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Effect of Dwell Time and Lag Time on IDEAL-CT and IDEAL-RT Results

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Effect of Dwell Time and Lag Time on IDEAL-CT and IDEAL-RT Results – Expanded Study

By

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Background

Several agencies throughout the U.S. are in the process of adopting a Balanced Mix Design (BMD) approach in some form and doing the necessary background work for implementation (NAPA, 2025). A significant portion of the research effort behind BMD implementation has been trying to gain an understanding of potential variables that impact BMD mixture test results for both rutting and cracking tests. Work has either been completed or is ongoing related to testing equipment variability (Moore and Taylor, 2023), quantifying test variability (Taylor, Moore, and Moore, 2022) (Rodezno, Taylor, and Moore 2023), cracking test method ruggedness (Zhou, Newcomb, and Hu, 2022), and specimen preparation variables in the laboratory that may impact BMD test results (Boz et al., 2025). A remaining need is a better understanding of how asphalt mixture storage may or may not impact BMD mixture test results. NCHRP Synthesis 552 *Practices for Fabricating Asphalt Specimens for Performance Testing in Laboratories* identified specimen storage time and its impact on mixture performance testing results as a knowledge gap (Sias, Dave, and McCarthy, 2020). One concern for practitioners is that asphalt mixtures oxidize and stiffen during storage – potentially leading to loss of cracking resistance and an increase in rutting resistance that does not properly represent the materials placed on the roadway.

Plant-produced asphalt mixture storage can be divided into two categories: asphalt 'sample' storage and asphalt 'specimen' storage. 'Sample' refers to the bulk sample of loose plant-produced mix that is commonly collected either at the plant site or at the paving location. The mixture sample can be stored in various containers, ranging from metal buckets to assorted cardboard boxes and canvas bags (Figure 1). 'Lag Time' refers to the length of time between the mixture being sampled and the splitting and compacting of individual test specimens from that bulk sample. Lag time may or may not involve the re-heating of the plant-produced mix. Some practitioners will take the asphalt sample and split the mix down into specimens and compact them the same day as testing. These types of specimens are commonly referred to as 'hot-compacted' or 'production day' specimens. In other situations, the mixture sample may be set aside to completely cool and then re-heated and split into individual specimens days or weeks later. These specimens are commonly referred to as 're-heated' specimens. For example, a producer may wish to split and compact specimens the same day the mixture is produced to get rapid feedback on their mix, while the state agency may have to re-heat a sample of the same mix later for comparison. Hence, it is extremely important to understand how differences in sample storage may impact BMD test results.

The second category of storage relates to the compacted mixture specimens. 'Specimen' refers to the mixture after it has already been split out and compacted into individual test specimens, typically in the Superpave gyratory compactor (SGC) (Figure 2). 'Dwell Time' is the length of time between the individual test specimens being compacted and when they are conditioned and tested. The testing may occur the same day or may occur days or weeks later. Producers may end up conditioning and testing their specimens the same day, while agency labs or consulting labs may have to store compacted specimens for an extended period prior to testing due to having a large volume of specimens in queue for testing. Understanding how both lag time and dwell time impact BMD test results is vital to establishing Quality Assurance policies and specifications.

The Federal Highway Administration (FHWA) and its Mobile Asphalt Technology Center (MATC) recently collaborated with NCAT on an exploratory lag and dwell time study evaluating two mixtures from Alabama and one from Virginia using the IDEAL-CT and IDEAL-RT tests (Nener-Plante, 2023). This evaluation showed minimal impact of dwell time (specimen storage). Some effects of lag time were evident, but they were within the overall test variability of these mixes. Given the limited nature of that exploratory study, it was desirable to expand the evaluation to mixtures from different climate regions and mixtures made with different raw materials to make more definitive conclusions. This effort was made possible by the Consortium for Asphalt Pavement Research and Implementation (CAPRI). CAPRI allocated funding for interested participating laboratories to replicate the testing plan used in the exploratory study by MATC and NCAT. Through this effort, six additional participating labs produced data from eight additional mix designs from six states. These data help provide a more comprehensive understanding of the effects of mixture storage on the IDEAL-CT and IDEAL-RT BMD tests.

Figure 1. Common Mixture Sample Containers (Boxes, Metal Bucket, Canvas Bag) – Lag Time

Figure 2. Compacted Asphalt Specimens – Dwell Time

Objective and Scope

The objective of this study was to quantify the impact of lag time (mixture sample storage) and dwell time (BMD testing specimen storage) on BMD test results. Two BMD tests were used for this evaluation: the IDEAL-CT test for mixture cracking (ASTM D8225-19) and the IDEAL-RT test for mixture rutting (ASTM D8360-22). Data from seven total participating laboratories and ten unique mix designs were tested using a common testing plan in support of this objective. These mix designs were from different areas of the country with a diverse range of materials. Mixture lag time was evaluated to a maximum of two months of loose mixture sample storage, and individual specimen dwell time was evaluated up to one week of compacted specimen storage.

Testing Plan

A flow chart of the testing plan for this study is shown in Figure 1. This testing plan was developed by Derek Nener-Plante (formerly with the FHWA) and utilized for the original exploratory testing at the MATC and NCAT (Nener-Plante, 2023). Each participating lab was required to acquire a large sample of plant-produced mix. For the testing at NCAT, a minimum of 13 x 5-gallon buckets of mix were sampled (roughly 750 lbs.) plus a factor of safety.

Prior to being selected, participating labs attended a mandatory webinar hosted by NCAT in April 2024 detailing the requirements of the specimen preparation process. This included a detailed discussion of good specimen sampling and splitting practices, randomizing test groups of specimens from the larger population, and limiting specimen oven aging in individual mixture pans. Randomizing test groups from a larger population of specimens was particularly important so that the specimens in individual test groups would not have markedly different oven aging times prior to compaction. Good laboratory practices were essential to collect data in this study that would not confound or mask any effects of lag or dwell time.

There were four re-heating conditions in the testing plan to evaluate lag time: production (no re-heating), re-heating after two days (2-day RH), re-heating after two weeks (2-week RH), and re-heating after two months (2-month RH). These lag times were selected for the original testing plan based on the assumption that most agencies would conduct acceptance testing within two days and that dispute resolution may take between two weeks and up to two months. For the production (no RH) test, it was required that the plant-produced mix sample be transported to the testing labs, split, and the necessary specimens compacted the same day the mix was produced. Within each re-heating condition, a large volume of specimens was compacted and then randomized for testing at multiple specimen storage (dwell time) conditions. For this study, it was vital for the participating labs to schedule which days sample splitting, compaction, and testing would occur. Table 1 gives an example using dates required to execute this testing plan for a single mix. Each lab had to ensure it would have personnel available to conduct the required activities on the required days to satisfy the testing matrix.

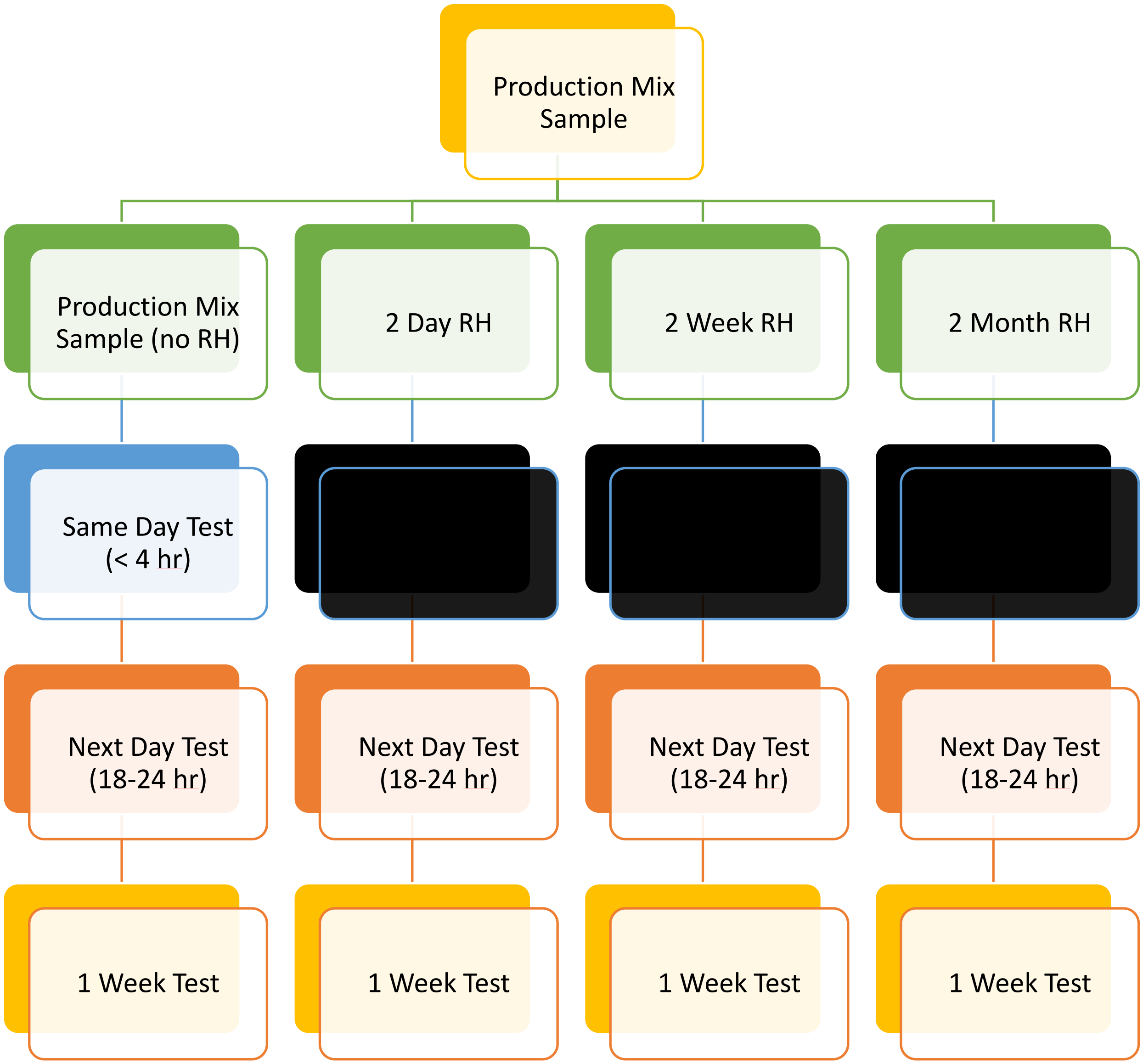

Figure 3. Testing Plan – Lag and Dwell Experiment

For the production day test, a total of 30 compacted specimens were required for this testing plan. This allowed for a set of IDEAL-CT (six replicates/set) and IDEAL-RT (four replicates/set) specimens to be tested at three different dwell conditions: the same day as specimen compaction (less than four hours storage), the next day after compaction (18-24 hours storage), and one week after compaction. For each of the re-heated tests (2-day, 2-week, 2-month), 20 specimens each were required for this testing plan. For each of those re-heated tests, a set of IDEAL-CT and IDEAL-RT specimens would be tested at two different dwell conditions: the next day after compaction (18-24 hours storage), and one week after compaction.

Table 1. Example Scheduling of Test Dates – Lag and Dwell Experiment

Reheating Time	Splitting and Compaction Day	Same Day (< 4 Hr. Dwell)	Next Day Test (18-24 Hrs. Dwell)	One Week Dwell Test
No Reheating (Production Day)	7/1/2024	7/1/2024	7/2/2024	7/8/2024
2 Day RH	7/3/2024	n/a	7/4/2024	7/10/2024
2 Week RH	7/15/2024	n/a	7/16/2024	7/22/2024
2 Months RH	8/31/2024	n/a	9/1/2024	9/7/2024

The cracking and rutting tests selected for this study were the IDEAL-CT (ASTM D 8225-19) and IDEAL-RT (ASTM D8360-22) tests, respectively (Figure 4). IDEAL-CT was performed in accordance with ASTM D8225-19 *Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature.* IDEAL-RT was performed in accordance with ASTM D8360-22 *Standard Test Method for Determination of Rutting Tolerance Index of Asphalt Mixture Using the Ideal Rutting Test.* For each mixture in this study, a total of 90 x 62 mm tall SGC specimens were tested by each participating lab. All specimens were required to be compacted to 7.0 ± 0.5 percent air voids based on a G_{mm} test result on the same sample of mix at the same re-heating condition. Participating labs were instructed to condition the IDEAL-CT specimens in an environmental chamber verified at 25°C for two hours prior to testing, and IDEAL-RT specimens were to be conditioned in a water bath verified at 50°C for one hour prior to testing, with no bags around the specimens. All testing was performed at a target load rate of 50 mm/minute. Participating labs were required to test six replicates of IDEAL-CT and four replicates of IDEAL-RT per dwell/lag time condition for each mixture. This totaled 54 IDEAL-CT and 36 IDEAL-RT specimens per mixture. For the ten mixtures tested for this study, this testing plan yielded a total of 540 IDEAL-CT specimens and 360 IDEAL-RT specimens for a total of 900 specimens in the database. The database was compiled at NCAT, and individual sets were examined for outliers using the procedure outlined in ASTM E178-21. Only two total replicates (one for IDEAL-CT and one for IDEAL-RT) were removed from the database using this outlier screening method.

It should be noted that one of the participating labs (MD-1 mix design) communicated with the project panel that they did not have the breaking head required to run the IDEAL-RT test. This lab was allowed to run the high-temperature indirect tension test (HT-IDT) for rutting resistance instead. In recent research at NCAT, a very strong correlation (R^2 = 0.97) has been observed between HT-IDT and IDEAL-RT test results for re-heated plant-produced mixtures (Chen, Taylor, and Moore, 2023). For this mix design, the correlation from that study, shown in Figure 5 was utilized to convert the HT-IDT results into IDEAL-RT test results for consistency with the other labs.

Figure 4. IDEAL-CT (ASTM D8225-19, left) and IDEAL-RT (ASTM D8360-22, right)

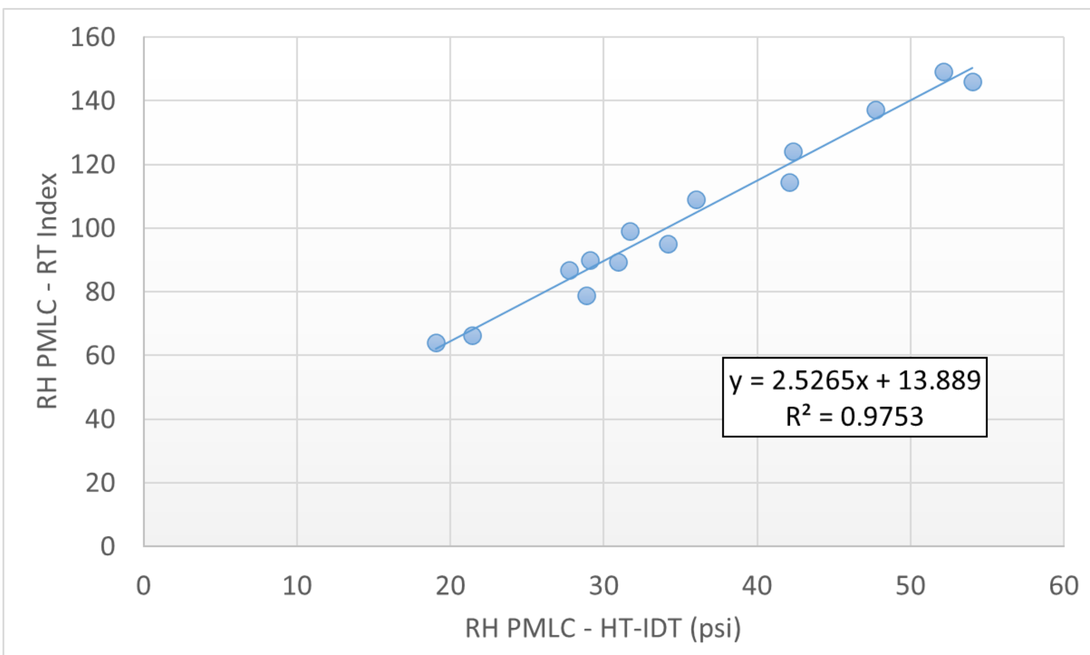

Figure 5. Correlation Between HT-IDT and IDEAL-RT Test Results – Re-heated PMLC – 2021 Test Track (Chen, Taylor, and Moore, 2023)

The data set for this study includes ten unique mix designs from eight participating labs. These data include the two mixes tested at NCAT from the original exploratory study. The mix designs are designated by state of origin and number (i.e., AL-1 and AL-2 are Alabama mix designs 1 and 2, respectively). The participating lab names and associated mix design IDs are as follows:

- National Center for Asphalt Technology – Auburn, AL
    - Mixes AL-1 and AL-2
- Blankenship Asphalt Tech and Training (BATT) – Richmond, KY
    - Mixes KY-1 and KY-2
- Brox Industries, Inc. - Andover, MA
    - Mix MA-1
- Maryland Department of Transportation
    - Mix MD-1
- Rowan University CREATEs - Glassgow, NJ
    - Mixes NJ-1 and NJ-2
- Atlas Technical Consultants (Texas)
    - Mix TX-1
- Wisconsin Department of Transportation
    - Mix WI-1

A summary of the key mix design information for the mix designs from this study is shown in Table 2. The ten mix designs used in this study represent a wide range of component materials. A few of the highlights from these designs are as follows:

- This study featured both 9.5 mm (6) and 12.5 mm (4) mix designs.
- This study featured a wide range of coarse and fine mixes, as measured by the primary control sieve (PCS). The PCS is defined as the #8 sieve (2.36 mm) by AASHTO M323-17 *Superpave Volumetric Mix Design* for both 9.5 mm and 12.5 mm NMAS mixtures and can be used to gauge the relative coarseness or fineness of an asphalt mixture.
    - The percent passing the PCS (#8 sieve) ranged from 62 percent on the fine side to 30 percent on the coarse side.
- Six of the mix designs utilized a PG 64-22/PG 67-22 unmodified base binder. Two of the designs featured PG 76-22, and the remaining two utilized softer binder grades (PG 58S-28 and PG 64E-28).
- RAP contents ranged from a low of 15 percent to a high of 35 percent by weight.
- The air voids at N_{des} ranged from 4.7 percent on the high end to 3.0 percent on the low end. Most of the mixes were at or around 4.0 percent design air voids.
- The production day (no re-heating, same day test) average CT_{Index} values had a very wide range, from an average CT_{Index} of 14 at the low end to an average of 141 at the high end.
- Production day RT_{Index} values were also wide ranging, from an average low RT_{Index} of 32 to an average high of 152.

Table 2. Summary of Key Mix Design Information

Mix ID	AL-1	AL-2	KY-1	KY-2	NJ-1	NJ-2	MA-1	MD-1	TX-1	WI-1
NMAS (mm)	9.5	9.5	9.5	9.5	9.5	12.5	12.5	12.5	9.5	12.5
$P_{\#8}$ (PCS)	62	53	41	36	38	36	44	30	41	56
Binder PG	67-22	76-22	76-22	64-22	64-22	64-22	64E-28	64S-22	64-22	58S-28
RAP (%)	20	20	17	15	25	15	15	35	20	25
N_{des}	60	60	65	65	75	75	75	65	50	75
Total AC (%)	5.9	5.5	6.3	5.9	5.9	5.3	5.0	4.9	5.4	5.7
Virgin AC (%)	4.9	4.6	5.4	5.2	4.7	4.6	4.1	3.0	4.5	4.5
VMA (%)	17.6	16.5	16.2	16.2	16.4	15.6	16.1	14.5	16.3	15.3
Air Voids (%)	4.7	4.2	3.7	3.6	4.0	4.0	4.1	4.0	4.0	3.0
CT_{Index} *	30	62	66	68	81	117	141	125	14	98
RT_{Index} *	111	88	152	101	107	55	85	104**	125	32

* = Average of Production Day Test

** = HT-IDT test correlated to IDEAL-RT value for scale

Results and Analysis

Individual summary tables of the IDEAL-CT and IDEAL-RT test results for each individual mix design are provided in APPENDIX A and APPENDIX B, respectively. The analyses that follow examine whether there are statistical effects of lag time and dwell time, along with the magnitude of any differences. In addition to statistical changes, it is also necessary to evaluate how much practical impact dwell time and lag time would have on the average IDEAL-CT and IDEAL-RT test results. It is important to understand how much these values change on average with additional specimen storage and whether these changes are meaningful in the context of test results and possible specification criteria.

Analysis – Dwell Time

As previously mentioned, the major concern with specimen storage is that the asphalt mixture may stiffen over time due to oxidation, which may meaningfully impact mixture test results. The effect of dwell time in this study was evaluated by statistically comparing the test results conducted at a common lag time for the ten available mix designs. This totaled 40 statistical comparisons for both the IDEAL-CT and IDEAL-RT tests. For the production day test (no RH), an ANOVA ($\alpha = 0.05$) was used to statistically evaluate the three groups of data available for each mixture (< 4 hr. dwell, 18-24 hr. dwell, and one week dwell test results). For the re-heated test results (2-day, 2-week, 2-month), a student's t-test ($\alpha = 0.05$) was used to compare the two dwell time groups (18-24 hr. dwell vs. one week dwell).

Table 3 shows an example of the data used for dwell time statistical comparisons for a single mix (AL-1). An ANOVA was conducted to statistically compare the same day, next day, and one week dwell results at the no RH (production) condition. For the IDEAL-CT data in Table 3, this would be statistically comparing the groups of data with averages of 29.9, 29.0, and 32.0 in the Production (no RH) row. For the remaining 3 rows of data (2-day RH, 2-week RH, 2-month RH), a t-test was used to compare the next day and one week dwell data. For example, for the data in Table 3 a t-test would be used to compare the next day and one week dwell data at the 2-day RH condition (average CT of 25.6 vs. 25.5). Hypothetically, a meaningful impact of dwell time would show a statistical reduction in CT_{Index} and a statistical increase in RT_{Index}, and that trend would continue with additional specimen storage time for a given mix design. Such an impact would be more consequential if it occurred for more than one mixture.

Table 3.Example Dwell Time Statistical Comparison – AL-1 IDEAL-CT

Re-heating (Lag) Time	Same Day (<4 hr. Dwell)			Next Day (18-24 hr. Dwell)			1 Week Dwell			Statistical Comparison
	Avg.	St Dev.	CV (%)	Avg.	St Dev.	CV (%)	Avg.	St Dev.	CV (%)	
Production (No RH)	29.9	4.0	13.6	29.0	4.3	14.8	32.0	3.5	11.0	ANOVA
2-day RH				25.6	2.9	11.4	25.5	4.1	16.0	t-test
2-week RH				29.5	4.4	14.8	29.2	5.1	17.6	t-test
2-month RH				24.7	2.2	8.9	25.2	2.0	7.8	t-test

A summary of the statistical comparison p-values for dwell time is shown in Table 4 for the IDEAL-CT test. A p-value less than α (0.05) indicates a statistically significant difference in CT_{Index} values related to dwell time. Only four of the 40 total comparisons (ten mixtures x four lag times) had a statistically significant increase or decrease in IDEAL-CT with additional dwell time. However, only one of these comparisons (TX-1 production day, highlighted in green) had the expected statistical reduction in CT_{Index} with additional specimen storage time. The three other statistically significant comparisons (highlighted in yellow) all trended in the opposite direction of the expected trend – a statistical increase or improvement in CT_{Index} with additional specimen storage time. Given the low percentage of statistically significant comparisons (10%), and most of those comparisons trending in the unexpected direction, the results suggest dwell time did not have a statistically meaningful overall impact on IDEAL-CT results for the ten mixes in this study.

Table 4. P-values (α = 0.05) – Dwell Time Statistical Comparisons for Individual Mixes at Constant Lag Time – IDEAL-CT Results

Mix ID	Production (no RH) (ANOVA)	2-Day RH (t-test)	2- Week RH (t-test)	2-Month RH (t-test)
AL-1	0.419	0.981	0.915	0.706
AL-2	0.576	0.448	0.005	0.434
KY-1	0.960	0.508	0.881	0.658
KY-2	0.093	0.891	0.249	0.793
NJ-1	0.791	0.538	0.891	0.729
NJ-2	0.737	0.348	0.851	0.985
MA-1	0.122	0.653	0.168	0.018
MD-1	0.535	0.292	0.151	0.393
TX-1	0.040	0.701	0.521	0.611
WI-1	0.074	0.956	0.491	0.021

The statistical comparison results for the IDEAL-RT test versus dwell time are shown in Table 5. Nine of the forty total comparisons (22.5%) had a p-value less than 0.05, indicating a statistically significant change in the RT_{Index} as a function of dwell time. Relative to the IDEAL-CT, the IDEAL-RT test had more statistically significant dwell time comparisons. This was expected, given that the IDEAL-RT test generally has better repeatability than the IDEAL-CT test as measured by within-lab coefficient of variation (CV) on individual sets (Rodezno, Taylor, and Moore, 2023). For this study, the IDEAL-CT test had an average within-lab CV of 15.4 percent, while the IDEAL-RT test had an average within-lab CV of 5.5 percent across all ten mixtures. Of the nine statistically significant RT_{Index} comparisons, five comparisons (green highlighting in Table 5) trended in the expected direction of having a higher RT_{Index} with additional storage time. The remaining four statistically significant comparisons trended in the opposite direction of the expected trend, with the RT_{Index} getting statistically lower with additional specimen storage time. Similarly to the IDEAL-CT, the IDEAL-RT test results had a low percentage of paired test results that showed statistical changes as a function of dwell time, and those changes did not all trend in the same direction. Hence, the statistical analysis did not show dwell time to be a major driver of IDEAL-RT test results.

Table 5. P-values (α = 0.05) – Dwell Time Statistical Comparisons for Individual Mixes at Constant Lag Time – IDEAL-RT

Mix ID	Production (no RH) (ANOVA)	2-Day RH (t-test)	2-Week RH (t-test)	2-Month RH (t-test)
AL-1	0.167	0.032	0.017	0.369
AL-2	0.110	0.482	0.409	0.029
KY-1	0.904	0.748	0.008	0.222
KY-2	0.000	0.003	0.392	0.455
NJ-1	0.799	0.919	0.875	0.745
NJ-2	0.013	0.002	0.164	0.638
MA-1	0.002	0.902	0.057	0.784
MD-1	0.151	0.996	0.334	0.392
TX-1	0.152	0.145	0.367	0.888
WI-1	0.169	0.752	0.127	0.464

To further examine whether dwell time influenced the IDEAL-CT and IDEAL-RT data, a 1:1 plot was generated comparing paired test results at different dwell times to one another. Each data point on these plots represents a single mixture tested with the same loose mixture sample storage (lag) time. A significant deviation from the line of equality (1:1 line) would indicate a consistent bias in test results because of dwell time. These 1:1 plots also show the upper and lower 95% confidence intervals for the regression equation. If the line of equality falls within this regression confidence interval, that indicates minimal test result bias due to dwell time when the variability of the test results are considered.

Figure 6 compares the CT_{Index} values collected on the day of production (< 4 hrs. dwell) to the CT_{Index} values collected the next day (18-24 hrs. dwell). Only ten data points are available for this comparison since only one production day test is available for each of the ten mixtures. The data in Figure 6 track very well along the line of equality, with a slope of less than 10% from equality and the line of equality falling well within the regression confidence interval. Figure 7 compares the CT_{Index} values collected on the day after compaction (18-24-hour dwell) to those collected on specimens that were stored for one week after compaction. Forty data points were available for this comparison. Despite some scatter at the higher CT values, the trendline tracks almost exactly along the line of equality, with the line of equality falling well within the regression confidence interval. This scatter of data around the line of equality indicates that the effect of dwell time (one day to one week) is within the typical variability of the test results. Hence, the 1:1 plot analysis did not show significant impacts of dwell time for the IDEAL-CT test for specimens stored up to a week after compaction.

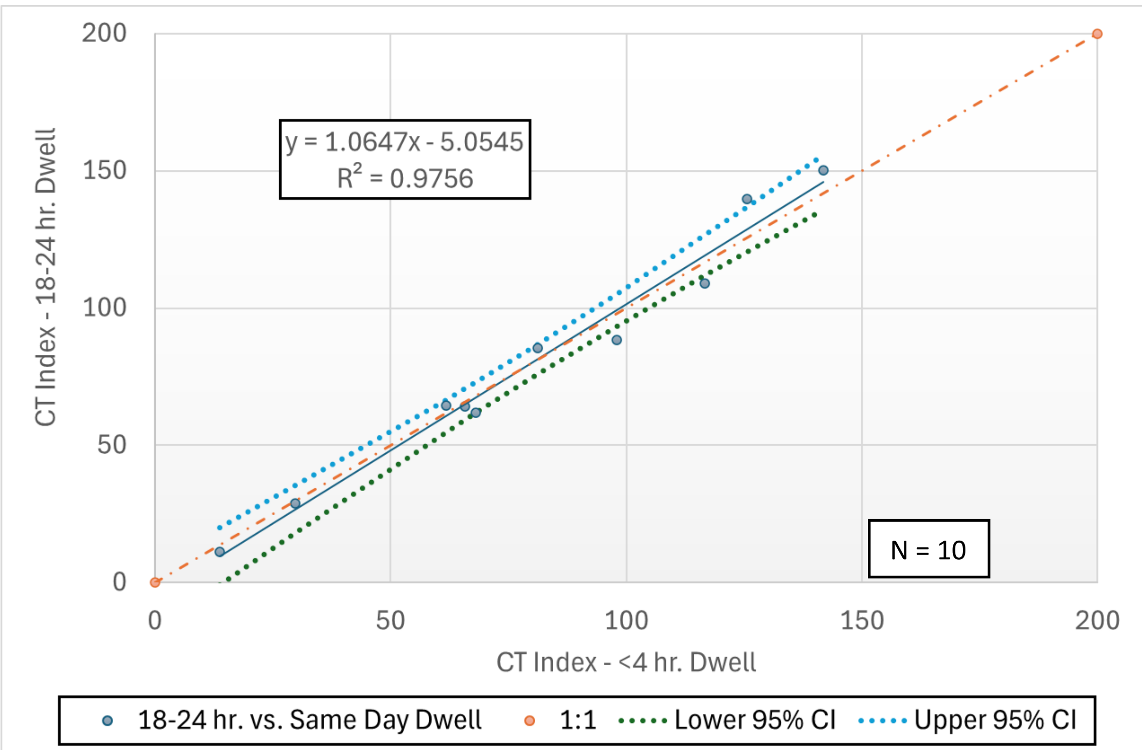

Figure 6. 1:1 Plot - Dwell Time Comparison – IDEAL-CT – Same Day (Production) vs. Next Day

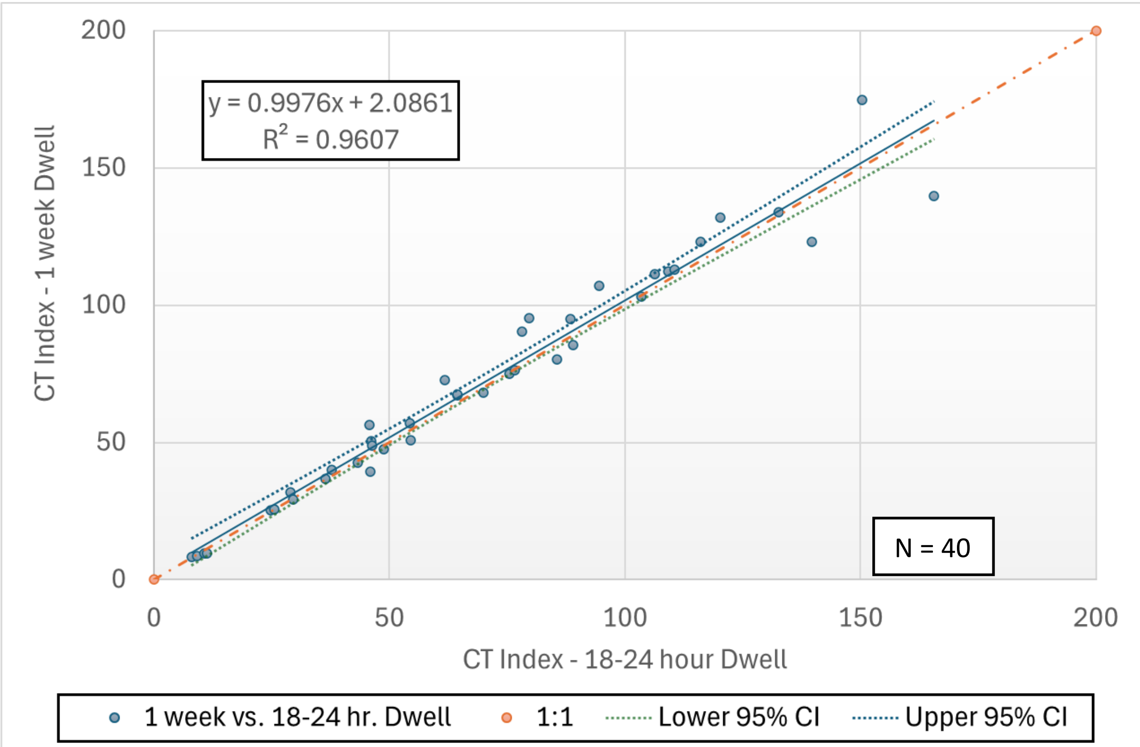

Figure 7. 1:1 Plot - Dwell Time Comparison – IDEAL-CT – Next Day vs. One Week After Production

Figure 8 compares the RT_{Index} values collected on the day of production (< 4-hour dwell) to the RT_{Index} values collected the next day (18-24 hrs. dwell). Figure 9 compares the RT_{Index} values collected on the day after compaction (18-24-hour dwell) to those collected on specimens that were stored for one week after compaction. Again, these data tracked very well along the line of equality with a slope of less than 6% from the 1:1 line for both comparisons. For both comparisons, the line of equality fell within the confidence interval of the regression. However, there is a slight bias of the trend line in Figure 8 towards the 18-24-hour dwell specimens relative to the RT_{Index} values collected the day of production (< 4-hour dwell). This may be due in part to there being a more limited number of data points (ten) available for comparison. The overall 1:1 plot analysis did not show significant impacts of dwell time for the IDEAL-RT test for specimens stored up to a week after compaction.

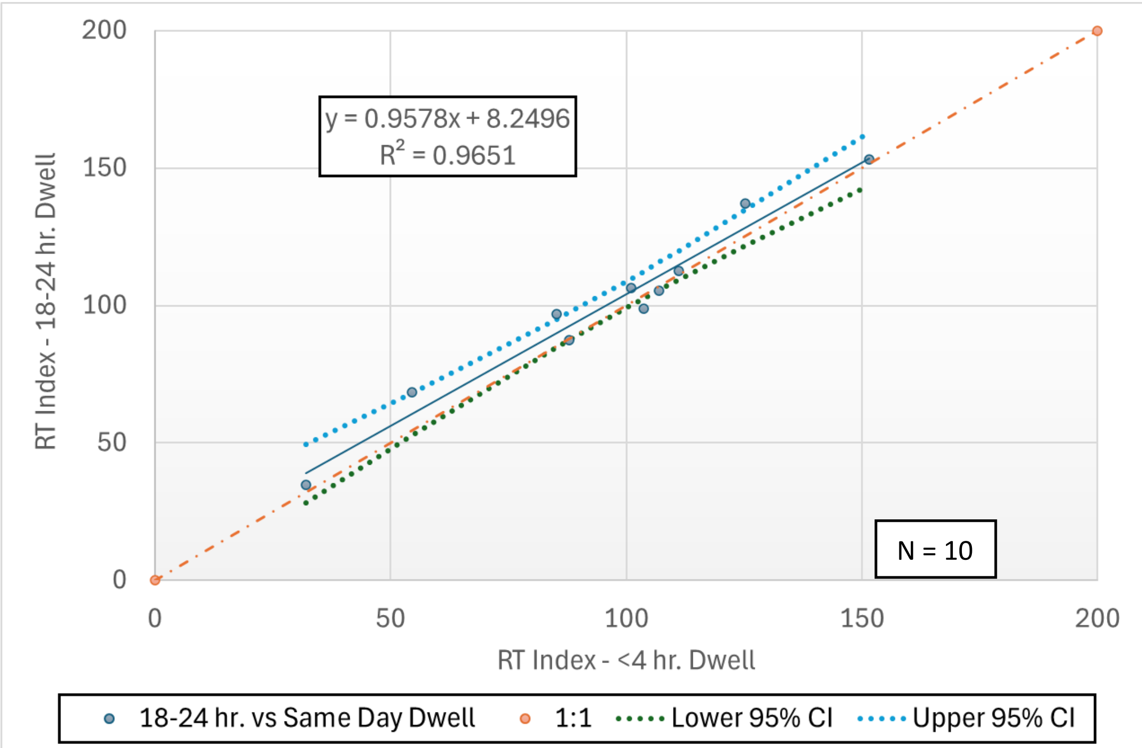

Figure 8. 1:1 Plot - Dwell Time Comparison – IDEAL-RT – Same Day (Production) vs. Next Day

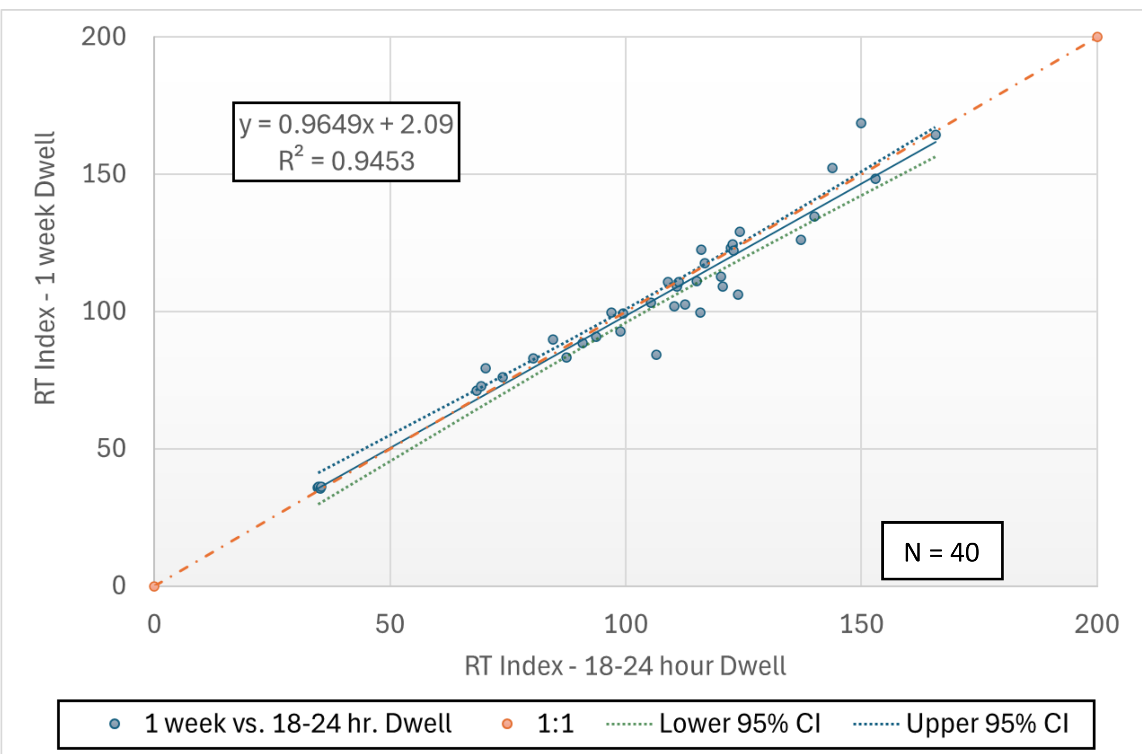

Figure 9. 1:1 Plot - Dwell Time Comparison – IDEAL-RT – Next Day vs. One Week After Production

Lastly, the average change in CT_{Index} and RT_{Index} were evaluated as a function of dwell time. Figures 10 and 11 are boxplots showing the average percentage change in CT_{Index} and RT_{Index}, respectively, as a function of dwell time. There are two comparisons in each boxplot – first, on the left side, comparing specimens after one week of storage to specimens after one day of storage (next day), and second, on the right, comparing specimens after one day of storage to specimens compacted the day of mixture production. The blue rectangle on the boxplot represents the middle 50 percent of the measured data, or interquartile range (IQR). The single line within the IQR represents the median of the data set. An IQR that is shifted largely above or below zero would indicate and consistent increase or decrease in the average test results.

The IQR for CT_{Index} comparing specimens one week after compaction versus specimens the day after compaction ranges from approximately a 7 percent increase to a 3 percent decrease in CT_{Index} (Figure 10). The average change for these 40 pairs of data was an increase in CT_{Index} of 2.5 percent. Comparing the specimens tested for CT_{Index} the day after production to the same day as production showed a slightly larger IQR, ranging from an approximately 9 percent reduction in CT_{Index} to a 6 percent increase. The wider IQR is likely due to fewer pairs of data relative to the previous comparison. The average change for these ten pairs of data was a reduction in CT_{Index} of 2.2 percent. The IQR for both comparisons includes zero (no difference), indicating that dwell time does not have a consistent effect on CT_{Index}. The boxplot analysis shows that while there is some variation in how dwell time may impact a single mixture's CT_{Index}, the average dwell time effect across the ten mixtures tested in this study was inconsequential.

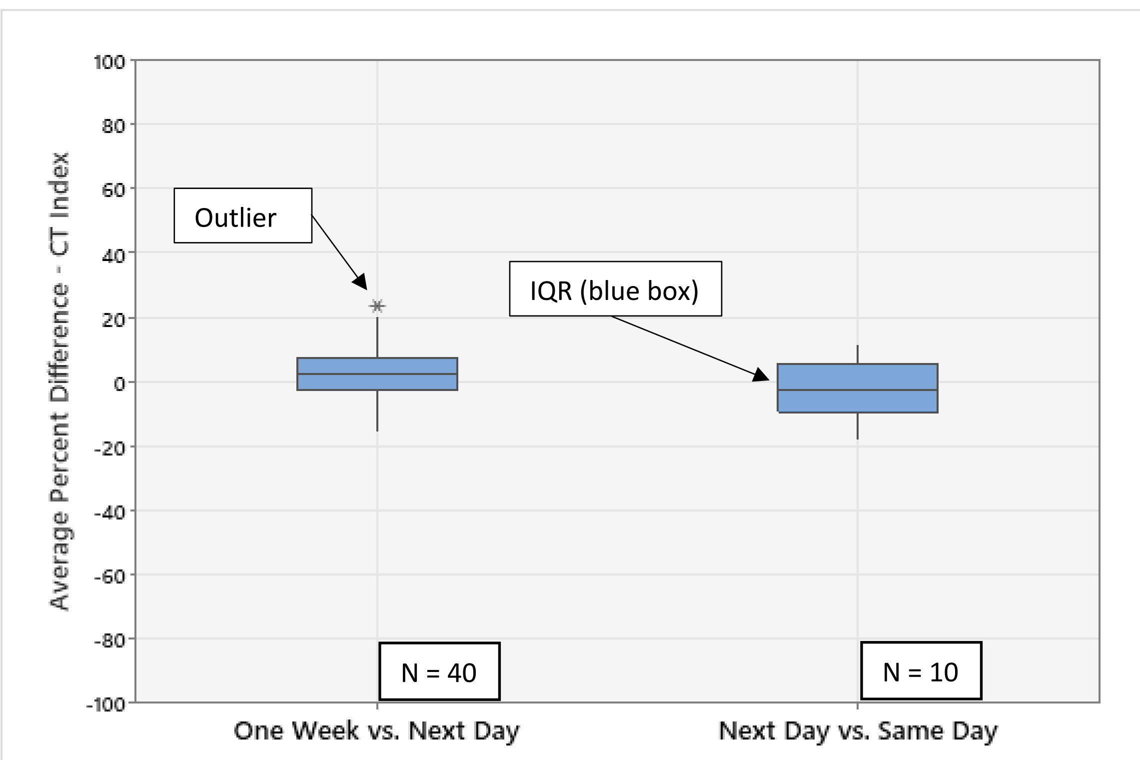

Figure 10. Boxplot of CT_{Index} Value Changes vs. Dwell Time

As shown in Figure 11, the IQR for RT_{Index} comparing results for specimens tested one week after compaction versus the results for specimens tested the day after compaction ranged from approximately a 3 percent increase to a 4 percent decrease in RT_{Index}. The average change for these 40 pairs of data was a reduction in RT_{Index} of less than 1 percent with additional storage time, with the IQR bracketing zero percent difference. Comparing the results of specimens tested for RT_{Index} the day after production to the same day as production showed an IQR that shifted more into positive territory, ranging from a reduction of 1 RT unit to an increase of 11 RT units. The average increase in RT_{Index} was 5.9 percent for specimens compacted and tested the day of production compared to specimens compacted the day of production and tested the next day. The IQR for this comparison shifted further into positive territory, but still bracketing zero percent difference. Overall, impact of dwell time on IDEAL-RT was inconsequential when comparing specimens tested the day after compaction to specimens tested a week after compaction. However, there was a slight increase in RT_{Index} for specimens tested the day after production compared to specimens tested the same day as production.

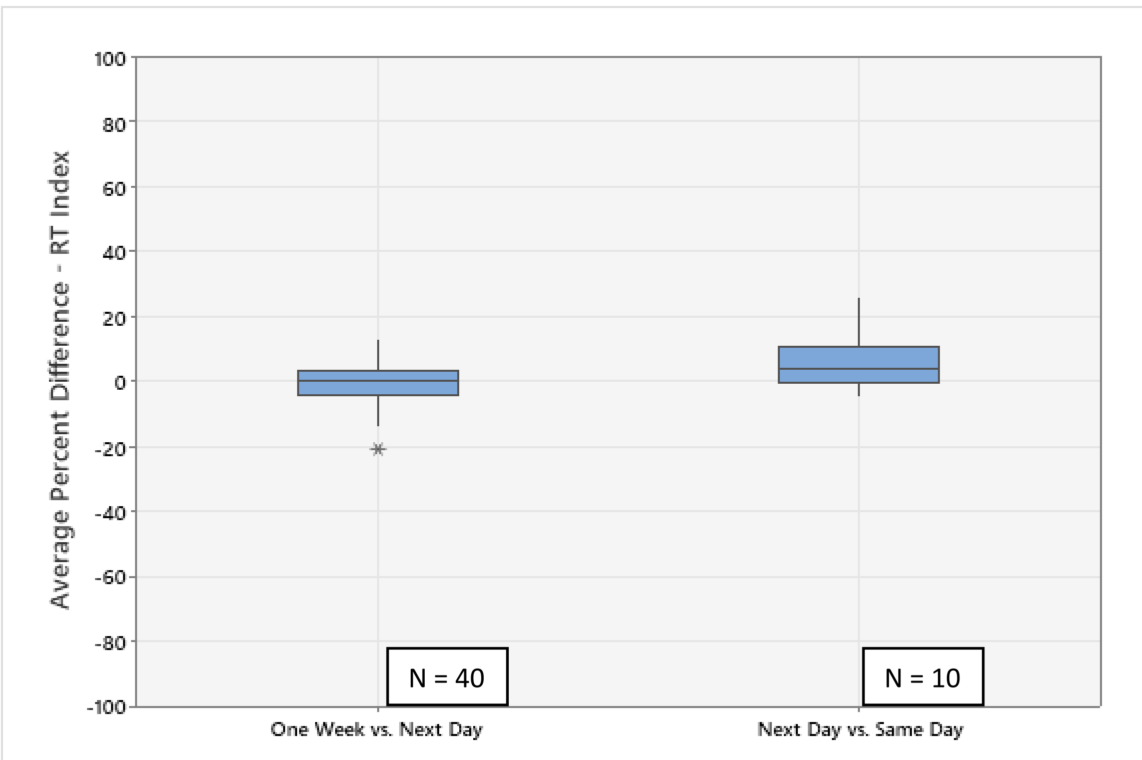

Figure 11. Boxplot of RT_{Index} Value Changes vs. Dwell Time

Analysis – Lag Time

An ANOVA with statistical groupings (α = 0.05) was used to evaluate the statistical impact of lag time on the IDEAL-CT and IDEAL-RT test results. Prior to running the ANOVA, a test for equal variances was performed on the data from each individual mixture. For data sets with equal variances, Tukey statistical groupings were utilized. For data sets with unequal variances, Games-Howell statistical groupings were used instead. Given the minimal statistical impacts of dwell time, the data from each mixture that had the same lag time were pooled for analysis to increase replication. For example, at the 2-day RH lag time condition, the next day (18-24-hour) dwell time and one-week dwell time sets from a single mixture were combined into a single lag time condition for analysis.

Table 6 summarizes the ANOVA statistical groupings as a function of lag time for the IDEAL-CT test for all ten mixtures in this study. In this table, statistical comparisons for lag time effects are observed in the columns under each mixture. First, the production day (no RH) IDEAL-CT test results were always in the top statistical grouping for CT_{Index}. This indicates that the production day CT_{Index} values were always the highest for each individual mix and could only decrease or stay statistically similar with additional lag time or re-heating. When comparing the earliest available test (production day – no RH) to the latest test (2-month RH), eight of the ten mixes showed a statistical reduction in CT_{Index} values over that lag time. Comparing the production day (no RH) test to the earliest RH test (2-day RH), nine of the ten mixes showed a statistical reduction in lag time as well. The statistical reduction from the production day (no RH) test to the 2-week RH test was not as pronounced, with four of ten mixes showing a statistical reduction from the production day. This difference from the other testing conditions is likely attributable to random variation within the specimen selection and testing process. This raises the question whether the reduction in CT_{Index} values is driven by the time difference in specimen preparation or by whether the mix was re-heated. Comparing the earliest re-heat test results (2-day RH) to the latest re-heat test results (2-month RH), nine of the ten mixes were in the same statistical grouping, with the remaining mix (NJ-1) showing a statistical increase in CT_{Index}, which was opposite of the expected trend. Hence, the statistical grouping analysis suggests that there are effects of specimen storage on CT_{Index}, but the differences seem to be driven more by the effect of re-heating than by mixture storage time.

Table 6. ANOVA Statistical Groupings ($\alpha = 0.05$) – Lag Time – IDEAL-CT – CT_{Index}

Lag Time	N	AL-1		AL-2		KY-1		KY-2		NJ-1	
		Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group
Production	18	30.3	A	64.6	A	65.8	A	67.6	A	82.4	A
2-Day RH	12	25.6	B C	55.7	B	39.0	B	42.9	B	52.7	C
2-Wk. RH	12	29.3	A B	51.1	B	48.1	B	42.7	B	75.3	A B
2-Mo RH	12	25.0	C	48.3	B	47.7	B	36.6	B	69.0	B

Lag Time	N	NJ-2		MA-1		MD-1		TX-1		WI-1	
		Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group
Production	18	112.7	A	155.6	A	129.5	A B	11.6	A	93.8	A
2-Day RH	12	119.5	A	108.8	B C	126.1	B	8.9	B	76.4	C
2-Wk. RH	12	111.8	A	100.9	B C	152.7	A	10.2	A B	87.3	A B
2-Mo RH	12	103.4	A	87.4	C	133.1*	A B	8.2	B	84.3	B C

* = one outlier removed (ASTM E178 procedure)

Table 7 summarizes the ANOVA statistical groupings as a function of lag time for the IDEAL-RT test for all ten mixtures in this study. For eight of the ten mixtures, the production day (no RH) test result was in the lowest statistical grouping for RT_{Index}. The two exceptions to this were mixes TX-1 and MD-1. This indicates that RT_{Index} typically was at its lowest point for production day test results and would either increase or stay statistically similar for the re-heated test results. When comparing the earliest test results (production day – no RH) to the latest test results (2-month RH), five of the ten mixes showed a statistical increase in RT_{Index}, while four of the ten mixes were statistically similar. One mix (MD-1) had a statistical reduction in RT_{Index}, in contrast to the expected trend. Similar behavior relative to the production day result was seen at the 2-day RH and 2-week RH condition, with six and four mixes, respectively, showing a statistical increase in RT_{Index} relative to the production test. Finally, the earliest re-heated test result (2-day RH) was compared to the latest re-heated test result (2-month RH) to help discern whether the statistical effects of lag time on RT_{Index} could be attributed to the effect of mixture re-heating. For these comparisons, five of the ten mixes were statistically similar, while two showed a statistical increase in RT_{Index}, and three mixes showed a statistical reduction in RT_{Index}. Hence, while the general trend is an increase in RT_{Index} with storage time, the primary driver appears to be caused by mixture re-heating.

Table 7. Statistical Groupings (α = 0.05) – Lag Time – IDEAL-RT – RT_{Index}

Lag Time	**N**	**AL-1**		**AL-2**		**KY-1**		**KY-2**		**NJ-1**	
		Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group
Production	12	108.8	B	86.3	C	151.0	B	97.3	C	105.3	B
2-Day RH	8	119.3	A	89.7	B C	165.1	A	115.1	B	122.5	A
2-Wk. RH	8	107.8	A B	92.3	B	159.3	A B	126.3*	A B	122.8	A
2-Mo RH	8	109.9	B	114.9	A	148.1	B	137.4	A	123.6	A

Lag Time	**N**	**NJ-2**		**MA-1**		**MD-1****		**TX-1**		**WI-1**	
		Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group	Avg.	Group
Production	12	64.8	B	94.0	B	97.5	A	129.5	A	34.2	A
2-Day RH	8	74.9	A	111.1	A	99.4	A	121.9*	A B	35.8	A
2-Wk. RH	8	71.1	A B	106.2	A	81.7	B	113.1	B	35.5	A
2-Mo RH	8	75.0	A	110.0	A	87.2	B	117.2	A B	35.5	A

* = one outlier removed (ASTM E178 procedure)

** = correlated from HT-IDT ITS

A 1:1 plot analysis was conducted to visualize any effects of lag time on the IDEAL-CT or IDEAL-RT test results. Each data point in these plots represents a single mix at a constant dwell time, comparing two different lag time results to each other. Figures 12 and 13 show the 1:1 plot for IDEAL-CT for the production day (no RH) test results versus the 2-day and 2-month RH test results, respectively. Both plots show a significant bias toward the production (no RH) test results with the regression confidence interval tracking below the line of equality. This indicates that the CT_{Index} values for most of these data points are higher for the production test results than for the corresponding re-heated test results. Figure 14 shows a 1:1 plot comparing the earliest re-heated IDEAL-CT test result (2-day RH) to the latest re-heated test results (2-month RH). This comparison largely tracks along the line of equality, with the line of equality falling within the regression confidence interval. This indicates no clear bias due to additional storage time after the initial mix re-heating.

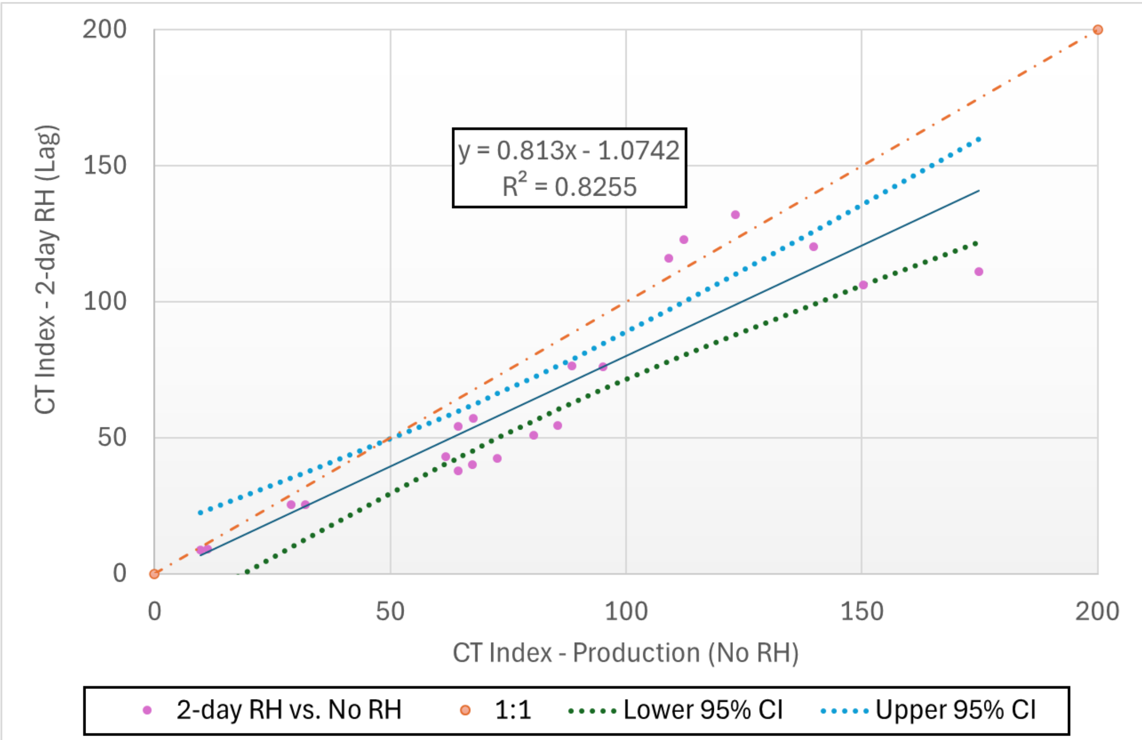

Figure 12. 1:1 Plot - Lag Time Comparison – IDEAL-CT – Production (no RH) vs. 2-day RH

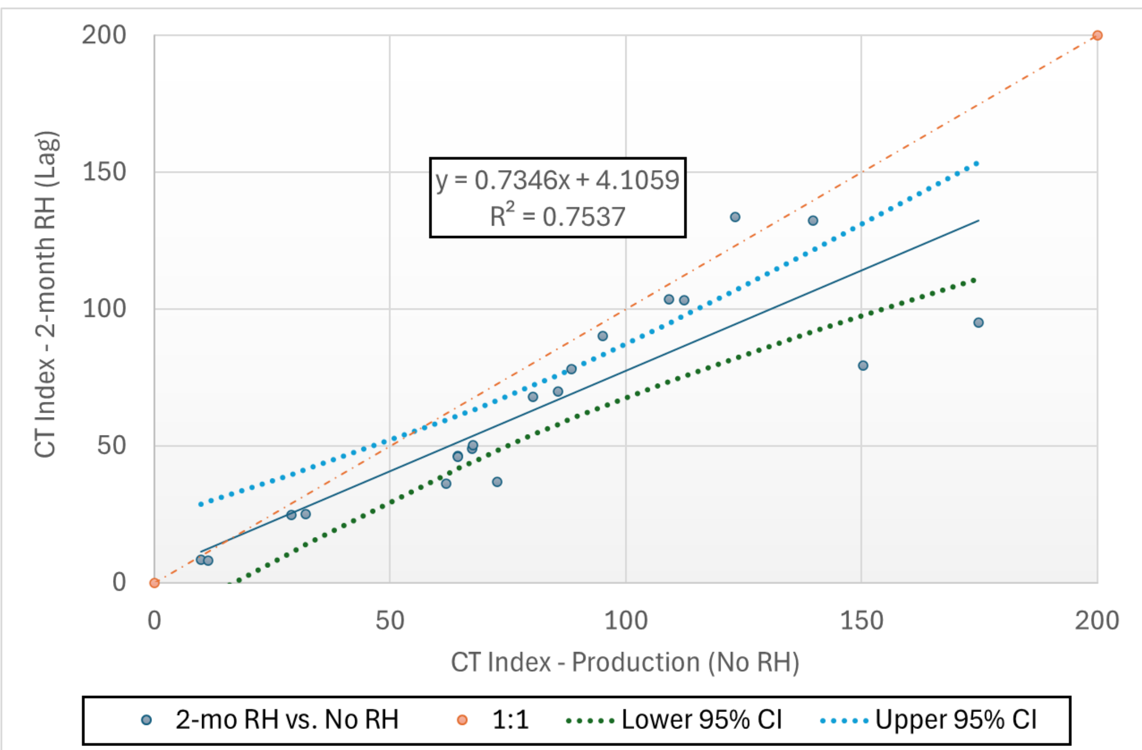

Figure 13. 1:1 Plot - Lag Time Comparison – IDEAL-CT – Production (no RH) vs. 2-month RH

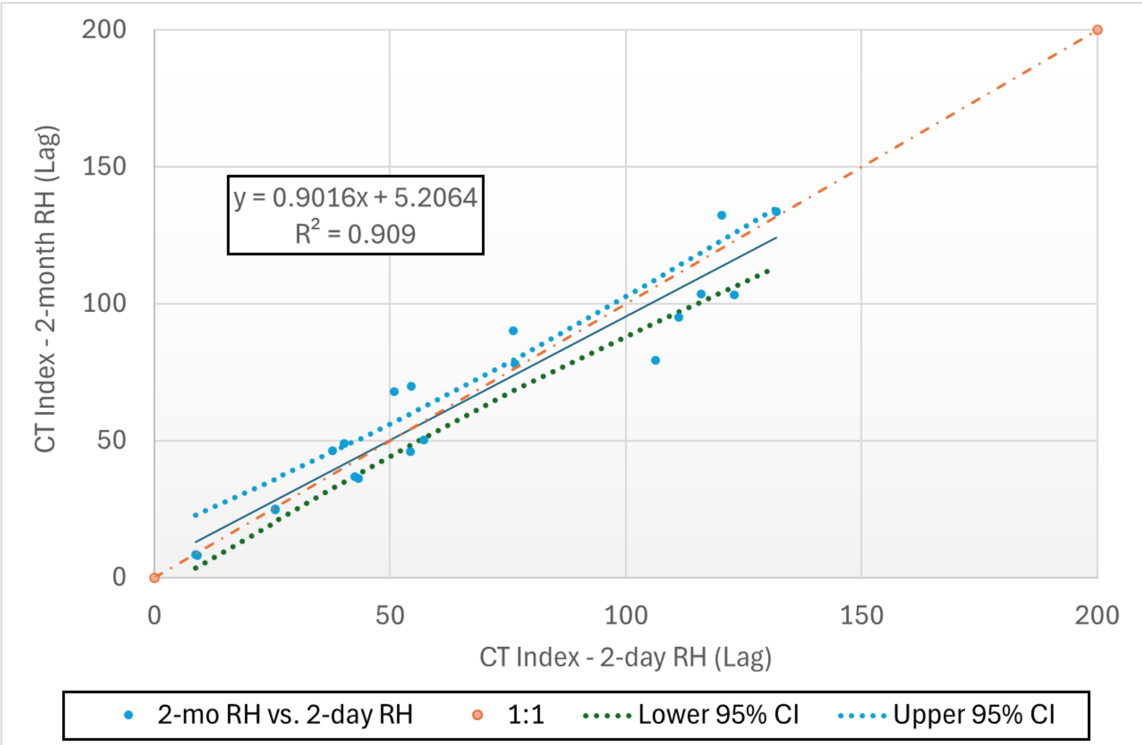

Figure 14. 1:1 Plot - Lag Time Comparison – IDEAL-CT – 2-day RH vs. 2-month RH

Figures 15 and 16 show the 1:1 plots for IDEAL-RT for the production day (no RH) test results versus the 2-day and 2-month RH test results, respectively. Both plots track above the line of equality, indicating generally higher RT_{Index} results for the re-heated test versus the production day test. However, the effect for IDEAL-RT is less pronounced than for the IDEAL-CT test. For both comparisons, the lower 95% confidence interval for the regression tracks generally along the line of equality. Figure 17 shows a 1:1 plot comparing the earliest re-heated test result (2-day RH) to the latest re-heated test results (2-month RH). This comparison largely tracks along the line of equality, with the line of equality falling within the regression confidence interval. Similarly to IDEAL-CT, this suggests initial storage time beyond the initial re-heating has a minimal impact on the IDEAL-RT test results up to the maximum 2-month storage time.

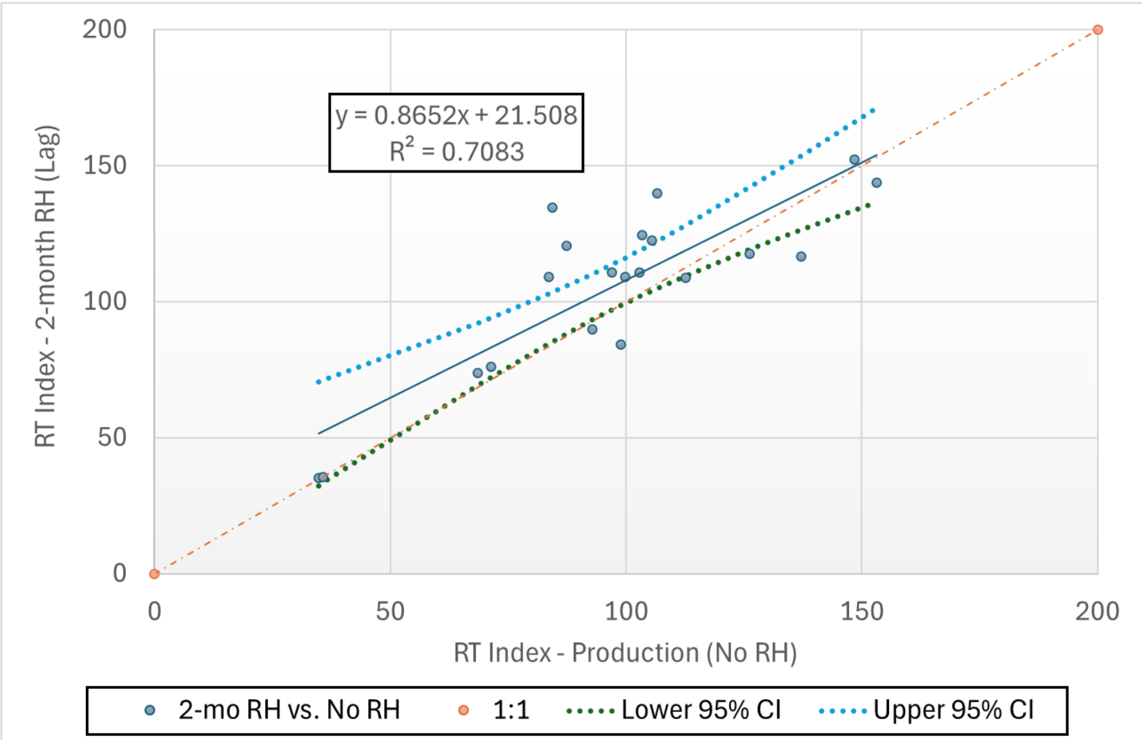

Figure 15. 1:1 Plot - Lag Time Comparison – IDEAL-RT – Production (no RH) vs. 2-day RH

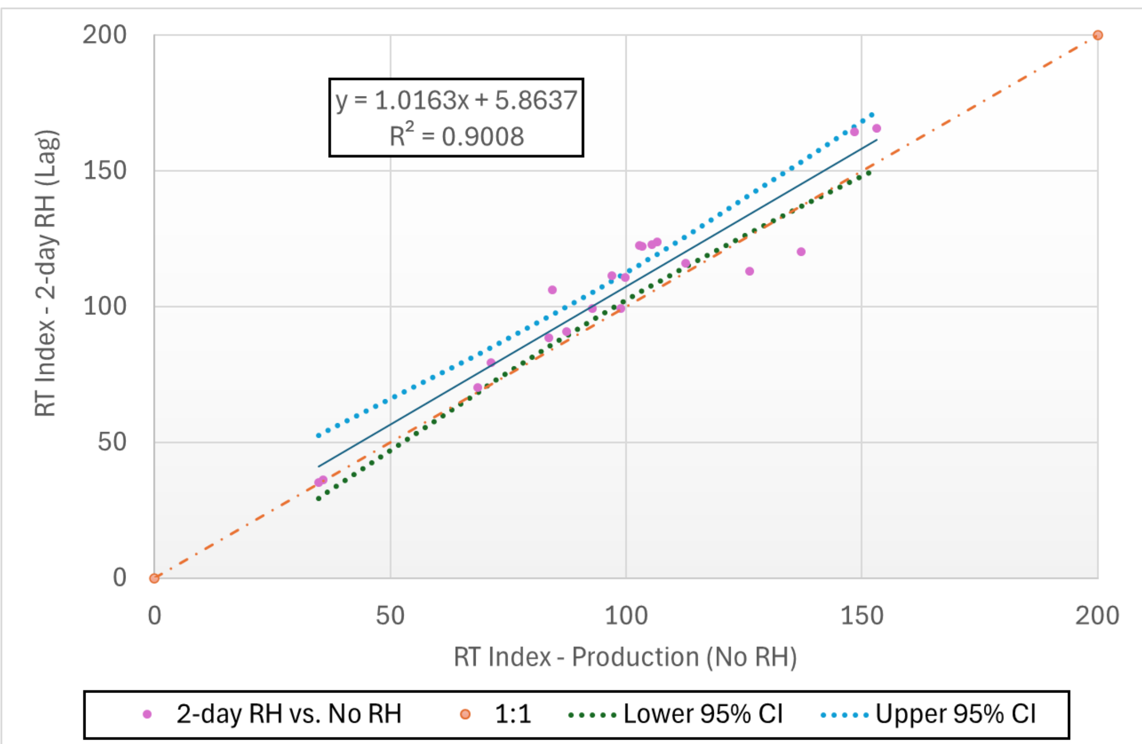

Figure 16. 1:1 Plot - Lag Time Comparison – IDEAL-RT – Production (no RH) vs. 2-month RH

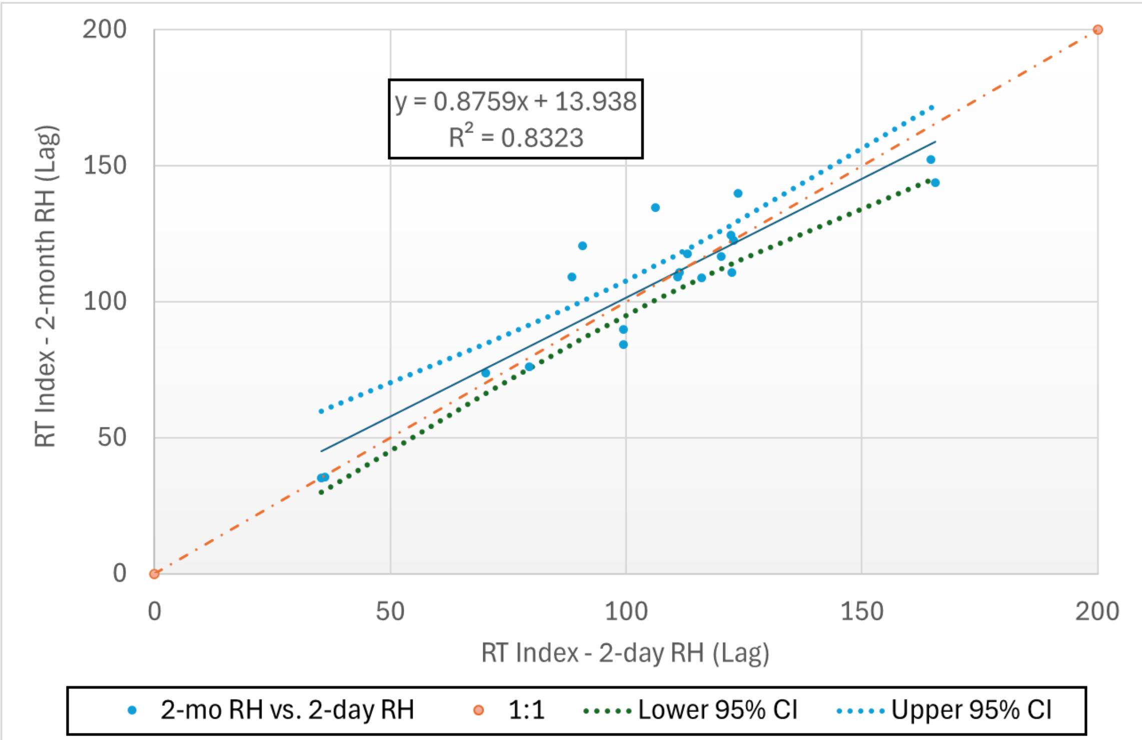

Figure 17. 1:1 Plot - Lag Time Comparison – IDEAL-RT – 2-day RH vs. 2-month RH

Finally, the average changes in magnitude of the CT_{Index} and RT_{Index} were evaluated as a function of lag time. Figures 18 and 19 are boxplots showing the average percentage change in CT_{Index} and RT_{Index}, respectively, as a function of lag time. There are four comparisons in each chart. The first three boxplots compare the re-heated test results (2-day RH, 2-week RH, 2-month RH) to the production (no RH) condition. The last comparison is the latest re-heated test (2 months) versus the earliest re-heated test (2 days) to help assess how much lag time is affecting these results when re-heating is constant. There are 20 comparisons in each series, and the dwell time is constant for each comparison.

Comparing the production day (no RH) test results to the re-heated test results for IDEAL-CT (Figure 17), the average CT_{Index} reduction is between 13 percent and 22 percent, depending on the lag time. The majority of the IQRs for each condition are below zero, indicating that most of these comparisons see a reduction in CT_{Index}. Comparing the latest (2-month RH) versus the earliest (2-day RH) re-heated IDEAL-CT test results, there was a range of percent changes in CT_{Index} values, but the average percent change in CT_{Index} across all ten mixes was near zero. In practical terms, re-heating appears to have a much greater impact on CT_{Index} values than storage times.

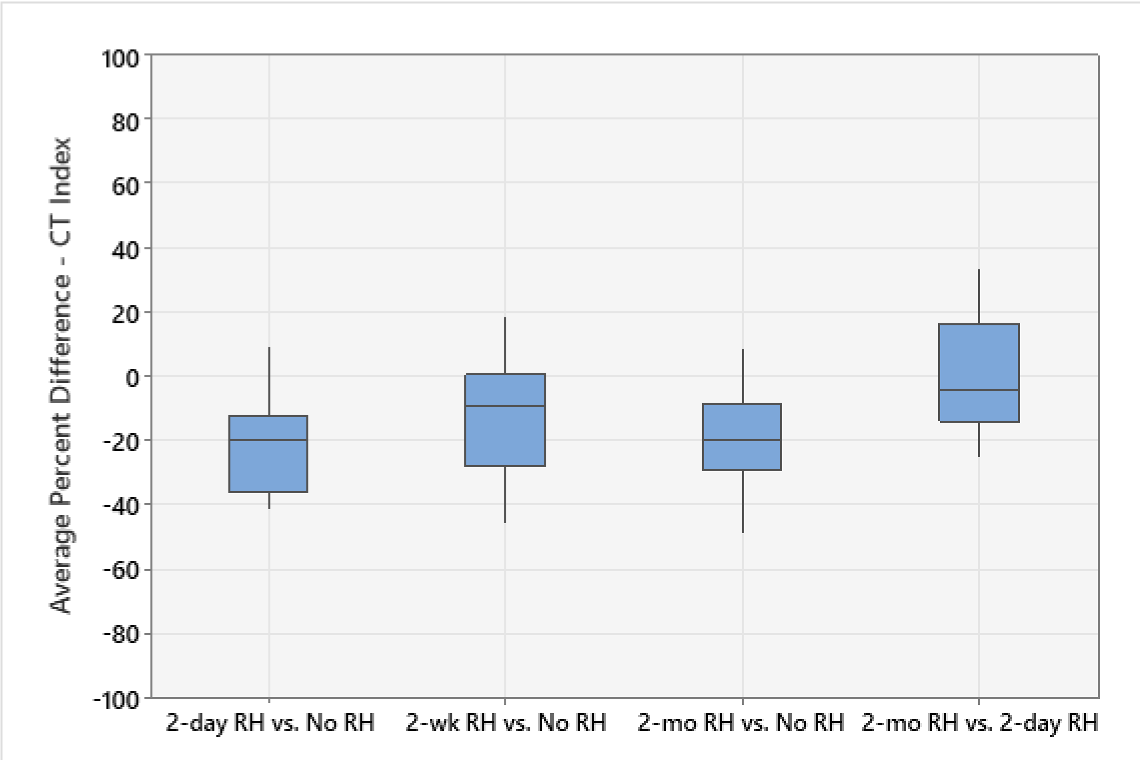

Figure 18. Boxplot of CT_{Index} Value Changes vs. Lag Time

Figure 19 shows that RT_{Index} generally increases for tests on re-heated mixtures compared to the production day (no RH) tests; with an average RT_{Index} increase between 5 and 10 percent. Comparing the latest to the earliest re-heated tests, the average percent increase was only 2 percent. From a practical perspective, the effects of lag time appears to be greater on the CT_{Index} than the RT_{Index} for the mixtures in this study. As with CT_{Index}, the greatest impact on RT_{Index} appears to be due to re-heating rather than additional storage time.

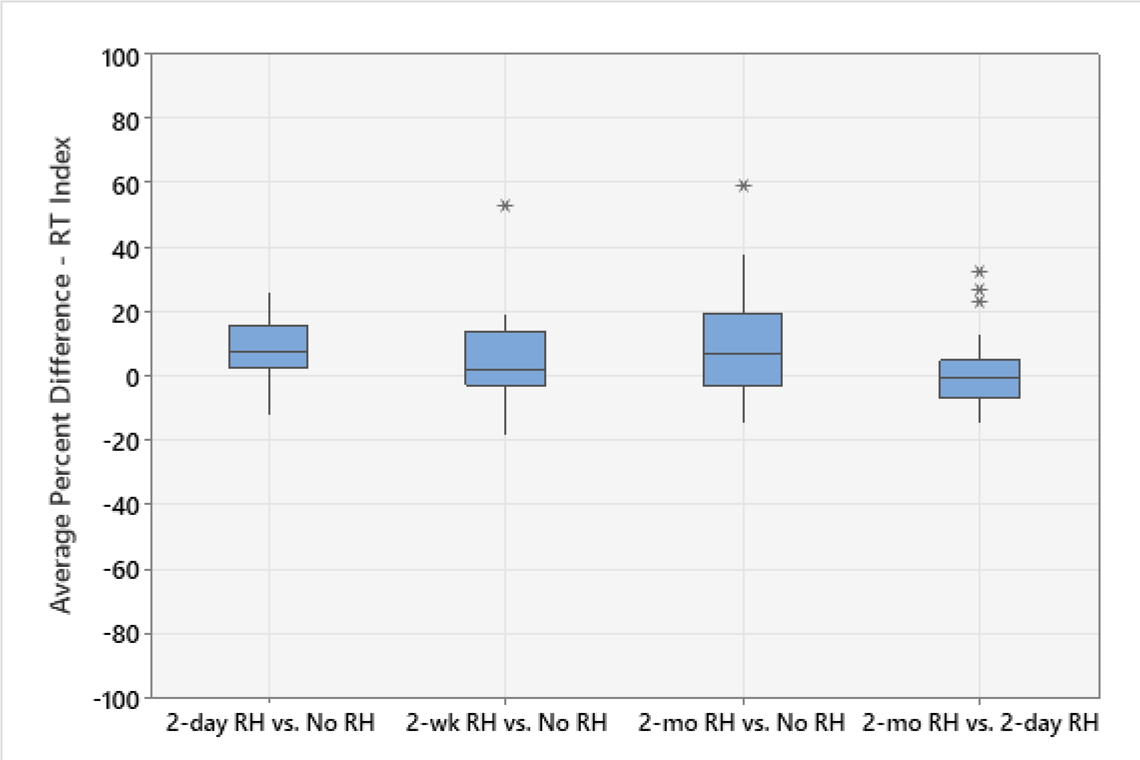

Figure 19. Boxplot of CT_{Index} Value Changes vs. Lag Time

Conclusions and Recommendations

A multi-laboratory study was conducted with mixtures from multiple states to evaluate the effect of loose asphalt mixture sample storage (lag time) and compacted specimen storage (dwell time) on results for two common BMD mixture tests – the IDEAL-CT cracking test (ASTM D8225-19) and IDEAL-RT rutting test (ASTM D8360-22). Sampled mixtures were split and compacted on the day of production (no re-heating) and re-heated after three different lag times (2 days, 2 weeks, and 2 months). Compacted specimens were randomized and tested at multiple different specimen storage times to evaluate the effect of dwell time (< 4 hours dwell, 18-24 hours dwell, one week dwell). Both statistical and numerical methods were used to evaluate the dataset and determine whether there were meaningful effects related to sample or specimen storage. The following observations were made from that data…

- The effects of compacted specimen storage (dwell time) up to one week of storage time appear to be minimal and should be considered inconsequential for IDEAL-CT and IDEAL-RT testing.
    - For IDEAL-CT results, only one testing condition for one of the ten mixtures (2.5% of the total comparisons) was significantly affected by dwell time in the expected manner (i.e., a decrease in CT_{Index}).
    - For the IDEAL-RT results, 12.5% of the comparisons were significantly affected by dwell time in the expected manner (i.e., an increase in RT_{Index}). In practical terms, the largest increase in RT_{Index} due to specimen storage time was 6 percent.

- The effects of mixture re-heating were evident in the analysis of lag time data. The effect of mixture re-heating of loose mixtures prior to compaction of BMD test specimens has also been noted by other researchers (Boz, Diefenderfer, and Habbouche, 2022). Re-heating of stored asphalt paving mixtures in the oven from ambient to compaction temperatures causes additional aging of the asphalt binder, as evident through mixture stiffness properties and embrittlement or loss of strain tolerance.
  - Re-heating mixtures stored for as little as two days resulted in a statistically significant decrease in CT_{Index} for 9 of 10 mixtures, and a statistically significant increase in RT_{Index} for 6 of 10 mixtures. Similar statistical differences were seen at the 2-month RH condition as well.
  - Re-heating loose asphalt mixture samples appears to lower the average CT_{Index} by 13 to 22 percent and increase the RT_{Index} by 5 to 10 percent relative to the production (no RH) samples.
- The lag time data were also evaluated without the production (no RH) data to evaluate the effect of lag time without the effect of mixture re-heating.
  - There was no statistical difference in CT_{Index} for mixtures stored between 2 days and 2 months for 9 of the 10 mixtures in this study. For the one mixture with a statistical difference, the CT_{Index} increased when the mixture was stored for 2 months compared to storing for 2 days.
  - There was no statistical difference in RT_{Index} for mixtures stored between 2 days and 2 months for 5 of the 10 mixtures in this study. Of the remaining five mixtures, two mixtures had a statistically significant increase in RT_{Index} when the mixture was stored for 2 months compared to storing for 2 days, and the other three mixtures had a statistically significant decrease in RT_{Index} over the same timeframe.
  - Therefore, after accounting for the effect of re-heating, there is insufficient evidence to indicate that storing mixtures up to two months has a meaningful impact on IDEAL-CT and IDEAL-RT results. Nonetheless, laboratories should maintain consistent mixture sample and compacted specimen storage protocols when preparing and testing BMD specimens.
- Re-heated and production (no RH) test results should not be treated interchangeably in the same database, and therefore, different specification criteria should be developed for results based on re-heated versus hot-compacted production samples.
  - For example, Virginia sets different BMD production requirements for IDEAL-CT based on whether the specimens were re-heated (NAPA, 2025).
- For this study, specimen storage (dwell time) was evaluated up to one week, and loose mixture sample storage (lag time) was evaluated up to two months. Storage times beyond this were not evaluated and may need to be examined in future research. These results are also limited to two common test procedures (IDEAL-CT and IDEAL-RT) evaluated in this study.

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APPENDIX A. Summary Tables – IDEAL-CT Results

Table A1. Summary of IDEAL-CT Results – Mix AL-1

Lag Time - Sample	**Dwell Time -Specimen**	**N**	**Air Voids (%)**	**Peak Load (kN)**	**FE (J/m^2)**	**Slope (kN/mm)**	**L_{75} (mm)**	**CT_{Index}**		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.9	15.581	6,650	5.652	3.766	29.9	4.0	13.6
	18-24 hrs	6	6.9	15.543	6,632	5.654	3.654	29.0	4.3	14.8
	1 week	6	7.0	16.471	7,217	5.640	3.725	32.0	3.5	11.0
2-day RH	18-24 hrs	6	7.0	16.704	7,066	6.948	3.741	25.6	2.9	11.4
	1 week	6	7.0	16.913	7,249	7.058	3.684	25.5	4.1	16.0
2-wk RH	18-24 hrs	6	7.2	16.079	6,804	5.658	3.629	29.5	4.4	14.8
	1 week	6	7.1	16.221	6,735	5.621	3.578	29.2	5.1	17.6
2-mo RH	18-24 hrs	6	7.1	17.758	7,116	6.693	3.476	24.7	2.2	8.9
	1 week	6	7.1	17.738	7,328	6.810	3.506	25.2	2.0	7.8

Table A2. Summary of IDEAL-CT Results – Mix AL-2

Lag Time - Sample	**Dwell Time -Specimen**	**N**	**Air Voids (%)**	**Peak Load (kN)**	**FE (J/m^2)**	**Slope (kN/mm)**	**L_{75} (mm)**	**CT_{Index}**		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.8	14.928	8,121	4.081	4.589	61.8	9.0	14.5
	18-24 hrs	6	6.9	14.853	8,159	3.916	4.625	64.4	5.1	7.9
	1 week	6	7.1	14.766	8,234	3.963	4.796	67.5	12.2	18.1
2-day RH	18-24 hrs	6	7.2	15.608	8,275	4.669	4.528	54.3	7.9	14.5
	1 week	6	7.2	15.596	8,462	4.592	4.637	57.1	3.6	6.4
2-wk RH	18-24 hrs	6	7.1	16.528	8,286	5.215	4.283	45.8	5.6	12.3
	1 week	6	7.1	15.270	8,130	4.359	4.502	56.4	4.6	8.2
2-mo RH	18-24 hrs	6	7.0	17.058	8,476	5.280	4.251	46.2	7.2	15.7
	1 week	6	6.9	16.469	8,372	4.975	4.374	50.5	10.5	20.8

Table A3. Summary of IDEAL-CT Results – Mix KY-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	7.2	18.455	10,112	-5.204	5.017	65.9	10.3	15.7
	18-24 hrs	6	7.1	19.594	10,945	-5.751	4.995	64.4	11.5	17.8
	1 week	6	7.2	20.829	11,775	-6.445	4.888	67.3	26.4	39.3
2-day RH	18-24 hrs	6	6.8	22.416	10,740	-8.267	4.277	37.8	6.3	16.6
	1 week	6	6.8	21.127	10,274	-7.637	4.442	40.2	6.0	14.8
2-wk RH	18-24 hrs	6	6.8	19.979	10,204	-6.877	4.755	48.7	11.3	23.2
	1 week	6	6.7	22.031	11,105	-7.858	4.713	47.6	13.8	28.9
2-mo RH	18-24 hrs	6	7.0	22.250	11,283	-7.662	4.617	46.4	10.6	22.8
	1 week	6	7.0	21.800	11,327	-7.484	4.733	49.0	9.5	19.3

Table A4. Summary of IDEAL-CT Results – Mix KY-2

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.7	14.977	8,623	-4.181	4.895	68.1	9.0	13.3
	18-24 hrs	6	6.6	15.856	8,864	-4.655	4.855	61.8	3.0	4.8
	1 week	6	6.7	14.746	8,804	-4.110	5.023	72.7	10.2	14.0
2-day RH	18-24 hrs	6	7.2	17.294	8,663	-5.941	4.360	43.2	7.0	16.3
	1 week	6	7.1	16.788	8,504	-6.034	4.455	42.6	7.5	17.7
2-wk RH	18-24 hrs	6	6.8	17.377	8,730	-5.734	4.473	46.0	6.8	14.8
	1 week	6	6.8	17.356	8,445	-6.491	4.358	39.4	11.2	28.4
2-mo RH	18-24 hrs	6	6.6	12.663	8,834	-7.070	4.317	36.3	4.3	11.7
	1 week	6	6.7	12.266	8,824	-7.045	4.400	36.9	3.2	8.5

Table A5. Summary of IDEAL-CT Results – Mix NJ-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.9	18.925	9,469	5.857	7.465	81.1	10.7	13.2
	18-24 hrs	6	7.0	18.189	9,638	5.288	6.907	85.5	15.8	18.5
	1 week	6	7.0	18.933	9,752	5.697	6.861	80.4	15.0	18.7
2-day RH	18-24 hrs	6	7.0	22.838	10,205	7.496	5.885	54.5	11.8	21.7
	1 week	6	6.9	20.710	9,921	7.624	5.782	50.9	6.9	13.6
2-wk RH	18-24 hrs	6	6.9	18.059	9,985	6.770	7.555	75.4	7.7	10.3
	1 week	6	7.0	18.163	9,832	5.206	5.905	75.1	6.4	8.5
2-mo RH	18-24 hrs	6	7.0	17.000	9,164	5.121	5.834	70.0	8.6	12.3
	1 week	6	7.0	20.190	10,253	6.897	6.798	68.0	10.1	14.8

Table A6. Summary of IDEAL-CT Results – Mix NJ-2

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	7.0	11.444	7,286	2.420	5.697	116.7	22.1	18.9
	18-24 hrs	6	7.0	15.127	8,954	3.632	6.576	109.1	12.6	11.5
	1 week	6	7.0	14.679	9,223	3.415	6.163	112.3	14.0	12.4
2-day RH	18-24 hrs	6	7.0	13.004	8,198	3.075	6.492	116.0	11.7	10.1
	1 week	6	7.1	13.889	8,675	3.440	7.235	123.0	12.9	10.5
2-wk RH	18-24 hrs	6	7.0	14.868	8,016	3.096	6.274	110.6	20.5	18.6
	1 week	6	6.9	14.457	8,479	3.525	6.878	112.9	21.5	19.0
2-mo RH	18-24 hrs	6	7.0	14.797	8,628	3.387	6.072	103.5	21.5	20.8
	1 week	6	7.0	15.013	8,971	3.740	6.371	103.3	15.5	15.0

Table A7. Summary of IDEAL-CT Results – Mix MA-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	7.0	10.890	7,410	1.934	5.456	141.8	30.4	21.5
	18-24 hrs	6	7.2	11.407	7,983	2.096	5.816	150.3	23.0	15.3
	1 week	6	7.1	14.020	10,240	2.268	5.724	174.8	26.7	15.3
2-day RH	18-24 hrs	6	6.8	13.485	8,655	2.804	5.131	106.3	12.9	12.1
	1 week	6	6.8	14.418	9,371	2.990	5.174	111.3	22.5	20.3
2-wk RH	18-24 hrs	6	6.7	17.204	10,609	3.753	4.941	94.6	14.6	15.4
	1 week	6	6.8	14.905	9,705	3.224	5.266	107.2	14.9	13.9
2-mo RH	18-24 hrs	6	6.8	18.572	10,631	4.243	4.725	79.6	10.4	13.0
	1 week	6	6.8	14.560	8,944	3.150	5.016	95.3	8.9	9.3

Table A8. Summary of IDEAL-CT Results – Mix MD-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.9	15.237	10,139	-3.023	5.417	125.6	33.8	26.9
	18-24 hrs	6	7.0	14.890	10,274	-2.808	5.617	139.7	22.3	16.0
	1 week	6	6.9	15.532	10,532	-3.124	5.383	123.1	23.7	19.3
2-day RH	18-24 hrs	6	7.2	14.905	10,125	-3.080	5.467	120.3	12.5	10.4
	1 week	6	7.1	15.618	10,621	-3.064	5.667	131.9	21.9	16.6
2-wk RH	18-24 hrs	6	7.1	14.382	10,808	-2.717	6.117	165.7	36.6	22.1
	1 week	6	7.0	14.525	10,111	-2.736	5.650	139.8	14.5	10.4
2-mo RH	18-24 hrs	6	7.3	13.745	9,628	-2.727	5.567	132.6	17.7	13.3
	1 week	5	7.4	13.726	9,755	-2.821	5.720	133.8	19.6	14.7

Table A9. Summary of IDEAL-CT Results – Mix TX-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.8	15.467	5,173	7.864	3.082	13.8	2.7	19.6
	18-24 hrs	6	6.5	17.323	5,538	11.032	3.311	11.3	2.2	19.5
	1 week	6	6.6	17.238	5,535	13.341	3.404	9.8	2.5	25.2
2-day RH	18-24 hrs	6	6.7	17.485	5,298	12.038	3.051	9.1	1.6	17.9
	1 week	6	6.8	17.377	5,199	12.501	3.125	8.8	1.3	15.3
2-wk RH	18-24 hrs	6	7.1	17.213	5,313	10.979	3.149	10.7	3.0	28.1
	1 week	6	7.0	18.105	5,716	13.306	3.217	9.6	2.5	26.2
2-mo RH	18-24 hrs	6	6.7	18.422	5,218	12.569	2.858	8.0	0.9	11.1
	1 week	6	6.6	18.242	5,414	13.408	3.049	8.3	1.4	17.2

Table A10. Summary of IDEAL-CT Results – Mix WI-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	FE (J/m²)	Slope (kN/mm)	L_{75} (mm)	CT_{Index}		
			Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	6	6.9	8.732	5,439	1.793	6.549	98.0	6.1	6.2
	18-24 hrs	6	6.6	9.552	5,667	2.015	7.164	88.5	3.7	4.2
	1 week	6	6.7	9.631	5,896	2.003	7.223	95.0	9.2	9.7
2-day RH	18-24 hrs	6	6.7	9.723	5,503	2.196	7.292	76.6	12.0	15.6
	1 week	6	6.7	10.569	6,016	2.424	7.927	76.2	10.3	13.5
2-wk RH	18-24 hrs	6	7.1	8.797	5,243	1.881	6.597	89.1	7.6	8.5
	1 week	6	7.0	9.933	5,938	2.212	7.450	85.5	9.7	11.3
2-mo RH	18-24 hrs	6	6.9	9.772	5,651	2.222	7.329	78.2	8.6	11.0
	1 week	6	6.7	10.351	6,272	2.218	7.764	90.3	6.1	6.8

APPENDIX B. Summary Tables – IDEAL-RT Results

Table B1. Summary of IDEAL-RT Results – Mix AL-1

Lag Time - Sample	**Dwell Time -Specimen**	**N**	**Air Voids (%)**	**Peak Load (kN)**	**RT_{Index}**		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.9	5.493	111.1	7.2	6.5
	18-24 hrs	4	6.9	5.569	112.6	8.8	7.8
	1 week	4	6.9	5.083	102.8	4.9	4.7
2-day RH	18-24 hrs	4	7.0	5.737	116.0	2.9	2.5
	1 week	4	7.1	6.058	122.5	3.7	3.0
2-wk RH	18-24 hrs	4	6.8	5.732	115.9	3.1	2.7
	1 week	4	7.0	4.927	99.6	7.6	7.6
2-mo RH	18-24 hrs	4	6.9	5.390	109.0	2.3	2.1
	1 week	4	7.0	5.475	110.7	2.7	2.4

Table B2. Summary of IDEAL-RT Results – Mix AL-2

Lag Time - Sample	**Dwell Time -Specimen**	**N**	**Air Voids (%)**	**Peak Load (kN)**	**RT_{Index}**		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.9	4.349	87.9	3.7	4.2
	18-24 hrs	4	6.8	4.322	87.4	3.0	3.5
	1 week	4	7.0	4.129	83.5	1.2	1.5
2-day RH	18-24 hrs	4	7.2	4.492	90.8	5.1	5.6
	1 week	4	7.0	4.377	88.5	3.4	3.9
2-wk RH	18-24 hrs	4	7.1	4.637	93.8	4.2	4.5
	1 week	4	7.0	4.496	90.9	4.8	5.3
2-mo RH	18-24 hrs	4	6.9	5.965	120.6	6.2	5.2
	1 week	4	7.0	5.395	109.1	4.3	3.9

Table B3. Summary of IDEAL-RT Results – Mix KY-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	7.0	7.573	151.5	15.3	10.1
	18-24 hrs	4	7.1	7.653	153.1	7.6	5.0
	1 week	4	6.9	7.421	148.4	19.0	12.8
2-day RH	18-24 hrs	4	7.0	8.283	165.7	3.9	2.3
	1 week	4	7.0	8.229	164.6	5.1	3.1
2-wk RH	18-24 hrs	4	6.9	7.492	149.8	7.3	4.9
	1 week	4	6.9	8.433	168.7	5.1	3.0
2-mo RH	18-24 hrs	4	6.8	7.187	143.7	10.0	6.9
	1 week	4	7.0	7.619	152.4	7.8	5.1

Table B4. Summary of IDEAL-RT Results – Mix KY-2

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.5	5.050	101.0	2.1	2.1
	18-24 hrs	4	6.6	5.327	106.5	4.3	4.0
	1 week	4	6.6	4.220	84.4	4.6	5.4
2-day RH	18-24 hrs	4	6.9	6.191	123.8	3.5	2.8
	1 week	4	7.0	5.315	106.3	5.5	5.2
2-wk RH	18-24 hrs	4	6.6	6.209	124.2	3.7	3.0
	1 week	3	6.8	6.451	129.0	7.8	6.0
2-mo RH	18-24 hrs	4	6.6	6.999	140.0	8.8	6.3
	1 week	4	6.6	6.738	134.8	9.7	7.2

Table B5. Summary of IDEAL-RT Results – Mix NJ-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.9	5.351	107.0	5.3	5.0
	18-24 hrs	4	6.9	5.271	105.4	8.0	7.6
	1 week	4	6.9	5.171	103.4	8.8	8.5
2-day RH	18-24 hrs	4	7.0	6.140	122.8	6.4	5.2
	1 week	4	7.0	6.113	122.3	8.1	6.7
2-wk RH	18-24 hrs	4	7.0	6.111	122.2	13.2	10.8
	1 week	4	7.0	6.169	123.4	4.3	3.5
2-mo RH	18-24 hrs	4	7.0	6.129	122.6	7.7	6.3
	1 week	4	6.9	6.231	124.6	9.1	7.3

Table B6. Summary of IDEAL-RT Results – Mix NJ-2

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	7.0	2.726	54.5	3.6	6.6
	18-24 hrs	4	6.9	3.421	68.4	6.5	9.5
	1 week	4	7.0	3.570	71.4	8.9	12.5
2-day RH	18-24 hrs	4	7.0	3.515	70.3	2.7	3.9
	1 week	4	7.0	3.974	79.5	2.1	2.6
2-wk RH	18-24 hrs	4	6.9	3.466	69.3	3.4	4.9
	1 week	4	7.0	3.639	72.8	2.7	3.7
2-mo RH	18-24 hrs	4	7.0	3.692	73.8	8.3	11.3
	1 week	4	7.0	3.804	76.1	2.1	2.8

Table B7. Summary of IDEAL-RT Results – Mix MA-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	7.3	4.258	85.2	2.8	3.3
	18-24 hrs	4	7.2	4.848	97.0	6.5	6.7
	1 week	4	7.4	4.991	99.8	2.5	2.5
2-day RH	18-24 hrs	4	7.2	5.567	111.3	5.5	4.9
	1 week	4	6.9	5.546	110.9	3.2	2.9
2-wk RH	18-24 hrs	4	6.6	5.517	110.3	5.8	5.2
	1 week	4	6.8	5.101	102.0	2.5	2.4
2-mo RH	18-24 hrs	4	6.7	5.545	110.9	6.8	6.1
	1 week	4	6.7	5.454	109.1	10.6	9.7

Table B8. Summary of IDEAL-RT Results – Mix MD-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index} *		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	7.0	3.575	103.6	10.2	9.9
	18-24 hrs	4	7.2	3.387	98.9	4.7	4.8
	1 week	4	7.1	3.149	92.9	4.5	4.8
2-day RH	18-24 hrs	4	7.0	3.410	99.4	12.7	12.8
	1 week	4	6.9	3.409	99.4	4.3	4.3
2-wk RH	18-24 hrs	4	7.0	2.652	80.4	3.7	4.6
	1 week	4	7.0	2.756	83.0	3.4	4.1
2-mo RH	18-24 hrs	4	7.3	2.816	84.5	2.4	2.8
	1 week	4	7.5	3.027	89.8	10.3	11.5

* RT_{Index} values correlated from HT-IDT ITS (psi) values

Table B9. Summary of IDEAL-RT Results – Mix TX-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.5	6.263	125.3	4.6	3.7
	18-24 hrs	4	6.5	6.855	137.1	8.3	6.0
	1 week	4	6.6	6.311	126.2	11.5	9.1
2-day RH	18-24 hrs	3	6.9	6.009	120.2	2.6	2.2
	1 week	4	7.1	5.648	113.0	7.4	6.5
2-wk RH	18-24 hrs	4	7.2	5.750	115.0	3.3	2.9
	1 week	4	7.2	5.561	111.2	6.7	6.0
2-mo RH	18-24 hrs	4	6.6	5.840	116.8	8.2	7.0
	1 week	4	6.7	5.882	117.6	8.1	6.9

Table B10. Summary of IDEAL-RT Results – Mix WI-1

Lag Time - Sample	Dwell Time -Specimen	N	Air Voids (%)	Peak Load (kN)	RT_{Index}		
			Avg.	Avg.	Avg.	St Dev.	CV (%)
No RH (Prod.)	<4 hours	4	6.8	1.581	32.0	2.4	7.5
	18-24 hrs	4	6.6	1.716	34.7	1.9	5.4
	1 week	4	6.7	1.770	35.8	3.5	9.7
2-day RH	18-24 hrs	4	6.7	1.751	35.4	2.5	7.0
	1 week	4	6.9	1.789	36.2	3.8	10.5
2-wk RH	18-24 hrs	4	7.0	1.725	34.9	1.1	3.2
	1 week	4	6.9	1.788	36.2	0.9	2.6
2-mo RH	18-24 hrs	4	6.6	1.743	35.2	0.8	2.2
	1 week	4	6.6	1.766	35.7	0.9	2.5