312
MTO Laboratory Standard LS-264

3) How often do you run the Dry-back procedure?



4) Under what conditions do you decide to run the Dry-back procedure?



Other Responses:

NA
every 8th QC sample
Water absorption typically below 1.5%
Not applicable with very low absorption.
pavement cores & aggr not well coated
used with field cores - investigation
At the initial mix design stage.
>0.2% Difference b/w Air v. Fan Drying
blast furnace slag or plum run dolomite
For investigative work only

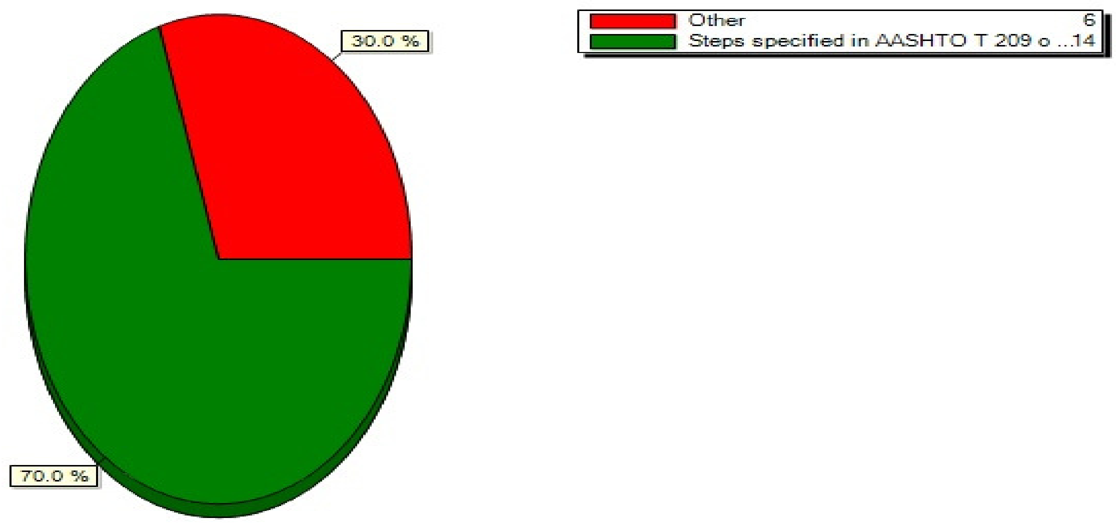
5) What trigger values (i.e., specific values of water or asphalt absorption) do you use to determine if the dry-back procedure to be used (e.g. 1.5 % aggregate water absorption, etc.)?

What trigger values (i.e., specific values of water or asphalt absorption) do you use to determine if the dry-back procedure to be used (e.g. 1.5 % aggregate water absorption, etc.)?
when aggregate asphalt absorption is greater than 1.2%
NA
dry-back is conducted on every mix
n/a
Aggregate water absorption. All the aggregates in our state are with absorption in the range between 0.38% and 0.73%, which is less than 1.5%, the absorption required in Section 15 of T-209.
>1.5 % aggregate water absorption. We have identified the specific quarries with these absorption values and any asphalt containing these aggregates require Dryback.
No trigger.
We have low absorption materials like granite, but if we have cut or uncoated aggregate, we will run the dry-back procedure.. Not typically going to have 2.0% or more either way.
We run dry-backs only when testing rap.
N/A
Dry-back (fan dry) and Air dry are performed on the first four samples at the beginning of production. If the difference in resultant air voids is >0.2%, we continue to perform fan drying.
1.5% absorption in the aggregate
-
Water absorption over 2.0%.
SDDOT prefers to run the maximum specific gravity test at a higher asphalt content and not use the dry-back procedure

type of aggregate used (by experience)
The majority of aggregate sources available in Virginia have lower absorption values. Therefore, we don't explore the dry-back procedure.
Note 12 AASHTO T 209
We don't use dry-back procedure at our lab.
We have a limit for absorption of 2% so unless it is a non-standard mix, there would not be an aggregate considered porous in our mixes.

6) What steps do you take in achieving the SSD condition as part of the dry-back procedure?

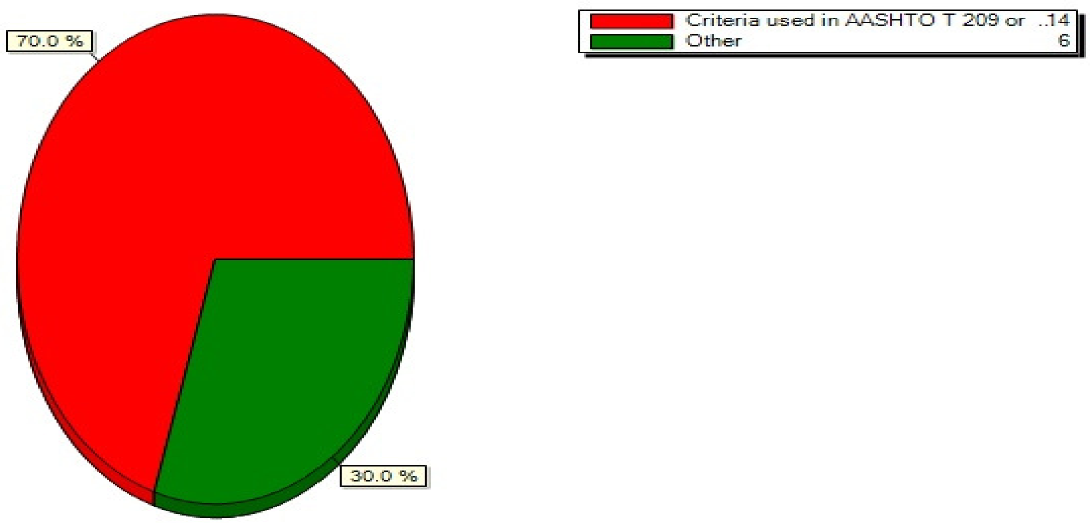
6) What steps do you take in achieving the SSD condition as part of the dry back procedure?



Other Responses:

Drain water from sample over a #40 sieve
NA
NA
n/a
Not applicable
ARIZ 417 steps are similar to T209

7) How do you determine if the mix has reached SSD condition?



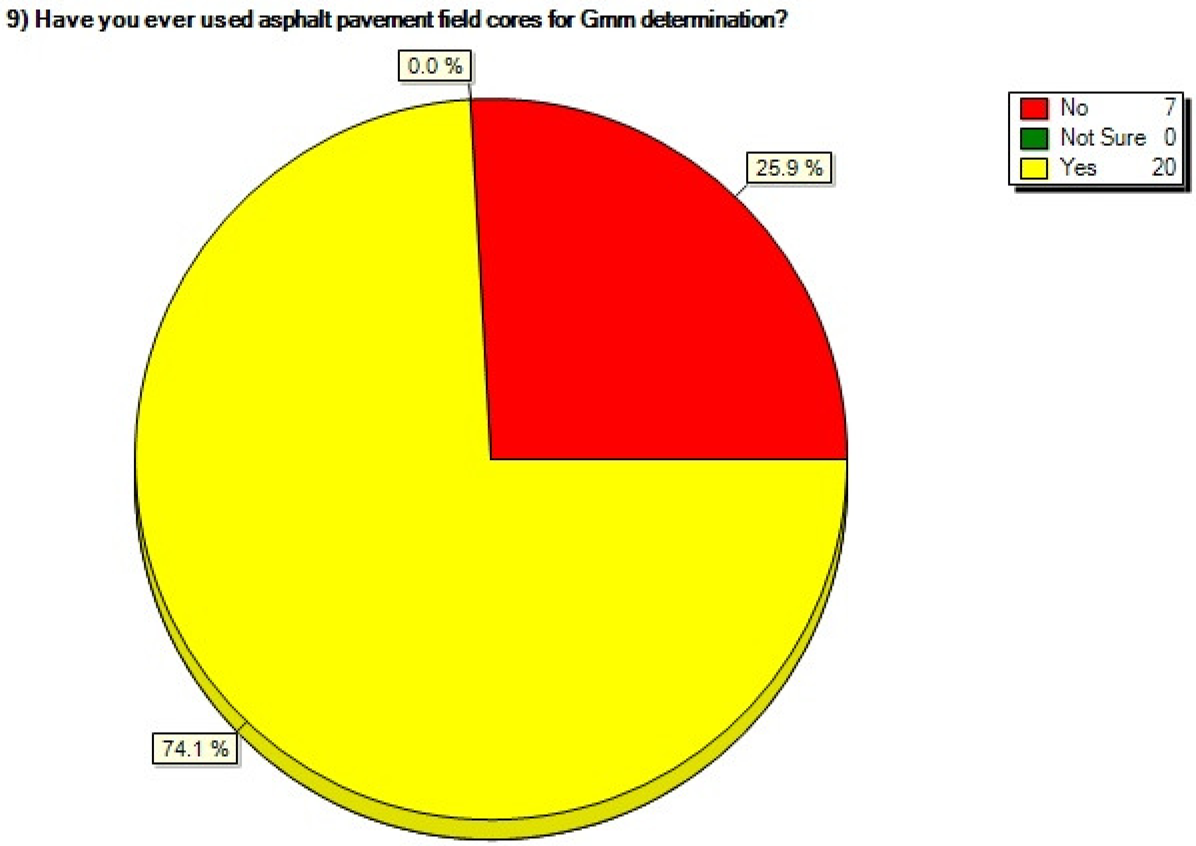
Other Responses:

less than 0.5g loss after 15 minutes
NA
NA
n/a
shringes to remove visible water
Weight loss less than 0.5g in 15 min.
ARIZ 417 steps are simlilar to T209
ASTM D2041-95, Section 11

8) Have you made any modifications to the test method or used any specific device for improving the subjectivity of SSD determination and/or the shortening the time specified for the dry-back procedure? Please explain.

	Have you made any modifications to the test method or used any specific device for improving the subjectivity of SSD determination and/or the shortening the time specified for the dry-back procedure? Please explain.
NC	We allow the use of newspaper or wax-coated paper to speed up moisture removal. Care must be taken to prevent loss of sample during removal from the paper.
SC	CoreDry or CoreLok Device Low heat - incubator, dry at 125 degrees F similar to T166 (section 6.1) to speed process??
SD	SDDOT prefers to run the maximum specific gravity test at a higher asphalt content and not use the dry-back procedure and coat the aggregate so the dry-back procedure is not needed during the mix design testing.

9) Have you ever used asphalt pavement field cores for Gmm determination?



	How did you resolve the minimum mass requirement in the test method since the mass of compacted samples are typically smaller than the minimum sample size?
AZ	Add together multiple cores or take larger cores

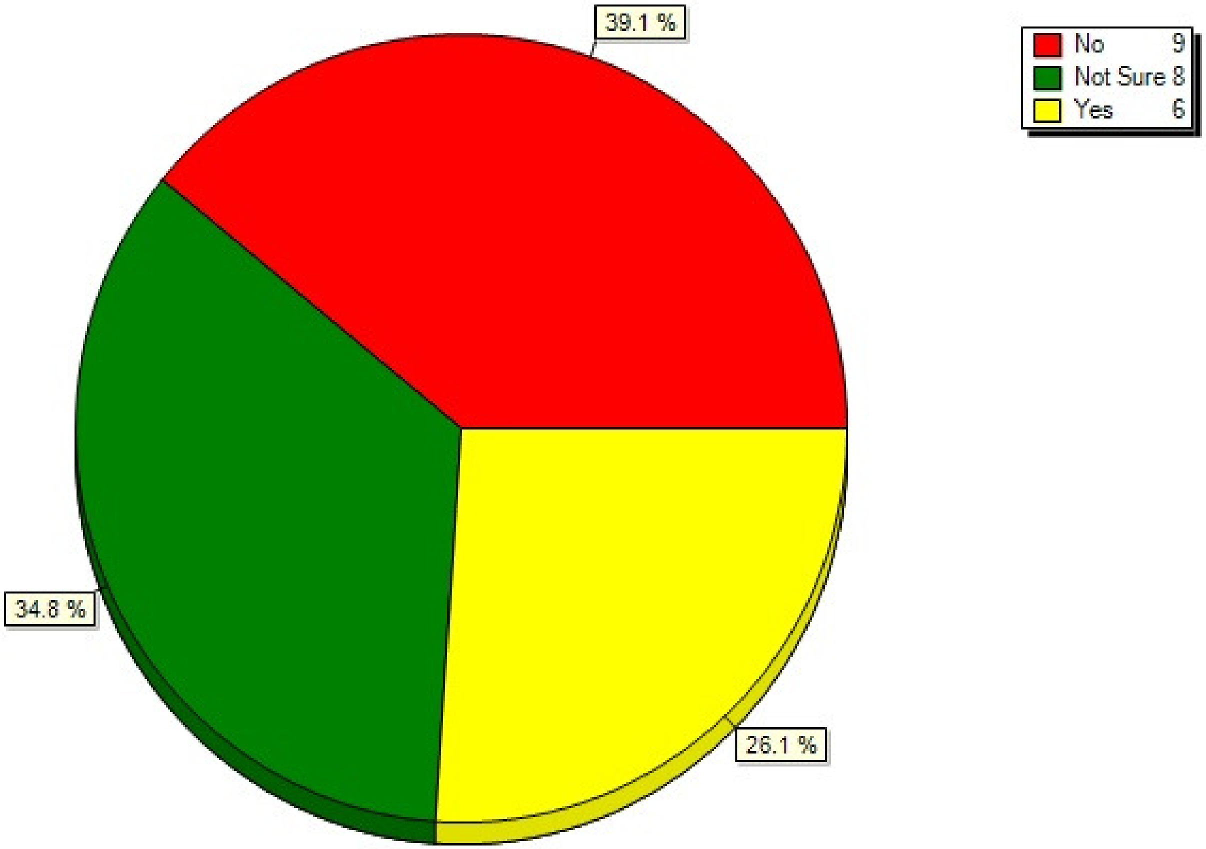
CT	6" cores used. Mass typically over the minimum required.
DE	Cut larger cores.
FL	Used enough cores to get the proper mass.
GA	Yes. We had to cut several cores in the same sub lot and combined the materials to meet minimum sample size of Table 1 in Section 7 of T-209.
MN	Tested as is.
MO	Several cores are taken from the HMA lift the maximum specific gravity value is desired. May need 4 to 10 cores depending on lift thickness.
MS	Only conducted for forensic studies and not for acceptance. In this case the procedure is modified to fit the available material.
NC	Mix multiple cores together to meet minimum mass requirements.
NJ	We use 6 inch diameter cores so lifts over 1.5 inches usually have sufficient mass. In our specification we waive the minimum mass requirement.
NY	Combine cores from the same day's production.
OR	Don't use cores
PA	Waived minimum mass requirement when necessary.
SC	Try to cut 6-8" cores to ensure enough material. Also combining cores by heating and quartering samples down to NMA size.
SD	Combine two or more cores to get the minimum mass needed for the maximum specific gravity test
TN	We combine material from several core specimens to form a representative sample
VA	We try to use 6" cores whenever possible, and typically combine to make a representative specimen for testing.
WA	WSDOT has a standard operating procedure (SOP) for forensic testing that allows use of roadway cores to determine Gmm even though the samples may meet the minimum mass requirements. The results are not use for acceptance.
WV	We only calculate Gmm from field core for forensic investigation of pavement problems. Typically we pull multiple cores to get the minimum sample size.
MTO Ontario	We moved back to using loose mix MRD for that very reason.

11) Have you made any modifications to the test method for the purpose of determining SSD condition of the field core mixtures having cut/exposed faces of aggregates resulted from drilling operation?

	Have you made any modifications to the test method for the purpose of determining SSD condition of the field core mixtures having cut/exposed faces of aggregates resulted from drilling operation? (Please give details)
AZ	No, only would be used for forensic purposes.
FL	No. We only perform Gmm on field cores in rare instances, such as forensic investigations.
GA	No needs, since all our aggregates have very low water absorption (0.38% to 0.73%).
MO	Cores are heated up so as to break them apart. Asphalt mix from the middle of the cores is removed for testing purposes. Exposed aggregate along the outside edge is excluded. The HMA mixture is mixed and split down to the testing size.
MS	The core is heated and the cut aggregate is scraped away from the core and removed from the sample.
NC	We have tried removing cut faces from the sample - not sure if there is any appreciable difference in test results.
OR	Don't use cores
PA	For pavement cores, we use the dry-back procedure in AASHTO T 209.
SC	No. I do not feel like visually removing cut or broken aggregates is a good approach. This affects the blend and percentage of binder in the sample. Fines hold more binder. lowering Gmm.
SD	We mix the core sample or sometimes add a set percent of binder to the cores to coat all aggregate particles and then run the maximum specific gravity test
TN	During sample preparation all cut/exposed aggregate is removed and remain material remixed.
VA	We try to pick them out from the specimen. Therefore, SSD determination is not necessary.
WA	WSDOT uses AASHTO T 331 for Gmb determination of cores.

12) Would you provide a 5-gallon bucket of the mixture that you typically use the Dry-back procedure on?

12) Would you provide a 5-gallon bucket of the mixture that you typically use the Dry Back procedure on?



13) Please feel free to make any comments or suggest any changes for improving the Dry-back procedure.

	Please feel free to make any comments or suggest any changes for improving the Dry-back procedure.
AZ	For additional information, ARIZ 417 can be found here: http://azdot.gov/docs/default-source/businesslibraries/ariz-417d.pdf?sfvrsn=4
NC	Please further investigate the "Cut-faces" issue. We have only attempted this on larger investigations where we had enough cores to combine for larger Rice samples. Our typical investigations only involve minimal numbers of cores and so sample sizes are limited to the point that we do not remove cut-faces.
NM	We don't use the dry-back procedure, but our Independent Testing Labs used it sometime on RAP for Mix designs, if they don't have time to air dry the millings.
SC	We do not run the dry-back often, only for in place field pavement investigations.
SD	SDDOT does not like to use the dry-back method and prefers to try to get the aggregate coated well enough to not need the dry-back procedure
VA	Develop similar procedure for RAP materials

APPENDIX B- DRY-BACK INSTRUCTIONS AND DATA SHEET

Dry-back Measurement Instructions

The following instructions have been prepared based on AASHTO T 209:

1. Place the entire bag, box, or bucket of each mixture in the oven at 105 ± 5°C (221 ± 9°F) until mixture is sufficiently soft to be separated manually.
2. Separate the particles by hand, so that the particles of the fine aggregate portion are not larger than 6.3 mm ($^{1}/_{4}$ in.) take care to avoid fracturing the aggregate.
3. Spilt the entire mixture into 1500 g (for mixtures with NMAS of 9.5 mm and 12.5 mm) or 2500 g (for mixture with NMAS of 19-mm) replicate samples.
4. Use two split samples of each mixture for the Gmm (dry-back) measurement. Pack the remaining split samples in individual bags for future testing. Identify each bag accordingly.
5. Cool the test sample to room temperature, and place it in a tared vacuum container.
6. Determine the net mass of the sample.
7. Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely.
8. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mm Hg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents using the mechanical device during the vacuum period.
9. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mm Hg) per second.
10. *Mass Determination in Water*—Suspend the container and contents in the water bath at 25 ± 1°C (77 ± 2°F) and determine the mass after a 10 ± 1 min immersion.
11. Drain the water from the sample. To prevent the loss of fine particles, decant the water through a 75-µm (#200) sieve.
12. Spread the sample on a flat, non- absorptive tray, breaking any agglomerations by hand, and dry the sample in front of a fan.
13. Immediately after emptying the vacuum container, determine its mass by itself, when totally submerged in the water bath.
14. Periodically, stir the sample by rolling it over upon itself.
15. Weigh the tray and sample at 15-min intervals, and when the loss in mass is less than 0.05 percent for this interval, the sample may be considered to be surface dry. This procedure requires about 2 h and shall be accompanied by intermittent stirring of the sample. This is a saturated surface dry mass and is substituted for A in the denominator in the equation for determining the maximum specific gravity (Equation 2 of AASHTO T 209).
16. Enter the data in the provided Excel sheet.

Dry-back Measurement Data Sheet

Mixture ID		
	Replicate 1	Replicate 2
Mass of Oven Dried Mix Sample in Air (0.1 g)		
Mass of bowl+Mix in water@25C (0.1 g)		
Mass of Bowl in water @25C (0.1 g)		
Temperature of water bath (0.1C)		
Mass of Mix Sample in Air after the Dry-Back (0.1 g)		
Maximum Specific Gravity Gmm (0.001)	#DIV/0!	#DIV/0!

Dry-Back mass measurments:

Replicate 1

Time, min	Mass, g
0	
15	
30	
45	
60	
75	
90	
105	

Replicate 2

Time, min	Mass, g
0	
15	
30	
45	
60	
75	
90	
105	

APPENDIX C- RESULTS OF ANALYSIS OF NCHRP 9-26 PHASE 4 ILS DATA

Table C-1- Comparison from physical and statistical point of view of conventional and dry-back Gmm of mixture with 9.5-mm Source 1 absorptive aggregate from NCHRP 9-26 Phase 4 Interlaboratory Study; shaded cells indicate significance of difference

Lab #	Dried Mass	Dry-back Mass	Diff. Dry and Dry-back WT. (Allow =5 g)	% Diff. Dry and Dryback WT. (Allow =0.17 %)	Dry-back Gmm	Reg. Gmm	Diff. Gmm (Allow =0.011)	% Diff Gmm (Allow =1%)	Gmb Reg.	Air Void % Dry-back	Diff. Air Voids (Allow =0.2%)	t-stat.	P-value (Threshold =0.05)
1	2056.4	2060.2	3.8	0.184	2.276	2.285	0.010	0.42	2.194	3.59	0.41	14.50	0.000
1	2055.5	2059.9	4.4	0.214	2.277	2.288	0.011	0.49	2.196	3.53	0.47		
1	2056.1	2060.3	4.2	0.204	2.276	2.286	0.011	0.46	2.195	3.55	0.45		
2	2041.1	2042.7	1.6	0.078	2.282	2.286	0.004	0.18	2.195	3.83	0.17	2.88	0.022
2	2053.1	2055.3	2.2	0.107	2.278	2.284	0.006	0.24	2.193	3.77	0.23		
2	2045.8	2047.3	1.5	0.073	2.283	2.287	0.004	0.17	2.195	3.84	0.16		
4	2043.5	2047.7	4.2	0.205	2.286	2.297	0.011	0.47	2.205	3.55	0.45	1.62	0.090
4	2031.8	2039.2	7.4	0.363	2.298	2.318	0.019	0.84	2.225	3.19	0.81		
4	2049.4	2054.1	4.7	0.229	2.283	2.295	0.012	0.52	2.203	3.49	0.51		
6	2047.7	2050.2	2.5	0.122	2.286	2.293	0.006	0.28	2.201	3.73	0.27	2.37	0.038
6	2052.7	2055.4	2.7	0.131	2.286	2.293	0.007	0.30	2.201	3.71	0.29		
6	2047.7	2048.3	0.6	0.029	2.292	2.294	0.002	0.07	2.202	3.94	0.06		
7	1031.8	1034.3	2.5	0.242	2.281	2.294	0.013	0.55	2.202	3.47	0.53	2.35	0.039
7	1020	1021.5	1.5	0.147	2.286	2.294	0.008	0.34	2.202	3.68	0.32		
7	1054	1056	2	0.189	2.284	2.294	0.010	0.43	2.202	3.58	0.42		
9	2056.3	2058.4	2.1	0.102	2.282	2.288	0.005	0.23	2.196	3.78	0.22	6.65	0.001
9	2057.3	2059.7	2.4	0.117	2.287	2.294	0.006	0.27	2.202	3.74	0.26		
9	2057.3	2059.2	1.9	0.092	2.285	2.289	0.005	0.21	2.198	3.80	0.20		
13	2051.7	2055.1	3.4	0.165	2.274	2.283	0.009	0.38	2.192	3.64	0.36	2.57	0.031
13	2055.4	2058.1	2.7	0.131	2.281	2.288	0.007	0.30	2.196	3.71	0.29		

13	2055.6	2059.6	4	0.194	2.271	2.281	0.010	0.44	2.190	3.57	0.43		
17	2052.6	2054.4	1.8	0.088	2.286	2.291	0.005	0.20	2.199	3.81	0.19	3.30	0.015
17	2053.9	2056	2.1	0.102	2.282	2.287	0.005	0.23	2.196	3.78	0.22		
17	2047.8	2049.8	2	0.098	2.285	2.290	0.005	0.22	2.198	3.79	0.21		
18	2054.8	2057.5	2.7	0.131	2.273	2.280	0.007	0.30	2.188	3.71	0.29	3.20	0.016
18	2055.1	2058.2	3.1	0.151	2.277	2.285	0.008	0.34	2.193	3.67	0.33		
18	2050.4	2053.9	3.5	0.170	2.277	2.286	0.009	0.39	2.195	3.63	0.37		
21	2047.7	2049.9	2.2	0.107	2.273	2.278	0.006	0.24	2.187	3.77	0.23	3.94	0.008
21	2051.9	2054.8	2.9	0.141	2.276	2.283	0.007	0.32	2.192	3.69	0.31		
21	2052.1	2056.4	4.3	0.209	2.273	2.284	0.011	0.48	2.192	3.54	0.46		
22	2052.7	2056.7	4	0.194	2.272	2.282	0.010	0.44	2.191	3.57	0.43	6.53	0.001
22	2049.7	2054	4.3	0.209	2.275	2.286	0.011	0.48	2.195	3.54	0.46		
22	2062.9	2068.9	6	0.290	2.271	2.286	0.015	0.66	2.195	3.36	0.64		
23	2050.8	2052.3	1.5	0.073	2.286	2.290	0.004	0.17	2.198	3.84	0.16	1.81	0.073
23	2056.9	2061.4	4.5	0.218	2.276	2.287	0.011	0.50	2.196	3.52	0.48		
23	2055	2058.5	3.5	0.170	2.287	2.296	0.009	0.39	2.204	3.62	0.38		
24	2052.9	2056.2	3.3	0.160	2.269	2.278	0.008	0.36	2.187	3.65	0.35	1.68	0.084
24	2049.1	2051.6	2.5	0.122	2.281	2.287	0.006	0.28	2.196	3.73	0.27		
24	2058.8	2062	3.2	0.155	2.273	2.281	0.008	0.35	2.189	3.66	0.34		
25	2040.1	2043.5	3.4	0.166	2.283	2.291	0.009	0.38	2.200	3.63	0.37	4.34	0.006
25	2046.9	2050.2	3.3	0.161	2.281	2.290	0.008	0.37	2.198	3.65	0.35		
25	2033.6	2036.7	3.1	0.152	2.279	2.286	0.008	0.35	2.195	3.67	0.33		
26	2054.1	2056.2	2.1	0.102	2.271	2.276	0.005	0.23	2.185	3.78	0.22	1.35	0.125
26	2051.8	2054.7	2.9	0.141	2.260	2.267	0.007	0.32	2.177	3.69	0.31		
26	2050.5	2052.8	2.3	0.112	2.270	2.276	0.006	0.25	2.185	3.75	0.25		

Table C-2- Comparison from physical and statistical point of view of conventional and dry-back Gmm of mixture with 19.0-mm Source 1 absorptive aggregate from NCHRP 9-26 Phase 4 Interlaboratory Study; shaded cells indicate significance of difference

Lab #	Dried Mass	Dry-back Mass	Diff. Dry and Dry-back WT. (Allow =5 g)	% Diff. Dry and Dryback WT. (Allow =0.17 %)	Dry-back Gmm	Reg. Gmm	Diff. Gmm (Allow =0.011)	% Diff Gmm (Allow =1%)	Gmb Reg.	Air Void % Dry-back	Diff. Air Voids (Allow =0.2%)	t-stat.	P-value (Threshold =0.05)
1	2087	2094.8	7.8	0.372	2.258	2.277	0.019	0.84	2.186	3.18	0.82	2.36	0.039
1	2094.6	2101.5	6.9	0.328	2.276	2.293	0.017	0.75	2.201	3.27	0.73		
1	2096.5	2101.9	5.4	0.257	2.273	2.286	0.013	0.59	2.195	3.43	0.57		
4	2081.8	2089.4	7.6	0.364	2.289	2.308	0.019	0.84	2.216	3.19	0.81	7.08	0.001
4	2078.6	2086.9	8.3	0.398	2.287	2.309	0.021	0.91	2.216	3.12	0.88		
4	2089.2	2097.7	8.5	0.405	2.282	2.303	0.021	0.93	2.211	3.10	0.90		
6	2055.7	2059.5	3.8	0.185	2.274	2.283	0.010	0.42	2.192	3.59	0.41	2.19	0.047
6	2077.9	2081.2	3.3	0.159	2.276	2.284	0.008	0.36	2.193	3.65	0.35		
6	2061.7	2065.3	3.6	0.174	2.283	2.293	0.009	0.40	2.201	3.62	0.38		
7	2081.3	2085.7	4.4	0.211	2.276	2.287	0.011	0.48	2.196	3.54	0.46	4.24	0.007
7	2089.1	2095.2	6.1	0.291	2.275	2.291	0.015	0.66	2.199	3.36	0.64		
7	2091.8	2097.7	5.9	0.281	2.281	2.296	0.015	0.64	2.204	3.38	0.62		
9	2092.8	2095.4	2.6	0.124	2.284	2.291	0.007	0.28	2.199	3.73	0.27	2.41	0.037
9	2090.9	2095.8	4.9	0.234	2.288	2.300	0.012	0.54	2.208	3.48	0.52		
9	2092.2	2093.6	1.4	0.067	2.289	2.292	0.004	0.15	2.201	3.85	0.15		
10	2094.5	2098.7	4.2	0.200	2.273	2.283	0.010	0.46	2.192	3.56	0.44	4.90	0.004
10	2096.1	2100.2	4.1	0.195	2.269	2.279	0.010	0.44	2.188	3.57	0.43		
10	2088.5	2091.8	3.3	0.158	2.270	2.278	0.008	0.36	2.187	3.65	0.35		
13	2095.5	2097.9	2.4	0.114	2.276	2.282	0.006	0.26	2.191	3.75	0.25	1.89	0.066

13	2089.9	2099	9.1	0.434	2.265	2.288	0.023	0.99	2.196	3.04	0.96		
13	2085.8	2088.5	2.7	0.129	2.264	2.271	0.007	0.29	2.180	3.72	0.28		
17	2082.8	2086	3.2	0.153	2.278	2.286	0.008	0.35	2.194	3.66	0.34	2.81	0.024
17	2095.5	2097.5	2	0.095	2.283	2.288	0.005	0.22	2.197	3.79	0.21		
17	2095.7	2098.4	2.7	0.129	2.283	2.290	0.007	0.29	2.199	3.72	0.28		
18	2083.4	2087.8	4.4	0.211	2.265	2.276	0.011	0.48	2.185	3.54	0.46	3.26	0.016
18	2085.8	2094.3	8.5	0.406	2.268	2.289	0.021	0.92	2.198	3.10	0.90		
18	2112.5	2116.4	3.9	0.184	2.270	2.280	0.010	0.42	2.189	3.60	0.40		
21	2034.5	2037.6	3.1	0.152	2.266	2.274	0.008	0.35	2.183	3.67	0.33	3.28	0.015
21	2048.3	2055.7	7.4	0.360	2.267	2.286	0.019	0.82	2.194	3.21	0.79		
21	2084.5	2087.9	3.4	0.163	2.268	2.277	0.008	0.37	2.186	3.64	0.36		
22	2094.5	2098.6	4.1	0.195	2.272	2.282	0.010	0.44	2.191	3.57	0.43	1.79	0.074
22	2099.3	2103.7	4.4	0.209	2.258	2.269	0.011	0.47	2.178	3.54	0.46		
22	2099.7	2103.5	3.8	0.181	2.262	2.271	0.009	0.41	2.180	3.61	0.39		
24	2098.6	2104.6	6	0.285	2.254	2.269	0.015	0.64	2.178	3.38	0.62	1.67	0.085
24	2097.3	2099.5	2.2	0.105	2.271	2.276	0.005	0.24	2.185	3.77	0.23		
24	2092.7	2096.9	4.2	0.200	2.269	2.279	0.010	0.46	2.188	3.56	0.44		
25	2061.2	2065.5	4.3	0.208	2.279	2.289	0.011	0.48	2.198	3.54	0.46	1.25	0.139
25	2054.4	2059.3	4.9	0.238	2.266	2.278	0.012	0.54	2.187	3.48	0.52		
25	2067	2070.5	3.5	0.169	2.288	2.297	0.009	0.39	2.205	3.63	0.37		
26	2095.8	2098.8	3	0.143	2.262	2.269	0.007	0.32	2.178	3.69	0.31	2.13	0.050
26	2085.3	2091.1	5.8	0.277	2.266	2.281	0.014	0.63	2.189	3.39	0.61		
26	2095.8	2099.7	3.9	0.186	2.257	2.267	0.010	0.42	2.176	3.60	0.40		

Table C-3- Comparison from physical and statistical point of view of conventional and dry-back Gmm of mixture with 9.5-mm Source 2 absorptive aggregate from NCHRP 9-26 Phase 4 Interlaboratory Study; shaded cells indicate significance of difference

Lab #	Dried Mass	Dry-back Mass	Diff. Dry and Dry-back WT. (Allow =5 g)	% Diff. Dry and Dryback WT. (Allow =0.17 %)	Dry-back Gmm	Reg. Gmm	Diff. Gmm (Allow =0.011)	% Diff Gmm (Allow =1%)	Gmb Reg.	Air Void % Dry-back	Diff. Air Voids (Allow =0.2%)	t-stat.	P-value (Threshold =0.05)
1	2195.2	2202.7	7.5	0.340	2.293	2.311	0.018	0.78	2.219	3.24	0.76	6.29	0.002
1	2190.1	2196.9	6.8	0.310	2.291	2.307	0.016	0.71	2.215	3.31	0.69		
1	2195.5	2201.4	5.9	0.268	2.298	2.312	0.014	0.62	2.220	3.40	0.60		
4	2197.6	2199.9	2.3	0.105	2.302	2.308	0.006	0.24	2.215	3.77	0.23	3.35	0.014
4	2190.1	2198.2	8.1	0.368	2.299	2.319	0.020	0.85	2.226	3.18	0.82		
4	2194.4	2199	4.6	0.209	2.304	2.316	0.011	0.48	2.223	3.53	0.47		
6	2180.2	2186.3	6.1	0.279	2.301	2.316	0.015	0.64	2.224	3.38	0.62	9.54	0.000
6	2185.5	2191.7	6.2	0.283	2.298	2.313	0.015	0.65	2.220	3.37	0.63		
6	2174.8	2182.5	7.7	0.353	2.297	2.315	0.019	0.81	2.223	3.21	0.79		
7	1546	1546.6	0.6	0.039	2.308	2.311	0.002	0.09	2.218	3.91	0.09	1.65	0.087
7	1547	1548	1	0.065	2.304	2.307	0.003	0.15	2.215	3.86	0.14		
7	1551	1551.9	0.9	0.058	2.307	2.310	0.003	0.13	2.218	3.87	0.13		
9	2205.7	2207.7	2	0.091	2.303	2.308	0.005	0.21	2.216	3.80	0.20	7.78	0.001
9	2200.9	2204.1	3.2	0.145	2.302	2.309	0.008	0.33	2.217	3.68	0.32		
9	2196.7	2199.1	2.4	0.109	2.304	2.310	0.006	0.25	2.217	3.76	0.24		
10	2194.5	2198.1	3.6	0.164	2.294	2.302	0.009	0.38	2.210	3.64	0.36	16.26	0.000
10	2189	2192.2	3.2	0.146	2.295	2.303	0.008	0.34	2.211	3.68	0.32		
10	2187.7	2191.6	3.9	0.178	2.294	2.303	0.009	0.41	2.211	3.61	0.39		
12	2191.6	2194.8	3.2	0.146	2.308	2.316	0.008	0.34	2.223	3.68	0.32	2.69	0.027

12	2188.3	2190.1	1.8	0.082	2.311	2.315	0.004	0.19	2.223	3.82	0.18		
12	2192.2	2193.2	1	0.046	2.308	2.311	0.002	0.11	2.218	3.90	0.10		
13	2186.3	2188.5	2.2	0.101	2.306	2.311	0.005	0.23	2.219	3.78	0.22	4.97	0.004
13	2190.6	2193.4	2.8	0.128	2.306	2.313	0.007	0.29	2.221	3.72	0.28		
13	2188.7	2191.5	2.8	0.128	2.303	2.310	0.007	0.29	2.218	3.72	0.28		
16	2192	2192.6	0.6	0.027	2.312	2.313	0.001	0.06	2.220	3.94	0.06	1.01	0.186
16	2192.2	2192.7	0.5	0.023	2.309	2.310	0.001	0.05	2.218	3.95	0.05		
16	2187.4	2188	0.6	0.027	2.308	2.310	0.001	0.06	2.217	3.94	0.06		
17	2187.2	2195	7.8	0.355	2.292	2.311	0.019	0.82	2.219	3.21	0.79	11.01	0.000
17	2193.5	2203.1	9.6	0.436	2.288	2.311	0.023	1.00	2.218	3.03	0.97		
17	2189.1	2196.1	7	0.319	2.294	2.311	0.017	0.73	2.218	3.29	0.71		
18	2193.2	2194.5	1.3	0.059	2.307	2.311	0.003	0.14	2.218	3.87	0.13	1.68	0.084
18	2199.6	2201.2	1.6	0.073	2.311	2.315	0.004	0.17	2.223	3.84	0.16		
18	2185.9	2186.8	0.9	0.041	2.310	2.312	0.002	0.10	2.220	3.91	0.09		
19	2178.7	2187.9	9.2	0.420	2.284	2.306	0.022	0.96	2.214	3.07	0.93	15.11	0.000
19	2163.9	2172	8.1	0.373	2.286	2.306	0.020	0.86	2.213	3.17	0.83		
19	2185.8	2193.7	7.9	0.360	2.288	2.307	0.019	0.83	2.215	3.20	0.80		
21	2194.7	2196.6	1.9	0.086	2.300	2.305	0.005	0.20	2.213	3.81	0.19	1.80	0.074
21	2188.5	2194.3	5.8	0.264	2.308	2.322	0.014	0.61	2.229	3.41	0.59		
21	2193.1	2198.7	5.6	0.255	2.297	2.311	0.014	0.59	2.219	3.43	0.57		
22	2193.5	2197.5	4	0.182	2.301	2.311	0.010	0.42	2.219	3.60	0.40	1.50	0.104
22	2197.3	2199.8	2.5	0.114	2.305	2.311	0.006	0.26	2.218	3.75	0.25		
22	2192.7	2197.1	4.4	0.200	2.290	2.300	0.011	0.46	2.208	3.56	0.44		
24	2189.8	2192.9	3.1	0.141	2.300	2.308	0.008	0.33	2.215	3.69	0.31	4.10	0.007
24	2188	2192.2	4.2	0.192	2.296	2.306	0.010	0.44	2.214	3.58	0.42		
24	2188.8	2191.3	2.5	0.114	2.302	2.308	0.006	0.26	2.216	3.75	0.25		
25	2191.6	2200	8.4	0.382	2.292	2.312	0.020	0.88	2.220	3.15	0.85	14.29	0.000

25	2176.6	2184.8	8.2	0.375	2.289	2.309	0.020	0.86	2.216	3.17	0.83		
25	2199.7	2207.4	7.7	0.349	2.291	2.310	0.019	0.80	2.217	3.22	0.78		
26	2182.4	2185.9	3.5	0.160	2.291	2.300	0.008	0.37	2.208	3.65	0.35	1.35	0.124
26	2192.6	2195.8	3.2	0.146	2.282	2.289	0.008	0.33	2.198	3.68	0.32		
26	2197	2201.2	4.2	0.191	2.275	2.285	0.010	0.43	2.194	3.58	0.42		

Table C-4- Comparison from physical and statistical point of view of conventional and dry-back Gmm of mixture with 19.0-mm Source 2 absorptive aggregate from NCHRP 9-26 Phase 4 Interlaboratory Study; shaded cells indicate significance of difference

Lab #	Dried Mass	Dry-back Mass	Diff. Dry and Dry-back WT. (Allow =5 g)	% Diff. Dry and Dryback WT. (Allow =0.17 %)	Dry-back Gmm	Reg. Gmm	Diff. Gmm (Allow =0.011)	% Diff Gmm (Allow =1%)	Gmb Reg.	Air Void % Dry-back	Diff. Air Voids (Allow =0.2%)	t-stat.	P-value (Threshold =0.05)
1	2519	2522.6	3.6	0.143	2.312	2.320	0.008	0.33	2.227	3.68	0.32	1.70	0.082
1	2525.4	2527.5	2.1	0.083	2.308	2.312	0.004	0.19	2.220	3.82	0.18		
1	2518.7	2521.9	3.2	0.127	2.304	2.310	0.007	0.29	2.218	3.72	0.28		
3	2516.8	2519.4	2.6	0.103	2.313	2.318	0.006	0.24	2.225	3.77	0.23	2.36	0.039
3	2521.7	2525.2	3.5	0.139	2.305	2.313	0.007	0.32	2.220	3.69	0.31		
3	2524	2527.8	3.8	0.150	2.305	2.313	0.008	0.35	2.221	3.67	0.33		
4	2501.5	2508.4	6.9	0.275	2.307	2.322	0.015	0.64	2.229	3.39	0.61	9.37	0.000
4	2505.8	2513.1	7.3	0.290	2.305	2.320	0.016	0.67	2.227	3.35	0.65		
4	2509.1	2514.7	5.6	0.223	2.305	2.317	0.012	0.51	2.224	3.50	0.50		
6	2512.5	2516.8	4.3	0.171	2.309	2.318	0.009	0.40	2.226	3.62	0.38	6.42	0.002
6	2509.2	2514.3	5.1	0.203	2.305	2.316	0.011	0.47	2.224	3.55	0.45		
6	2507.5	2512.9	5.4	0.215	2.304	2.316	0.011	0.50	2.223	3.52	0.48		
7	2069.3	2071.2	1.9	0.092	2.305	2.310	0.005	0.21	2.218	3.80	0.20	5.41	0.003
7	2072	2074	2	0.096	2.307	2.312	0.005	0.22	2.220	3.79	0.21		
7	2073.1	2075.4	2.3	0.111	2.307	2.313	0.006	0.26	2.220	3.75	0.25		
9	2524.8	2527.4	2.6	0.103	2.314	2.319	0.006	0.24	2.226	3.77	0.23	2.59	0.030
9	2524.1	2526.9	2.8	0.111	2.309	2.315	0.006	0.26	2.222	3.75	0.25		
9	2519.7	2521.9	2.2	0.087	2.310	2.314	0.005	0.20	2.222	3.81	0.19		
13	2521.5	2523.3	1.8	0.071	2.300	2.304	0.004	0.16	2.212	3.84	0.16	0.64	0.279

13	2518.1	2520.9	2.8	0.111	2.308	2.314	0.006	0.26	2.222	3.75	0.25		
13	2501.3	2503.1	1.8	0.072	2.318	2.321	0.004	0.17	2.229	3.84	0.16		
18	2508.3	2510.2	1.9	0.076	2.310	2.314	0.004	0.17	2.221	3.83	0.17	3.70	0.010
18	2511.2	2514.3	3.1	0.123	2.307	2.314	0.007	0.28	2.221	3.73	0.27		
18	2510.2	2511.9	1.7	0.068	2.311	2.315	0.004	0.16	2.222	3.85	0.15		
19	2491.5	2506.8	15.3	0.610	2.278	2.310	0.032	1.40	2.218	2.64	1.36	10.74	0.000
19	2484.5	2500.1	15.6	0.624	2.275	2.308	0.033	1.43	2.215	2.61	1.39		
19	2496.1	2512.8	16.7	0.665	2.281	2.316	0.035	1.53	2.223	2.51	1.49		
21	2169.9	2172.7	2.8	0.129	2.299	2.305	0.007	0.30	2.213	3.71	0.29	0.64	0.279
21	2114.8	2117.2	2.4	0.113	2.322	2.328	0.006	0.26	2.235	3.75	0.25		
21	2143.2	2146.4	3.2	0.149	2.321	2.330	0.008	0.35	2.236	3.67	0.33		
22	2521.3	2525.6	4.3	0.170	2.303	2.312	0.009	0.39	2.220	3.62	0.38	4.09	0.007
22	2499.8	2504.1	4.3	0.172	2.303	2.312	0.009	0.40	2.220	3.62	0.38		
22	2524.7	2534.4	9.7	0.383	2.294	2.314	0.020	0.88	2.222	3.15	0.85		
23	2505.2	2508.6	3.4	0.136	2.304	2.312	0.007	0.31	2.219	3.70	0.30	2.80	0.024
23	2501.3	2505.1	3.8	0.152	2.309	2.317	0.008	0.35	2.225	3.66	0.34		
23	2522.7	2525.9	3.2	0.127	2.311	2.317	0.007	0.29	2.225	3.72	0.28		
24	2500.2	2501.3	1.1	0.044	2.312	2.315	0.002	0.10	2.222	3.90	0.10	4.16	0.007
24	2524.2	2527.8	3.6	0.142	2.308	2.316	0.008	0.33	2.223	3.68	0.32		
24	2467.2	2471.1	3.9	0.158	2.309	2.318	0.008	0.37	2.225	3.65	0.35		
25	2505.8	2510.2	4.4	0.175	2.308	2.317	0.009	0.41	2.225	3.61	0.39	2.36	0.039
25	2517.3	2521.6	4.3	0.171	2.301	2.311	0.009	0.39	2.218	3.62	0.38		
25	2517	2519.8	2.8	0.111	2.310	2.316	0.006	0.26	2.224	3.75	0.25		
26	2526.3	2528.3	2	0.079	2.292	2.296	0.004	0.18	2.204	3.83	0.17	1.88	0.067
26	2518.2	2520.3	2.1	0.083	2.294	2.298	0.004	0.19	2.206	3.82	0.18		
26	2512	2514.6	2.6	0.103	2.297	2.302	0.005	0.24	2.210	3.77	0.23		