CONSORTIUM FOR ASPHALT PAVEMENT RESEARCH AND IMPLEMENTATION

Balanced Mix Design with Absorptive Aggregates: Challenges and Solutions

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ALDOT	Alabama Department of Transportation
ANOVA	Analysis of variance
ASTM	ASTM International
BMD	Balanced mix design
CRD	Corrected rut depth
CTindex	Cracking tolerance index
Gmm	Maximum specific gravity of the mixture
Gsb	Bulk specific gravity of the aggregate
Gse	Effective specific gravity of the aggregate
HL	Hydrated lime
HWTT	Hamburg Wheel Track Test
IDEAL-CT	Indirect Tensile Asphalt Cracking Test
IDEAL-RT	Indirect Tensile Asphalt Rutting Test
LTA	Long-term aged (long-term aging)
Pba	Percent binder absorbed
Pbe	Percent binder effective
PG	Performance grade
PMA	Polymer-modified asphalt
RRI	Rutting resistance index
RTindex	Rutting tolerance index
SBS	Styrene-butadiene-styrene
SIP	Stripping inflection point
SN	Stripping number
STA	Short-term aged (short-term aging)
UA	Unaged
WMA	Warm mix asphalt

ABSTRACT

Asphalt mixtures are generally made using locally available aggregates, which, in many regions, are absorptive. For absorptive aggregates, mix designers typically add more asphalt binder to meet Superpave volumetric requirements and maintain compactability. However, this approach does not fully address cracking and rutting resistance, which are important under Balanced Mix Design (BMD).

This study investigates how highly absorptive aggregates impact effective binder content and BMD performance. It also explores whether three selected technologies can help mitigate absorption and the associated reduction in mechanical performance. The technologies examined include a chemical warm-mix asphalt (WMA) additive used with reduced mixing and compaction temperatures, styrene-butadiene-styrene polymer modification, and dry hydrated lime.

For this study, two mix designs were tested: one utilizing a less absorptive aggregate and the other using a highly absorptive aggregate. These mixtures were tested for binder absorption, cracking resistance (using the IDEAL-CT test), rutting resistance (using the IDEAL-RT test), and rutting and moisture susceptibility (using the HWTT) under unaged, short-term-aged, and long-term-aged conditions. The three mitigation strategies were then evaluated following the same testing plan.

All three strategies effectively reduced absorption; the WMA additive, with reduced mixing and compaction temperatures, achieved the greatest reduction under the short-term aged condition. Hydrated lime and polymer modification also demonstrated effectiveness through long-term aging. However, none of the strategies were as effective as using a less absorptive aggregate.

Each strategy improved the cracking tolerance index (CT_{index}) of the highly absorptive mixture, thereby making it higher than that of the low-absorptive mixture under unaged and short-term-aged conditions. However, this improvement was not maintained after long-term aging. With long-term aging, polymer modification and the addition of hydrated lime increased the average CT_{index} by 50.0% and 48.9%, respectively, compared with the untreated high-absorption mixture. Polymer modification was the only treatment that enhanced all measured aspects of performance.

Finally, given that the selected long-term aging protocol conditioned specimens at a slightly higher temperature than the short-term aging protocol for WMA, the appropriateness of the specific 20-hour conditioning duration and temperature used in this procedure for WMA mixtures containing highly absorptive aggregates warrants further investigation.

1. BACKGROUND

Absorptive aggregates present a challenge to designers of asphalt mixtures. Asphalt mixtures are typically composed of locally available aggregates for economic viability. In areas where local aggregates are absorptive, mix designers typically add asphalt binder to the mix design to compensate for absorption that occurs during mixture production, storage, and shipping, as simulated by short-term laboratory aging. The small amount of binder typically added during mix design is sufficient to ensure the mixture meets Superpave design air void requirements and remains compactable during construction, but it is unknown how these changes will affect resistance to rutting and cracking, as required for Balanced Mix Design (BMD). Variability in silo storage time and shipping times could lead to some areas of a project being either binder-rich or binder-deficient, which, in turn, could cause distress, reduced service life, and increased maintenance costs.

Other methods of mitigating absorption could be useful to designers and beneficial to owner agencies if they prove effective at either mitigating absorption itself or mitigating the distresses associated with asphalt binder absorption. Three commonly available technologies are tested for this purpose: warm mix asphalt, polymer-modified asphalt, and dry hydrated lime. Warm-mix asphalt, which incorporates a chemical warm-mix additive, enables the mixture to be produced, stored, and transported at lower temperatures. These reduced temperatures help minimize the absorption of binder into the aggregate particles. Additionally, producing the mixture at lower temperatures slows binder aging, which can enhance resistance to cracking but may reduce resistance to rutting. Polymer modification increases the binder's viscosity at mixing and compaction temperatures, thereby reducing absorption. Polymer modification also provides the mixture with mechanical benefits, including increased resistance to cracking and rutting. Hydrated lime can seal the pores in aggregates, reducing absorption and enhancing adhesion, thereby improving performance.

2. OBJECTIVE AND SCOPE

This project was to measure the effect of highly absorptive aggregates on effective binder content and mixture performance using balanced mix design tests after both short-term and long-term laboratory aging protocols. Three additive technologies were also evaluated for their ability to mitigate asphalt binder absorption and the associated degradation of mechanical performance, as measured by BMD tests. First, two mix designs were acquired and verified in the laboratory, one using a less absorptive aggregate and one using a highly absorptive aggregate. The designs were then adapted to have similar CT_{index} values with no mixture aging if necessary. Each design was tested for binder absorption, rutting, and cracking performance under unaged, short-term aged, and long-term aged conditions. Three absorption mitigation strategies were tested using the same protocol to determine whether they could mitigate binder absorption and the associated reduction of mechanical performance. Recommendations were developed to mitigate the effects of absorptive aggregates during balanced mix design.

3. TESTING PLAN

In Task 1, the research team procured two asphalt mix designs, along with the materials needed to reproduce each in the laboratory. One design uses a highly absorptive aggregate, and another uses a low absorption aggregate. To limit variables, neither mixture will use recycled materials. The aggregates for these mix designs were sampled and tested for specific gravity, absorption, and gradation. Each mix design was then reproduced in the laboratory to verify volumetric properties. Asphalt binders were also procured: an unmodified performance grade (PG) 67-22 and a styrene-butadiene-styrene (SBS) polymer-modified PG 76-22 from the same source. Both binders were PG graded. If necessary, the mix designs would have been redesigned so that they had a similar CT_{index} in the unaged condition. This was not necessary as they performed similarly without modification.

In Task 2, both highly and low-absorptive mixtures were produced under 3 aging conditions: unaged, in which the asphalt and aggregate were mixed and immediately compacted; short-term aged; and long-term aged. Each aging procedure is described in detail in its own subsection. Each mixture in unaged and short-term aged conditions was tested for maximum specific gravity (G_{mm}), the Indirect Tensile Asphalt Cracking Test (IDEAL-CT), the Indirect Tensile Asphalt Rutting Test (IDEAL-RT), and the Hamburg Wheel Track Test (HWTT). In the long-term aged condition, each mixture was tested only for G_{mm} and IDEAL-CT, since rutting tests are not informative in this aging condition. This data was used to determine the amount of asphalt absorbed in each mixture for each aging condition, and to assess changes in mixture mechanical performance resulting from binder absorption and binder aging. Figure 1 illustrates the testing plans for Tasks 1 and 2.

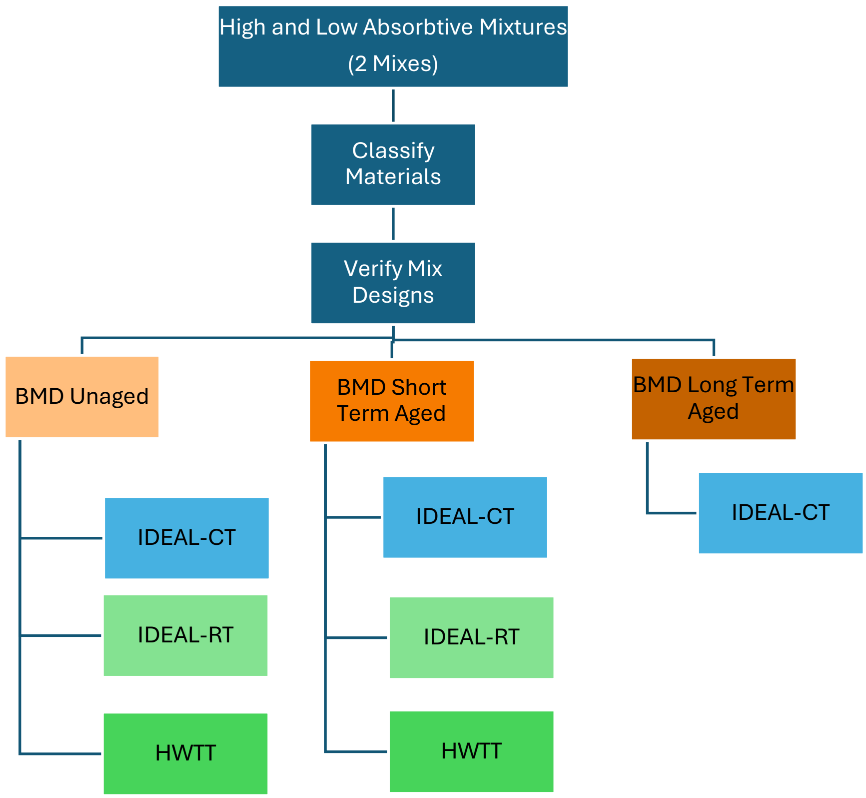

Figure 1. Task 1 and 2 Testing Plan

Three different binder absorption mitigation strategies were evaluated in Task 3: warm mix asphalt (WMA), hydrated lime (HL), and polymer-modified asphalt binders (PMA). WMA may mitigate performance loss through two mechanisms. First, reduced mixing, aging, and compaction temperatures will reduce asphalt binder aging, leaving the binder more flexible, and second, reduced temperatures will mitigate absorption. WMA will be incorporated into the binder at 0.5% by weight of virgin binder. PMA will improve mechanical properties by increasing binder elasticity and reducing absorption by increasing binder viscosity at aging and compaction temperatures. PMA will be incorporated into the mix by using a PG 76-22 binder from the same source as the PG 67-22 control binder. HL will reduce binder absorption by clogging aggregate pores and improve mechanical performance by promoting adhesion. Hydrated lime will be incorporated into the mix by mixing 1% hydrated lime with the virgin aggregate before adding the asphalt binder. The Task 3 testing plan is illustrated in Figure 2. Each strategy will be evaluated in the same unaged, short-term aged, and long-term aged conditions as the untreated designs. Each mix will once again be tested for G_{mm}, IDEAL-CT, and HWTT at each aging condition. HWTT and IDEAL-RT will not be performed in the long-term aged condition since rutting tests are not informative in this condition.

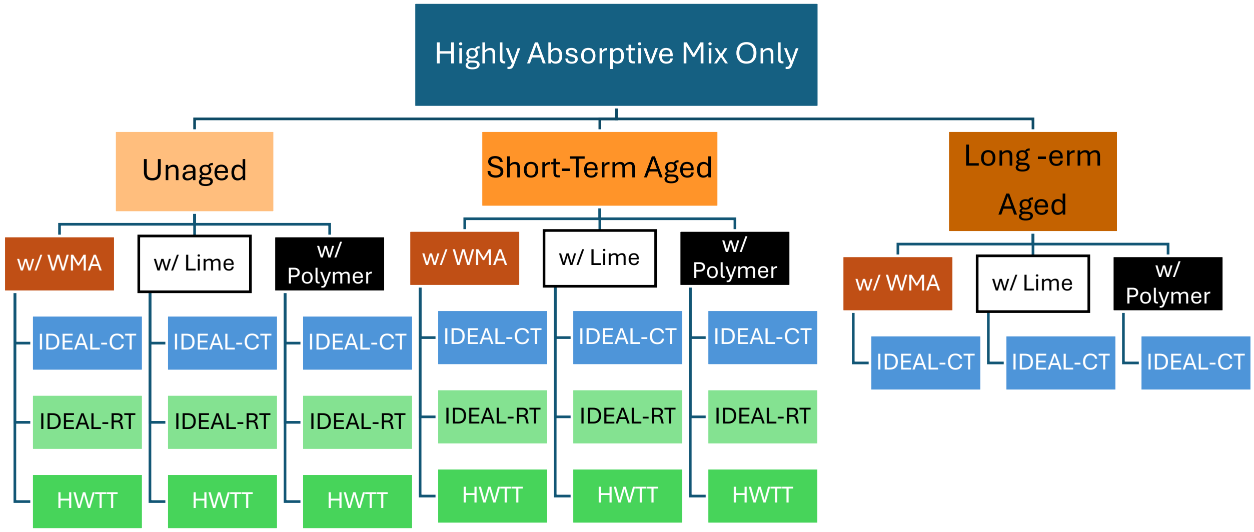

Figure 2. Task 3 Testing Plan

3.1 Mixing Procedure

Unmodified hot-mix asphalt and mixtures using hydrated lime were mixed and compacted using the same temperatures. PG 67-22 binder was heated at 310 – 320°F (154.4-160°C) for 3 hours prior to mixing. Aggregate was heated to 370°F (187.7°C) overnight prior to mixing. For the WMA mixture, the PG 67-22 binder was heated to 300°F – 310°F(148.9°C – 154.4°C) for 3 hours prior to mixing 0.5% by mass of binder WMA additive, which was then combined with the binder, and allowed to continue heating for 30 minutes at the same temperature prior to mixing. Aggregates for the WMA mixtures were heated overnight at 370°F (187.7°C) and cooled to 300°F (148.9°C) prior to mixing. PG 76-22 binder for polymer-modified mixtures was heated to 325–335°F (162.8–168.3°C) for 3 hours prior to mixing. The SBS polymer was included in the binder by the producer prior to sampling. Aggregates for PMA mixtures were heated to 370°F (187.7°C) overnight prior to mixing. Temperatures are summarized in Table 1 (AASHTO, 2022).

Table 1 Mixing Temperatures

Mix ID	Binder Grade	Binder Heating	Aggregate Heating
Unmodified	PG 67-22	310-320°F (154.4 - 160°C) 3 hrs.	370°F (187.7°C) over night
WMA	PG 67-22 w/ 0.5% WMA	300-310°F (148.9-154.4°C) 3 hrs.	370°F (187.7°C) overnight allowed to cool 300°F (148.9°C) before mixing
PMA	PG 76-22 w/ SBS Polymer	325-335°F (162.8-168.3°C) 3 hrs.	370°F (187.7°C) over night
HL	PG 67-22	310-320°F (154.4 - 160°C) 3 hrs.	370°F (187.7°C) over night

3.2 Aging Conditions and Compaction Temperatures

3.2.1 Unaged Condition

In the unaged (UA) condition, specimens are mixed at the correct mixing temperature for the binder and additive, then compacted immediately to minimize absorption and binder aging. Care was taken not to let the samples cool below the compaction temperatures of 275°F (135°C) for all hot-mix specimens and 240°F (115.6°C) for all warm-mix specimens. Aging conditions are summarized in Table 2. For comparison with other aging conditions, this will be considered 0°C-hrs. of aging.

Table 2 Aging and Compaction Temperatures

Aging Condition	Unmodified, PMA, and HL	WMA
UA	Compacted immediately after mixing	Compacted immediately after mixing
STA	2 hrs. @ 275°F (135°C) = 270°C-hrs.	2 hrs. @ 240°F (115.6°C) = 231.2°C-hrs.
LTA	STA + 20 hrs. @ 120°C + 0.5 hrs. @ 135°C = 2737.5°C-hrs.	STA + 20 hrs. @ 120°C + 0.5 hrs. @ 115.6°C = 2689.0°C-hrs.

3.2.2 Short-Term Aged Condition

Short-term aging (STA) was conducted in accordance with American Association of State Highway and Transportation Officials (AASHTO) R 30-24 to simulate aging and absorption that occurs during asphalt plant operations. After mixing, all hot-mix samples were aged for 2 hours at 275°F (135°C), then compacted. This yields 270°C-hrs. of aging. All warm-mix samples were aged for 2 hours at 240°F (115.6°C) prior to compaction, per the WMA additive manufacturers' recommendations, yielding 231°C-hrs. of aging (AASHTO, 2024a).

3.2.3 Long-Term Aged Condition

Long-term aging (LTA) was performed according to AASHTO R 121-24 Method D to simulate approximately 8 years of field aging in the top 25mm of pavement in South Alabama, as recommended by Zhou et al. (Zhou et al., 2025). All mixtures were first mixed and aged according to their respective STA procedures, then spread to a thickness of one nominal maximum aggregate size and cooled to room temperature. Next, each mixture was placed in a pan at a thickness of 25 to 50mm and heated at 120°C (248°F) for 20 hours, adding 2400°C-hrs. of mixture aging. Each mixture was allowed to cool to room temperature, then reheated to its compaction temperature and compacted. Reheating to compaction temperature takes approximately 30 minutes, adding 67.5°C-hrs. of aging for hot-mixed samples and 57.8°C-hrs. for warm-mixed samples. In the LTA condition, total aging is 2737.5°C-hrs. for hot-mixed samples and 2689.0°C-hrs. for warm-mixed samples (AASHTO, 2024b).

3.3 BMD Tests

3.3.1 IDEAL-CT

The IDEAL-CT is used to measure an asphalt specimen's resistance to intermediate temperature cracking via indirect tension. The test uses a 150mm diameter, 62mm high specimen of laboratory-compacted asphalt mix compacted to 7 ± 0.5% air voids. Each specimen was conditioned at 25°C (77°F) for 2 hours in an environmental chamber before testing. Each specimen is broken in a single load-frame movement at 50mm/min. The load-displacement curve is used to calculate the failure energy, the post-peak slope at 75% of the peak load, and the post-peak displacement at 75% of the peak load. Each of these is used, along with the specimen's dimensions, to calculate the $CT\text{-}_{Index}$, which is unitless. Equation 1 is used to calculate CT_{index} (Zhou, 2019)(ASTM, 2019).

Equation 1

$$CT_{index} = \frac{t}{62} * \frac{G_f}{|m_{75}|} * \frac{L_{75}}{D}$$

Where:

G_f	= failure energy (J/m^2)
m_{75}	= slope at 75% of post-peak load (kN/mm)
l_{75}	= displacement at 75% post-peak load (mm)
t	= thickness of sample (mm)
D	= specimen diameter (mm).

3.3.2 IDEAL-RT

The IDEAL-RT test is a monotonic rutting test used to determine a unitless index measure for an asphalt mixture's susceptibility to rutting. A gyratory specimen 62mm in height is loaded across its diameter while supported in the RT supporting cradle. For this study, testing was performed on specimens conditioned at 50°C. Each specimen is deformed with a single load-frame movement at 50mm/min, and the maximum load is recorded. The maximum load is used to calculate shear stress, then shear stress is used to calculate the RT_{index} as seen in Equation 2 (ASTM, 2022).

Equation 2

$$RT_{Index} = 6.618 \times 10^{-5} \times \frac{\tau_f}{1\ Pa}$$

Where:
RT_{Index} = rutting tolerance index
τ_f = shear strength (Pa)

3.3.3 HWTT

The Hamburg Wheel Track Test measures an asphalt mixture's susceptibility to rutting, moisture-induced damage, and, in some cases, aggregate breakdown. The HWTT uses sets of two 150mm diameter, 62mm high gyratory specimens compacted to 7±0.5% air voids. The specimens are cut flat on one side and fitted together. The samples are submerged in 50°C (122°F) water for 45 minutes prior to testing. Submersion and water temperature are maintained while a steel wheel with a 158 lb. load is passed over the pairs of specimens 20,000 times, and the rut depth is measured in mm. Results may be reported as rut depth at a specific number of passes, or passes to a failure criterion, typically 12.5mm of rutting (AASHTO, 2023b). Since this is a cyclic loading test, it better simulates traffic loading than monotonic tests like the IDEAL-RT; however, it is much more time-consuming to perform.

3.3.3.1 Corrected Rut Depth

Corrected Rut Depth (CRD) is a mathematically determined HWTT parameter that estimates the rut depth of a specimen at 20,000 passes, as though deformation is due solely to the specimen's plasticity. Deformation due to stripping is excluded from CRD. For this project, CRD was calculated using the HWTTXpert online system (Yin et al., 2020).

3.3.3.2 Stripping Number

Stripping Number (SN) can be thought of as the first pass of the HWTT, where stripping occurred. SN and CRD are frequently used together to characterize plastic deformation separately from the onset of stripping. SN for this project was calculated using the HWTTXpert online system (Yin et al., 2020).

3.3.3.3 Rutting Resistance Index

The Rutting Resistance Index (RRI) is a unitless index used to compare HWTT data which allows easy comparison between specimens with highly varied performance. RRI does not separate stripping from plastic deformation; all deformation is treated equally. For samples that deform more than 12.5mm before 20,000 passes, RRI accounts for the number of passes that the sample endures before the final rut depth is reached. The index can be thought of as giving 10,000 "points" to a sample for surviving 20,000 passes, and an additional 10,000 "points" inversely proportional to rut depth at 20,000 passes. For specimens that do not survive 20,000 passes, 10,000 "points" are awarded proportionally for passes survived from 0 to 20,000. RRI is calculated using Equation 3 (Wen et al., 2016).

Equation 3

$$RRI = N \times (1 - RD)$$

Where:
RRI = Rutting Resistance Index (unitless)
N = Number of cycles at completion of test
RD = Rut Depth at Completion of Test

3.3.3.4 Stripping Inflection Point

Stripping Inflection Point (SIP) is the number of HWTT passes at which the creep slope and the stripping slope intersect, marking the onset of moisture-induced damage within the specimen. A higher SIP indicates greater resistance to the initiation of stripping. SIP for this project was calculated using the HWTTXpert online system (Yin et al., 2020).

4. RESULTS AND ANALYSIS

4.1 Component Material Testing

Two binders from a single source were selected for this project: PG 67-22 and SBS polymer-modified PG 76-22 to be used for the polymer-treated sample group. While it is not a common AASHTO grade, PG 67-22 is the unmodified binder grade most used by the Alabama Department of Transportation (ALDOT). Both binders were tested and graded in accordance with AASHTO M 320. Both binders meet ALDOT's minimum specifications for their respective grade (AASHTO, 2023a; ALDOT, 2022).

Table 3. Asphalt Binder Test Results

Binder	**RV, 135°C, PaS**	**Tcont, High**	**Tcont, int**	**Tcont, S**	**Tcont, m**	**Delta Tc**	**High PG**	**Low PG**
PG 67-22	0.46	67.5	23.3	-27.0	-22.3	-4.7	67	-22
PG 76-22	1.38	76.8	20.2	-29.3	-26.7	-2.5	76	-22

The results of all aggregate specific gravity and absorption tests are summarized in Tables 4 and 5 for the highly absorptive and low absorptive aggregates, respectively. Gradations are shown in Appendix A along with mix designs and volumetric properties for each mixture. Aggregates were dried according to AASHTO T 255 and split into correct testing masses according to AASHTO R 76. Coarse and fine aggregates were tested for specific gravity and absorption according to AASHTO T 85 and AASHTO T 84, respectively. Sieve analysis was performed on all aggregates according to AASHTO T 11 and AASHTO T 27. The highly absorptive aggregate was sampled from a river deposited gravel source being used for a paving project at the time this research project was initiated. The low absorptive aggregate source was sampled from an asphalt plant and is composed mostly of quarried dolomite.

Table 4 Highly Absorptive Aggregate Properties

Aggregate	Gsa	Gsb	Gssd	Abs.	% Feed
5/8 Rock	2.693	2.554	2.606	2.0	47
Base	2.693	2.442	2.535	3.8	20
Cr. Fines	2.713	2.458	2.552	3.8	13
Wash Sand	2.821	2.557	2.650	3.7	20
Weighted Avg	2.721	2.520	2.593	2.94	

Table 5 Low Absorptive Aggregate Properties

Material	Gsa	Gsb	Gssd	Abs	% Feed
Coarse Dolomite	2.810	2.752	2.773	0.7	41
Fine Dolomite	2.806	2.719	2.750	1.1	33
Manufactured Sand	2.595	2.547	2.565	0.7	25
Wt. Avg	2.754	2.690	2.713	0.86	

4.2 Volumetric Mix Design Verification

Cold feed percentages were adjusted for each mix design such that the air voids of the gyratory specimens produced in the lab at N_{design} matched those stated in the mix design within ±1%, and gradations were within ±1% on each sieve. Verifying the mix design for the low-absorption mix was challenging: the larger aggregate particles contained enough adhered fines, so no material passing the No. 200 sieve needed to be batched from the dolomite aggregate.

4.3 Effect of Mitigation Strategies on Asphalt Absorption

Each mixture was tested for G_{mm} according to AASHTO T 209 in unaged, short-term aged, and long-term aged conditions. The highly absorptive mix was also tested in each aging condition using each mitigation strategy. Equations 4, 5, and 6 were used to calculate the effective specific gravity of the aggregate (G_{se}), percent binder absorbed (P_{ba}), and percent binder effective (P_{be}), respectively.

Equation 4

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{p_b}{G_b}}$$

Where:

G_{se} = Effective specific gravity of the aggregate

G_{mm} =Maximum specific gravity of the mixture

P_{mm} = percent by mass of total loose mixture = 100

P_b = percent binder

G_b = specific gravity of asphalt binder

Equation 5

$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{sb}G_{se}} \times G_b$$

Where:

P_{ba} = Percent binder absorbed

G_{se} = Effective specific gravity of the aggregate

G_{sb} = Bulk Specific Gravity of the stone

G_b = specific gravity of asphalt binder

Equation 6

$$P_{be} = P_b - \left(\frac{P_{ba}}{100}\right) P_s$$

Where:

P_{be} = Percent binder effective

P_s = Percent aggregate

Tables 6 and 7 below present the G_{sa}, P_{ba}, and P_{be} for each mixture, along with all properties used in the calculations. A binder specific gravity of 1.03 was assumed for all mixes. Figure 3 is a chart of P_{ba} vs aging for each mixture, which allows visualization of how the absorption of each mix relates to the others in this study. Absorption across all mixes increases from the UA to STA condition. The increase in absorption between STA and LTA conditions is smaller for all mixes except the high absorption mix with WMA additive. This was an unexpected result for the WMA mix, and may be explained by the long-term aging temperature being greater than the short-term aging temperature for the WMA mixture causing a greater change in absorption between the STA and LTA conditions than for other mixtures. Because field aging occurs at a similar rate for a given mixture regardless of production temperature, the long-term aging protocol itself is expected to be equally applicable to WMA; however, more research is needed to determine whether the 20-hour conditioning duration and temperature used in this procedure are appropriate for WMA mixtures using highly absorptive aggregates.

Table 6. Absorption characteristics of low absorption and high absorption mixes

	Low Abs UA	Low Abs STA	Low Abs LTA	High Abs No Add UA	High Abs No Add STA	High Abs No Add LTA
Additive	None	None	None	None	None	None
P_{mm}	100	100	100	100	100	100
P_b	5.8	5.8	5.8	6.7	6.7	6.7
G_{mm}	2.507	2.510	2.518	2.366	2.391	2.396
G_b	1.03	1.03	1.03	1.03	1.03	1.03
G_{se}	2.750	2.754	2.764	2.609	2.642	2.648
G_{sb}	2.690	2.690	2.690	2.520	2.520	2.520
P_{ba}	0.83	0.88	1.02	1.39	1.88	1.98
P_{be}	5.02	4.97	4.84	5.40	4.94	4.85
Aging C*hrs.	0	270	2737.5	0	270	2737.5

Table 7. Absorption characteristics of high absorption mix with mitigation strategies

	High Abs Poly UA	High Abs Poly STA	High Poly Abs LTA	High Abs WMA UA	High Abs WMA STA	High Abs WMA LTA	High Abs Lime UA	High Abs Lime STA	High Abs Lime LTA
Additive	Polymer	Polymer	Polymer	WMA	WMA	WMA	Hyd. Lime	Hyd. Lime	Hyd. Lime
P_{mm}	100	100	100	100	100	100	100	100	100
P_b	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
G_{mm}	2.364	2.377	2.386	2.362	2.375	2.400	2.365	2.382	2.387
G_b	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
G_{se}	2.606	2.623	2.635	2.604	2.621	2.653	2.608	2.630	2.636
G_{sb}	2.520	2.520	2.520	2.520	2.520	2.520	2.520	2.520	2.520
P_{ba}	1.36	1.61	1.79	1.32	1.57	2.06	1.37	1.71	1.81
P_{be}	5.44	5.20	5.03	5.47	5.23	4.78	5.42	5.11	5.02
Aging C*hrs.	0	270	2737.5	0	231.2	2689	0	270	2737.5

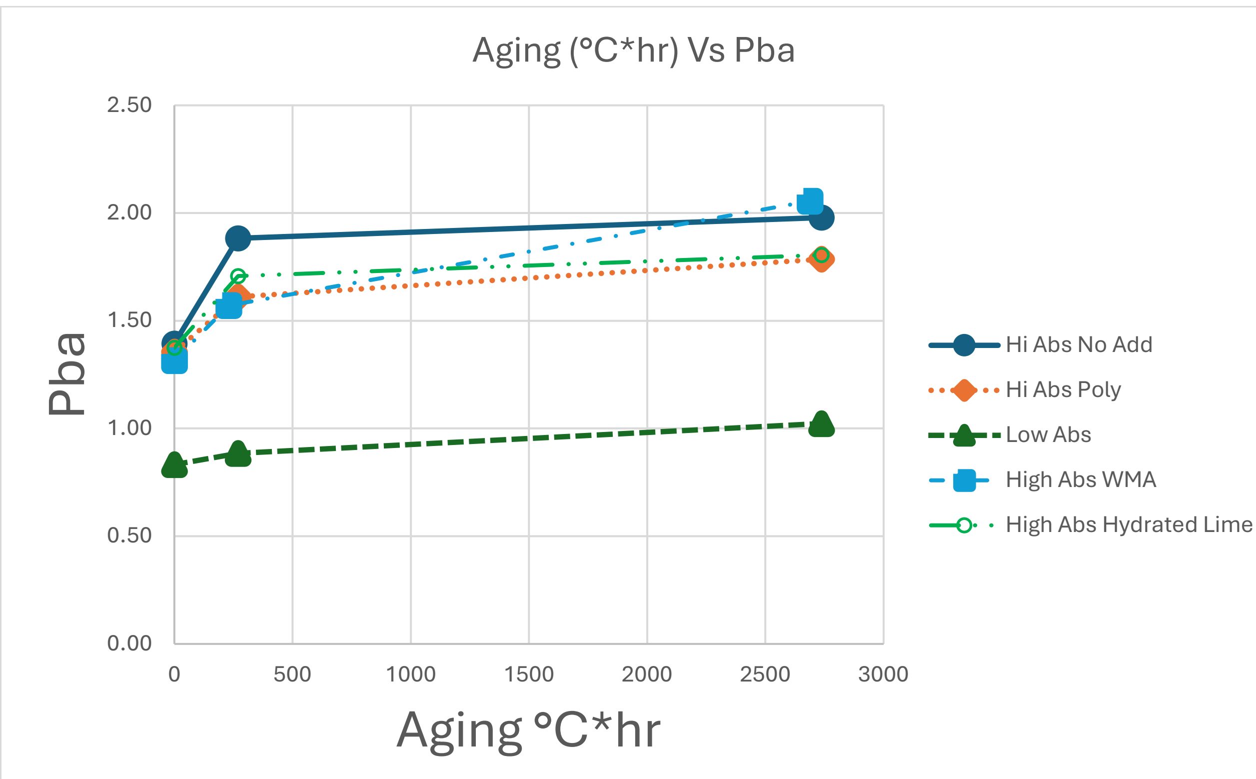

Figure 3 P_{ba} vs. Aging for all mixes

4.4 Effect of Mitigation Strategies on IDEAL-CT Results

The IDEAL-CT test specified in ASTM D8225-19 was performed on all mixtures in this study, and in all aging conditions. The high- and low-absorption mixes were designed to have a similar CT CT_{index} in the unaged condition. High-absorption mixes with all mitigation strategies had better IDEAL-CT performance than either the low or high-absorption (with no additive) mixes in both the unaged and short-term aged conditions. The polymer-modified mix performs best in both unaged and short-term aged conditions, as shown in Figure 4. In the short-term aged condition, intended to simulate aging that occurs during the production and placement of an asphalt mixture, all treatments again improve performance to levels greater than either the untreated high-absorption mix or the low-absorption mix. The mix with low-absorption aggregate outperforms all others in the long-term aged condition; the performance of the high-absorption mix is improved by both the hydrated lime and polymer treatments. This suggests that both polymer and hydrated lime can improve the cracking performance and longevity of an asphalt mixture with high absorption, but not to the extent achieved with less absorptive aggregate. IDEAL-CT results for the WMA mixture in the long-term aged condition may not be a reliable predictor of the mix's cracking resistance in the field. The long-term aging temperature for the WMA mixture was higher than the short-term aging temperature, which caused a surprising change in binder absorption between the STA and LTA conditions. As discussed in Section 4.3, more research is needed to determine whether the 20-hour conditioning duration and temperature used in the LTA procedure are appropriate for WMA mixtures with highly absorptive aggregates. Long-term aged CT_{index} data is presented separately in Figure 5 for clarity, with error bars representing ±1 standard deviation.

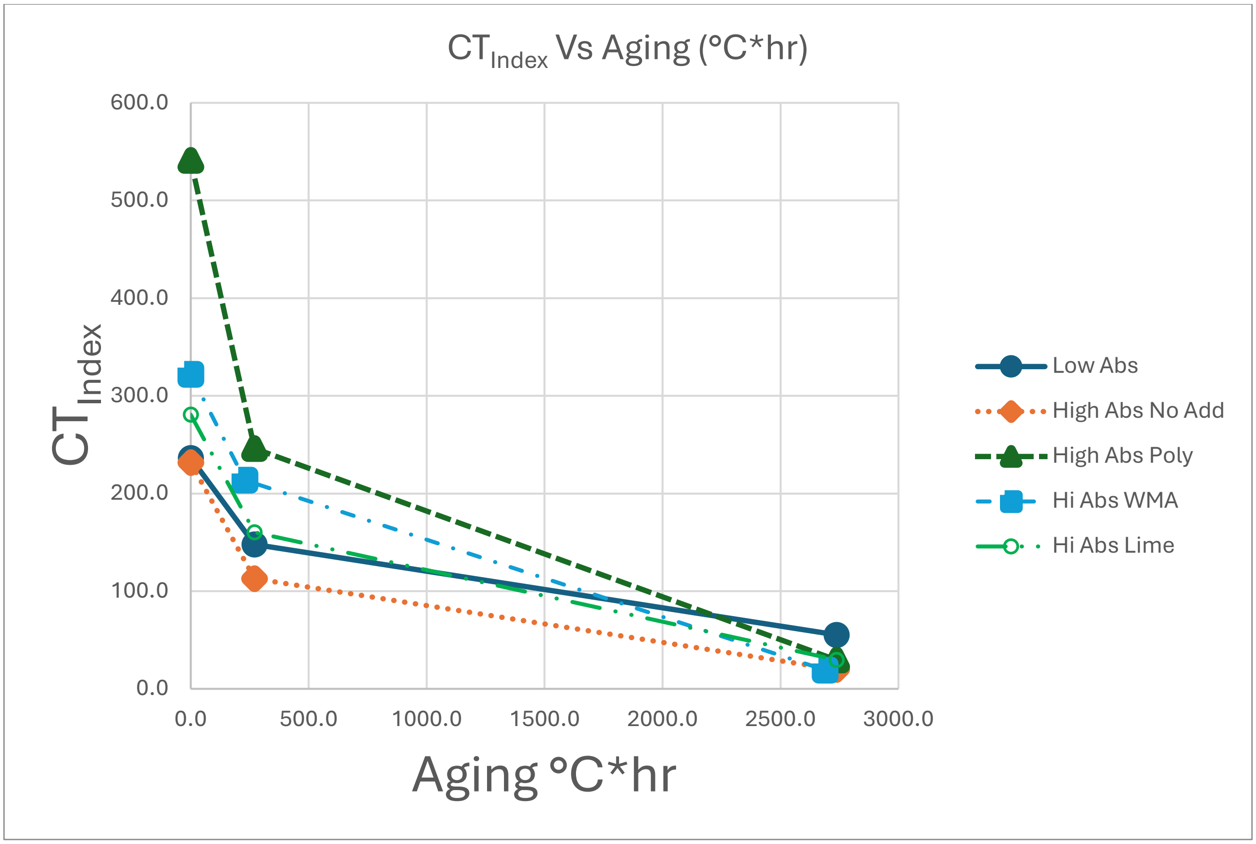

Figure 4 CT_{index} vs Aging °C-hrs.

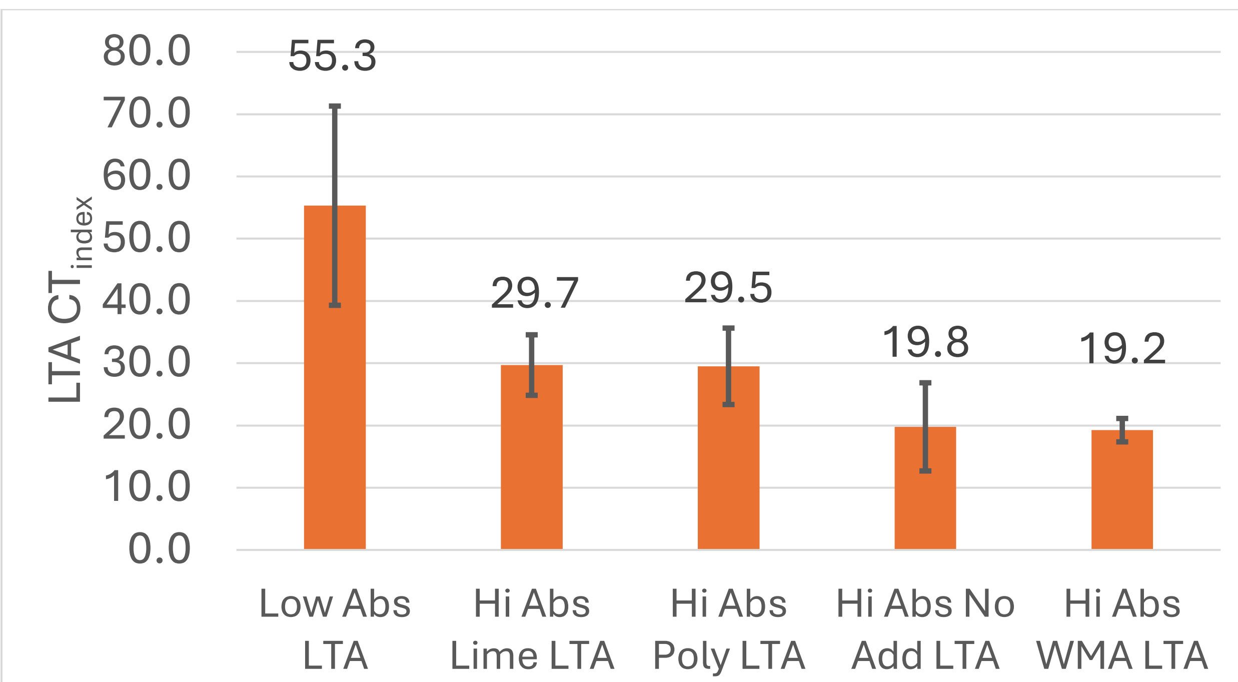

Figure 5 Long Term Aged CT_{index}

4.5 Effect of Mitigation Strategies on IDEAL-RT Results

The IDEAL-RT was performed under unaged and short-term aged conditions, since rutting typically occurs early in a pavement's life when the binder is at its softest. Unlike with the IDEAL-CT, the mixes were not intended to have similar RT_{index} results in the unaged condition. In the unaged condition, high absorption mixes with no additive, hydrated lime, and WMA show similar performance at 30.6, 28.5, and 27.9, respectively. The polymer additive increases the performance of the high-absorption mix to 48.0, above that of the low-absorption mix at 41.1.

In the short-term aged condition, results are more varied. RT_{index} of all mixes improves at least some since more binder is absorbed, and the effective binder that remains is stiffened, improving resistance to rutting. The low-absorption mix and high-absorption mix with no additive show similar performance with RT indices of 55.5 and 54.2, respectively. WMA and hydrated lime mixes do not improve in performance as much over their unaged counterparts. This is likely due to their increased effective binder contents, and in the case of WMA, less binder aging due to reduced mixing, compacting, and aging temperature. The polymer-modified mix stands out as the most rutting-resistant with an RT_{index} of 75.6. All IDEAL-RT data are shown in Figure 6 and Table 8 below.

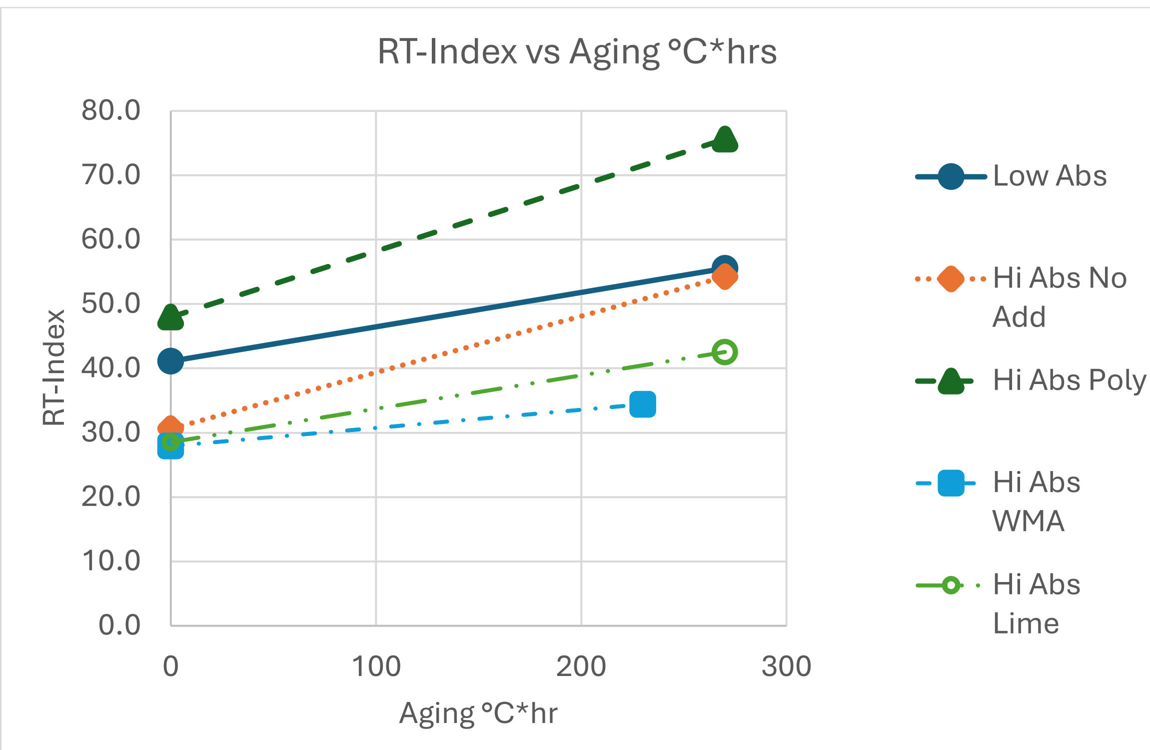

Figure 6 RT_{index} vs Aging

Table 8 RT_{index} data with aging condition

Mix ID	Average of RT-Index	Aging (°C-hrs.)
Low Abs UA	41.1	0
Low Abs STA	55.5	270
Hi Abs No Add UA	30.6	0
HI Abs No Add STA	54.2	270
Hi Abs Poly UA	48.0	0
HI Abs Poly STA	75.6	270
Hi Abs WMA UA	27.9	0
Hi Abs WMA STA	34.4	230
Hi Abs Lime UA	28.5	0
Hi Abs Lime STA	42.5	270

4.6 Effect of Mitigation Strategies on HWTT Results

Before the HWTT results are presented, one caveat should be noted: these results may not be broadly applicable to other absorptive aggregates. The high-absorption mixture used in this study is susceptible to moisture-induced damage, which, in turn, drives all test results. Controlling this stripping problem was outside the scope of this study.

HWTT was performed only under unaged and short-term aged conditions, since long-term-aged rutting tests are not representative of field conditions where rutting typically occurs. All specimens were tested in water at 50°C. None of the specimen sets in this study remained below 12.5mm of rutting after 20,000 HWTT passes. This poor performance was primarily driven by stripping. If a similar study is conducted again, it would be advantageous to determine an effective anti-strip agent and dosage rate for the specific aggregate and binder to be used before beginning production of test specimens. Alternative HWTT parameters were used to examine performance, including corrected rut depth, stripping number, rutting resistance index, stripping inflection point, and passes to 12.5mm of rutting. HWTT Displacement vs. Pass count diagrams are available in Appendix A.

The corrected rut depth for each mix is shown in Figure 7 below. Specimens with lower corrected rut depths are more resistant to rutting. CRD excludes deformation caused by stripping. The low-absorption mix and the high-absorption mix with no additive had corrected rut depths of 6.22mm and 8.45mm, respectively, in the short-term aged condition. Both the polymer and the WMA additive improved the STA CRD of the high absorption mix to 5.11mm and 6.61mm, respectively. Hydrated lime did not improve the CRD, yielding an STA CRD of 14.12mm. Polymer modification likely improves CRD in several ways: first, by stiffening the mixture; second, by allowing elastic recovery of the mixture between passes of the HWTT; and finally, by mitigating absorption. The WMA mixture performs poorly in the unaged condition, with a CRD of 16.28mm, which is significantly greater than that of any other mixture in the study. This is likely due to the reduced mixing and compaction temperatures, which will stiffen the asphalt binder less than for other mixtures, yielding more deformation under the load of the HWTT. This may not be a concern in a plant-produced mix since the binder would experience more time at high temperature, as simulated by the STA condition, which does show performance improvements over the untreated mix.

Stripping Number for each mix is shown in Figure 8. A higher stripping number indicates that the mix has greater resistance to stripping initiation than those with lower SNs. The low-absorption mix and the high-absorption mix with no additive do not show similar performance on this metric, with SNs of 5432 and 2408, respectively. Polymer and hydrated lime both show improvements in SN over the untreated mix at 3189 and 3873, respectively. This is expected since lime is a common treatment for stripping, and increased rutting resistance of polymer would be likely to delay the onset of stripping as well. The WMA additive improves the SN of the mix in the UA condition, but not in the STA condition. This was unexpected since this particular WMA additive is also commonly used as an anti-stripping additive. There may be a compatibility problem between this aggregate, binder, and additive combination.

The rutting resistance index of each mix is shown in Figure 9. A higher rutting resistance index indicates better performance in the HWTT. RRI is a unitless index that treats all deformations the same, no matter the cause. As with SN, the low- and high-absorption mixes are not similar at STA RRIs of 8012 and 3550, respectively. The mix showing the most significant improvement in RRI is the one with polymer at 7607. In this case, WMA is affecting performance, with an RRI of 1600, likely due to reduced binder aging and higher effective binder content. Hydrated lime showed approximately the same performance as the unmodified mix at 3825.

The stripping inflection point for each mix is shown in Figure 10. Stripping is the primary driver of the poor HWTT performance across all mixes in this study. In all cases, SIP improves in the STA condition relative to the UA condition. Polymer shows the most improvement in stripping inflection point of any of the treatments examined here. Polymer improves HWTT performance in two ways: stiffening the binder and allowing the binder to recover elastically between passes of the HWTT. In this case, it is likely that the polymer improves stripping performance by preventing plastic deformation. Another way to think of this is that, since the mix moves less overall, it appears to strip less, even though the polymer may have had no effect on the binder's adhesion to the aggregate. WMA was detrimental to the stripping performance of the mixture in this case. This is a surprising result since the WMA additive used in this study is also an effective anti-stripping agent. It is likely that this particular binder-aggregate-additive combination is not compatible. Since the binder was softer due to reduced aging at WMA temperatures, there was greater deformation and, consequently, greater measured stripping. It is also surprising that hydrated lime was not very helpful in controlling stripping here. The research team cannot offer an explanation for its inefficacy.

HWTT passes to failure are shown in Figure 11. No mix in this study remained below 12.5mm of rutting for 20,000 passes. Polymer again stands out as the treatment that provided the greatest improvement over the unmodified mix, due to stiffness and elastic recovery. Lime did not improve performance over the unmodified mix. WMA is affecting performance due to reduced binder aging.

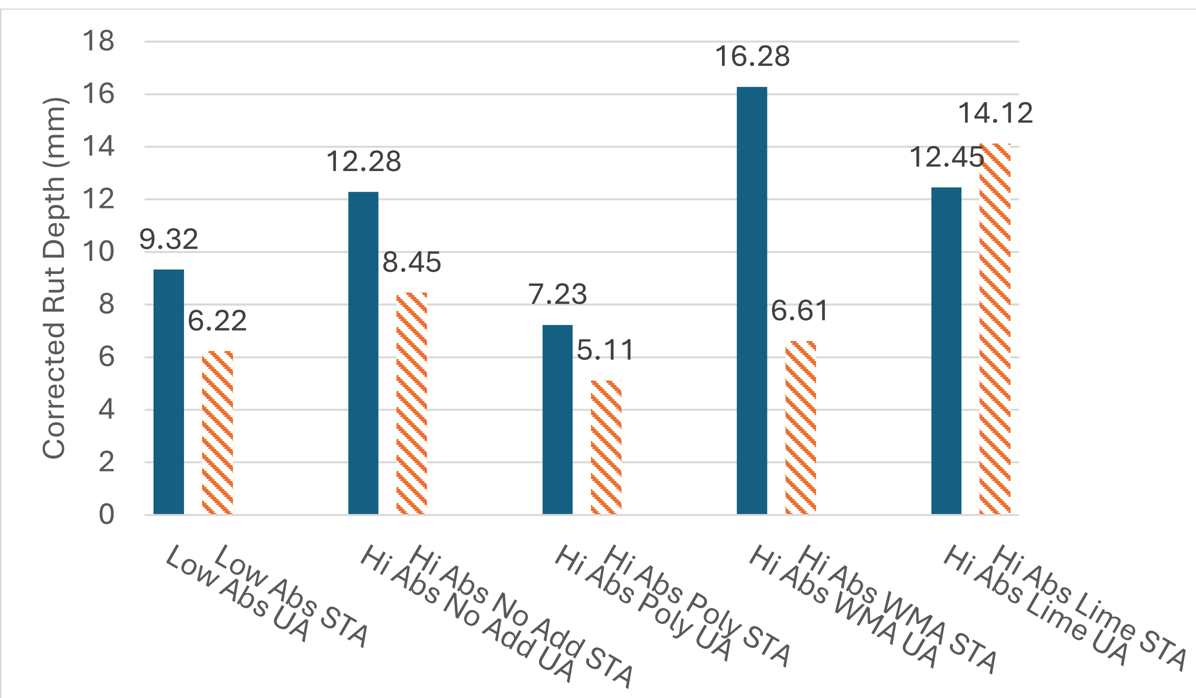

Figure 7 HWTT Corrected Rut Depth

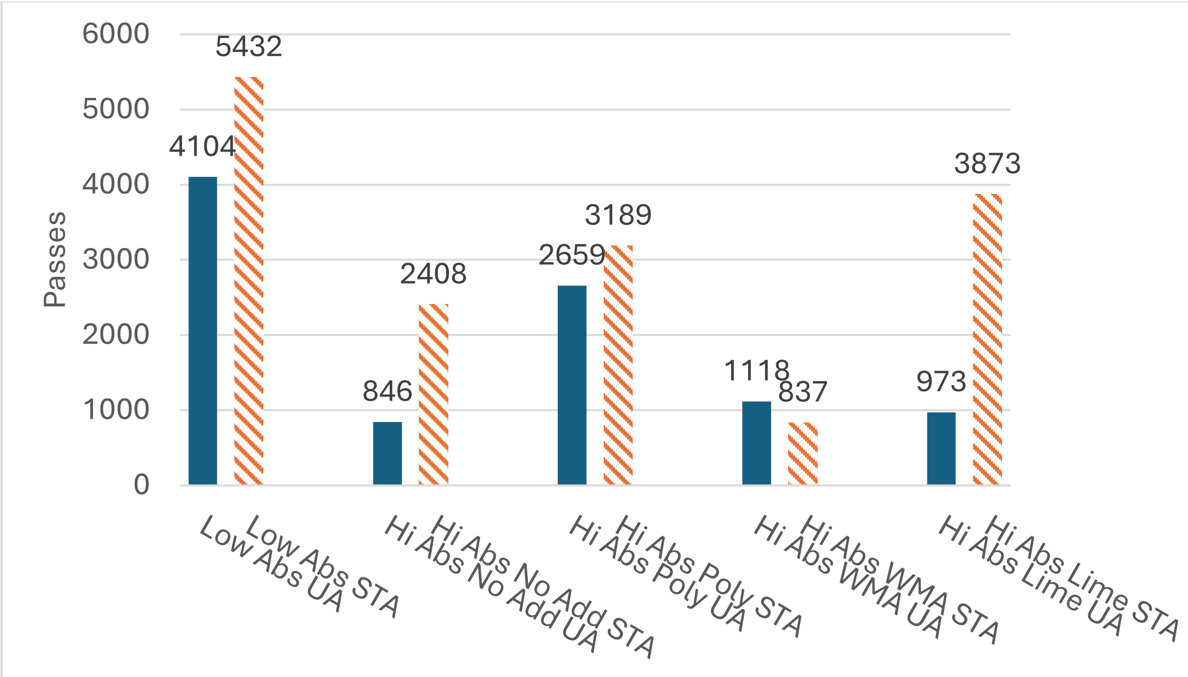

Figure 8 HWTT Stripping Number

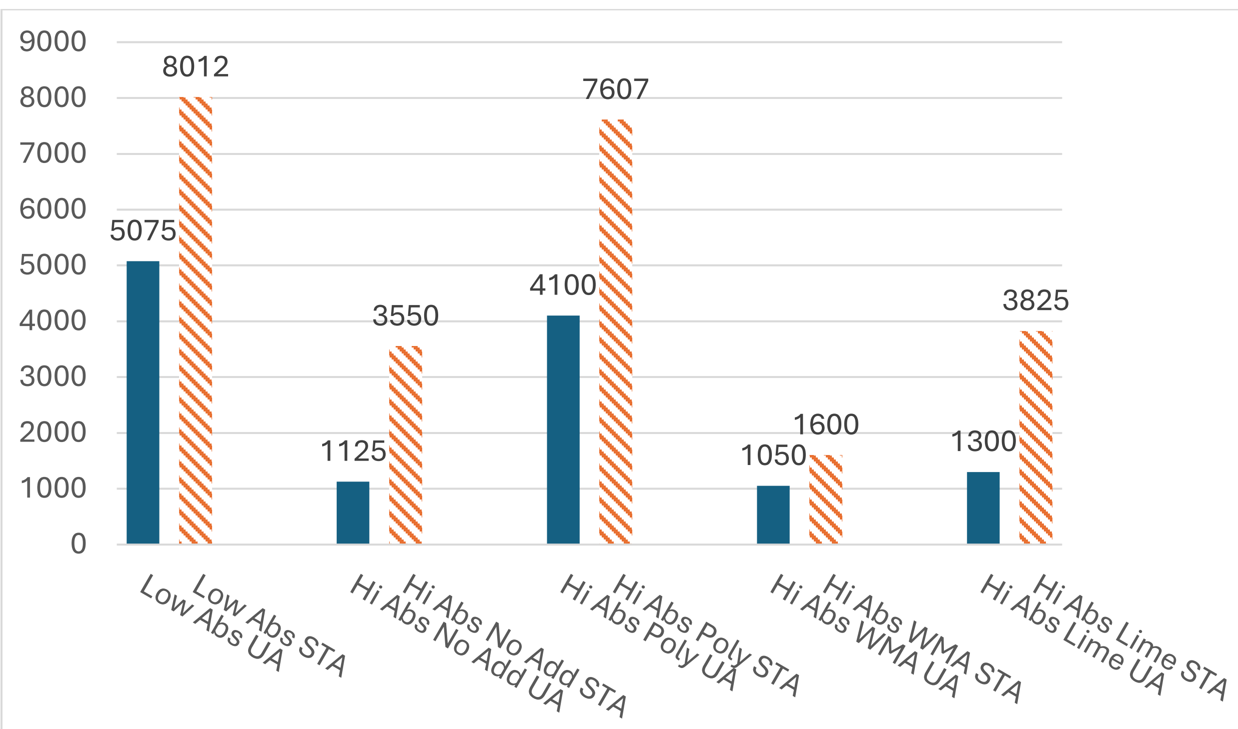

Figure 9 Rutting Resistance Index

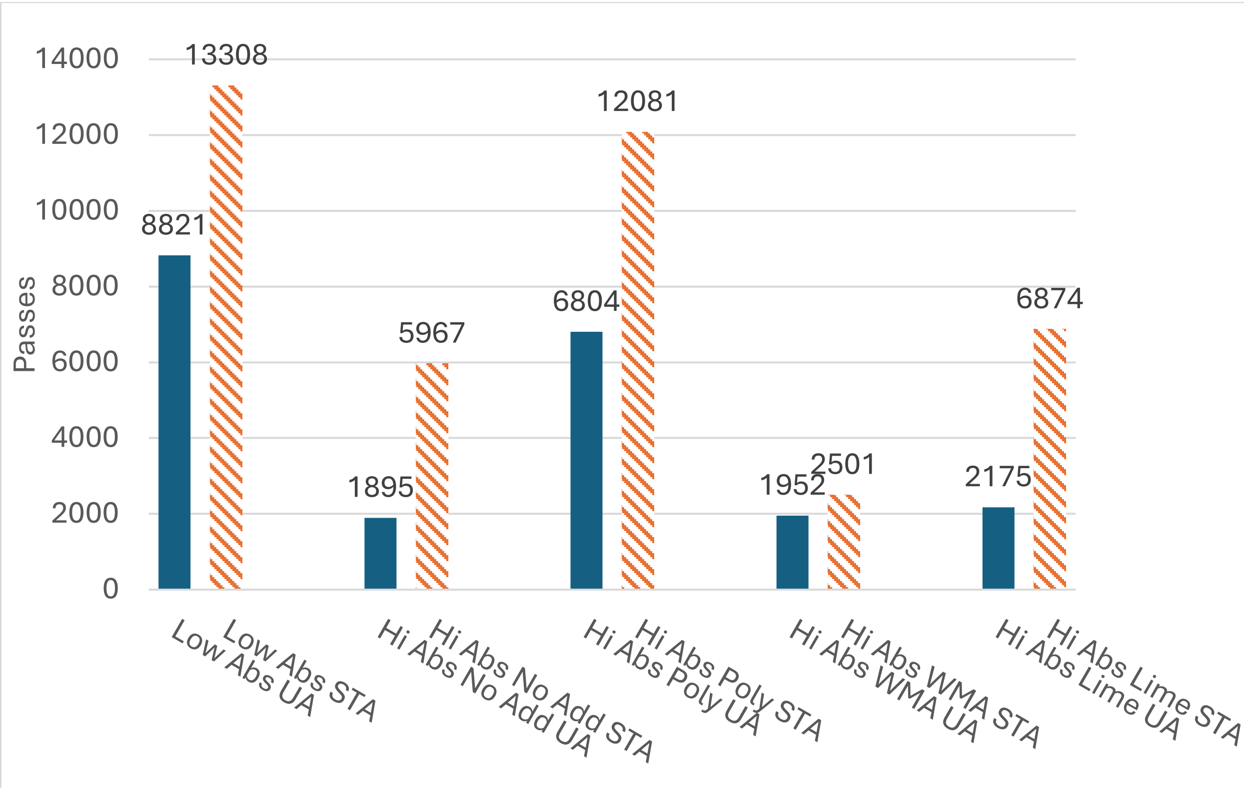

Figure 10 HWTT Stripping inflection point

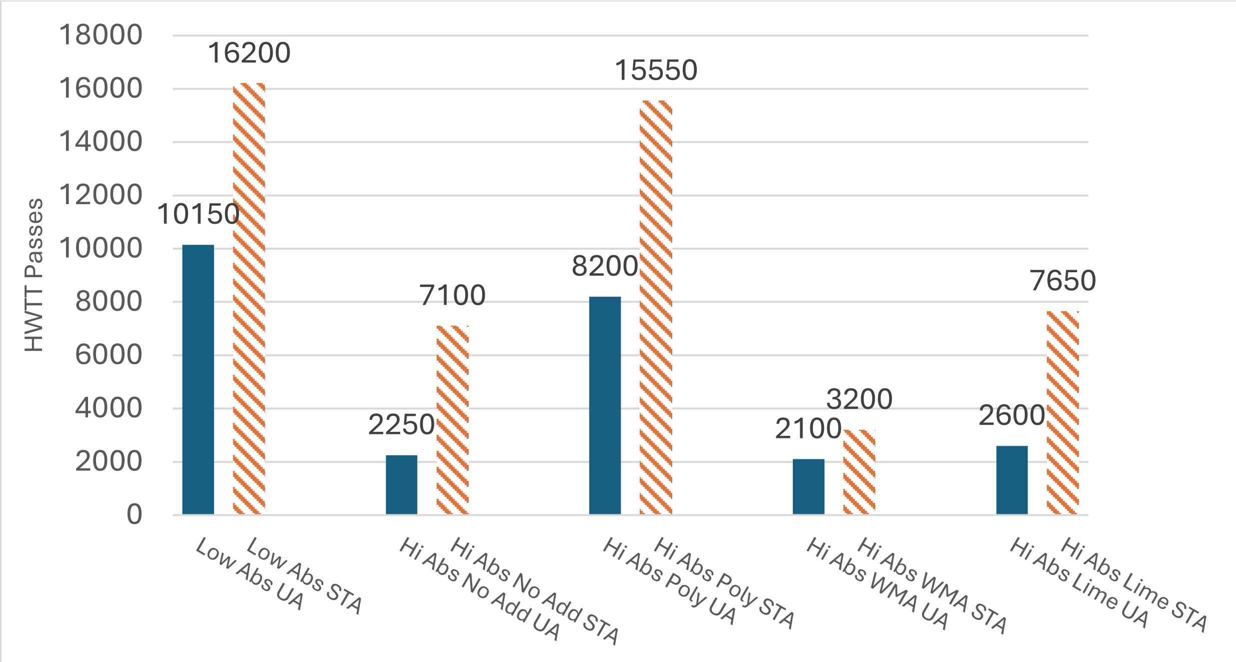

Figure 11 HWTT Passes to 12.5mm

4.7 ANOVA of IDEAL-CT Results

The performance trends described in Sections 4.4 through 4.6 were evaluated statistically to determine which differences between treatments are significant. Figures 12, 13, and 14 below show IDEAL-CT results for all tested mixes in each aging condition, with analysis of variance (ANOVA) grouping overlaid using the method noted on each chart. The error bars on each chart represent one standard deviation above and below the mean of that specimen set. Levene's test for equal variances was performed on each group. For the UA and LTA groups, it was determined that variances were unequal, so the Games-Howell Grouping was used. For the STA set, the variances were determined to be equal, so Tukey Groupings were applied. At the time of writing, ASTM recently published a revised test method for the IDEAL-CT, ASTM D8225-26, which states that a minimum of 5 specimens should be tested to determine a single average result for a mixture (ASTM, 2026). This is a very small sample size for ANOVA. The groupings for the UA and STA sets appear reasonable to the research team. Groupings for the LTA data set appear too inclusive, including hydrated lime results in the grouping with all other treatments. A contributing factor to these inclusive groupings of the LTA Hydrated Lime set is that only 5 specimens were tested, and one of those was determined to be an outlier using ASTM E178. Fewer data points can lead to unexpected behavior in ANOVA groupings.

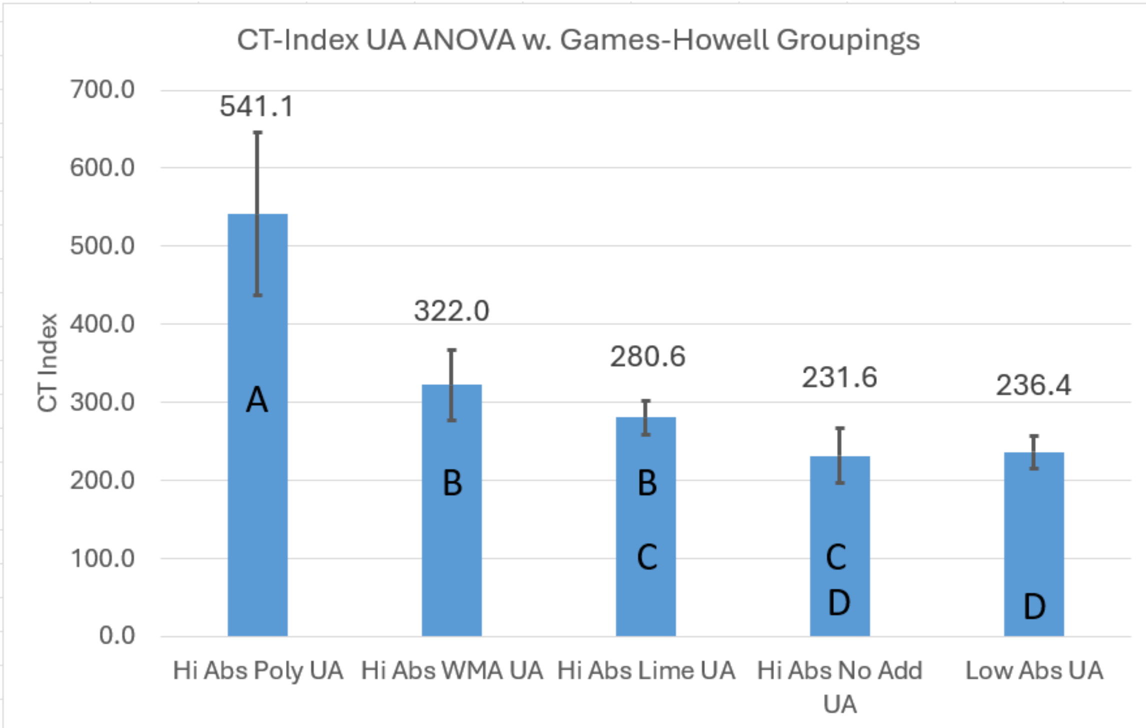

Figure 12 CT_{index} Unaged ANOVA with Games-Howell Groupings

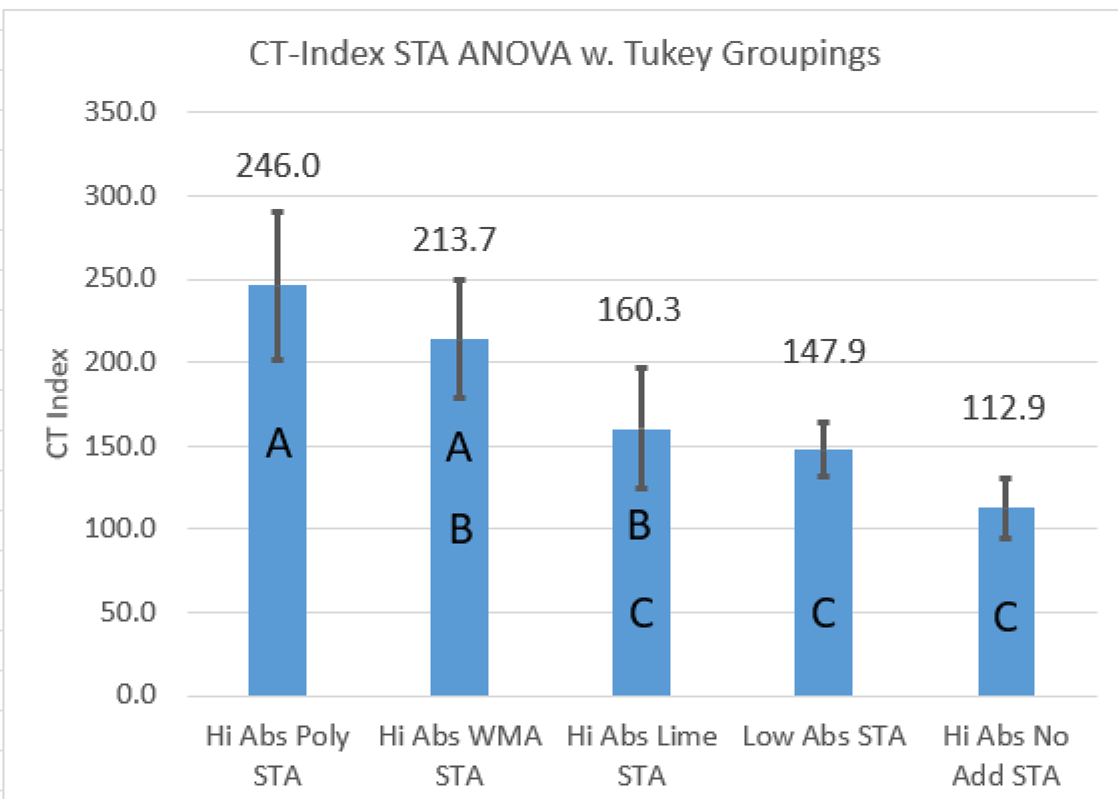

Figure 13 CT_{index} Short-Term Aged ANOVA with Tukey Groupings

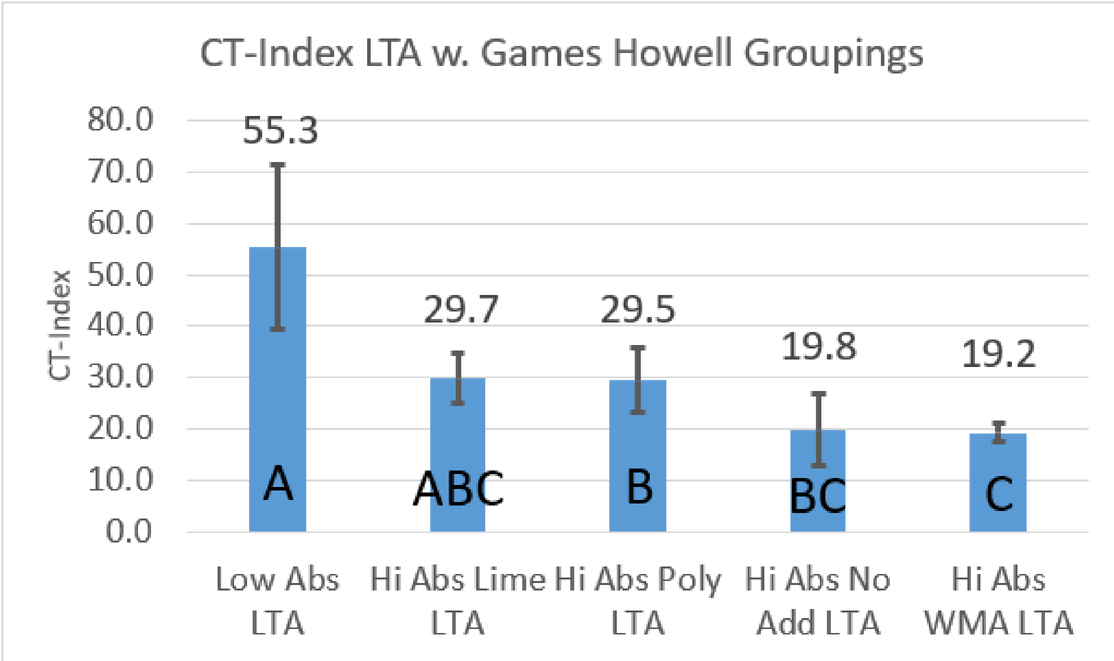

Figure 14 CT_{index} Long-Term Aged with Games Howell Groupings

4.8 Analysis of IDEAL-CT results using repeatability limit

The repeatability limit, r, for the IDEAL-CT test was recently reported as 48.6% (0.486), meaning that test results whose means differ by less than 48.6% may be considered equivalent (ASTM, 2026). Tables 9, 10, and 11 below show the absolute value of the difference between each set of IDEAL-CT results divided by the average of those two results. If this number is less than r for the set of results given in each column and row, those results may be considered equivalent. In Tables 12, 13, and 14, a "/" indicates that the results are not considered equivalent by this analysis, while "=" indicates that the results may be considered equivalent.

For the unaged group, this method treats the results of all treatments as equivalent, except for the group produced with polymer-modified asphalt, which has the highest CT_{index}. The long-term aged group is also simple to analyze, as this method treats all treatments as equivalent except for the low-absorption aggregate, which again has the highest CT_{index}. The short-term aged group is more complex.

To summarize the STA set:

- Polymer may be considered equivalent to WMA and lime.
- WMA may be considered equivalent to polymer, lime, and low absorption.
- Lime may be considered equivalent to all other treatments.

- Low absorption may be considered equivalent to WMA, lime, and high absorption with no additive.
- High absorption with no additive may be considered equivalent to lime and low absorption.

Table 9 Repeatability Limit Comparison Values for Unaged IDEAL-CT

	Hi Abs Poly UA	Hi Abs WMA UA	Hi Abs Lime UA	Low Abs UA	Hi Abs No Add UA
Hi Abs Poly UA		0.508	0.634	0.784	0.801
Hi Abs WMA UA	0.508		0.137	0.307	0.327
Hi Abs Lime UA	0.634	0.137		0.171	0.191
Low Abs UA	0.784	0.307	0.171		0.020
Hi Abs No Add UA	0.801	0.327	0.191	0.020	

Table 10 Repeatability Limit Comparison Values for Short-Term Aged IDEAL-CT

	Hi Abs Poly STA	Hi Abs WMA STA	Hi Abs Lime STA	Low Abs STA	Hi Abs No Add STA
Hi Abs Poly STA		0.141	0.422	0.498	0.742
Hi Abs WMA STA	0.141		0.286	0.364	0.617
Hi Abs Lime STA	0.422	0.286		0.080	0.347
Low Abs STA	0.498	0.364	0.080		0.268
Hi Abs No Add STA	0.742	0.617	0.347	0.268	

Table 11 Repeatability Limit Comparison Values for Long-Term Aged IDEAL-CT

	Low Abs LTA	Hi Abs Lime LTA	Hi Abs Poly LTA	Hi Abs No Add LTA	Hi Abs WMA LTA
Low Abs LTA		0.602	0.608	0.947	0.968
Hi Abs Lime LTA	0.602		0.007	0.401	0.427
Hi Abs Poly LTA	0.608	0.007		0.395	0.421
Hi Abs No Add LTA	0.947	0.401	0.395		0.027
Hi Abs WMA LTA	0.968	0.427	0.421	0.027	

Table 12 Repeatability Limit Equivalency for Unaged IDEAL-CT

	Hi Abs Poly UA	Hi Abs WMA UA	Hi Abs Lime UA	Low Abs UA	Hi Abs No Add UA
Hi Abs Poly UA		/	/	/	/
Hi Abs WMA UA	/		=	=	=
Hi Abs Lime UA	/	=		=	=
Low Abs UA	/	=	=		=
Hi Abs No Add UA	/	=	=	=	

Table 13 Repeatability Limit Equivalency for Short-Term Aged IDEAL-CT

	Hi Abs Poly STA	Hi Abs WMA STA	Hi Abs Lime STA	Low Abs STA	Hi Abs No Add STA
Hi Abs Poly STA		=	=	/	/
Hi Abs WMA STA	=		=	=	/
Hi Abs Lime STA	=	=		=	=
Low Abs STA	/	=	=		=
Hi Abs No Add STA	/	/	=	=	

Table 14 Repeatability Limit Equivalency for Long-Term Aged IDEAL-CT

	Low Abs LTA	Hi Abs Lime LTA	Hi Abs Poly LTA	Hi Abs No Add LTA	Hi Abs WMA LTA
Low Abs LTA		/	/	/	/
Hi Abs Lime LTA	/		=	=	=
Hi Abs Poly LTA	/	=		=	=
Hi Abs No Add LTA	/	=	=		=
Hi Abs WMA LTA	/	=	=	=	

4.9 ANOVA of IDEAL-RT Results

Figures 15 and 16 below show RT_{index} for each mixture in the study in unaged and short-term aged conditions, respectively. IDEAL-RT test data generally has a lower variability than IDEAL-CT test data. Analysis of variance using Levene's test indicates equal variances across treatments at both aging conditions, so Tukey groupings are used in both cases.

In the unaged condition, the polymer-modified mix in group A and the low-absorption mix in group B stand out from the rest in their respective groups. The remaining three mixes are grouped together in C and may be considered equivalent results. In the STA condition, polymer is once again alone in group A, with low absorption and high absorption with no additive together in group B, followed by lime and WMA in group C. It is expected that the polymer would perform well in a high-temperature test that measures peak load. It is unexpected that the specimens treated with hydrated lime would perform more poorly than an untreated set.

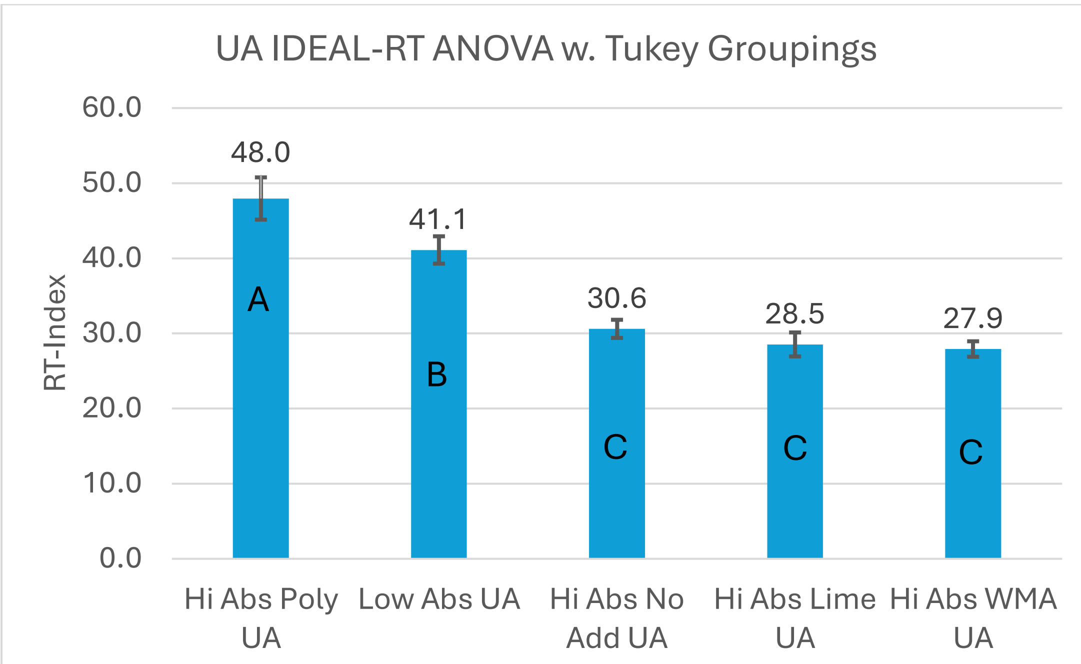

Figure 15 Unaged IDEAL-RT with Tukey Groupings

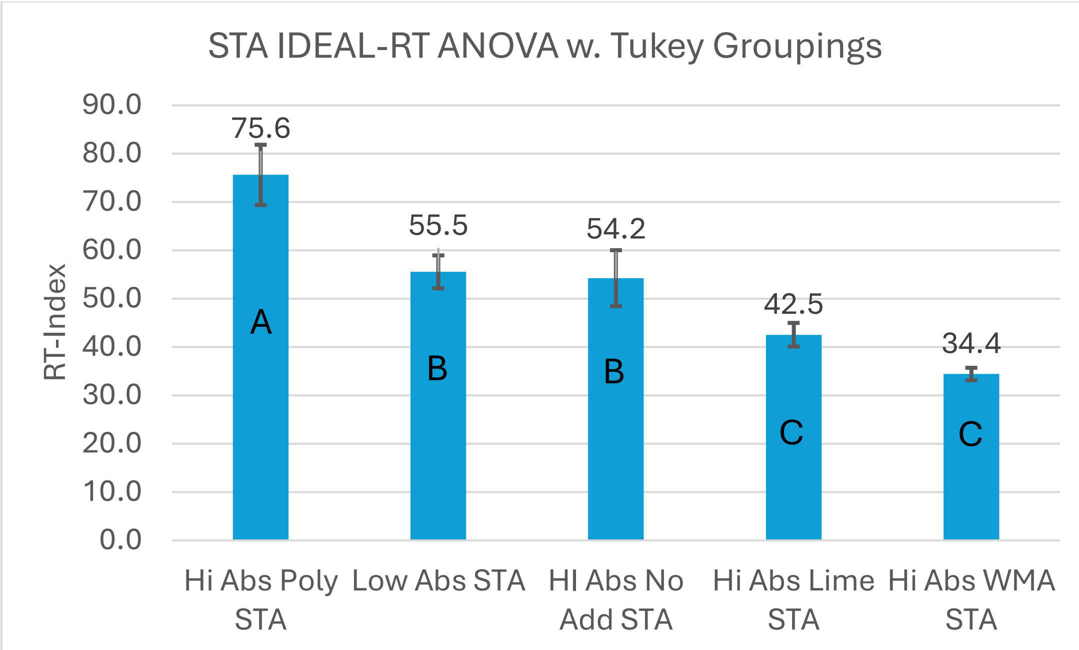

Figure 16 Short-Term Aged IDEAL-RT with Tukey Groupings

5. CONCLUSIONS

Regarding the long-term aging procedure:

- The long-term aging temperature used for all mixtures in this study was slightly higher than the short-term aging temperature used for the WMA mixtures, which may have contributed to the difference in absorption between the short- and long-term aged WMA mixtures.
- The long-term aging protocol itself is expected to be equally applicable to HMA and WMA mixtures, since field aging occurs at a similar rate regardless of production temperature; however, more research is needed to determine whether the 20-hour conditioning duration and temperature used in this study are appropriate for WMA mixtures with highly absorptive aggregate.

Regarding absorption mitigation:

- WMA, along with reduced mixing and compaction temperatures, mitigates absorption during these processes.
- Hydrated lime and polymer modification mitigated absorption under both short- and long-term aging.
- The maximum reduction in absorption under short-term aged conditions was achieved by adding WMA, along with reduced mixing and compacting temperatures.

- None of the mitigation strategies used in this study were able to mitigate absorption as well as using a less absorptive aggregate.

Regarding BMD performance:

- All mitigation strategies improved the CT_{index} of the high-absorption mix to greater than that of the low-absorption mix under both unaged and short-term-aged conditions.
- No mitigation strategy improved the CT_{index} of the high-absorption mix to be greater than or equal to that of the low-absorption mix under long-term aging conditions.
- Polymer and hydrated lime improved the average long-term aged CT_{index} by 50.0% and 48.9%, respectively. Polymer stands alone as the treatment that improved rutting performance above that of the low-absorption mix.
- Polymer was the only additive to improve every aspect of mixture performance measured in this study relative to the untreated high-absorption set.
- The HWTT results presented in this study may not be broadly applicable to all high-absorption mixes, as the poor performance of high-absorption mixes is primarily driven by moisture-induced damage, which is outside the scope of this study.

Further Research:

- Combine mitigation strategies, e.g., WMA additive with polymer modification, or hydrated lime with polymer modification.
- Perform the absorption-mitigation portion of the experiment with four replicates of G_{mm} to enable better statistical analysis of the absorption data.
- Repeat the experiment using an additional aging condition, e.g., 4 hrs. at 135°C or 10 hrs. at 115.6°C, to better understand the relationships between aging, absorption, and mechanical performance.
- Repeat the experiment with an aggregate whose absorption falls between those used in this study, perhaps around 2%.
- Evaluate other long-term aging procedures for WMA mixes using highly absorptive aggregates, with an emphasis on long-term aging temperatures below the short-term aging temperature of the WMA mixture.

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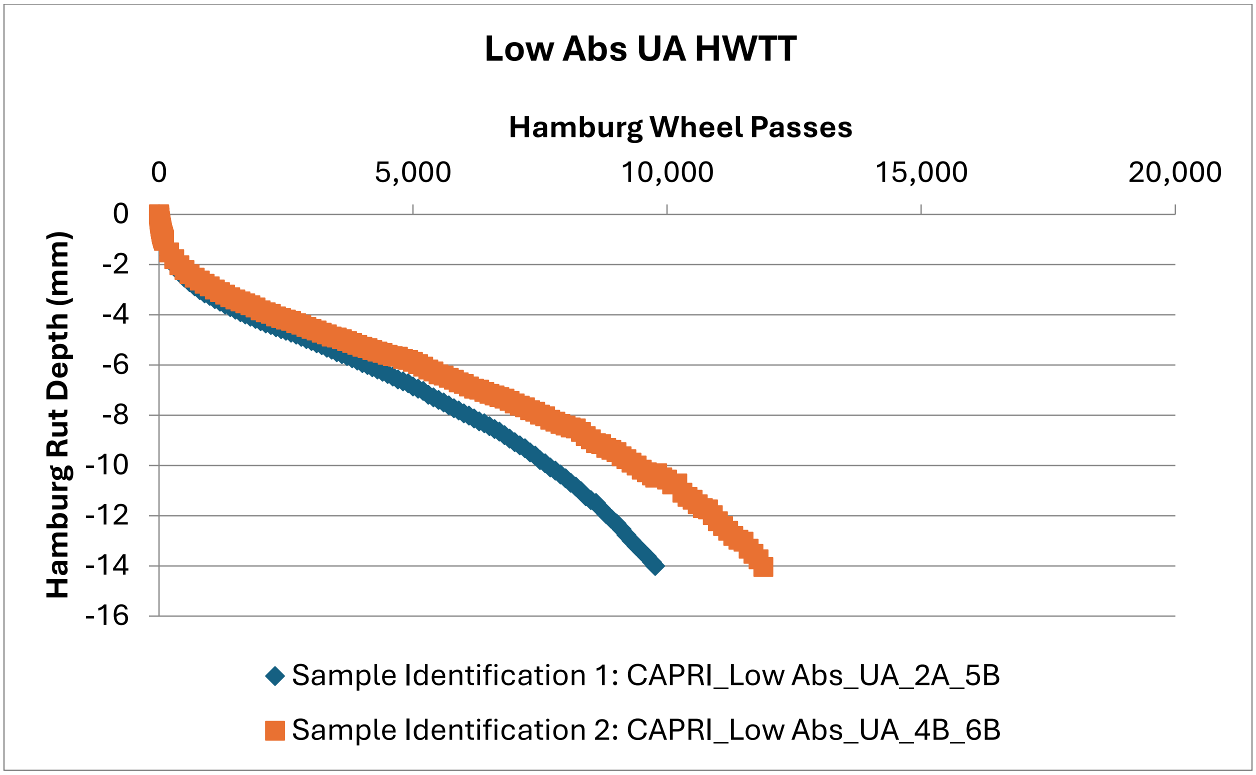
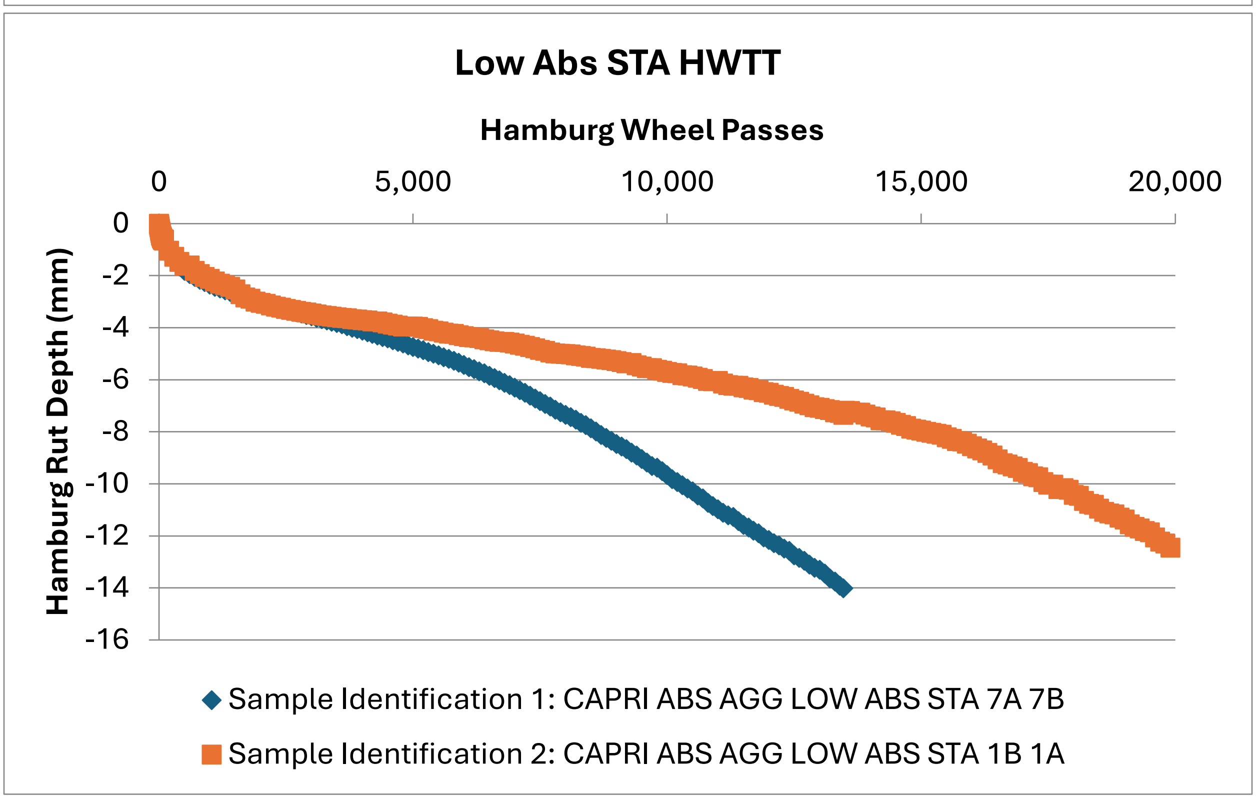
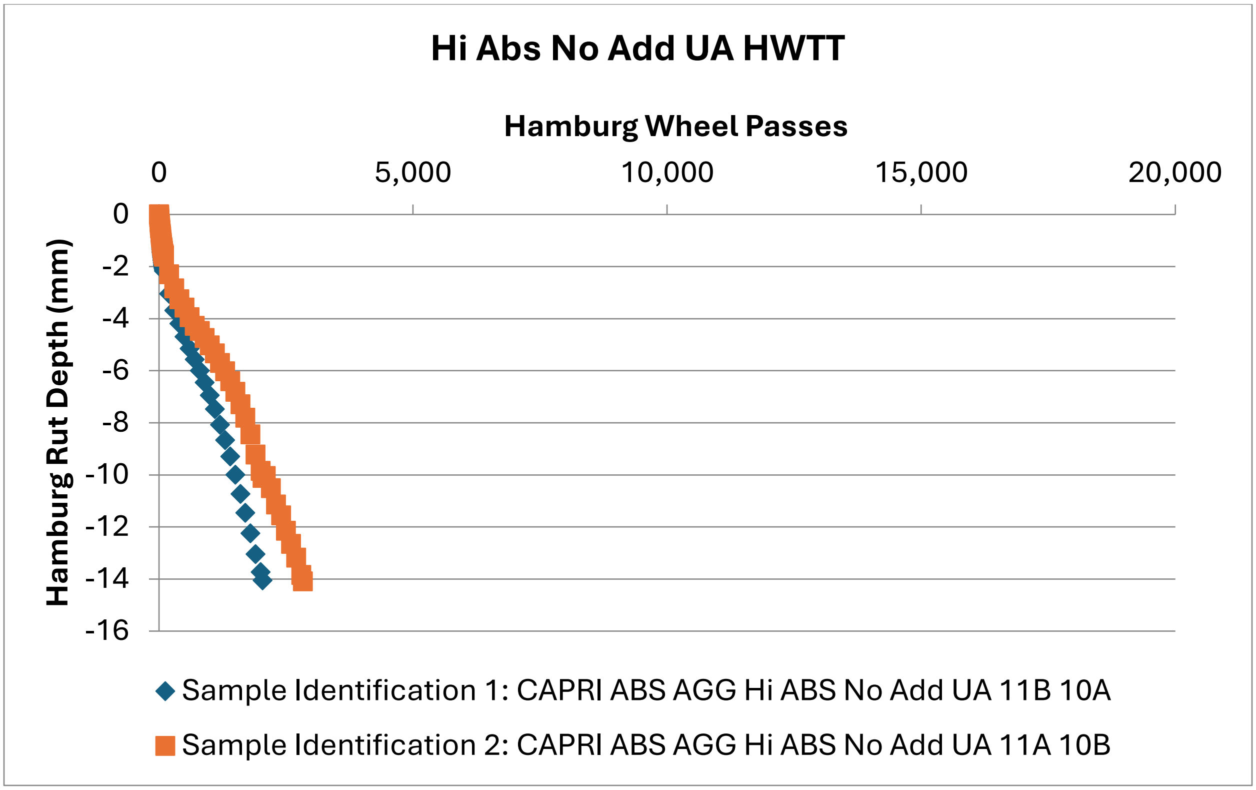
Appendix A Additional Data



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-4
-6
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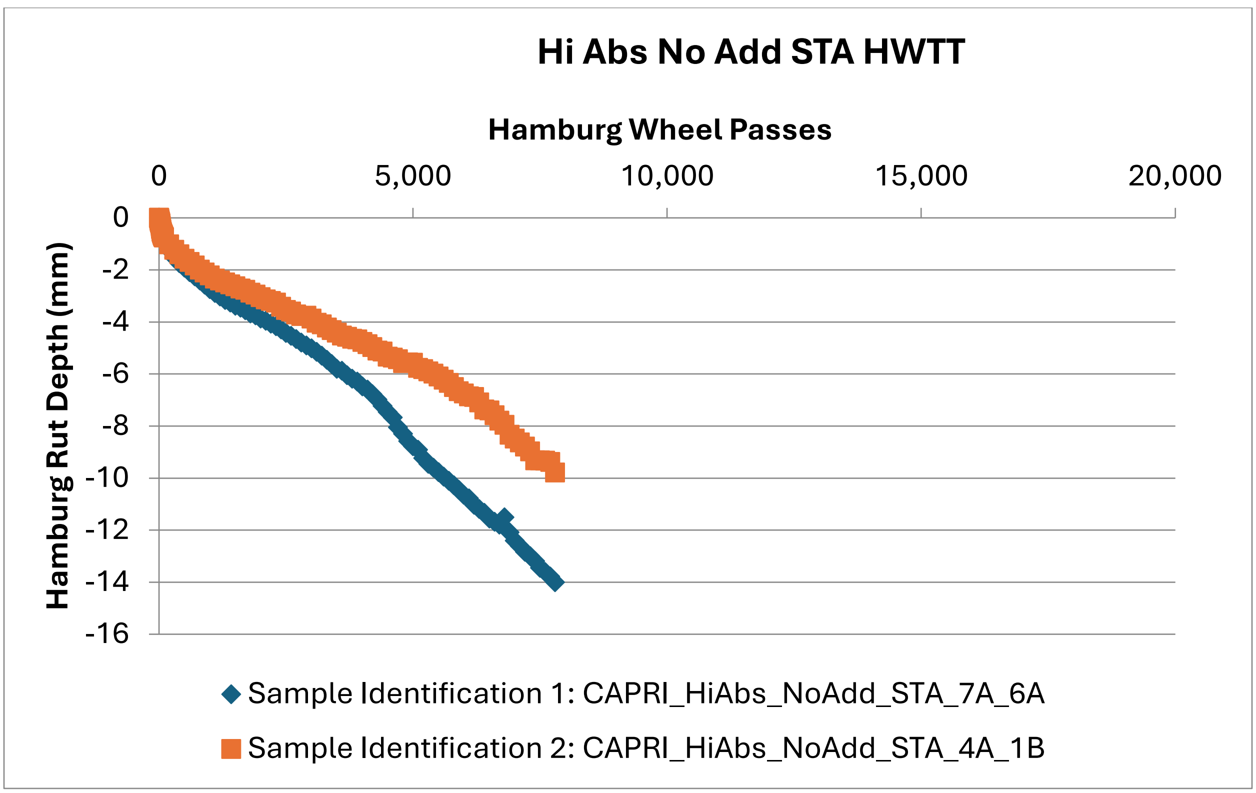
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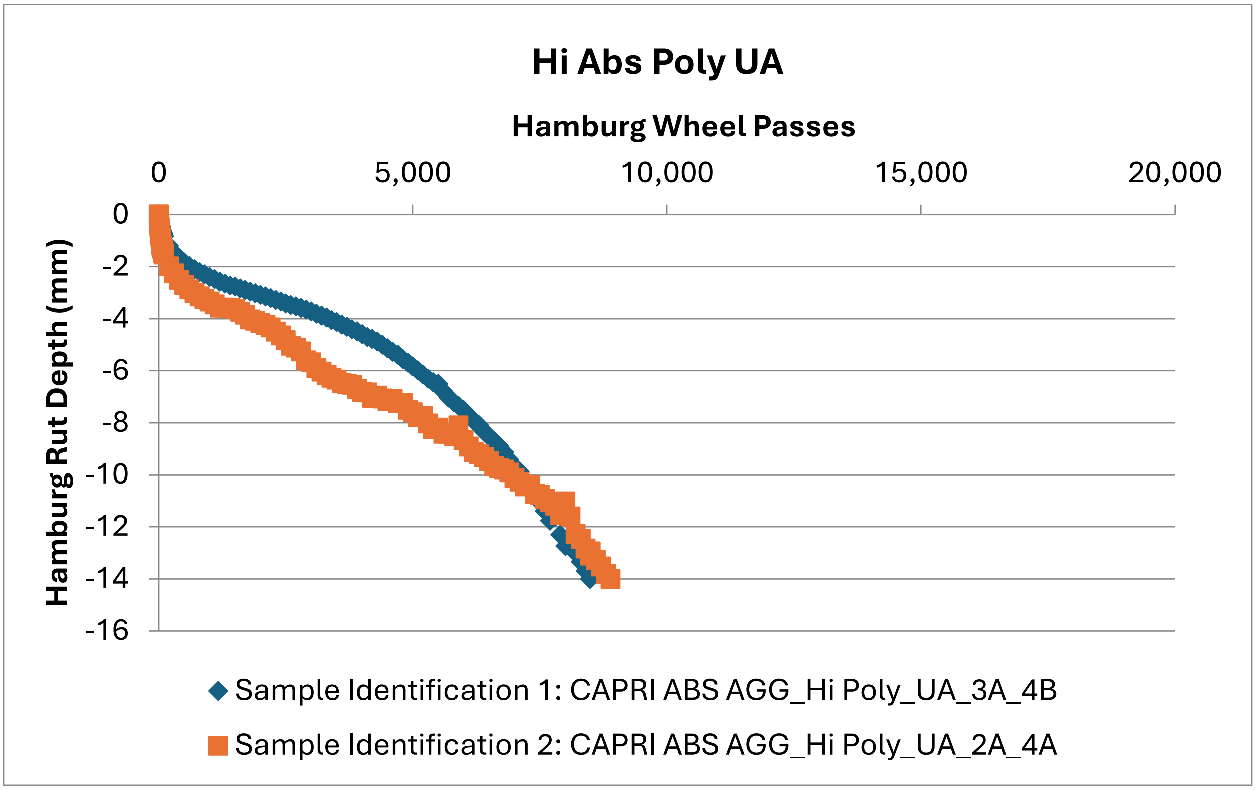
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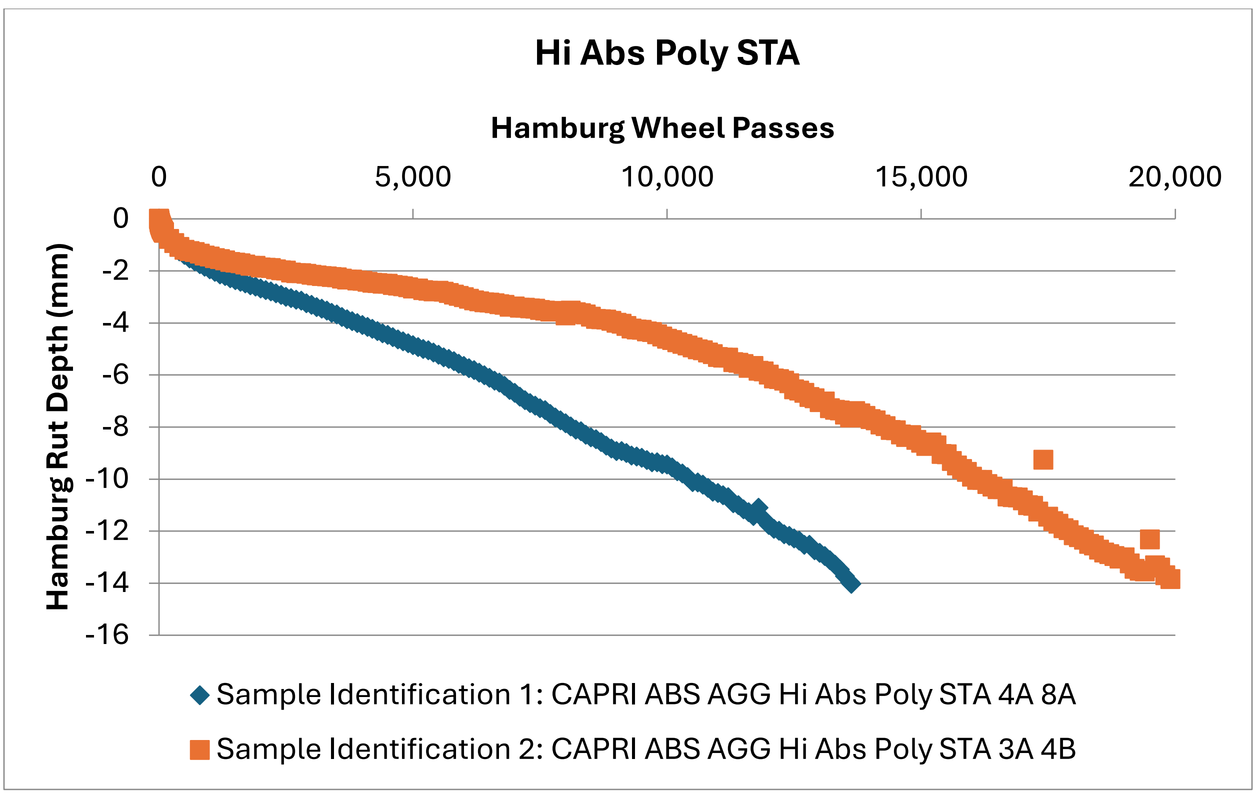
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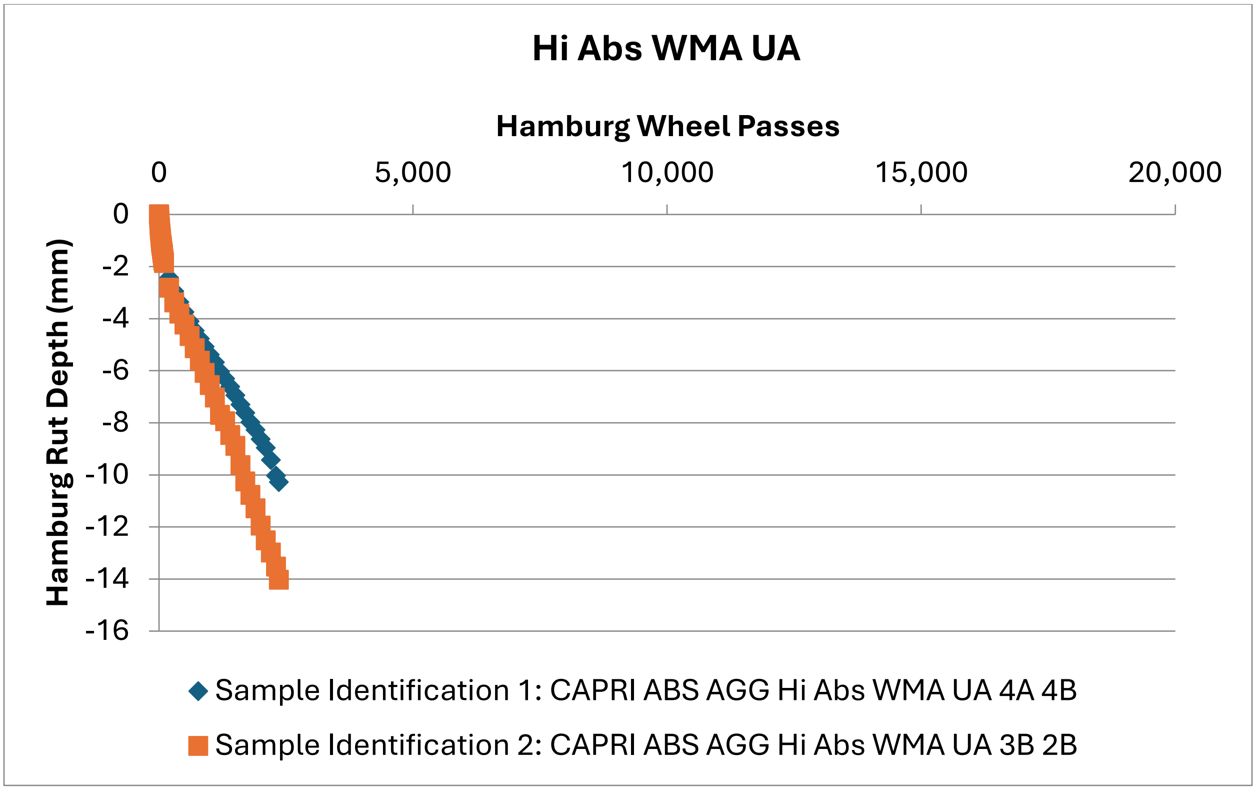
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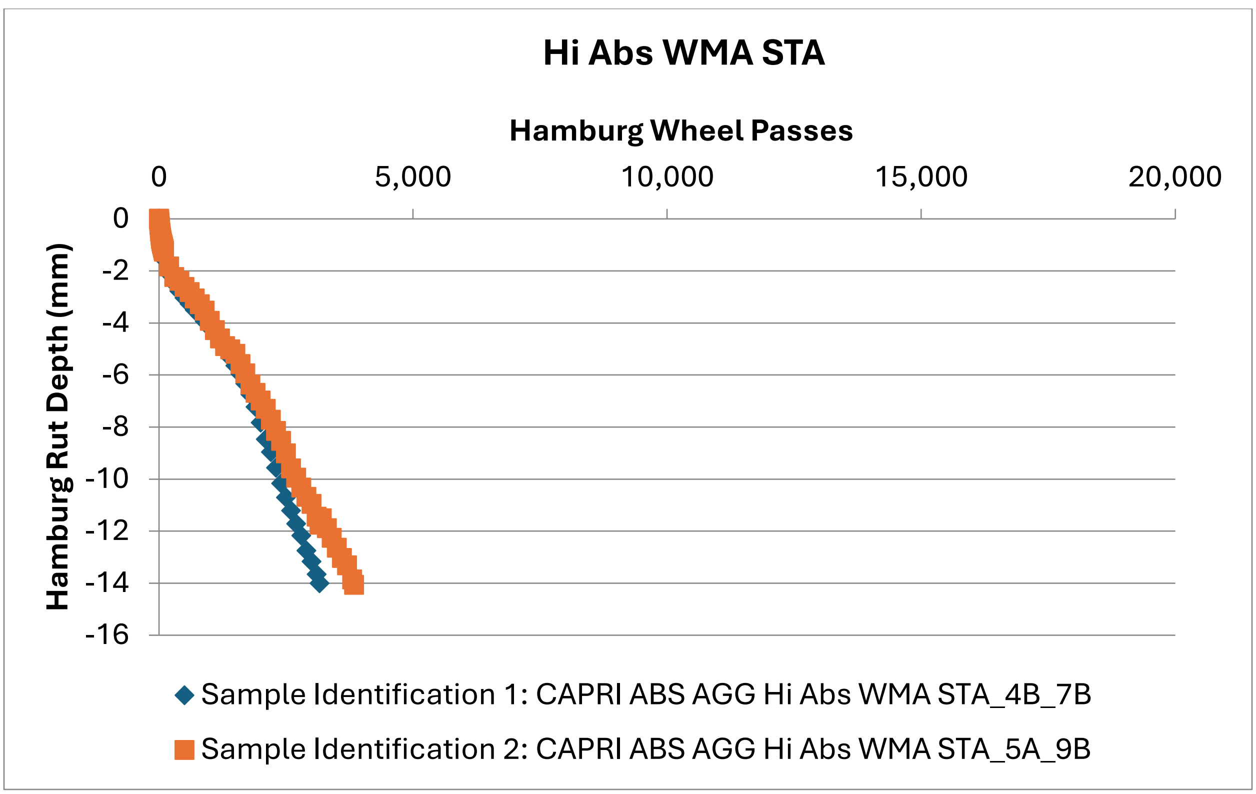
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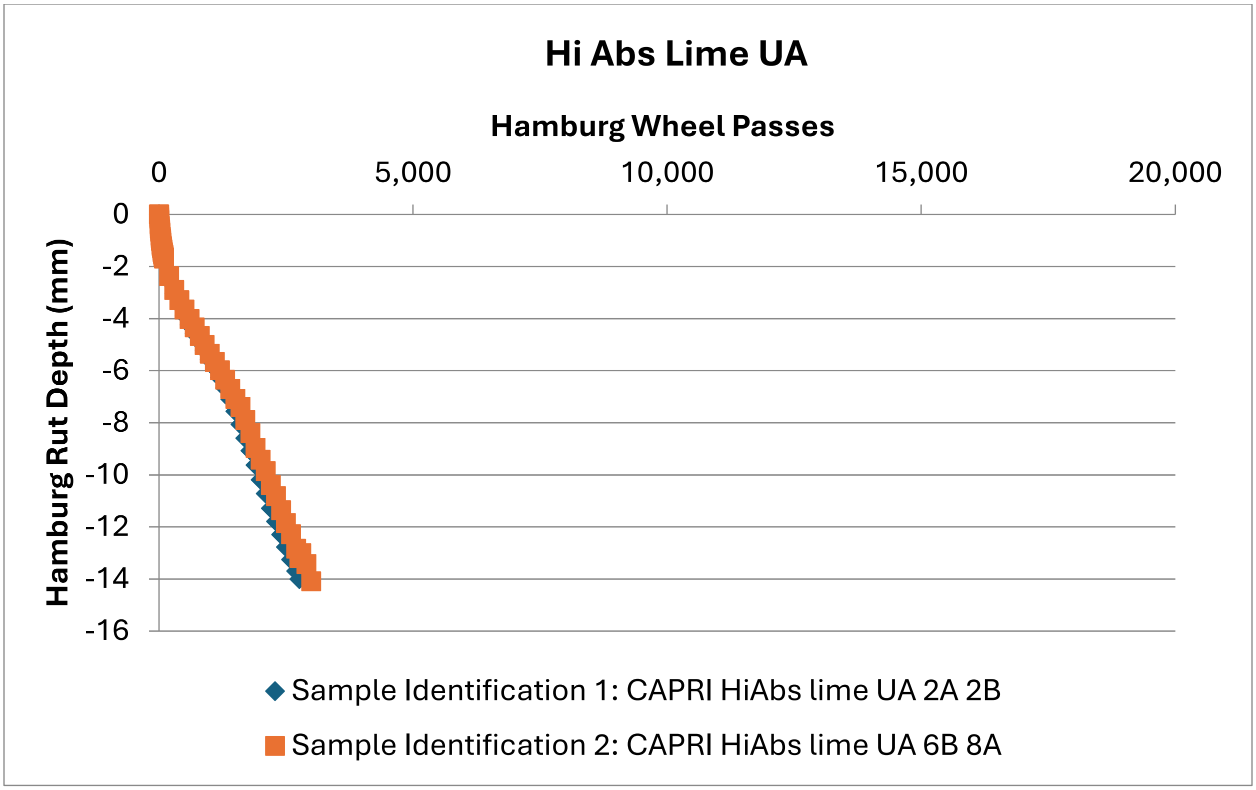

Hi Abs Lime UA
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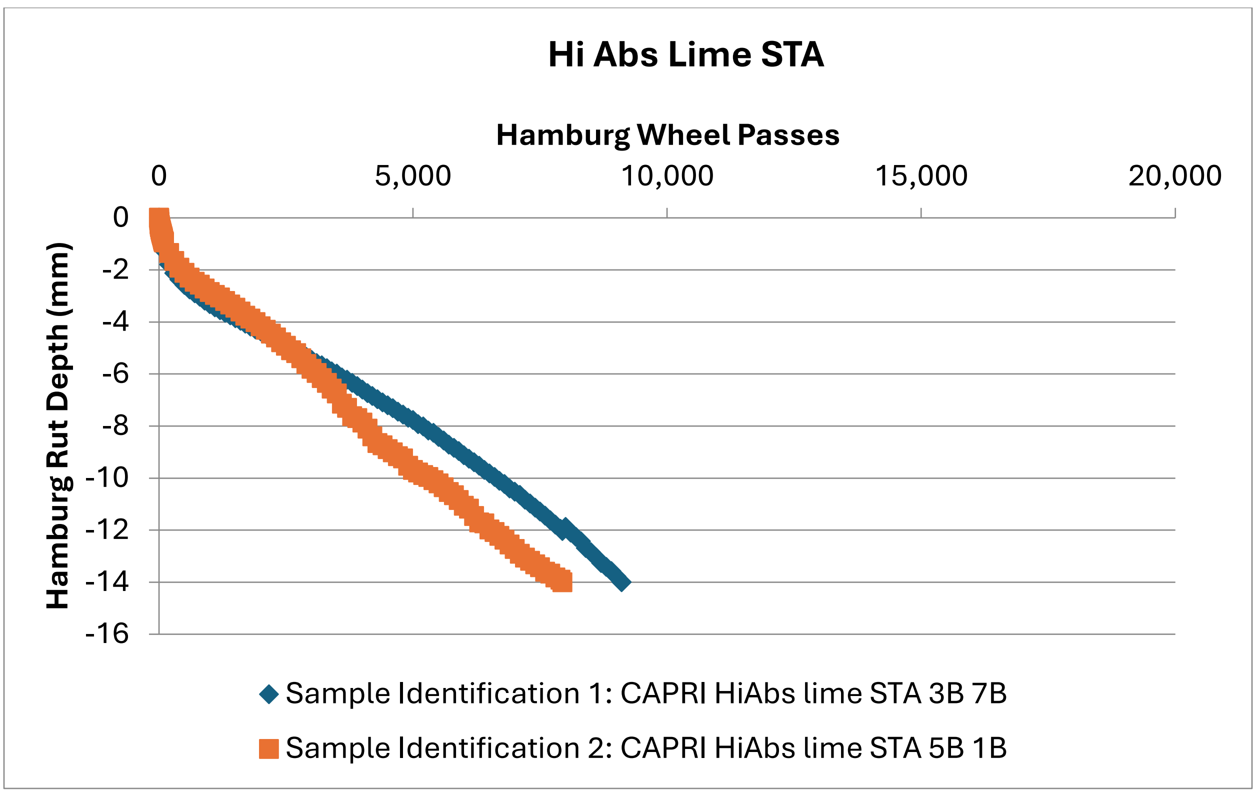
0
5,000
10,000
15,000
20,000
Hamburg Rut Depth (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
Sample Identification 1: CAPRI HiAbs lime UA 2A 2B
Sample Identification 2: CAPRI HiAbs lime UA 6B 8A



Hi Abs Lime STA
Hamburg Wheel Passes
0
5,000
10,000
15,000
20,000
Hamburg Rut Depth (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
Sample Identification 1: CAPRI HiAbs lime STA 3B 7B
Sample Identification 2: CAPRI HiAbs lime STA 5B 1B

Mix ID	Passes to 12.5mm	Creep Slope (mm/1k passes)	Corrected Rut Depth (mm)	Rutting Resistance Index	Stripping Inflection Point	Stripping Slope (mm/1k passes)	Stripping Number
Low Abs STA	16200	0.51	6.22	8012	13308	1.58	5432
Low Abs UA	10150	0.79	9.32	5075	8821	2.34	4104
Hi Abs No add STA	7100	1.10	8.45	3550	5967	2.39	2408
Hi Abs No Add UA	2250	4.21	12.28	1125	1895	8.82	846
Hi Abs Poly STA	15550	0.57	5.11	7607	12081	1.42	3189
Hi Abs Poly UA	8200	0.89	7.23	4100	6804	3.15	2659
Hi Abs WMA STA	3200	2.94	6.61	1600	2501	6.1	837
Hi Abs WMA UA	2100	3.77	16.28	1050	1952	6.38	1118
Hi Abs Lime STA	7650	1.37	14.12	3825	6874	1.83	3873
Hi Abs Lime UA	2600	3.69	12.45	1300	2175	6.49	973

IDEAL-CT Data

“ * ” denotes ASTM E178 outlier removed before data processing

Mix ID	*Mix additive*	*Aging (C*hrs.)*	*Specimen ID*	*Air Voids (%)*	CT Index	Peak Load (lbs)	Fracture Energy (J/m2)	Post Peak Slope (kN/mm)	Displacement @75% (mm)	Test Date
Low Abs LTA	None	2737.5	2B	7.0	64.3	3610.9	8756.4	3.599	3.965	10/1/2025
Low Abs LTA	None	2737.5	4B	7.0	48.3	3559.7	7907.1	4.451	4.077	10/1/2025
Low Abs LTA	None	2737.5	5B	7.0	60.7	3455.3	8166.7	3.866	4.31	10/1/2025
Low Abs LTA	None	2737.5	6B	6.9	79.2	3136	8459.4	3.26	4.579	10/1/2025
Low Abs LTA	None	2737.5	7A	6.9	34.2	3397.4	7403.1	5.544	3.84	10/1/2025
Low Abs LTA	None	2737.5	10B	7.0	45.1	3658.2	8269.1	4.811	3.934	10/1/2025
Low Abs STA	None	270	2A	7.0	146.7	2242.4	7144.6	1.822	5.615	9/26/2025
Low Abs STA	None	270	2B	7.0	153.6	2319.5	7645.9	1.829	5.511	9/26/2025
Low Abs STA	None	270	5B	7.0	121.3	2217.3	6694.6	1.929	5.24	9/26/2025
Low Abs STA	None	270	6A	7.0	140.2	2260.9	7107.7	1.927	5.701	9/26/2025
Low Abs STA	None	270	6B	7.0	171.3	2144.2	7024.1	1.541	5.636	9/26/2025
Low Abs STA	None	270	8B	7.1	154.5	2144.8	6910.9	1.783	5.98	9/26/2025
Low Abs UA	None	0	1A	7.1	264.8	1628.5	6226.2	1.05	6.698	10/1/2025
Low Abs UA	None	0	4A	7.2	226.2	1648.6	5898.8	1.089	6.263	10/1/2025
Low Abs UA	None	0	6A	7.1	210.4	1589.8	5575.4	1.111	6.29	10/1/2025
Low Abs UA	None	0	7B	7.2	246.6	1573.2	5937.9	1.027	6.399	10/1/2025
Low Abs UA	None	0	8A	7.2	220.1	1561.5	5660.8	1.071	6.248	10/1/2025
Low Abs UA	None	0	8B	6.9	250.2	1588	5915	1.032	6.546	10/1/2025
Hi Abs No Add LTA	None	2737.5	1B	6.9	16.5	3671.9	5501	5.802	2.611	3/4/2026
Hi Abs No Add LTA	None	2737.5	2A	6.9	15.5	3546.6	5073.3	5.773	2.652	3/4/2026
Hi Abs No Add LTA	None	2737.5	2B	6.7	11.5	3523.6	4397.2	5.677	2.231	3/4/2026
Hi Abs No Add LTA	None	2737.5	3A	6.9	31.8	3571.6	6502.7	3.833	2.816	3/4/2026
Hi Abs No Add LTA	None	2737.5	4A	6.8	20.7	3825.7	6426.1	6.023	2.916	3/4/2026

Hi Abs No Add LTA	None	2737.5	4B	6.8	22.6	3133.8	4868.6	3.58	2.492	3/4/2026
Hi Abs No Add STA	None	270	3A	7.2	117.2	2371.9	6940.5	2.247	5.689	3/6/2026
Hi Abs No Add STA	None	270	3B	6.5	118.8	2475.2	7394.2	2.444	5.892	3/6/2026
Hi Abs No Add STA	None	270	4B	7.1	113.9	2273.7	6543.9	1.961	5.12	3/6/2026
Hi Abs No Add STA	None	270	5B	7.2	77.6	2449.8	6365.2	2.492	4.559	3/6/2026
Hi Abs No Add STA	None	270	6B	7.2	120.6	2227	6323.8	1.825	5.22	3/6/2026
Hi Abs No Add STA	None	270	7B	7.1	129.4	2252.2	7013.9	1.904	5.269	3/6/2026
Hi Abs Poly LTA	Poly	2737.5	1B	6.7	19.3	3954.1	6085.5	5.827	2.776	3/4/2026
Hi Abs Poly LTA	Poly	2737.5	2A	7.0	33.9	4081.6	7264.3	5.102	3.57	3/4/2026
Hi Abs Poly LTA	Poly	2737.5	2B	6.8	27	4344.3	8356	6.84	3.311	3/4/2026
Hi Abs Poly LTA	Poly	2737.5	3A	7.2	28.9	4205.5	7142.9	5.229	3.171	3/4/2026
Hi Abs Poly LTA	Poly	2737.5	4A	7.2	37	3833.6	7408.5	4.778	3.581	3/4/2026
Hi Abs Poly LTA	Poly	2737.5	4B	6.9	30.9	4133.5	7394.1	5.449	3.412	3/4/2026
Hi Abs Poly STA	Poly	270	3B	7.3	186.1	2517	7959.4	1.539	5.395	3/6/2026
Hi Abs Poly STA	Poly	270	5B	7.2	268.3	2466.2	8829	1.35	6.156	3/6/2026
Hi Abs Poly STA	Poly	270	7B	7.2	199.4	2572.3	9009	1.848	6.134	3/6/2026
Hi Abs Poly STA	Poly	270	8B	7.3	249.4	2666	9982.6	1.787	6.699	3/6/2026
Hi Abs Poly STA	Poly	270	9A	7.0	273.2	2441.3	9425.3	1.628	7.081	3/6/2026
Hi Abs Poly STA	Poly	270	9B	7.1	299.7	2400.2	9494.8	1.514	7.17	3/6/2026
Hi Abs No Add UA	None	0	6A	7.0	240.3	1417.3	4981.7	0.886	6.409	2/5/2026
Hi Abs No Add UA	None	0	6B	6.8	206.3	1483.6	5349	0.994	5.75	2/5/2026
Hi Abs No Add UA	None	0	7A	7.2	296.5	1485.6	5874.4	0.875	6.625	2/5/2026
Hi Abs No Add UA	None	0	7B	6.6	220.3	1528.4	5417.8	1.05	6.402	2/5/2026
Hi Abs No Add UA	None	0	9A	6.5	228.7	1474.5	5438.9	1.029	6.49	2/5/2026
Hi Abs No Add UA	None	0	9B	7.1	197.2	1434	5039.3	1.06	6.223	2/5/2026
Hi Abs Poly UA	Poly	0	11A	7.3	599.8	1866	9105	0.911	9.003	3/25/2026
Hi Abs Poly UA	Poly	0	12A	7.1	513.1	1958.3	9578.2	1.102	8.853	3/25/2026
Hi Abs Poly UA	Poly	0	12B	7.1	371.4	1889	8105.3	1.183	8.131	3/25/2026
Hi Abs Poly UA	Poly	0	13A	7.0	657.1	1952.8	9630.9	0.841	8.603	3/25/2026
Hi Abs Poly UA	Poly	0	13B	7.3	491.9	1864.3	8485.2	0.959	8.338	3/25/2026
Hi Abs Poly UA	Poly	0	14B	7.1	613.3	1771.1	8882.8	0.926	9.589	3/25/2026

Hi Abs WMA LTA	WMA	2688.75	2A	6.8	17.1	3809.9	5589.2	5.708	2.615	3/24/2026
Hi Abs WMA LTA	WMA	2688.75	2B	6.9	18.7	3953.2	6097.7	5.58	2.572	3/24/2026
Hi Abs WMA LTA	WMA	2688.75	3A	6.9	20.3	3606.2	5791	5.469	2.882	3/24/2026
Hi Abs WMA LTA	WMA	2688.75	3B	6.8	18.2	3735.7	6053.7	6.867	3.099	3/24/2026
Hi Abs WMA LTA	WMA	2688.75	4A	6.8	21.9	3535.9	5799.8	5.195	2.943	3/24/2026
Hi Abs WMA LTA	WMA	2688.75	4B*	6.7*	27.6*	3754.4*	6503*	5*	3.178*	3/24/2026*
Hi Abs WMA STA	WMA	230	2A	7.5	247.2	1623.6	5943.8	1.005	6.271	3/24/2026
Hi Abs WMA STA	WMA	230	3A	7.3	163.6	1636.6	5149.6	1.152	5.487	3/24/2026
Hi Abs WMA STA	WMA	230	5B	7.0	180.3	1735.6	5723.5	1.216	5.744	3/24/2026
Hi Abs WMA STA	WMA	230	6A	7.1	212.1	1663.6	5813.6	1.145	6.264	3/24/2026
Hi Abs WMA STA	WMA	230	7A	7.3	227.8	1731.2	6420.7	1.251	6.66	3/24/2026
Hi Abs WMA STA	WMA	230	9A	7.1	251.3	1714.8	6329.1	1.067	6.357	3/24/2026
Hi Abs WMA UA	WMA	0	3A	6.8	346.2	1278.8	5392.7	0.756	7.284	3/25/2026
Hi Abs WMA UA	WMA	0	5B	6.9	321.8	1202.5	4801.8	0.696	6.998	3/25/2026
Hi Abs WMA UA	WMA	0	6B	7.1	335.9	1283	5201.3	0.722	6.992	3/25/2026
Hi Abs WMA UA	WMA	0	7A	6.9	364	1235.6	5207.2	0.712	7.466	3/25/2026
Hi Abs WMA UA	WMA	0	7B	6.7	328.6	1347.4	5427.3	0.72	6.535	3/25/2026
Hi Abs WMA UA	WMA	0	9B	7.0	235.4	1291.6	4711.8	0.887	6.647	3/25/2026
Hi Abs Lime LTA	Lime	2737.5	2A	7.5	26.7	3233.6	5758.2	4.381	3.043	4/14/2026
Hi Abs Lime LTA	Lime	2737.5	3A	7.1	33	3219.7	6250	4.463	3.539	4/14/2026
Hi Abs Lime LTA	Lime	2737.5	3B	7.3	24.5	3164.3	5787.6	4.865	3.093	4/14/2026
Hi Abs Lime LTA	Lime	2737.5	4A*	7.1*	58.1*	3031*	6974.2*	3.388*	4.233*	4/14/2026*
Hi Abs Lime LTA	Lime	2737.5	4B	7.3	34.6	3324.2	6584.8	4.265	3.365	4/14/2026
Hi Abs Lime STA	Lime	270	9B	7.2	133.1	2004.6	5976.1	1.448	4.837	4/20/2026
Hi Abs Lime STA	Lime	270	10A	7.1	171.8	1840.5	6057.6	1.248	5.306	4/20/2026
Hi Abs Lime STA	Lime	270	10B	6.7	120.1	2032.6	6136.8	1.62	4.757	4/20/2026
Hi Abs Lime STA	Lime	270	11A	6.9	165.5	1793.4	6046.6	1.399	5.745	4/20/2026
Hi Abs Lime STA	Lime	270	11B	7.5	148.5	1884.6	5898.8	1.368	5.164	4/20/2026
Hi Abs Lime STA	Lime	270	12A	7.3	222.5	1843.2	6463.6	1.149	5.932	4/20/2026
Hi Abs Lime UA	Lime	0	3B	6.9	245	1311.4	5069.3	0.915	6.635	4/14/2026
Hi Abs Lime UA	Lime	0	5A	6.8	309.2	1308.7	5382	0.821	7.074	4/14/2026

Hi Abs Lime UA	Lime	0	5B	7.0	294.7	1293.5	5201.6	0.841	7.15	4/14/2026
Hi Abs Lime UA	Lime	0	7A	7.1	274.1	1348.8	5146.1	0.843	6.738	4/14/2026
Hi Abs Lime UA	Lime	0	7B	7.1	287.1	1300	5219.1	0.856	7.064	4/14/2026
Hi Abs Lime UA	Lime	0	8B	6.6	273.6	1396.1	5400	0.857	6.509	4/14/2026

IDEAL-RT Data

Mix ID	*Mix Additive*	*Aging (°C-hrs.)*	*Specimen ID*	*Air Voids (%)*	*RT-Index*	*Test Date*
Low Abs UA	None	0	2B	7.5%	42.2	9/22/2025
Low Abs UA	None	0	5A	7.3%	42.1	9/22/2025
Low Abs UA	None	0	7A	7.0%	39.0	9/22/2025
Low Abs STA	None	270	3A	7.1%	55.2	9/22/2025
Low Abs STA	None	270	3B	6.8%	61.4	9/22/2025
Low Abs STA	None	270	4A	7.2%	53.9	9/22/2025
Low Abs STA	None	270	4B	6.8%	54.7	9/22/2025
Low Abs STA	None	270	8A	6.9%	52.6	9/22/2025
HI Abs No Add STA	None	270	2A	6.90%	52.9	3/6/2026
HI Abs No Add STA	None	270	2B	7.10%	60.6	3/6/2026
HI Abs No Add STA	None	270	5A	7.20%	49.2	3/6/2026
Hi Abs Poly STA	Poly	270	2B	6.80	83.4	3/6/2026
Hi Abs Poly STA	Poly	270	6A	7.20	69.1	3/6/2026
Hi Abs Poly STA	Poly	270	6B	7.10	77.5	3/6/2026
Hi Abs Poly STA	Poly	270	7A	7.00	72.5	3/6/2026
Hi Abs No Add UA	None	0	5B	7.20	31.8	2/5/2026
Hi Abs No Add UA	None	0	8A	7.00	29.4	2/5/2026
Hi Abs No Add UA	None	0	8B	6.70	30.6	2/5/2026
Hi Abs Poly UA	Poly	0	10B	7.00	51.0	3/24/2026
Hi Abs Poly UA	Poly	0	11B	7.50	47.6	3/24/2026

Hi Abs Poly UA	Poly	0	14A	7.10	45.4	3/24/2026
Hi Abs WMA STA	WMA	231.2	4A	7.10	33.7	3/24/2026
Hi Abs WMA STA	WMA	231.2	6B	7.30	36.3	3/24/2026
Hi Abs WMA STA	WMA	231.2	8A	7.10	33.6	3/24/2026
Hi Abs WMA STA	WMA	231.2	8B	7.10	34.1	3/24/2026
Hi Abs WMA UA	WMA	0	2A	7.4	27.9	3/25/2026
Hi Abs WMA UA	WMA	0	8A	6.9	28.5	3/25/2026
Hi Abs WMA UA	WMA	0	8B	7	26.5	3/25/2026
Hi Abs WMA UA	WMA	0	9A	7.1	28.8	3/25/2026
Hi Abs Lime UA	Lime	0	4A	7	30.4	4/14/2026
Hi Abs Lime UA	Lime	0	4B	6.9	27.4	4/14/2026
Hi Abs Lime UA	Lime	0	6A	7.1	27.9	4/14/2026
Hi Abs Lime STA	Lime	270	9A	7.3	45.9	4/20/2026
Hi Abs Lime STA	Lime	270	12B	7.4	42.7	4/20/2026
Hi Abs Lime STA	Lime	270	13A	7.1	40.1	4/20/2026
Hi Abs Lime STA	Lime	270	13B	6.9	41.5	4/20/2026

National Center for Asphalt Technology
Job-Mix Formula

NCAT at AUBURN UNIVERSITY

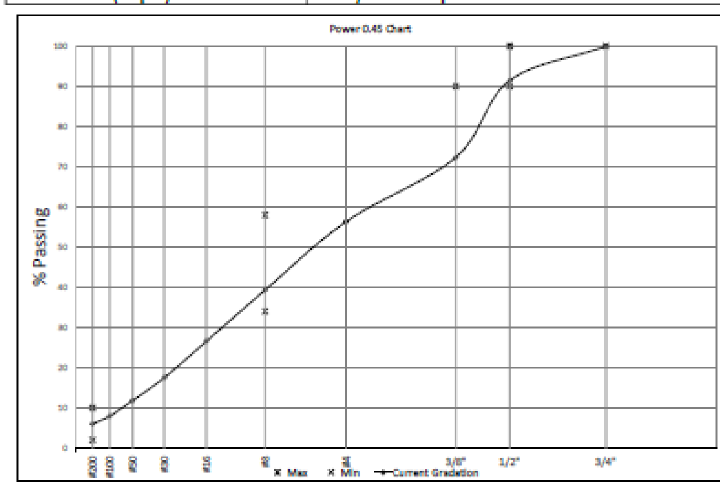
NCAT Project ID:	CAPRI Absorptive Aggregate	NCAT Mix ID:	Hi Absorption
Principal Investigator:	Nam Tran	Mix Design Engineer:	Zane Hartzog
Producer:	0	Design Completion Date:	10/16/2025
Intended Use:	0	Intended Section:	0

Mix Type:	Dense-Graded Superpave	Virgin Binder Grade:	PG 67-22
Nom. Max Agg. (NMAS):	12.5mm (1/2")	Virgin Binder Specific Gravity:	1.03
Max Agg. Size (MAS):	19.0mm (3/4")	Anti-Strip:	0
Mixing Temp, °F :	320	Anti-Strip Dosage (TOTAL Binder):	0.00%
Compaction Temp, °F :	2hrs at 275	A.S. Dose Rate for Virgin Binder:	0.00%
		Other Binder Additives:	0.00%

AASHTO Superpave Volumetric Mix Design

Cold Feed %	Aggregate Description	Pile ID	Source	Gsb	Gsa	% Abs.
43	5/8 Rock			2.554	2.693	2.0
14	Base CF			2.442	2.693	2.8
18	Cr. Fines			2.458	2.713	2.8
24.5	Wash Sand			2.557	2.821	3.7
0.5	BHF			--	--	--

Job Mix			Mix Design Information		Criteria
Sieve	Sieve	% Passing			
1 1/2"	(37.5 mm)	100.0	% Total AC Required	6.70	--
1"	(25 mm)	100.0	Max Spec. Gravity Mix (Gmm)	2.391	--
3/4"	(19.0 mm)	100.0	Bulk Spec. Gravity Mix (Gmb)	2.274	--
1/2"	(12.5 mm)	91.4	Design Air Voids (Va)	4.0	--
3/8"	(9.5 mm)	72.3	VMA	15.8	--
#4	(4.75 mm)	56.3	VFA	69.0	--
#8	(2.36 mm)	39.3	Dust/Asphalt Ratio	1.21	--
#16	(1.18 mm)	26.6	Effective AC (Pbe)	4.94	--
#30	(600 µm)	17.5	Absorbed AC (Pba)	1.88	--
#50	(300 µm)	11.9	% AC Contribution from RAP	0.00	--
#100	(150 µm)	8.0	% AC Contribution from RAS	0.00	--
#200	(75 µm)	6.0	% Virgin Binder	6.70	--
			% Recycled AC Replacement	0.0	--



Aggregate Information		Criteria
Agg. Bulk Gravity (Gsb)	2.520	--
Agg. Effective Gravity (Gse)	2.639	--
Agg. Apparent Gravity (Gsa)	2.727	--
Agg. Absorption (Abs)	3.01	--
Coarse Agg. Angularity (1)	--	--
Coarse Agg. Angularity (2+)	--	--
Fine Agg. Angularity (FAA)	--	--
Flat and Elongated 5:1 (F & E)	0	--
Sand Equivalency (SE)	0	--

Other Information	
Ndes Gyrations	50
Ignition Oven CF	NA
Design Sample Mass, g	4500
RAP % AC (Ignition)	NA
Corrected RAS % AC (TCE)	NA
Assumed RAS AC Contribution	NA
Uncorrected RAS % AC (TCE)	NA
RAP Binder True Grade	NA
RAS Binder True Grade	NA
TSR	NA
Uncond. Tensile Strength, psi	NA
Cond. Tensile Strength, psi	NA
Cantabro % Loss	NA

Additional Notes

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

National Center for Asphalt Technology
Job-Mix Formula

NCAT Project ID:	CAPRI Abs Agg	NCAT Mix ID:	Low Absorption
Principal Investigator:	Nam Tran	Mix Design Engineer:	Zane Hartzog
Producer:	--	Design Completion Date:	9/15/2025
Intended Use:	NA	Intended Section:	N/A

Mix Type:	Dense-Graded Superpave	Virgin Binder Grade:	PG 67-22
Nom. Max Agg. (NMAS):	12.5mm (1/2")	Virgin Binder Specific Gravity:	1.03
Max Agg. Size (MAS):	19.0mm (3/4")	Anti-Strip:	0
Mixing Temp, °F :	325	Anti-Strip Dosage (TOTAL Binder):	0.00%
Compaction Temp, °F :	275 2 hrs	A.S. Dose Rate for Virgin Binder:	0.00%
		Other Binder Additives:	0.00%

AASHTO Superpave Volumetric Mix Design

Cold Feed %	Aggregate Description	Pile ID	Source	Gsb	Gsa	% Abs.
41	Coarse Dolomite			2.752	2.810	0.7
33	Fine Dolomite			2.719	2.806	1.1
25	Manufactures Sand			2.547	2.595	0.7
1	Filler			2.720	2.720	
0	0					
0	0					

Job Mix

Sieve	Sieve	% Passing
1 1/2"	(37.5 mm)	100.0
1"	(25 mm)	100.0
3/4"	(19.0 mm)	97.5
1/2"	(12.5 mm)	82.9
3/8"	(9.5 mm)	58.0
#4	(4.75 mm)	39.9
#8	(2.36 mm)	27.1
#16	(1.18 mm)	20.3
#30	(600 µm)	15.5
#50	(300 µm)	10.2
#100	(150 µm)	6.1
#200	(75 µm)	6.1

Mix Design Information		Criteria
% Total AC Required	5.80	--
Max Spec. Gravity Mix (Gmm)	2.508	--
Bulk Spec. Gravity Mix (Gmb)	2.439	--
Design Air Voids (Va)	3.5	--
VMA	14.5	--
VFA	80.7	--
Dust/Asphalt Ratio	1.17	--
Effective AC (Pbe)	4.95	--
Absorbed AC (Pba)	0.90	--
% AC Contribution from RAP	0.00	--
% AC Contribution from RAS	0.00	--
% Virgin Binder	5.80	--
% Recycled AC Replacement	0.0	--

Aggregate Information		Criteria
Agg. Bulk Gravity (Gsb)	2.687	--
Agg. Effective Gravity (Gse)	2.751	--
Agg. Apparent Gravity (Gsa)	2.751	--
Agg. Absorption (Abs)	0.80	--
Coarse Agg. Angularity (1)	100 assumed*	--
Coarse Agg. Angularity (2+)	100 assumed*	--
Fine Agg. Angularity (FAA)	--	--
Flat and Elongated 5:1 (F & E)	--	--
Sand Equivalency (SE)	0	--

Other Information	
Ndes Gyrations	50
Ignition Oven CF	--
Design Sample Mass, g	4800
RAP % AC (Ignition)	NA
Corrected RAS % AC (TCE)	NA
Assumed RAS AC Contribution	NA
Uncorrected RAS % AC (TCE)	NA
RAP Binder True Grade	0
RAS Binder True Grade	NA
TSR	NA
Uncond. Tensile Strength, psi	NA
Cond. Tensile Strength, psi	NA
Cantabro % Loss	NA

Additional Notes