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Laboratory Accelerated Stripping Simulator for Hot Mix Asphalt

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16. Abstract

Moisture susceptibility of hot mix asphalt (HMA) pavements continues to be a major pavement distress. Past research has primarily focused on HMA stripping prevention through material component evaluation/testing and addition of preventative additives. Stripping is caused by traffic, water, and high in-place service temperatures. Today, agencies use various methods to evaluate HMA moisture susceptibility with varying degrees of success.

The study objective was to evaluate a prototype stripping simulator's ability to predict HMA moisture susceptibility. The simulator evaluates moisture susceptibility by measuring conditioning water turbidity. Boil test and indirect tensile strength testing were also conducted for comparison purposes. Stripping simulator results indicate further refinement is required before it can be used for moisture susceptibility prediction.

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CHAPTER 1 ITRODUCTION

1.1 INTRODUCTION AND PROBLEM STATEMENT

Stripping is defined as bond loss between mineral aggregate and asphalt binder and is generally caused by traffic, water, and high in-place service temperatures. Stripping is one of the most difficult distresses to recognize in hot mix asphalt (HMA) pavements because the surface appearance can take various forms such as rutting, shoving, raveling, or cracking (1). The only accurate way to determine if stripping is the cause of the distress is to observe the actual pavement structure, generally by obtaining cores. However, sometimes the HMA mix has become completely unbonded and cores can not be removed intact for observation.

Numerous test methods have been developed to evaluate HMA stripping potential in the laboratory. The most commonly used tests include the boiling test, static immersion test, Lottman test, modified Lottman test, and Root-Tunnicliff test. However, several disadvantages are associated with the current test methods such as: 1) visual examination of stripping is subjective leading to discrepancies among inspectors, 2) tests take substantial amount of time to complete, and 3) degree of saturation level can affect measured strength.

In response to the disadvantages associated with the current tests, a prototype device, the Moisture Induced Stress Tester (MIST), has been developed to evaluate HMA stripping. The MIST is designed to determine the ability of a laboratory prepared loose HMA sample, laboratory prepared compacted HMA sample, or field core to resist moisture induced damage. The conditioning method closely simulates the process occurring in the field when the pavement structure is exposed to water, repeated trafficking, and elevated in-place service temperatures.

1.2 OBJECTIVE AND SCOPE

The objectives of the research study were to determine the ability of the MIST to accurately predict HMA stripping and establish a relationship between stripping and turbidity within 3 hours so the test could be used for quality control/assurance.

The study was sponsored by the Mississippi Department of Transportation (MDOT) and consisted of evaluating HMA coarse-graded Superpave and stone matrix asphalt (SMA) mixes comprised of 100 percent gravel aggregate and a gravel/limestone aggregate at nominal maximum aggregate sizes of 12.5 and 19.0 mm. Three antistripping treatments were evaluated: none, hydrated lime, and hydrated lime plus a liquid antistripping agent. Two asphalt binders were evaluated: PG 67-22 (Neat Asphalt) and PG 76-22 (polymer modified asphalt). Using the Superpave gyratory compactor, HMA specimens were compacted to a 95 mm height at 7 percent air voids at an N_{design} gyration level of 96. Subsequently, the specimens were tested in the MIST device. Upon completion of testing compacted specimens, tensile strengths were determined and compared to dry tensile strengths determined in the "Resistance of Bituminous Paving Mixtures to Stripping – Vacuum Saturation Method" (MT-63) testing procedure. In addition to compacted specimens, loose HMA specimens were also tested in the MIST device. Turbidity and pH measurements were also made of the water before, during, and after the test for compacted and loose specimens. In addition, mixes were tested using the Boil test (MT-59) to compare results obtained from the MIST.

CHAPTER 2 LITERATURE REVIEW

This chapter includes a review of past research pertaining to hot mix asphalt (HMA) moisture susceptibility and current moisture susceptibility evaluation tests. The terms moisture susceptibility and stripping are often interchangeably used depending upon the author. This report will refer to the term as stated by the original author.

2.1 CAUSES OF STRIPPING

There are different types of HMA pavement distresses. Distresses such as permanent deformation (rutting) and cracking are evident to an observer. Stripping is not necessarily evident because it can manifest itself in different surface forms (1). There are a number of general stripping definitions provided by various researchers and agencies, some of which are listed in Table 2.1.

Table 2.1 Definitions of Stripping in Hot Mix Asphalt Mixes

Source	Reference	Definition
National Center for Asphalt Technology	1	Weakening or eventual loss of the adhesive bond usually in the presence of moisture between the aggregate surface and the asphalt cement in a HMA pavement or mixture.
Asphalt Institute	2	Breaking of the adhesive bond between the aggregate surface and asphalt cement.
Hunter, E., et al	3	Loss of integrity of a HMA mix through weakening of the bond between the aggregate and the asphalt cement.
White, T. et al	4	Loss of the adhesive bond between the bitumen and the aggregate surface.
Kennedy, T. et al	5	The physical separation of the asphalt cement from the aggregate produced by the loss of adhesion between the asphalt cement and the aggregate which is primarily due to the action of water or water vapor.
Tunnicliff, D. et al	6	Displacement of asphalt cement film from aggregate surfaces by water caused by conditions under which the aggregate surface is more easily wetted by water than by asphalt.

Many factors can have been acknowledged to cause stripping. A Canadian publication (7) cited several stripping factors as follows:

1) Aggregates mineral and chemical composition
2) Aggregates exposure history
3) Asphalt binder original properties
4) Asphalt binder modifications during storage and handling
5) Aggregate, asphalt binder, and additive interactions
6) Mix moisture content
7) Mix curing time (time, temperature, etc.)
8) Nature of water to which mix is exposed
9) Asphalt content
10) Special variables (climate, construction quality)

2.2 MECHANISMS OF STRIPPING

Taylor and Khosla (8) concluded the following mechanisms are primarily responsible for stripping:

1) Detachment
2) Displacement
3) Emulsification
4) Pore pressure

Although all four mentioned above are considered mechanisms for stripping, the primary mechanism responsible is displacement of asphalt binder from aggregate surface in the presence of water (9). The underlying principle used to describe the mechanisms above, comes from mechanical, thermodynamic, interfacial energy, and/or chemical concepts of adhesion. In mechanical adhesion, asphalt binder penetrates into pores and cracks on the aggregate surface and resulting in mechanical bond between the asphalt binder and aggregate. From a thermodynamic perspective, stripping is dependent on interfacial free energy at the aggregate-asphalt-water-air interface. In chemical adhesion, asphalt adsorbed on the aggregate surface chemically reacts with the constituents on the aggregate surface (9).

2.3 AGGREGATE SELECTION INFLUENCE

Aggregates are classified as hydrophilic or hydrophobic with regards to water affinity. Hydrophilic aggregates, which include granite, rhyolite, and siliceous gravel, have a stronger affinity for water than for asphalt binder. Hydrophobic aggregates, which include limestone and other carbonate rocks, have a stronger affinity for asphalt binder than water (10).

2.4 ANTISTRIPPING ADDITIVE INFLUENCE

Asphalt binder and antistripping additive are equally as important as aggregate. Antistripping agents can be added to the asphalt binder or aggregate to increase adhesion between the asphalt binder and aggregate surface. Additive types include liquid antistripping agents and solid additives, typically hydrated lime. Liquid antistripping agents are added to asphalt binder to reduce surface tension, which increases adhesion strength (1).

2.5 CURRENT MOISTURE SUSCEPTIBILITY TESTS

The most commonly used tests to evaluate moisture susceptibility of HMA include the following:

- Boiling Test (ASTM D-3625), (11)
- Texas Boiling Water Test (TBWT), (5)
- Static Immersion Test (AASHTO T-182 or ASTM D-1664), (12)
- Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage (AASHTO T-283), (13)
  - Lottman Test
  - Modified Lottman Test
  - Root-Tunnicliff Test
- Immersion-Compression Test (AASHTO T-165), (14)
- Hamburg Wheel Tracking Device (HWTD), (15)
- Purdue Wheel (PURWheel) Testing Device, (4)
- Environmental Conditioning System (ECS), (16)

Two main problems associated with many of the above tests are their subjective evaluation and high variability. The following sections provide the procedure of each test above.

2.5.1 Boiling Test (ASTM D-3625)

Approximately 100 g of loose HMA mix is placed into approximately 1000 ml of boiling water. The mix is boiled for 10 minutes, then allowed to cool, and placed on a white paper towel for visual observation. The percentage of the total aggregate area that retained its original coating is estimated. This test method, due to its subjective evaluation, is typically only used by agencies during mix production to determine the presence of an antistripping agent (11).

2.5.2 Texas Boiling Water Test (TBWT)

Steps for the TBWT are 1) heat asphalt binder at 163°C (325°F) for 24 to 26 hours, 2) heat 100 to 300 grams of unwashed aggregate at 163°C (325°F) for 1 to 1.5 hours, 3) mix asphalt binder and aggregate and allow to cool for two hours, 4) fill a 1000 ml beaker with distilled water, 5) place loose HMA mix in the beaker and boil for 10 minutes, 6) allow specimen to cool after boiling, decant and place loose mix on a paper towel, and 7) visual inspection of specimen by three-person panel. If the specimen retains 65 to 75 percent of asphalt binder, then the mix is permitted to be used in the field (5).

2.5.3 Static Immersion Test (AASHTO T-182 or ASTM D-1664)

Loose HMA mix is placed into a 600 ml beaker filled with distilled water for 16 to 18 hours, after which it is removed and visually examined. The percentage of the total visible area of the aggregate coated is subjectively recorded as above or below 95 percent (12).

2.5.4 Lottman Test

Nine compacted HMA specimens are separated into three sets so air void average is approximately equal (7 ± 1 percent). Set 1 is the control and Sets 2 and 3 are conditioning sets. Set 2 and 3 specimens are saturated under partial vacuum for 30 minutes. Each specimen in Set 2 is placed in a water bath at 60°C (140°F) for 24 ± 1 hour, removed and placed in a water bath at 25°C (77°F) for 2 ± 1 hour. Each specimen in Set 3 is then frozen at -18°C (0°F) for 15 hours and thawed at 60°C (140°F) for 24 hours, and placed in a water bath at 25ºC (77ºF) for 2 ± 1 hour. Once specimens have undergone the complete conditioning cycle, indirect tensile strength (ITS) is determined by applying a diametrical load of 50 mm/min (2 in/min) until the maximum load is reached. Figure 2.1 and 2.2 shows the ITS test apparatus and HMA specimen at failure, respectively. The ITS is determined for all specimens, and tensile strength ratios (TSR) calculated by dividing the ITS of Set 1 by the ITS of Set 2 and Set 3 (13). The TSR, from all versions of AASHTO T-283, is determined and compared to a specified minimum value, which varies among agencies.

Figure 2.1 ITS Test Apparatus

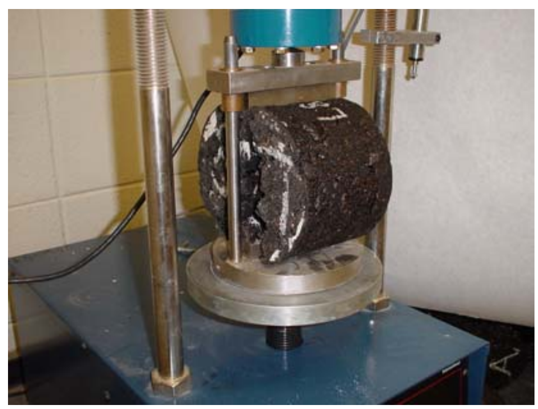


Figure 2.2 HMA Specimen at Failure

2.5.5 Modified Lottman Test

Six compacted HMA specimens are separated into two sets, Set 1 (Control) and Set 2 (Conditioned), so that the average air voids of the two sets are approximately equal (7 ± 1 percent). Set 1 is placed in a water bath at 25°C (77°F) for two hours and the ITS for each specimen is determined at a loading rate of 50 mm/min (2 in/min). Set 2 is vacuum saturated at 13 to 67 kPa absolute pressure (10 to 26 in. Hg partial pressure) for 5 to 10 minutes.

Saturation must be between 55 and 80 percent. Specimens are placed in a water bath at 60°C (140°F) for 24 ± 1 hour, removed and frozen at -18°C (0°F), and then thawed at 60°C (140°F) for 24 hours. Specimens are then placed in a water bath at 25°C (77°F) for 2 ± 1 hour and ITS for each specimen is determined. A TSR is calculated by dividing the ITS of Set 1 by the ITS of Set 2 (13).

2.5.6 Root-Tunnicliff

Six compacted HMA specimens are separated into two sets, Set 1 (control) and Set 2 (conditioned), so average air voids of the two subsets are approximately equal (7 ± 1 percent). Set 1 is placed in a water bath at 25°C (77°F) for two hours and the ITS determined at a loading rate of 50 mm/min (2 in/min). Set 2 is vacuum saturated at 13 to 67 kPa absolute pressure (10 to 26 in. Hg partial pressure) for 5 to 10 minutes. The degree of saturation must be between 55 and 80 percent. Specimens are then placed in a water bath at 60°C (140°F) for 24 ± 1 hours, removed and placed in a water bath at 25°C (77°F) for 2 ± 1 hour and the ITS for each specimen is determined. A TSR is calculated by dividing the ITS of Set 1 by the ITS of Set 2 (13).

2.5.7 Immersion-Compression Test (AASHTO T-165)

HMA compacted specimens are separated into two sets of three specimens so average air voids of the two subsets are approximately equal (7 ± 1 percent), Set 1 (Control) and Set 2 (Conditioned). Set 1 is placed in a water bath at 25°C (77°F) for a minimum of 4 hours and the compressive strength of each specimen is determined. Set 2 is placed in a water bath at 60°C (140°F) for 24 hours, transferred to a water bath at 25°C (77°F) for 2 hours, and the compressive strength of each specimen is determined (14). The retained compressive strength is calculated and compared to specified minimum values set by governing agencies.

The problem with this test is that loading does not simulate field conditions. Specimens sometimes have retained compressive strength near 100 percent even when visual stripping is evident. Stuart (17) stated that high retained compressive strengths have been reported due to internal pore water pressure and insensitivity of the compression test.

2.5.8 Hamburg Wheel Tracking Device

The Hamburg wheel tracking device, shown in Figure 2.3, evaluates two HMA specimens compacted to a length of 320 mm (12.6 in), width of 260 mm (10.2 in), and a thickness of 40, 80, or 120 mm (1.6, 3.1 or 4.7 in). Air void content is 7 ± 1 percent. Specimen thickness is usually determined to be three times the nominal aggregate size. Specimens are placed in a water bath at 25 to 70ºC (77 to 158ºF) for 45 minutes to reach test temperature, after which testing is initiated. Steel wheels [diameter of 203.5 mm (8.0 in) and width of 47.0 mm (1.9 in)] apply loading for 10,000 to 20,000 cycles to the specimen. Rut depths are recorded throughout testing and evaluated against specified pass/fail criteria, which varies among agencies (15).

Figure 2.3 Hamburg Wheel Tracking Device

2.5.9 Purdue Wheel (PURWheel) Testing Device

The PURWheel testing device (shown in Figure 2.4), developed at Purdue University, simulates field conditions (high moisture, high temperature, and traffic) that contribute to stripping and rutting. Two HMA specimens are compacted to 7 ± 1 percent air voids at dimensions [width of 290 mm (11.4 in) and length of 310 mm (12.2 in)] with the thickness based on the mix type (surface, binder, base, etc.) tested. The PURWheel tests two specimens simultaneously in either a hot/wet (with water) or hot/dry (without water) environment at a temperature range of 55 to 60ºC (131 to 140°F). Load is applied by a pneumatic tire with a pressure of 793 kPa (115 psi) creating a gross contact pressure of 620 kPa (90 psi). The tire passes over the specimen for 20,000 cycles or until 20.0 mm (0.8 in) deformation (4).

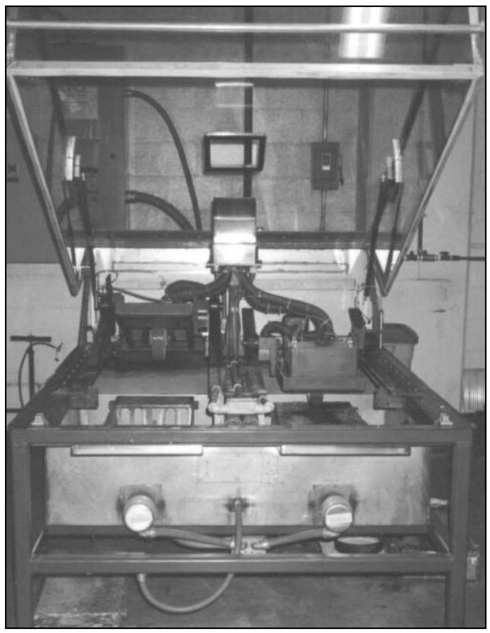


Figure 2.4 PURWheel Testing Device

2.5.10 Environmental Conditioning System (ECS)

The Environmental Conditioning System simulates field conditions (heat, repeated loading, and water). Specimens are compacted to 102 mm (4 in.) in diameter and 102 mm (4 in.) in height at an air void content of 7.5 ± 0.5 percent. Specimens are then encapsulated in a latex membrane with silicone and allowed to dry for 15 hours. Specimens are placed in the ECS load frame and air permeability and dry resilient modulus (MR) determined by the following steps: 1) vacuumed air flows through the specimen at 68 kPa (10 psi) to determine air permeability 2) loading and resting periods of 0.1 seconds and 0.9 seconds, respectively, are used over a three hour period to determine MR. After loading, the water permeability of the specimen is determined by vacuum saturating the specimen at 68 kPa (10 psi). Specimen temperature is elevated to 60°C (140°F) for six hours while be subjected to loading.

Specimens are cooled to 25°C (77°F) for two hours and the conditioned MR and water permeability determined. Specimens are conditioned once more by the same procedure above (elevated temperature, loading, and cooling period) and the conditioned MR and water permeability determined. The conditioned MR is divided by the dry MR with the mix considered to be moisture susceptible if the ratio falls below 0.7 (16).

2.6 LABORATORY EVALUATION OF CURRENT MOISTURE SUSCEPTIBILIYT TESTS

Yoon and Tarrer (9) evaluated five aggregates (granite, limestone, dolomite, chert gravel, and quartz gravel) by the boiling water test. Aggregate pore volume and surface area were evaluated as factors contributing to stripping. Additionally, aggregate pH was determined when immersed in water. The response variable was the percentage coating of asphalt binder retained after boiling.

Retention percentages for the aggregates were as follows: granite = 10%, dolomite = 35%, chert gravel = 55%, quartz gravel = 65%, limestone = 90%. It was concluded that aggregate pore volume and surface area were not contributing factors for stripping and aggregates with higher pH values were more susceptible to stripping.

Kennedy, et al (5) evaluated moisture susceptibility of asphalt mixes using the Texas boiling test. Eight HMA mixes with known field stripping performance were selected for testing. Five of the eight mixes had a history of stripping. Aggregates in the stripping mixes were siliceous river gravel and sand, while aggregates in nonstripping mixes were crushed limestone, caliche, and slag. Eleven antistripping additives were evaluated. Each specimen was exposed to three ten-minute boiling periods, with the specimen being evaluated for asphalt binder loss after each period.

Conclusions included the following: 1) number of boiling periods significantly affected the percent of retained asphalt binder, 2) aggregate temperature during mixing significantly influenced mix stripping potential, 3) Texas boiling test appeared successful in predicting mixes with known stripping potential and 4) Texas boiling test can accurately evaluate antistripping additive effectiveness. Recommendations were as follows: 1) Texas boiling test should be used to evaluate asphalt mix moisture susceptibility, 2) antistripping additive effectiveness should be evaluated by the Texas boiling test, 3) asphalt mix component changes should be evaluated by the Texas boiling test, and 4) other tests such as the Texas freeze-thaw pedestal test and wet-dry indirect tensile test should be used in conjunction with Texas Boiling Test.

Coplantz and Newcomb (18) evaluated four variations of water sensitivity tests as follows:

1) Vacuum saturation only
2) High vacuum saturation with single freeze-thaw cycle
3) Low vacuum saturation with single freeze-thaw cycle
4) Low vacuum saturation with several freeze-thaw cycles

Results indicated mixes subjected to only vacuum saturation may not show evidence of stripping potential. However, when mixes were subjected to freeze-thaw cycles plus a vacuum saturation, stripping potential was shown. The number of freeze-thaw cycles is directly related to stripping severity, with more freeze-thaw cycles yielding more severe stripping. In addition to freeze-thaw cycles, saturation level influenced the stripping potential, with higher levels of saturation yielding more stripping.

Parker and Gharaybeh (19) evaluated five aggregate blends, two asphalt binders, and three antistripping additives for stripping potential using the stress pedestal, boil, and indirect tensile tests. Boil and indirect tensile tests showed more ability to accurately predict mix stripping potential than the stress pedestal test. Although consistent, boil and indirect test results were not always accurate in correctly predicting stripping. The authors were able to establish reasonable correlation between boil and indirect tensile test, but suggest the results between the tests are mix dependent.

Ishai and Nesichi (20) evaluated bituminous paving mixtures for moisture damage. Mixtures were evaluated using a modified version of the hot immersion test. The modified version was used in an attempt to reduce the time and number of specimens needed for evaluation. Three mixtures were subjected to moisture immersion periods at 60°C (140°F) for six days, after which retained strength values (based on different immersion periods) were calculated for Marshall stability, Marshall quotient (stability/flow), and resilient modulus. Results from the modified version showed a strong correlation with original version.

However, further research was recommended to improve various aspects of the test (e.g., adding a vacuum saturation to further reduce the time necessary for immersion and performing a Lottman-type field study to correlate lab and field results).

Pan and White (4) conducted a laboratory study on asphalt mixture moisture sensitivity. Seven mixtures were evaluated including three No.11 surface mixes, three No.8 binder mixes, and No.5C coarse-graded base mixes. Mixes were evaluated using AASHTO T-283 and the PURWheel wheel tracking device. AASHTO T-283 results showed moisture conditioning plays a vital role in stripping severity. PURWheel tracking device results indicated temperature and moisture conditions significantly influence stripping severity. The authors suggested a field study be performed to correlate laboratory results with field performance.

Hunter and Ksaibati (3) evaluated freeze-thaw conditioning effects on HMA tensile strength and whether the Georgia Loaded Wheel Tester (GLWT) could predict moisture susceptibility. Eight asphalt mixtures were evaluated, including two aggregate types (granite and limestone) and four asphalt-additive-aging combinations. Results showed the GLWT was not effective in determining moisture susceptibility. Freeze-thaw results showed lower tensile strengths for all conditioned mixes. Tensile strength of the granite mixes decreased more rapidly than limestone mixes. It was recommended that a testing procedure that includes specimen saturation be designed for the GLWT to be effective in measure moisture susceptibility.

Mahoney and Stephens (21) compared AASHTO T-283 results with the Connecticut Department of Transportation Modified Test Method. The difference in the two methods is the method of calculating the saturation level for conditioned specimens. Connecticut Class 1 mixes used in this project were collected from 17 HMA plants. Results showed that AASHTO T-283 was more severe than the Connecticut method. The authors concluded that both tests have limitations in accurately predicting HMA stripping potential.

Aschenbrener, et al (22) tested HMA of known field stripping performance with four moisture susceptibility tests: 1) AASHTO T-283 (modified Lottman test), 2) ASTM D-3625 (boiling water test), 3) Environmental Conditioning System, and 4) Hamburg wheel-tracking device. Twenty pavements throughout Colorado with known field performance were selected for evaluation. AASHTO T-283 was successful in delineating between good and poor performing mixes. However, it was not successful in determining the reliability of the marginal mixes. ASTM D-3625 was not reliable in predicting mixes because it showed that all mixes failed the design requirements. The Environmental Conditioning System only correctly predicted the performance of one mix. The Hamburg wheel-tracking device correctly predicted the performance of fourteen mixes. The investigation concluded that none of the tests were completely accurate in predicting actual field stripping performance. It was recommended that modifications would be needed to each test prior to successful prediction of pavement performance.

Scherocman, et al (23) evaluated the effect of multiple freeze-thaw cycle conditioning on asphalt concrete mixture moisture damage. Asphalt mixes included aggregates from Georgia, Virginia, Washington, Tennessee, Kentucky, and Iowa. Additives evaluated included liquid antistripping additives, hydrated lime, and Portland cement. Results showed additional freeze-thaw cycles resulted in larger reductions in tensile strength. The magnitude of tensile strength decrease was a function of the additive utilized.

Parker and Wilson (24) evaluated boil and stress pedestal tests to determine stripping potential of Alabama asphalt mixes. There were two main research objectives: 1) to determine the stripping potential of each mix and 2) identify the mix components responsible for stripping. Mixes consisted of three aggregates, two asphalt binders, and three antistripping additives. Mixes evaluated had known field stripping performance. Boil tests results indicated all mix components (aggregate, asphalt binder, and antistripping additives) influence stripping. The boil test was successful in identifying antistripping additives that prevent stripping. The stress pedestal test was not successful in predicting mix stripping potential.

Parker and Gharaybeh (25) evaluated Alabama asphalt mixes to determine if the indirect tensile strength test is adequate in predicting stripping potential. Five mixes (five aggregates and one asphalt binder) common to Alabama with known field stripping performance were evaluated. Results indicated that aggregate and asphalt binder selections are equally important in preventing mix stripping. Even though tensile strength was highly variable, it was concluded the tensile strength test is adequate in predicting the mix stripping potential.

Akili (26) performed a laboratory evaluation of compacted and loose HMA using four test methods: 1) Marshall Stability Ratio Test (AASHTO T 245), 2) wet-dry indirect tensile strength test, 3) test method for coating and stripping of bitumen-aggregate mixtures (ASTM D 1664), and 4) test method for effect of water on bituminous-coated aggregate-quick field test (Boil Test - ASTM D 3625). Two asphalt mixes (A and B) were evaluated with two aggregate sources (coarse and fine) and one asphalt binder (60-70 pen). Marshall stability ratio results indicated that partial or complete replacement of the aggregate mineral filler portion with Portland cement or hydrated lime reduces the potential of moisture susceptibility. Marshall stability ratio test, Lottman test, and boil test results indicated mixes with higher natural sand content were more moisture susceptible. The test method for coating and stripping of bitumen-aggregate mixtures showed all specimens retained at least 95 percent asphalt binder coating. Further evaluation was recommended to effectively evaluate asphalt mixes for moisture susceptibility.

Maupin (27) evaluated antistripping agent effectiveness in preventing HMA pavement stripping. Twelve pavements with known field stripping performance were evaluated. Antistripping agents included hydrated lime and nine chemical additives. Pavement cores from in service pavements were evaluated using the Root-Tunnicliff test method and by visual examination. Visual examination indicated that eight of the nine projects with chemical additives showed moderate to moderate-severe stripping of coarse aggregate. Six of the nine projects with chemical additives showed moderate to moderate-severe stripping of fine aggregate. Three projects with hydrated lime showed no stripping in the fine or coarse aggregate. Root-Tunnicliff test results indicated only one of twelve projects showed stripping potential. Results from both test methods indicated hydrated lime to be more successful than chemical additives in preventing HMA pavement stripping.

Choubane, et al (28) evaluated a section of Interstate 75 in Florida for stripping potential by using AASHTO T 283. Six cores from six sites were obtained and tested for TSR two years after construction. Results showed that TSR decreased more for 12.5 mm mixes than 19.0 mm mixes. It was concluded that TSR difference between the two mixes was primarily a function of specimen air void content.

Additionally, Choubane, et al (28) evaluated the effect of air void content and degree of saturation on TSR. Aggregates and materials included granite, limestone, and reclaimed asphalt pavement. Asphalt binder was an AC-30 (PG 67-22). Specimens were saturated to 55 and 80 percent. Results showed TSR values decreased as the level of saturation increased. The following recommendations were reported: 1) coarse-graded Superpave mixes should be saturated to more than 90 percent and to include the freeze-thaw cycle when using AASHTO T-283, 2) a minimum TSR of 80 percent, 3) specimen air void content should be set to 7 ± 0.5 percent, and 4) a minimum requirement for wet indirect tensile strength should be 410 kPa (60 psi).

Izzo and Tahmoressi (29) evaluated HMA mix stripping potential with the Hamburg Wheel-Tracking Device (HWTD). The objective was to demonstrate the consistency of the HWTD in identifying HMA mixes that are moisture susceptible. Six mixes, comprised of six different aggregates and one asphalt binder (AC-20), along with antistripping additives consisting of hydrated lime and chemical additives, were evaluated. Specimens were tested at two temperatures: 40°C (104°F) and 50°C (122°F). Results showed the HWTD has low test variability, additives decreased the stripping potential at 40°C (104°F), and an AC-20 asphalt binder is not sufficient at a test temperature of 50°C (122°F).

Tandon, et al (16) evaluated the ability of the Environmental Conditioning System (ECS) to successfully predict HMA mix stripping potential. Modified Lottman testing was performed on similar specimens for comparison. Three HMA mixes were evaluated: one having a history of stripping and the other two having no stripping history. Mixes were comprised of limestone, sand, and siliceous gravel, with an AC-20 (PG 67-22) asphalt binder. Results indicated the procedure was unable to identify the performance of any of the three mixes. Additionally, ECS testing proved to be highly variable. Modified Lottman test results were correct in identifying mix performance while having lower variability than the ECS.

Study recommendations for the ECS were: 1) regulate the temperature of water flowing through the specimen, 2) improve the precision and accuracy of the resilient modulus measurement, and 3) increase the strain gauge capacity.

Alam, et al (30) evaluated HMA moisture susceptibility using a modified version of the Environmental Conditioning System (ECS). Four HMA mixes with known field performance were selected for evaluation. Results showed the ECS to be successful in predicting HMA mix moisture susceptibility of mixes with a known stripping history. However, further evaluation of the ECS was recommended before HMA mix stripping performance can be successfully predicted.

CHAPTER 3 TEST PLAN

3.1 TEST PLAN APPROACH

The research test plan for the study is shown in Figure 3.1. Coarse-graded Superpave mixes and stone matrix asphalt (SMA) mixes were evaluated at nominal aggregate sizes of 12.5 and 19.0 mm. Mixes consisted of 100 percent gravel and gravel/limestone aggregate blends. Gravel and limestone aggregates were acquired from Columbus, Mississippi, and Birmingham, Alabama, respectively.

Aggregate testing included the following:

- Gradation analysis
- Specific gravity and absorption
- Voids in coarse aggregate (VCA) – SMA mix blends only.

Each blend gradation is shown in Table 3.1 and Figures 3.2 through 3.5. Stockpile percentages for each aggregate blend are shown in Table 3.2. Superpave mix blends were developed to be typical of those used in Mississippi. Stone matrix asphalt blends were developed in accordance with the recently developed MDOT SMA specification. Asphalt binders utilized were PG 67-22 and PG 76-22, obtained from Ergon Inc.

Currently, the Mississippi Department of Transportation requires one percent hydrated lime to be added to all HMA mixes. It therefore decided to evaluate three levels of antistripping: 1) none, 2) one percent hydrated lime, and 3) one percent hydrated lime plus liquid antistripping agent. Hydrated lime was supplied by Falco Lime Inc., in Vicksburg, Mississippi. Liquid antistripping agent, Morlife(R) 2200, was supplied by Ergon Inc.

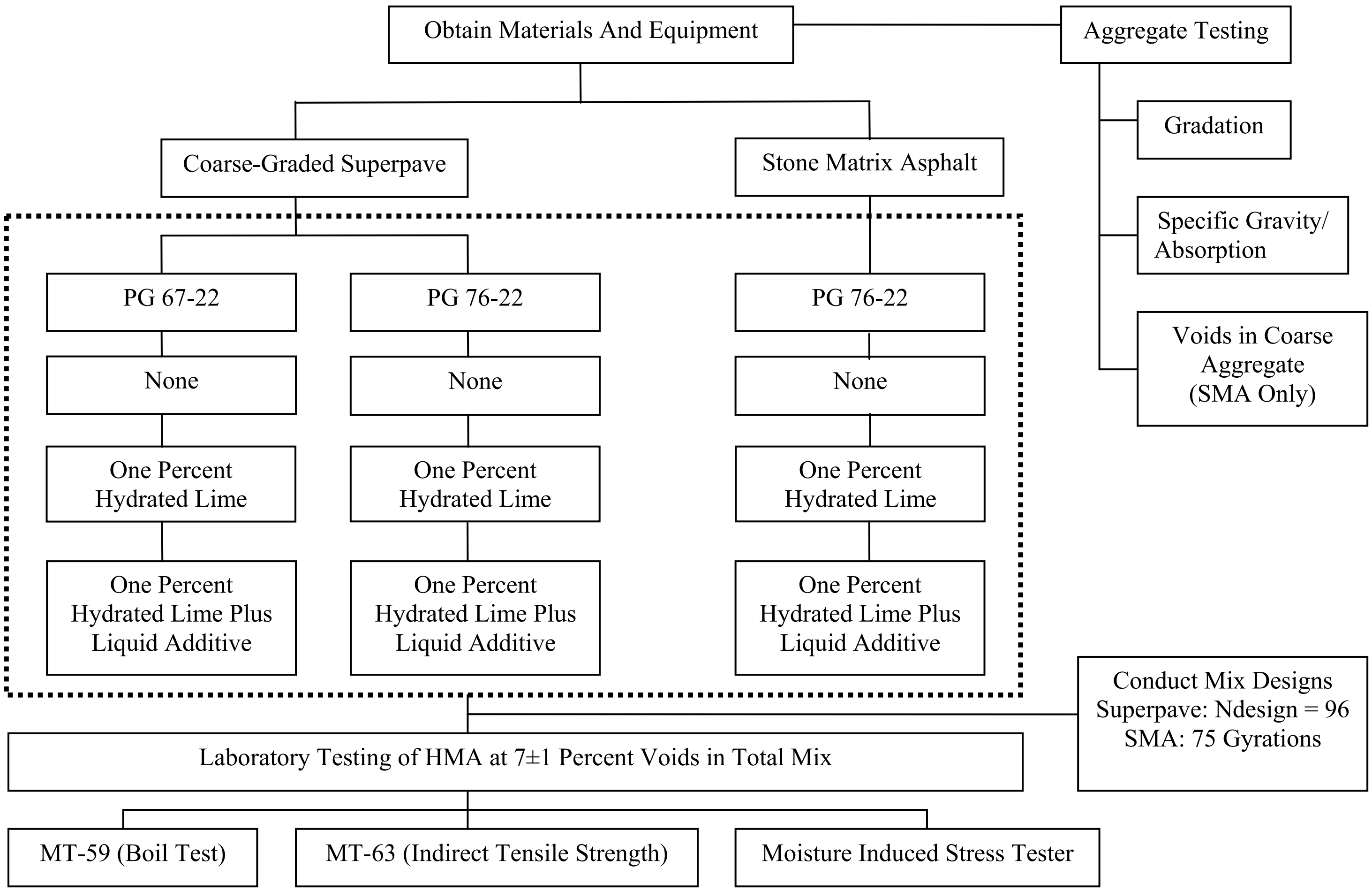


Figure 3.1 Research Test Plan

Table 3.1 Aggregate Blend Gradations

Sieve Size (mm)	Percent Passing							
	Superpave				Stone Matrix Asphalt			
	Gravel		Gravel / Limestone		Gravel		Gravel / Limestone	
	12.5 mm	19.0 mm	12.5 mm	19.0 mm	12.5 mm	19.0 mm	12.5 mm	19.0 mm
25	100	100	100	100	100	100	100	100
19	100	99.7	100	97.4	100	95.0	100	95.0
12.5	92.4	84.3	92.3	83.5	95.0	70.0	95.0	70.0
9.5	82.2	69.5	79.4	69.6	70.0	40.0	70.0	40.0
4.75	51.1	42.0	49.6	45.1	26.0	28.0	26.0	28.0
2.36	32.5	28.2	33.1	31.3	23.0	24.0	24.0	24.0
1.18	23.4	21.6	24.7	24.0	15.8	21.5	21.8	21.9
0.6	18.4	17.7	19.3	19.0	13.9	18.0	18.9	18.1
0.3	11.5	11.1	11.6	11.5	12.4	15.4	15.5	15.0
0.15	7.6	7.2	7.3	7.3	10.7	12.9	12.7	12.3
0.075	6.1	5.8	5.7	5.8	8.9	10.6	10.2	10.0

Table 3.2 Stockpile Percentages for Aggregate Blend Gradations

Aggregate Stockpile mm (in)	Aggregate Blend							
	Superpave				Stone Matrix Asphalt			
	Gravel		Gravel / Limestone		Gravel		Gravel / Limestone	
	12.5 mm	19.0 mm	12.5 mm	19.0 mm	12.5 mm	19.0 mm	12.5 mm	19.0 mm
25 (1)	0	17	0	0	0	44	0	0
19 (3/4)	35	65	27	40	71	45	36	41
12.5 (1/2)	0	0	18	0	25	9	24	0
9.5 (3/8)	47	0	0	0	0	0	0	0
Sand	15	15	15	15	1	0	0	0
No. 57 Limestone	0	0	0	10	0	0	0	28
No. 78 Limestone	0	0	22	15	0	0	35	22
No. 8910 Limestone	0	0	17	19	0	0	4	8
Agricultural Lime	2	2	0	0	1	1	1	0
Hydrated Lime	1	1	1	1	1	1	1	1

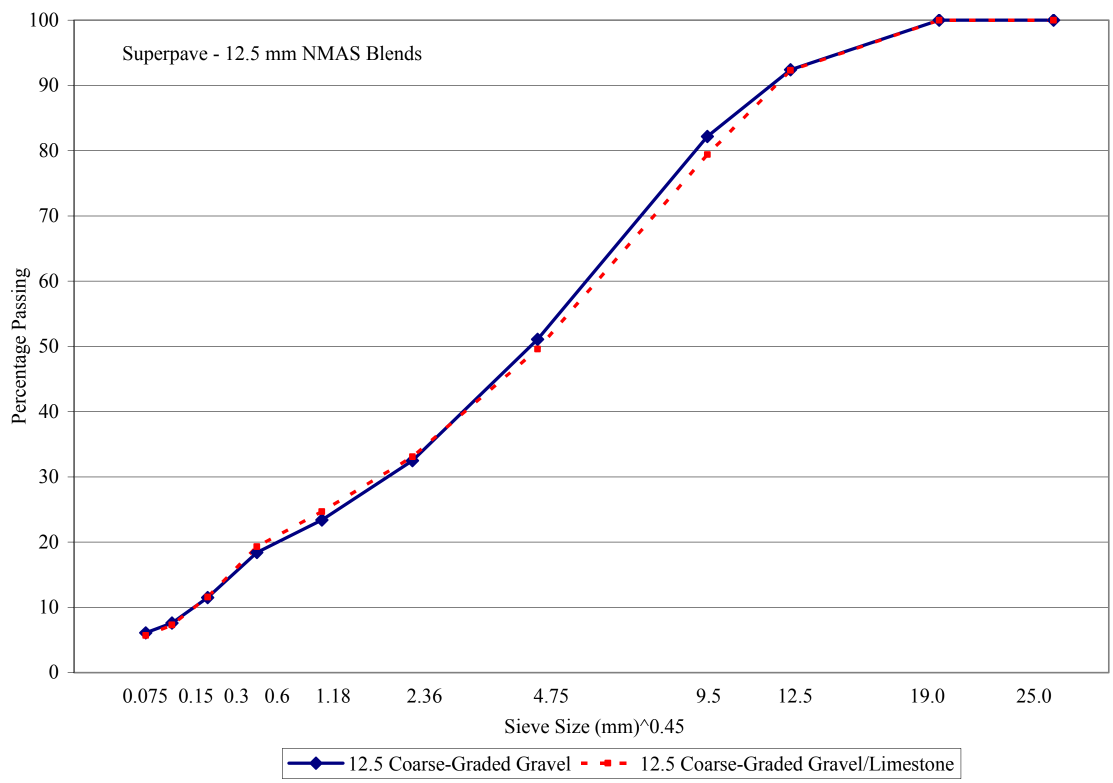


Figure 3.2 Superpave - 12.5 mm NMAS Aggregate Blend Gradations

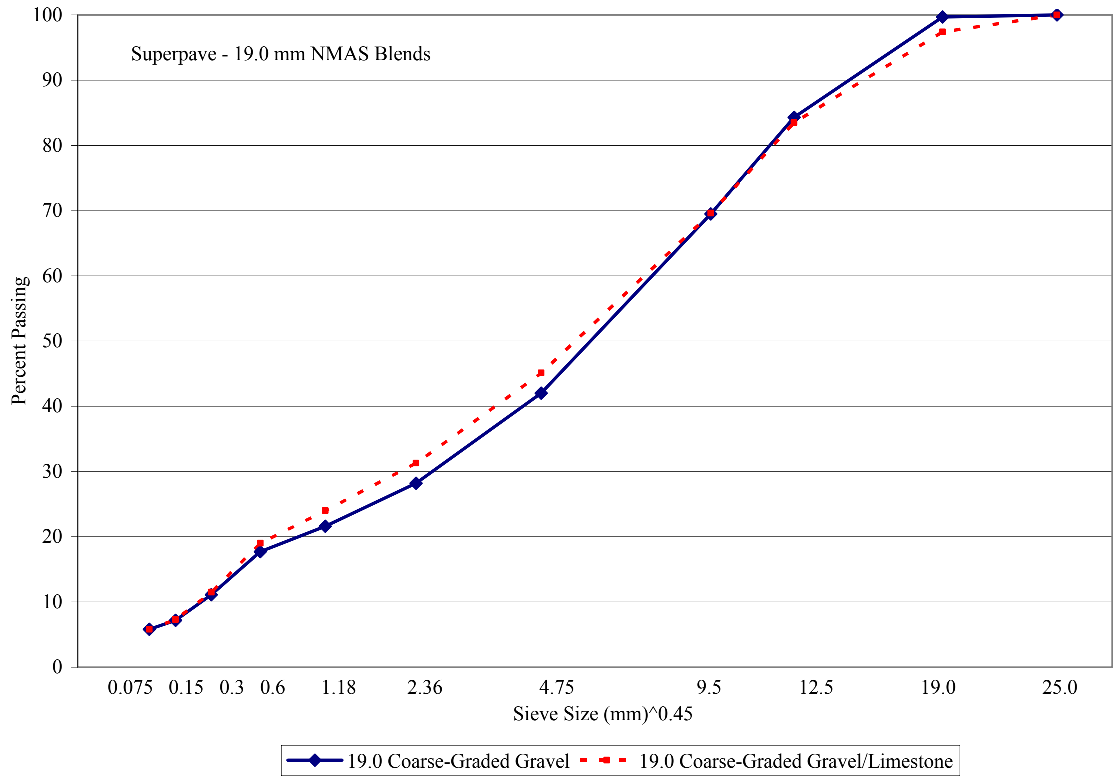


Figure 3.3 Superpave - 19.0 mm NMAS Aggregate Blend Gradations

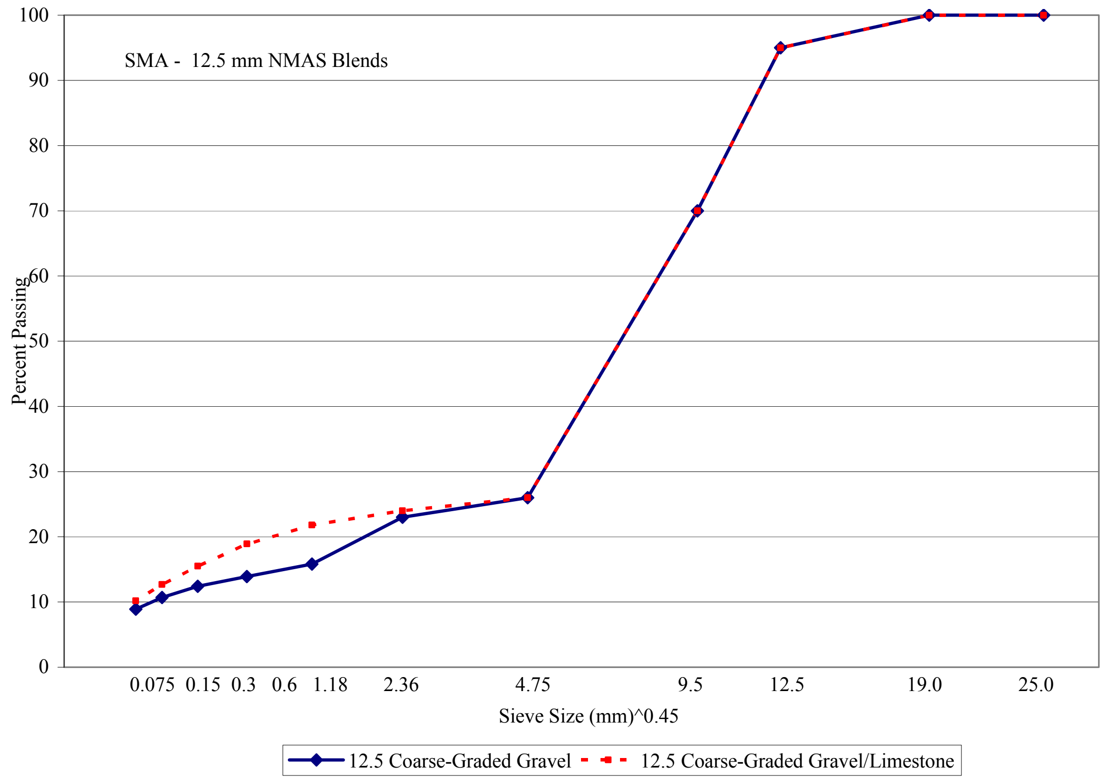


Figure 3.4 SMA – 12.5 mm NMAS Aggregate Blend Gradations

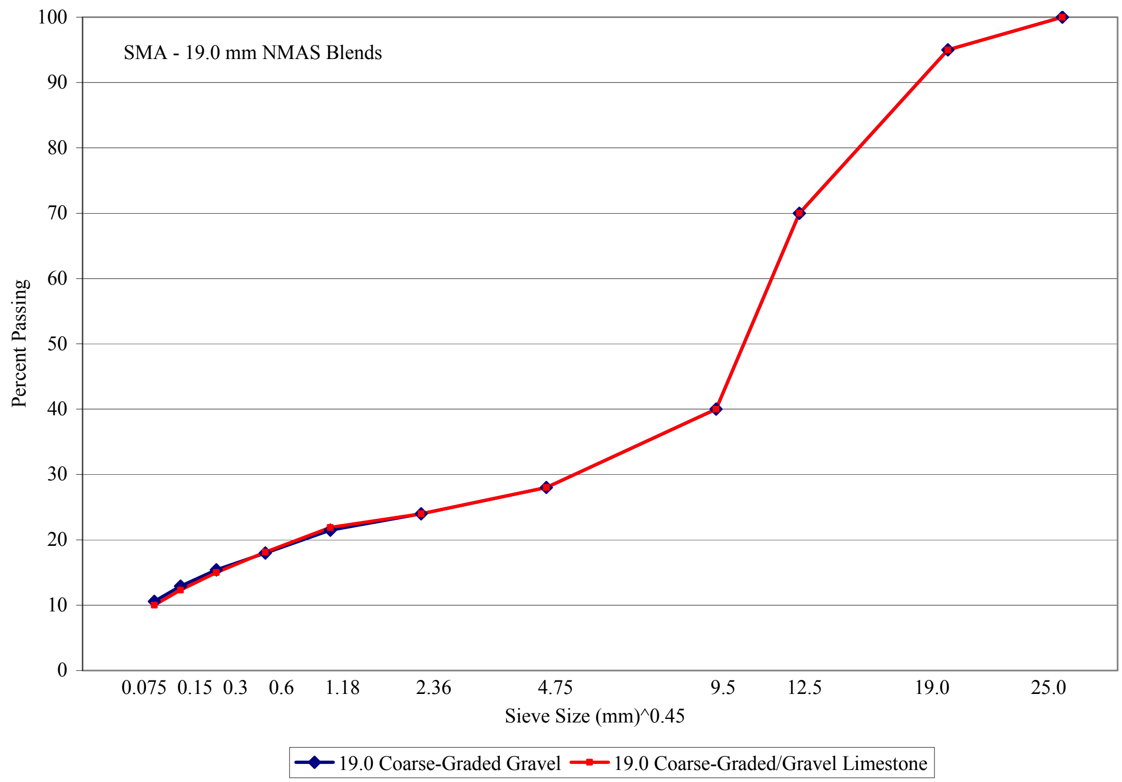


Figure 3.5 SMA 19.0 mm NMAS Aggregate Blend Gradations

3.1.1 Mix Design Procedure

Superpave mix designs were conducted in accordance with Mississippi Department of Transportation (MDOT) MT-78 (31). Stone matrix asphalt mix designs were conducted according to MDOT MT-80 (32). All mixes were designed for four percent air voids. Specimen bulk specific gravity was determined in accordance with AASHTO T-166 (33). Theoretical maximum gravity testing was conducted on duplicate specimens in accordance with AASHTO T-209 (34).

Aggregate batches were heated four hours at 171°C (340°F) and 188ºC (370ºF) prior to mixing with the PG 67-22 and PG 76-22 asphalt binders, respectively. The PG 67-22 asphalt binder was heated for four hours at 155°C (310°F) before mixing. The PG 76-22 asphalt binder was heated at 171°C (340°F) four hours and mixed with a low shear mixer one hour before mixing. Mixing was performed using a bucket mixer shown in Figure 3.6. After mixing, specimens prepared using the PG 67-22 and PG 76-22 were short-term aged (cured) at 155°C (311°F) and 165°C (329°F), respectively for 1.5 hours prior to compaction. Mixing and compaction temperatures used for the study are shown in Table 3.3. Once aging was completed, Superpave and SMA mix specimens were compacted to 96 and 75 design gyrations, respectively, using a Pine Gyratory Compactor (Model AFGC125X) shown in Figure 3.7.

Table 3.3 Mixing, Curing, and Compaction Temperatures

Asphalt Binder	Temperature °C, (°F)		
	Mixing	Curing	Compaction
PG 67-22	155 (310)	155 (311)	146 (295)
PG 76-22	163 (325)	165 (329)	155 (310)

Figure 3.6 Bucket Mixer

Figure 3.7 Pine Gyratory Compactor

3.1.1.1 Antistripping Additive Addition Procedure

Two forms of antistripping additives were selected for the study: 1) hydrated lime and 2) hydrated lime plus liquid additive (Morlife(R) 2200). The procedure used for hydrated lime addition is as follows:

1) Aggregate batch is dried to a constant weight.
2) Add 2.5 ± 0.5 percent water plus the percent water absorption for the blend.
3) Batch is mixed so water is uniformly distributed.
4) Damp batch is allowed to sit approximately four hours prior to introduction of hydrated lime (See Figures 3.8 and 3.9).
5) One-percent hydrated lime, by dry weight of total aggregate, is added to the damp batch.
6) Batch is mixed so lime is uniformly distributed.

The liquid additive, Morlife(R) 2200, was added to the asphalt binder at a dosage of one half percent, by weight of total asphalt binder, and then mixed with a low shear mixer for one hour.

Figure 3.8 Damp Aggregate Batch

Figure 3.9 Addition of Hydrated Lime

3.1.2 MT-63: Resistance of Bituminous Paving Mixtures to Stripping (Vacuum Saturation Method) Testing Procedure

Specimens were compacted at their respective design asphalt binder contents for MDOT MT-63 testing (35). Six specimens were compacted to 95 mm in height at 7 ± 1 percent air voids and separated into two subsets (control and condition sets) so the average air voids of the two subsets were approximately equal (7 ± 1 percent). Control set specimens were placed in a water bath at 25°C (77°F) for two hours and their indirect tensile strength (ITS) determined at a loading rate of 50 mm/min (2 in/min) using the Marshall stability tester.

Conditioned specimen sets were vacuumed saturated at 13 to 67 kPa absolute pressure (10 to 26 in. Hg partial pressure) for 5 to 10 minutes in the vacuum apparatus shown in Figure 3.10. The degree of saturation was between 55 and 80 percent for all specimens, with 70 percent saturation targeted for all mixes. After conditioning, specimens were placed in a water bath at 77°C (140°F) for 24 ± 1 hours, removed and placed in a water bath at 25°C (77°F) for 2 ± 1 hour, after which their ITS was determined. The tensile strength ratio (TSR) was calculated by dividing the ITS of the conditioned set by the ITS of the control set. After a specimen was tested, it was removed and visually evaluated for stripping as shown in Figure 3.11. MDOT's minimal acceptable TSR is 85 percent (35).

Figure 3.10 Vacuum Apparatus

Figure 3.11 Visual Stripping Evaluation of HMA Specimen After Testing

3.1.3 MT-59: Determination of Loss of Coating of HMA (Boiling Water Test) Testing Procedure

Loose HMA specimens (100 g) were placed into approximately 1000 ml of boiling water for 10 minutes (36). Figure 3.12 shows a loose HMA specimen during the boil process. Once boiling was complete, specimens were evaluated by estimating the percentage of total aggregate visible area retaining original binder coating. The value was reported as above or below 95 percent (36).

Figure 3.12 HMA Boil Test

3.1.4 Moisture Induced Stress Tester (MIST) Prototype Development

The moisture induced stress tester (MIST) prototype version 1, manufactured by Instrotek, Inc., in April 2002, was developed to provide a rational method for HMA moisture susceptibility evaluation. The MIST was designed to quickly (less than 3 hours) simulate stripping due to repeated pore pressure generation. To accomplish this task, the MIST 1, shown in Figure 3.13, was developed to simulate existing field conditions such as elevated in-service temperatures, traffic, and moisture. The MIST device quantifies stripping by use of a turbidity ratio (scattered light/transmitted light). A known quantity of light is sent into the conditioning water sample and the amount of light transmitted through determined. Scattered light is the quantity of light not transmitted through. Water samples with more turbidity will have a greater turbidity ratio since less light can be transmitted through the sample.

The MIST showed promise during preliminary testing, but several significant problems were observed:

- Inaccurate turbidity measurement
- Excessive water evaporation from tank
- Excessive cycle time
- Excessive footprint
- Lack of multiple specimen testing capability

In response to these problems, a second modified prototype (MIST 2), as shown in Figure 3.14, was developed by Instrotek Inc., in January 2003. The MIST 2 had several improvements when compared to the first prototype unit.

- More accurate turbidity measurements
- Closed system to prevent water evaporation
- Decreased cycle time
- Smaller footprint
- Multiple specimen testing capability

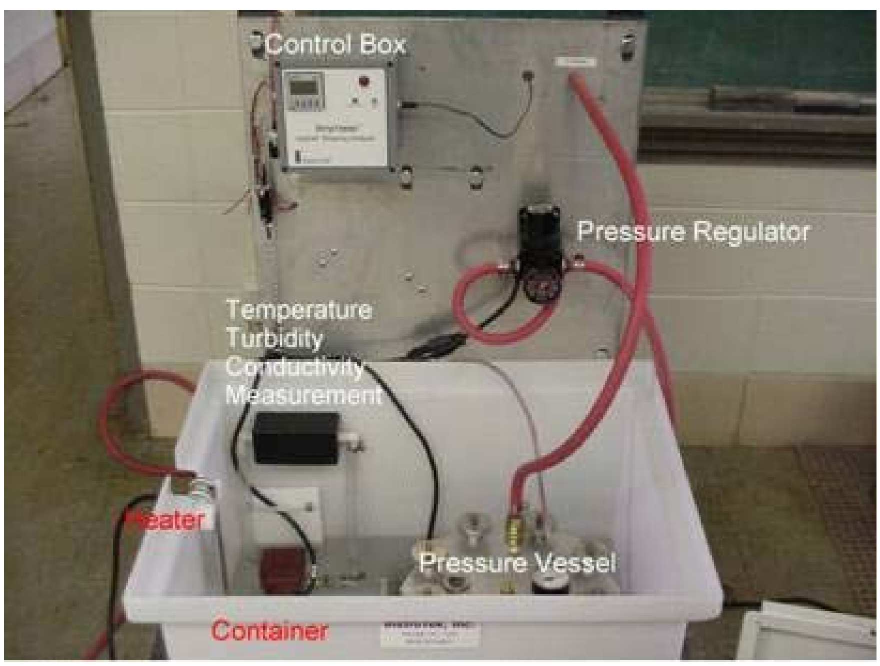


Figure 3.13 Moisture Induced Stress Tester 1

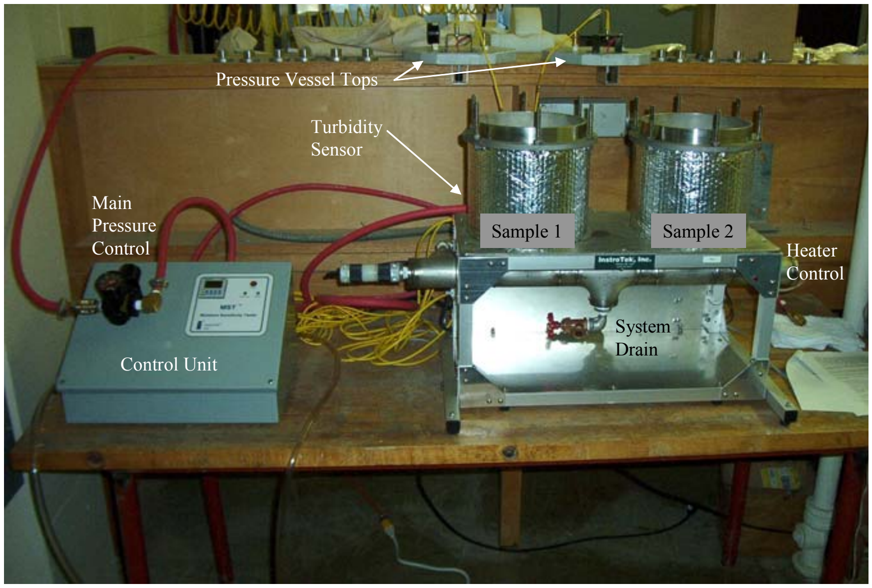


Figure 3.14 Moisture Induced Stress Tester 2

Table 3.4 summarizes various parameters for the two prototype units.

Table 3.4 Summary Table for Test Parameters

Parameter	Moisture Induced Stress Tester 1	Moisture Induced Stress Tester 2
Testing Capability	One Specimen	Two Specimens
Water Capacity	8 Gallons	4 Gallons
Rate of Evaporation	Open System	Closed System
Cycle Time	5.55 cycles / minute	8.33 cycles / minute
Footprint Size	1.49 m^2	0.38 m^2

3.1.4.1 MIST Testing Procedure

Before testing in the second MIST prototype, pressure vessels are filled with water to within 50 mm (2 in) of the vessel top and then heated for 45 minutes at 60°C (140°F). The MIST has the capability to test loose or compacted HMA specimens. When testing loose specimens, mix is placed in testing racks shown in Figure 3.15. Next, specimens, either loose or compacted, are placed in an external water bath for 45 minutes at 60°C (140°F) to reach equilibrium with the water in the vessels, as shown in Figure 3.16 for loose specimens. Specimens are then placed in the MIST for conditioning, as shown in Figure 3.17 for loose specimens. The MIST pressure and cycle timer are set on the control unit as shown in Figure 3.18. After conditioning, specimens are removed and visually examined.

In order to provide additional data, in addition to the turbidity measurements of the MIST device, two water specimens were taken before and after testing to manually evaluate turbidity [Nephlometric Turbidity Unit (NTU)] and pH using the equipment shown in Figure 3.19 and 3.20, respectively. For reference purposes, various turbidity standards are shown in Figures 3.21 (37).

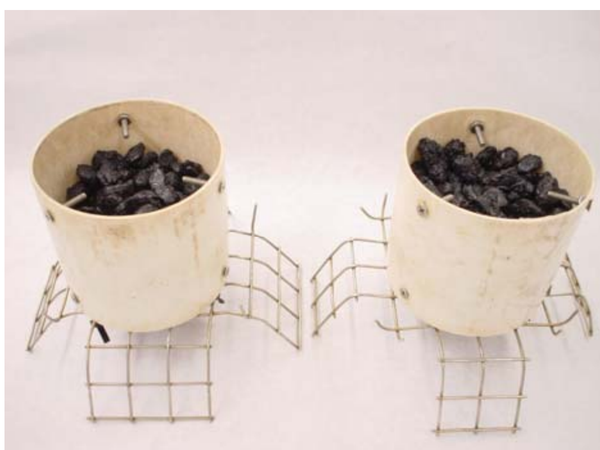


Figure 3.15 Loose HMA Specimens in Testing Rack

Figure 3.16 Loose Specimens in Water Bath

Figure 3.17 Loose Specimens in Vessel

Figure 3.18 Control Unit with Pressure Regulator and Timer

Figure 3.19 Turbidity Meter

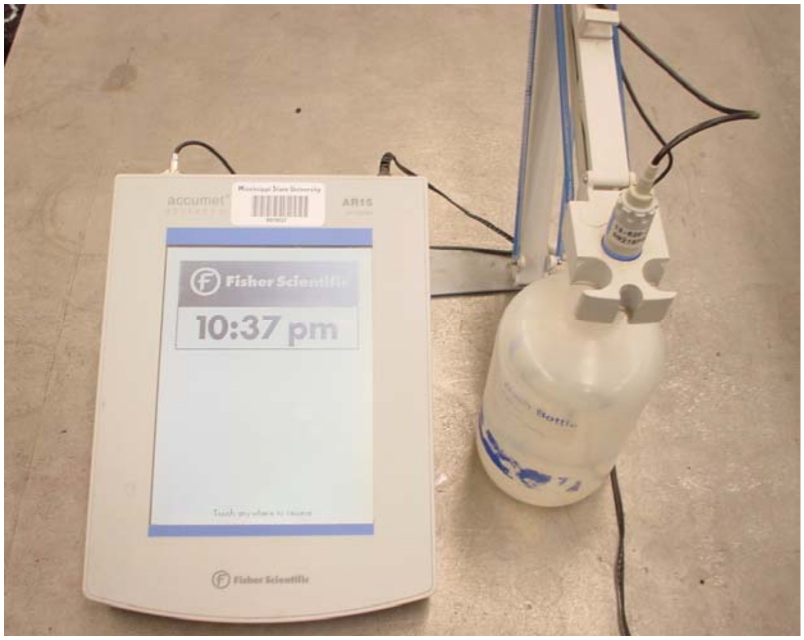


Figure 3.20 pH Meter

Figure 3.21 Turbidity Standards (1)

3.1.4.2 MIST Monitoring Procedure

Conditioning water samples are only obtained every 100 test cycles for turbidity ratio determination, however the MIST continually records turbidity ratio data throughout testing. Therefore, between sampling test cycles the same conditioning water is being tested, which results in the same turbidity ratio being determined. The end result is somewhat of a "step" relationship between test cycles and turbidity ratio with values remaining constant between 100 cycles sampling times and then changing when a "new" conditioning water sample is obtained.

During conditioning water sampling, turbulence typically exists in the water sample. This turbulence results in variable turbidity results for a number of cycles. Therefore, a standard point had to be determined at which the variability of turbidity ratio values decreased and were representative of the new conditioning water sample. The ratio value, used for analysis, was calculated as the average of the five ratio values after the last variable or "non-constant" value. An example of the method in which the MIST collected the data and how the average ratio value was calculated is shown in Table 3.5.

Once the test was complete, the turbidity ratio versus time was plotted. From the plot, the two lowest and two highest turbidity ratios were used to determine the change in turbidity ratio throughout the test. The maximum change in turbidity ratio throughout testing was used for analysis.

Table 3.5 Average Turbidity Ratio Calculation

Average Ratio	Ratio	Scattered Light	Transmitted Light
	0.2200	5423	24625
Constant Values →	0.2200	5423	24625
	0.2200	5423	24625
Nonconstant Value →	0.2960	6939	23461
	0.4390	10455	23789
	0.2450	6007	24533
	0.2920	6958	23841
(Average of 5 Values)	0.2440	5988	24491
0.2524 →	0.2420	5923	24510
	0.2420	5929	24492
	0.2420	5930	24473

CHAPTER 4 TEST RESULTS AND ANALYSIS

4.1 MIX DESIGN VOLUMETRIC PROPERTIES

As mentioned earlier, Superpave mix designs were conducted to determine design asphalt content. Superpave specimens were prepared and tested according to MT-78 (31). Hot mix asphalt (HMA) mix design volumetric properties at design asphalt content are shown in Table 4.1. Minimum VMA criteria for 12.5 and 19.0 mm NMS mixes are 14.0 and 13.0 percent, respectively. All Superpave mix designs met voids in mineral aggregate (VMA) criteria with the exception of the 19.0 mm gravel/limestone mix, which had a slightly low VMA of 12.8 percent. All Superpave mix designs met the dust/binder ratio (percent passing No. 200 sieve/effective binder percent) of 0.8 to 1.6. Stone matrix asphalt (SMA) mix designs were conducted according to MDOT MT-80 (32). All SMA designs met the minimum voids in mineral aggregate (VMA) criteria of 17 percent. Calculated film thicknesses of the Superpave mixes were slightly lower than expected, but are not unrealistic given the aggregate blends and asphalt contents. As expected, film thicknesses of the SMA mixes were substantially higher than for the Superpave mixes. Complete mix design volumetric properties for the mixes are shown in Appendix A (Tables A.1 through A.8).

Table 4.1 HMA Mix Design Volumetric Properties

Mix Type	Design Asphalt Content (%)	Gmm	Voids in Mineral Aggregate (%)	Voids Filled with Aggregate (%)	Effective Asphalt (%)	Dust / Effective Asphalt	Film Thickness (microns)
12.5 Gravel	5.90	2.311	14.4	71.5	4.70	1.25	9.12
19.0 Gravel	5.70	2.307	14.3	64.2	4.60	1.15	6.93
12.5 Gravel/Limestone	4.90	2.384	14.1	70.1	4.40	1.10	6.18
19.0 Gravel/Limestone	4.50	2.421	12.8	69.1	3.90	1.28	5.48
12.5 Gravel (SMA)	8.75	2.188	19.6	72.3	6.25	1.75	10.86
19.0 Gravel (SMA)	7.30	2.229	17.5	80.1	6.50	1.63	9.07
12.5 Gravel/Limestone (SMA)	8.50	2.282	19.3	84.3	7.10	1.40	10.29
19.0 Gravel/Limestone (SMA)	6.80	2.380	17.5	74.2	6.00	1.72	8.63

4.2 MT 59: BOILING TEST RESULTS

Approximately 100 g of loose HMA specimen was placed into a 1000 ml beaker of boiling water for 10 minutes. Specimens were then evaluated by estimating the percentage of the total aggregate visible area that retained its coating, with retained coating reported as above or below 95 percent. Test results from MT-59 testing procedure are shown in Table 4.2. All mixes tested showed less than five percent coating loss, which indicates all mixes would be non-stripping prone mixes. However, based on known stripping performance problems of some of these mixes (e.g., gravel aggregate with no anti-stripping additive); it does not appear the boil water test is able to delineate good and poor performance mix stripping performance. Possible reasons why the boil test not being capable of identifying stripping prone mixes include lack of induced pore pressure and lack of test severity or duration.

Table 4.2 Boiling Test Results

Aggregate Type	AC Type	Nominal Max Size	Additive	Retained Coating Greater than 95% (Yes/No)
Gravel	67	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
	76	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
	SMA[1]	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
Gravel/Limestone	67	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
	76	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
	SMA[1]	12.5	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes
		19.0	None	Yes
			Lime	Yes
			Lime + Liquid Additive	Yes

[1] SMA = Fiber Plus PG 76-22

4.3 MT 63 RESULTS

Six HMA specimens were compacted to a height of 95 mm (3.74 inches) at 7 ± 1 percent air voids and separated into two sets (control and conditioned) so the average air voids of the two subsets were approximately equal (7 ± 1 percent). Control set specimens were placed in a water bath at 25°C (77°F) for two hours and the indirect tensile strength determined at a loading rate 50 mm/min (2 in/min). Conditioned set specimens were vacuumed saturated, placed in a water bath at 60°C (140°F) for 24 ± 1 hour, removed and placed in a water bath at 25°C (77°F) for 2 ± 1 hour, after which their indirect tensile strength determined. Tensile strength values were determined from the equation shown below:

Tensile strength (kPa) = $[(2*P)/(\pi * d * t)] * 6.89$ Equation 4.1 (35)

where,

P = Load applied to specimen, lb,

d = Specimen diameter, in,

t = Specimen thickness, in,

6.89 = conversion from psi to kPa

Tensile strength ratio (TSR) was calculated by dividing the conditioned tensile strength by the unconditioned tensile strength. Results from MT-63 testing procedure are shown in Tables 4.3 through 4.5 and Figures 4.1 and 4.2.

The MT-63 test results were as expected with mixes with PG 67-22 asphalt binder and one-percent hydrated lime plus liquid additive having higher TSR than mixes with no lime and mixes with only one-percent hydrated lime. The higher TSR is likely due to the addition of the hydrated lime and liquid additive which increases the adhesion strength between the aggregate and asphalt binder.

For PG 76-22 asphalt binder mixes, the TSR for one-percent hydrated lime mixes is higher than that for mixes with no lime and mixes with one-percent hydrated lime plus a liquid additive. Superpave mixes with PG 76-22 showed higher TSR values than PG 67-22 mixes.

Comparison of the SMA (fibers plus PG 76-22 asphalt binder type) mixes indicates none of the antistripping agents had a significant role in effecting TSR. This is likely attributable to the increased asphalt binder film thickness and the use of the PG 76-22 asphalt binder in the SMA mixes.

Table 4.3 Indirect Tensile Strength Results (PG 67-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Conditioned / Unconditioned	Air Voids (%)	Saturation (%)	Tensile Strength (kPa)	Tensile Strength (psi)	Tensile Strength Ratio (TSR)
67	Gravel	12.5	None	Conditioned	7.5	66.7	642.4	93.2	69
				Unconditioned	7.5		926.8	134.5	
			Lime	Conditioned	7.4	70.2	698.5	101.4	82
				Unconditioned	7.4		855.3	124.1	
			Lime Plus Liquid Additive	Conditioned	7.3	68.9	843.7	122.5	96
				Unconditioned	7.3		880.9	127.9	
		19.0	None	Conditioned	7.6	72.6	644.9	93.6	76
				Unconditioned	7.6		847.5	123.0	
			Lime	Conditioned	7.5	69.8	646.6	93.9	84
				Unconditioned	7.5		773.2	112.2	
			Lime Plus Liquid Additive	Conditioned	7.8	70.6	654.1	94.9	88
				Unconditioned	7.8		740.8	107.5	
	Gravel/Limestone	12.5	None	Conditioned	6.6	72.9	689.2	100.0	62
				Unconditioned	6.6		1114.4	161.7	
			Lime	Conditioned	6.8	77.8	919.3	133.4	83
				Unconditioned	6.8		1113.4	161.6	
			Lime Plus Liquid Additive	Conditioned	6.9	78.1	865.7	125.7	87
				Unconditioned	6.9		998.9	145.0	
		19.0	None	Conditioned	7.2	69.6	756.2	109.8	67
				Unconditioned	7.1		1128.2	163.8	
			Lime	Conditioned	7.3	69.3	893.6	129.7	85
				Unconditioned	7.3		1049.4	152.3	
			Lime Plus Liquid Additive	Conditioned	7.2	68.4	856.2	124.3	87
				Unconditioned	7.2		986.2	143.1	

Table 4.4 Indirect Tensile Strength Results (PG 76-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Conditioned / Unconditioned	Air Voids (%)	Saturation (%)	Tensile Strength (kPa)	Tensile Strength (psi)	Tensile Strength Ratio (TSR)
76	Gravel	12.5	None	Conditioned	7.52	73.03	972.04	141.08	84
				Unconditioned	7.45		1155.66	167.73	
			Lime	Conditioned	7.36	71.17	948.00	137.59	92
				Unconditioned	7.22		1029.78	149.46	
			Lime Plus Liquid Additive	Conditioned	7.44	68.43	905.90	131.48	81
				Unconditioned	7.33		1121.69	162.80	
		19.0	None	Conditioned	7.42	69.04	889.02	129.03	82
				Unconditioned	7.39		1086.69	157.72	
			Lime	Conditioned	7.67	71.68	887.91	128.87	86
				Unconditioned	7.44		1036.53	150.44	
			Lime Plus Liquid Additive	Conditioned	7.40	68.31	846.71	122.89	84
				Unconditioned	7.35		1010.35	146.64	
	Gravel/Limestone	12.5	None	Conditioned	7.16	79.73	873.38	126.76	80
				Unconditioned	7.14		1092.89	158.62	
			Lime	Conditioned	6.83	75.77	1032.88	149.91	89
				Unconditioned	6.76		1158.14	168.09	
			Lime Plus Liquid Additive	Conditioned	6.92	79.04	884.26	128.34	81
				Unconditioned	6.91		1090.00	158.20	
		19.0	None	Conditioned	7.62	78.81	832.24	120.79	74
				Unconditioned	7.50		1121.07	162.71	
			Lime	Conditioned	7.31	70.88	977.35	141.85	81
				Unconditioned	7.19		1212.85	176.03	
			Lime Plus Liquid Additive	Conditioned	7.51	76.68	854.57	124.03	77
				Unconditioned	7.43		1107.98	160.81	

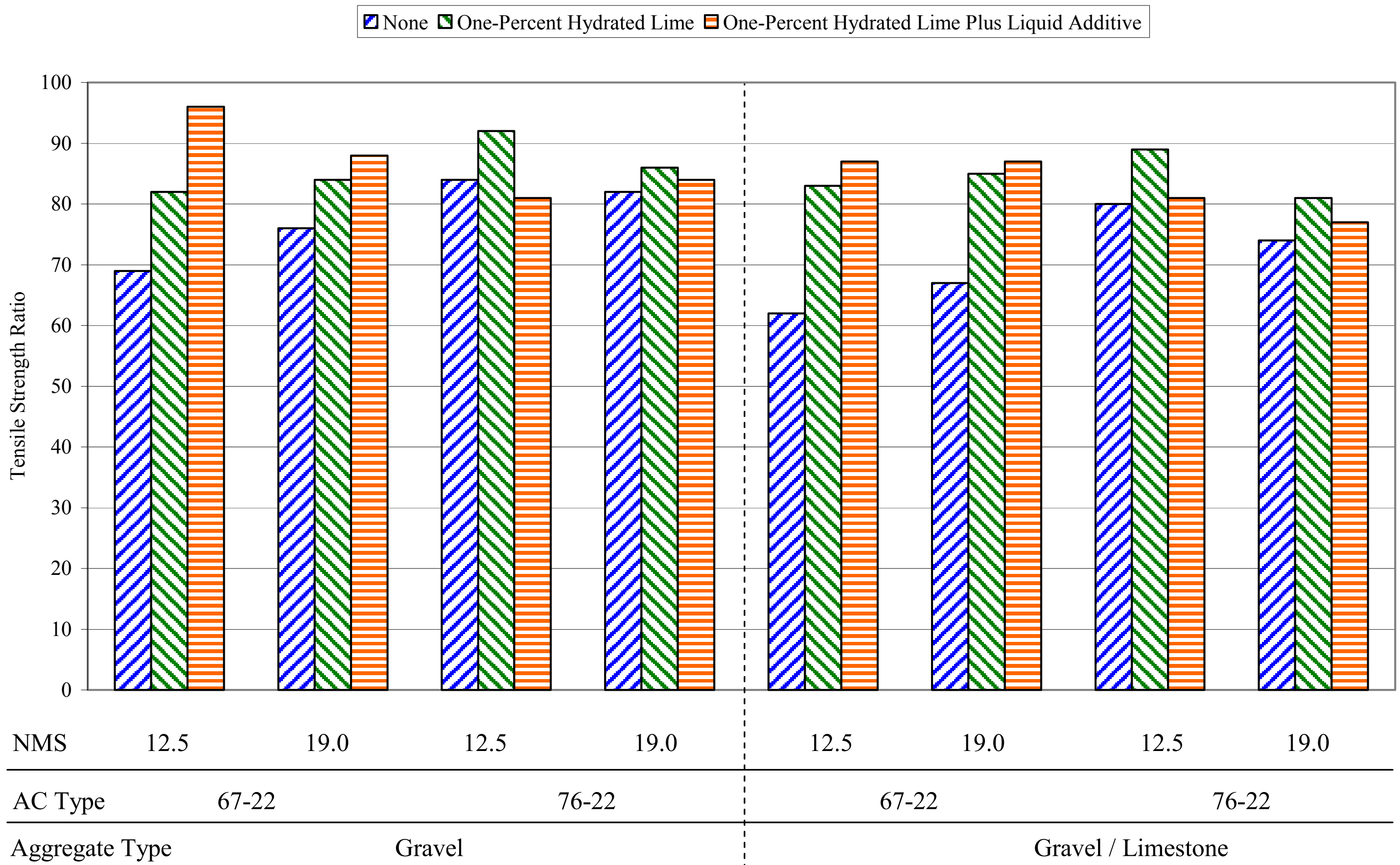
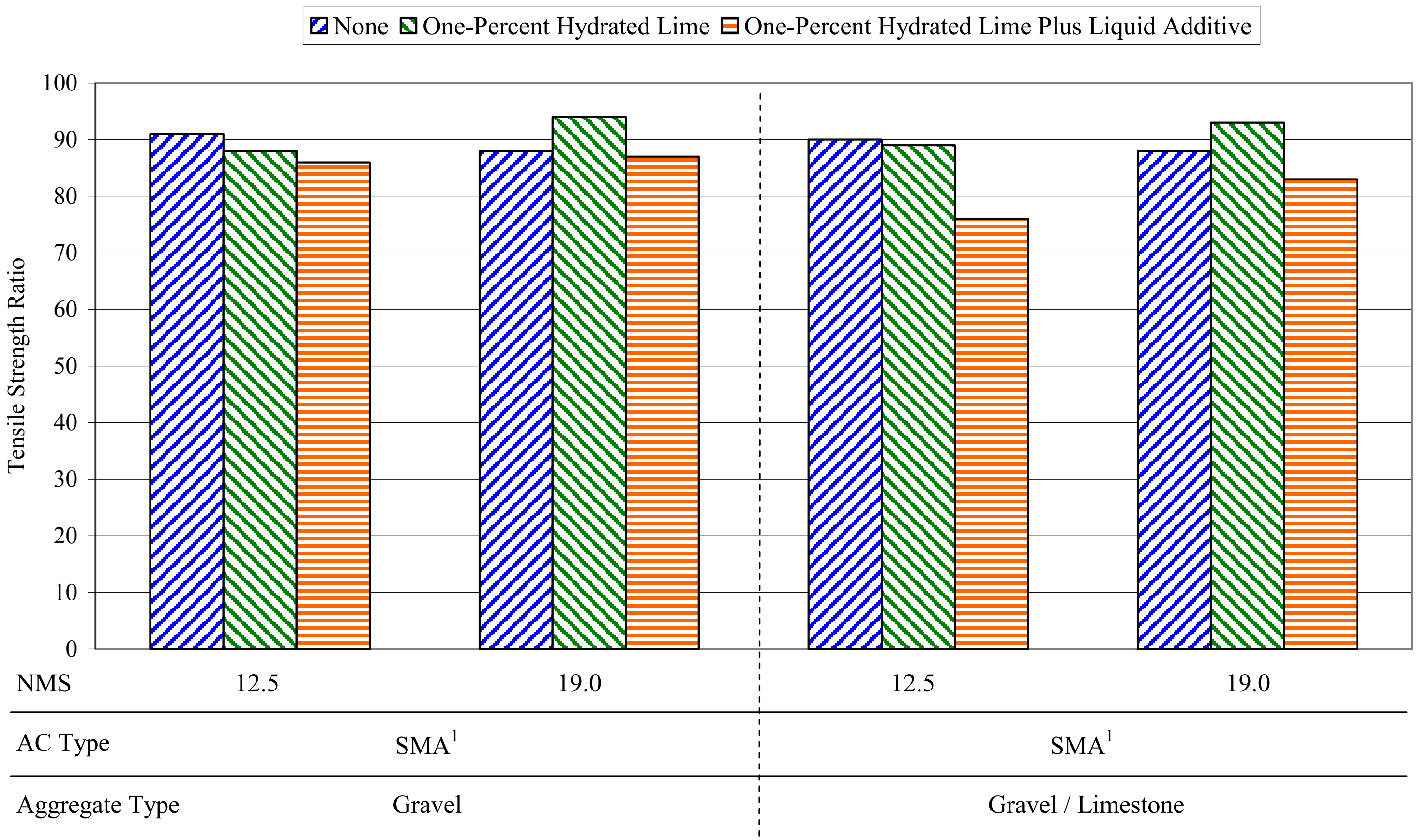


Figure 4.1 Tensile Strength Ratio Results (PG 67-22 and 76-22)

Table 4.5 Indirect Tensile Strength Results (SMA)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Conditioned / Unconditioned	Air Voids (%)	Saturation (%)	Tensile Strength (kPa)	Tensile Strength (psi)	Tensile Strength Ratio (TSR)
SMA[1]	Gravel	12.5	None	Conditioned	6.77	78.31	589.44	85.55	91
				Unconditioned	6.69		649.73	94.30	
			Lime	Conditioned	7.48	74.89	648.00	94.05	88
				Unconditioned	7.40		737.57	107.05	
			Lime Plus Liquid Additive	Conditioned	7.08	74.01	558.85	81.11	86
				Unconditioned	7.04		652.48	94.70	
		19.0	None	Conditioned	6.94	78.61	622.92	90.41	88
				Unconditioned	6.75		704.57	102.26	
			Lime	Conditioned	7.35	71.28	788.42	114.43	94
				Unconditioned	7.24		839.75	121.88	
			Lime Plus Liquid Additive	Conditioned	6.97	74.69	704.71	102.28	87
				Unconditioned	6.81		807.37	117.18	
	Gravel/Limestone	12.5	None	Conditioned	7.13	78.80	563.81	81.83	90
				Unconditioned	6.98		625.61	90.80	
			Lime	Conditioned	7.08	72.89	639.05	92.75	89
				Unconditioned	7.07		717.04	104.07	
			Lime Plus Liquid Additive	Conditioned	6.87	74.42	586.55	85.13	76
				Unconditioned	6.86		770.44	111.82	
		19.0	None	Conditioned	6.38	71.79	735.03	106.68	88
				Unconditioned	6.33		833.28	120.94	
			Lime	Conditioned	6.88	74.27	667.09	96.82	93
				Unconditioned	6.86		717.66	104.16	
			Lime Plus Liquid Additive	Conditioned	6.45	72.72	727.52	105.59	83
				Unconditioned	6.37		876.27	127.18	



[1] SMA = Fiber Plus PG 76-22

Figure 4.2 Tensile Strength Ratio Results (SMA)

4.4 Preliminary MIST Testing: Phase 1

Two testing phases were involved in the preliminary evaluation of the MIST. Phase 1 was conducted initially and consisted of evaluating compacted HMA specimens to determine appropriate test parameters. Various pressures and test cycles were evaluated different mixes to see if trends were evident from the results.

Initial testing was conducted on 12.5 mm gravel with no lime to evaluate the effect of test cycles (500, 750, and 1000 cycles) on turbidity ratio. Results are shown in Table 4.6 and Figure 4.3 and clearly show an increase in turbidity ratio with an increase in number of test cycles. An increase in turbidity ratio indicates some form of stripping has occurred.

Testing was conducted on 12.5 mm gravel/limestone mixes with no lime to evaluate the effect of test pressures [207, 345, and 482 kPa (30, 50, and 70 psi)] on turbidity ratio. Results are shown in Table 4.6 and Figure 4.4 and indicate an increase in turbidity ratio with an increase in pressure. Evaluated test pressures resulted in approximately the same TSR value.

Testing was also conducted on 19.0 mm gravel mixes with no lime to evaluate the effect of test cycles (500, 750, and 1000 cycles) on turbidity ratio. Results are shown in Table 4.6 and Figure 4.5 and clearly show an increase in turbidity ratio with an increase in test cycles. Contrary to the 12.5 mm gravel results, the TSR values were approximately equivalent for all test cycles.

It was decided to test the 19.0 gravel/limestone mix with no lime at 482 kPa (70 psi) and 1000 test cycles because those parameters seemed to have the highest increase in turbidity ratio. Results are shown in Table 4.6 and Figure 4.6 and indicate the average change in turbidity ratio was approximately 0.146.

A comparison was also conducted on 12.5 mm gravel with and without lime and the 19.0 mm gravel with and without lime at a pressure of 482 kPa (70 psi) and 1000 test cycles. Results are shown in Table 4.6 and Figures 4.7 through 4.8. The average change in turbidity ratio for the 12.5 mm mix with no lime was 0.141 compared to 0.079 with lime. Contrary to the 12.5 mm mix, the turbidity ratio for the 19.0 mm with lime (0.158) was higher than without lime (0.129).

Table 4.6 Preliminary Evaluation Test Results (Phase 1) – Compacted Specimens

Mix	Avg. Air Voids at Start	Avg. Air Voids at End	Air Void Change	Specimen Height (mm)	Conditioning		Maximum Turbidity Ratio	Minimum Turbidity Ratio	Turbidity Ratio Difference	MIST TSR	T283 TSR
					Pressure (kPa)	Cycles					
12.5 Gravel, 67-22, none	7.32	8.69	-1.37	95	482	1000	0.372	0.205	0.167	90	69
12.5 Gravel, 67-22, none	7.34	7.88	-0.54	95	482	750	0.286	0.206	0.080	79	69
12.5 Gravel, 67-22, none	7.28	8.33	-1.05	95	482	500	0.265	0.200	0.065	70	69
12.5 Gravel/LMS, 67-22, none	6.82	8.30	-1.48	95	242	1000	0.183	0.138	0.045	71	62
12.5 Gravel/LMS, 67-22, none	6.28	8.37	-2.09	95	345	1000	0.220	0.150	0.070	72	62
12.5 Gravel/LMS, 67-22, none	6.32	8.31	-1.99	95	482	1000	0.299	0.144	0.155	72	62
19.0 Gravel, 67-22, none	7.48	8.80	-1.32	95	482	1000	0.345	0.208	0.137	74	76
19.0 Gravel, 67-22, none	7.24	8.16	-0.92	95	482	750	0.337	0.197	0.140	70	76
19.0 Gravel, 67-22, none	7.42	8.04	-0.62	95	482	500	0.262	0.196	0.066	73	76
19.0 Gravel/LMS, 67-22, none	6.90	7.80	-0.90	95	482	1000	0.325	0.203	0.122	80	67
19.0 Gravel/LMS, 67-22, none	6.83	8.11	-1.28	95	482	1000	0.381	0.209	0.172	71	67
19.0 Gravel/LMS, 67-22, none	7.05	8.24	-1.19	95	482	1000	0.354	0.208	0.146	65	67
12.5 Gravel, 67-22, none	7.03	8.31	-1.28	55	482	1000	0.373	0.205	0.168	90	69
12.5 Gravel, 67-22, none	7.03	8.30	-1.27	55	482	1000	0.334	0.221	0.114	75	69
12.5 Gravel, 67-22, with lime	7.04	7.37	-0.33	55	482	1000	0.274	0.206	0.068	81	82
12.5 Gravel, 67-22, with lime	6.90	7.35	-0.45	55	482	1000	0.284	0.195	0.089	90	82
19.0 Gravel, 67-22, none	7.14	7.91	-0.77	55	482	1000	0.345	0.204	0.141	74	76
19.0 Gravel, 67-22, none	6.99	7.91	-0.92	55	482	1000	0.326	0.209	0.117	64	76
19.0 Gravel, 67-22, with lime	7.30	7.64	-0.34	55	482	1000	0.380	0.200	0.180	61	84
19.0 Gravel, 67-22, with lime	6.78	7.42	-0.64	55	482	1000	0.333	0.198	0.135	65	84

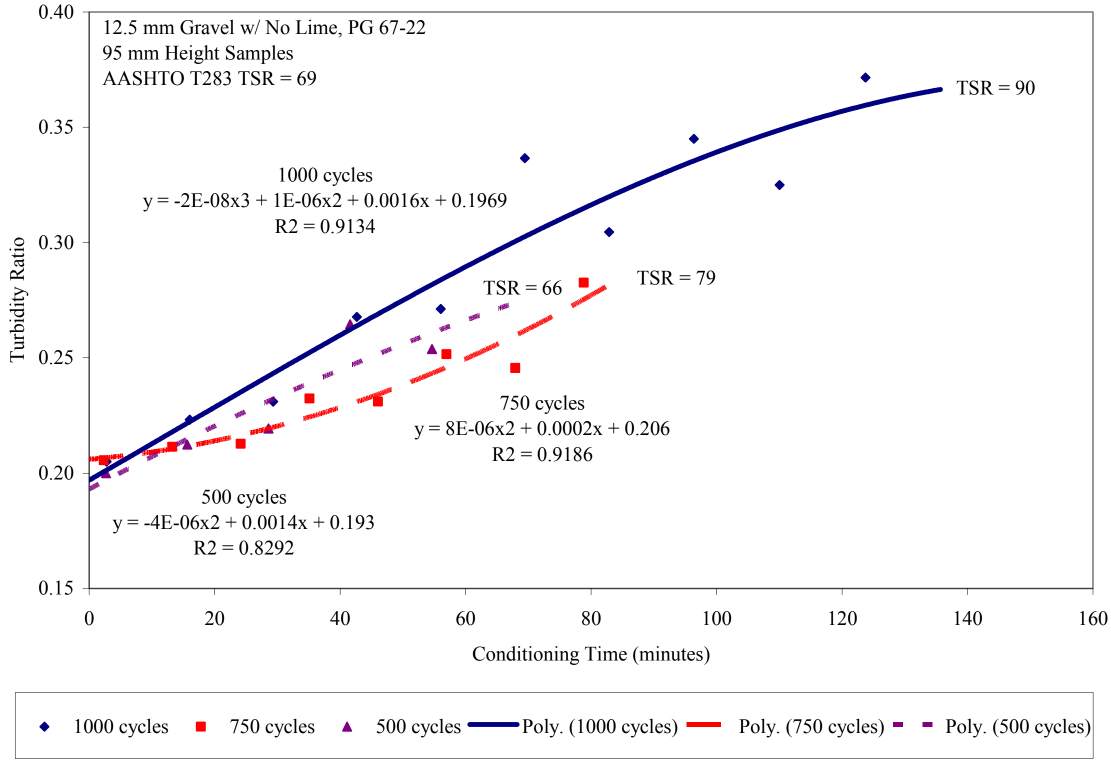


Figure 4.3 12.5 mm Gravel - None – Compacted Specimens - Preliminary Evaluation

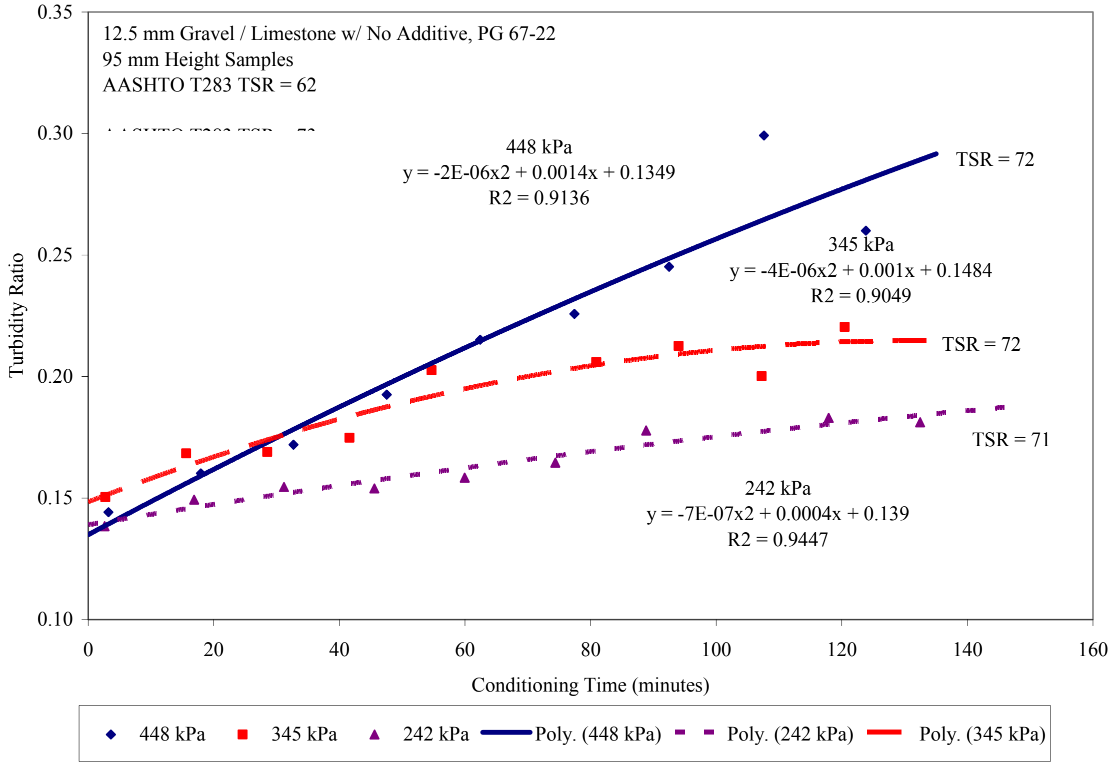


Figure 4.4 12.5 mm Gravel/Limestone - None – Compacted Specimens - Preliminary Evaluation

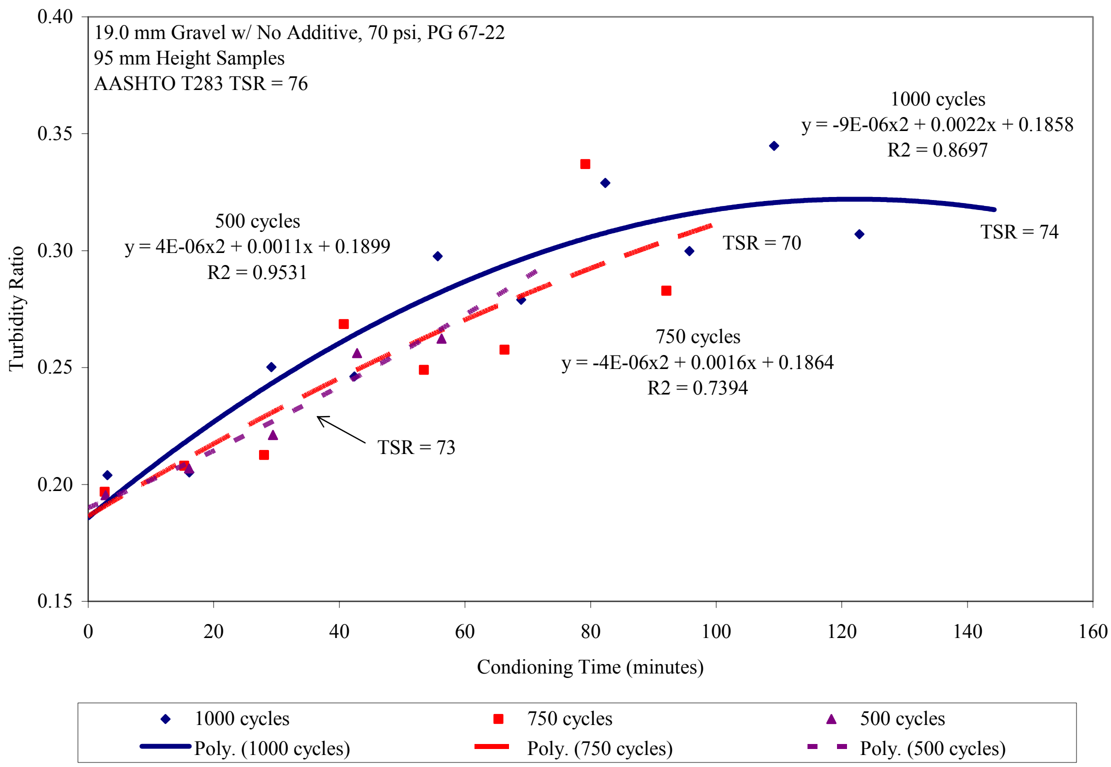


Figure 4.5 19.0 mm Gravel - None – Compacted Specimens - Preliminary Evaluation

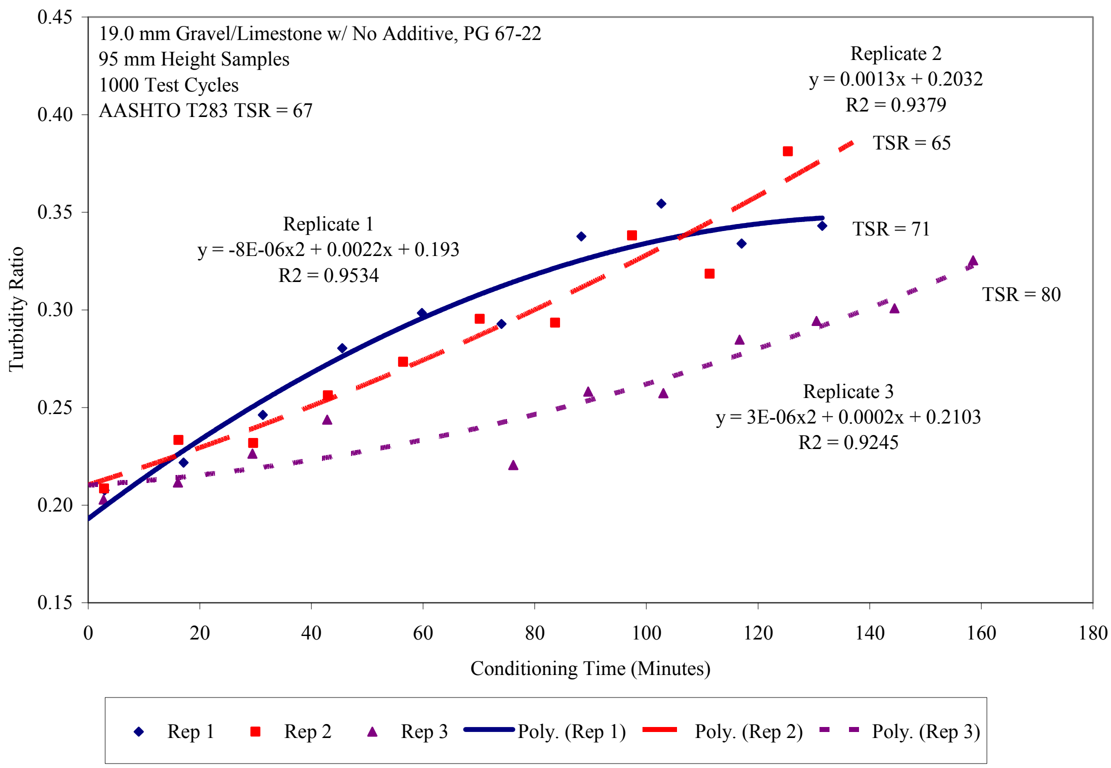


Figure 4.6 19.0 mm Gravel/Limestone – None – Compacted Specimens - Preliminary Evaluation

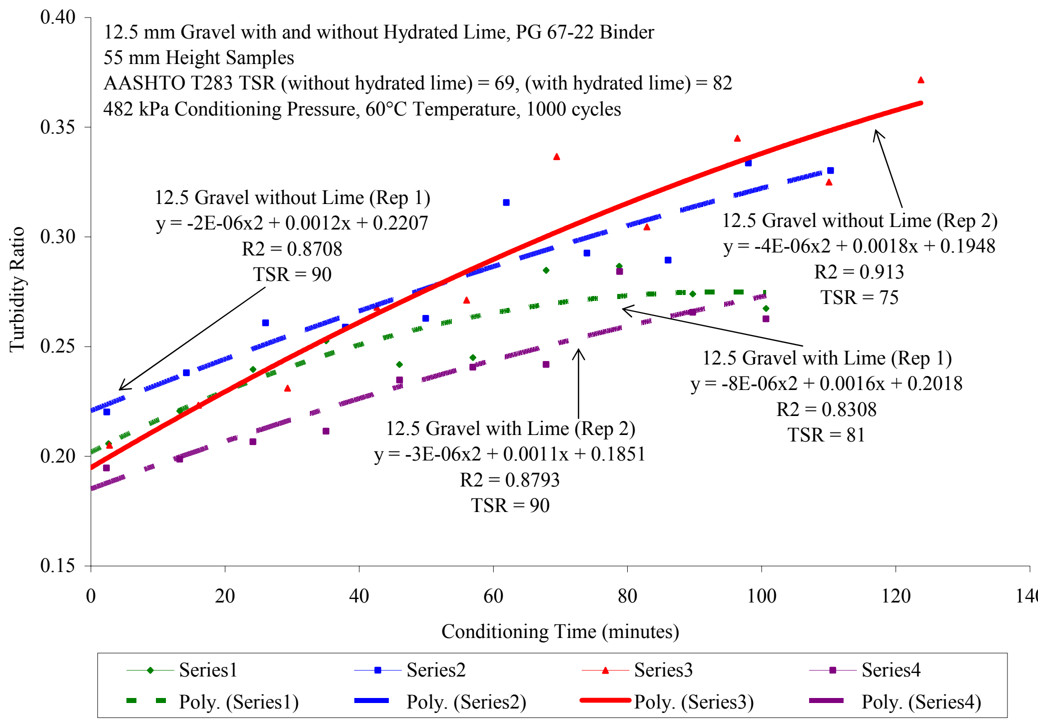


Figure 4.7 12.5 mm Gravel – With and Without Lime – Compacted Specimens - Preliminary Evaluation

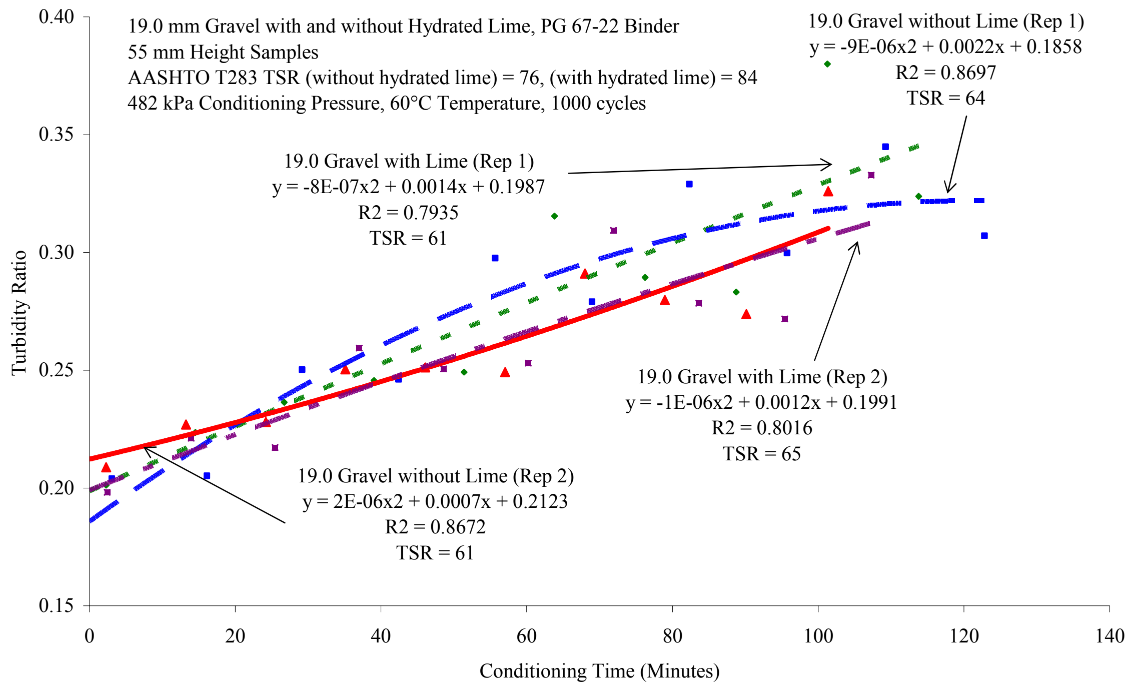


Figure 4.8 19.0 mm Gravel – With and Without Lime – Compacted Specimens - Preliminary Evaluation

In summary, Phase 1 testing indicated an increase of turbidity ratio for almost all mixes with an increase in number of test cycles and test pressure. Tensile strength data from the MIST did not follow the same trend as results from T-283. A possible explanation is MIST specimens deformed during conditioning due to the applied water pressure. This specimen deformation is likely to have resulted in a loss of specimen integrity, thus the true tensile strength was not able to be determined.

4.5 Preliminary MIST Testing: Phase 2

Phase 2 of the preliminary evaluation involved tests of loose HMA specimens. Loose specimens were evaluated because the Phase 1 results proved it would be difficult to impossible to correlate TSR from T63 to TSR from MIST. Mixes tested were 12.5 mm (1/2 inch) gravel with no additive at pressures of 207 kPa (30 psi) and 482 kPa (70 psi) and test cycles of 1000, 3000, and 5000. Results are shown in Table 4.7 and Figures 4.9 through 4.11. Results indicated the turbidity ratio increased for approximately 2000 cycles and then typically held constant for the next 3000 cycles.

Table 4.7 Preliminary Evaluation Test Results (Phase 2) – Loose Specimens

Mix Type	Pressure (kPa)	Number of Cycles	Low Ratio (1)	Low Ratio (2)	Average	High Ratio (1)	High Ratio (2)	Average	Difference
12.5 Gravel, 67-22, None	206	1000	0.2012	0.2028	0.2020	0.2074	0.2040	0.2057	0.0037
			0.1952	0.2023	0.1988	0.2068	0.2085	0.2077	0.0089
		3000	0.1667	0.1678	0.1673	0.1780	0.1724	0.1752	0.0079
			0.1874	0.1911	0.1893	0.1978	0.2015	0.1997	0.0104
		10000	0.1936	0.1968	0.1952	0.2102	0.2204	0.2153	0.0201
			0.1876	0.1953	0.1915	0.2146	0.2198	0.2172	0.0258
	482	1000	0.1680	0.1798	0.1739	0.2050	0.2110	0.2080	0.0341
			0.2202	0.2380	0.2291	0.2510	0.2564	0.2537	0.0246
		3000	0.1728	0.1876	0.1802	0.2506	0.2504	0.2505	0.0703
			0.1834	0.1965	0.1900	0.2464	0.2621	0.2543	0.0643
		10000	0.1920	0.1944	0.1932	0.2528	0.2540	0.2534	0.0602
			0.1852	0.1898	0.1875	0.2631	0.2742	0.2687	0.0812

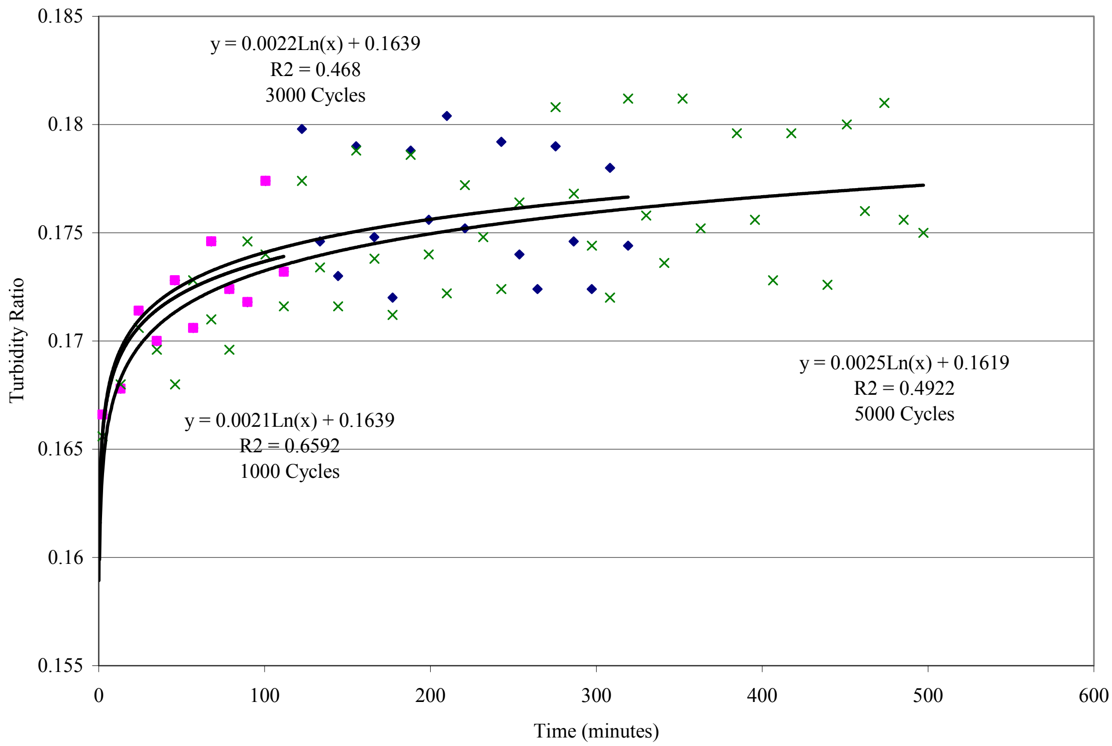


Figure 4.9 12.5 mm Gravel – 206 kPa (30 psi) – None – Loose Specimens - Preliminary Evaluation

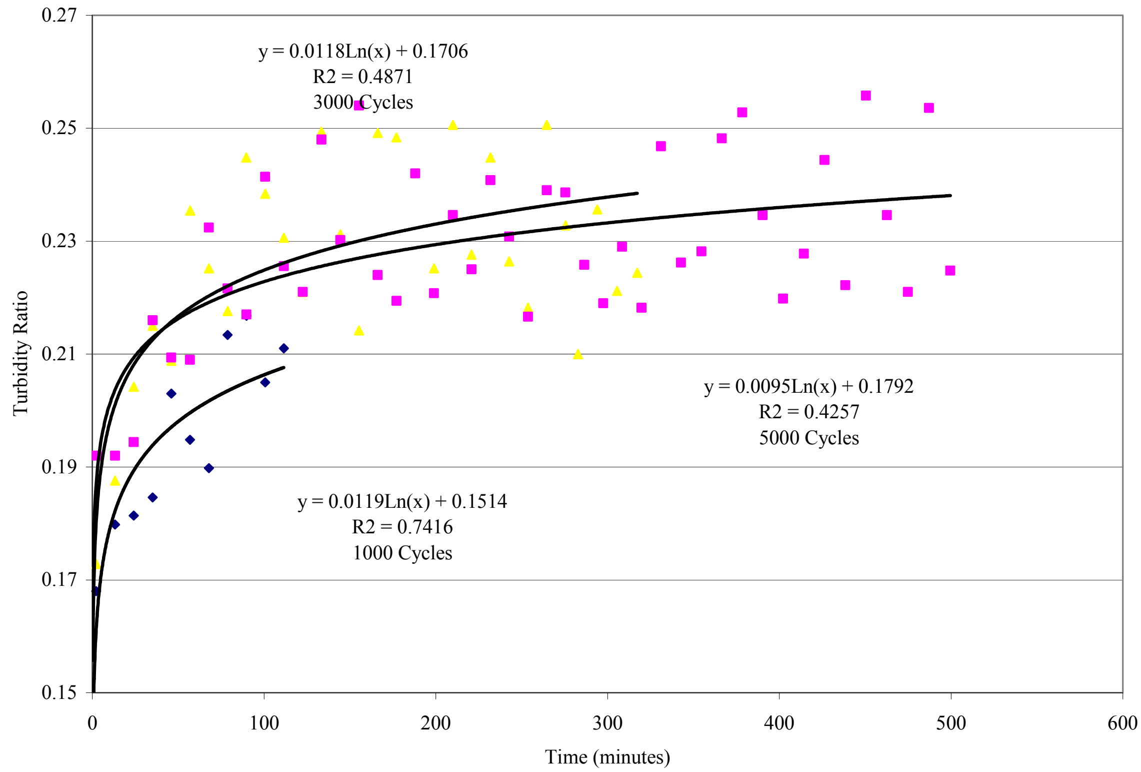


Figure 4.10 12.5 mm Gravel – 482 kPa (70 psi) – None – Loose Specimens - Preliminary Evaluation

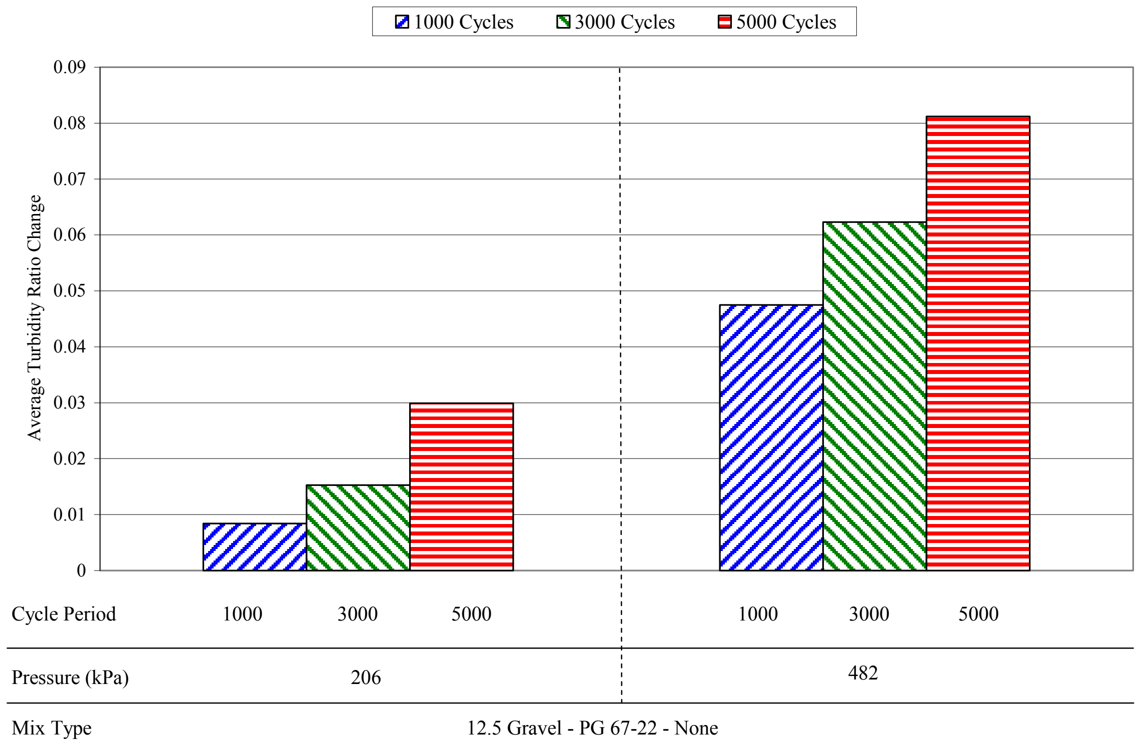


Figure 4.11 Preliminary Evaluation (Phase 2) Test Results – Loose Specimens

4.6 MIST Final Laboratory Evaluation

Once the preliminary evaluation was complete, test parameters were selected which consisted of testing loose specimens for each mix design for 2000 cycles (approximately 240 minutes) at a pressure of 482 kPa (70 psi). Loose specimens were selected for three primary reasons: 1) preliminary results indicated the same change in turbidity ratio could be achieved without having to compact specimens, 2) testing of loose specimens would decrease the time necessary to perform a quality control test, and 3) TSR results from compacted specimens conditioned in MIST did not follow the same trend as results from T63.

After each test was complete, the average low and high turbidity ratio values were calculated and are shown in Tables 4.8 through 4.10 and Figures 4.12 and 4.13. In addition to the turbidity ratio obtained from the computer, manual turbidity measurements were taken before and after testing and are shown in Tables 4.11 through 4.13 and Figures 4.14 and 4.15. Finally, the water pH before and after testing was measured and is shown in Tables 4.14 through 4.16 and Figures 4.16 and 4.17. Results will be discussed in the statistical analysis section, later in this chapter.

Table 4.8 Average Turbidity Ratio Difference (PG 67-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity Ratio (1)	Low Turbidity Ratio (2)	Average	High Turbidity Ratio (1)	High Turbidity Ratio (2)	Average	Difference
67	Gravel	12.5	None	0.1732	0.1904	0.1818	0.2414	0.2368	0.2391	0.0573
				0.1728	0.1846	0.1787	0.2506	0.2494	0.2500	0.0713
			Lime	0.2524	0.2692	0.2608	0.3984	0.3916	0.3950	0.1342
				0.2462	0.2502	0.2482	0.4986	0.4996	0.4991	0.2509
			Lime Plus Liquid Additive	0.2890	0.3492	0.3191	0.5678	0.5438	0.5558	0.2367
				0.2472	0.2624	0.2548	0.4034	0.3932	0.3983	0.1435
		19.0	None	0.1764	0.1916	0.1840	0.2388	0.2328	0.2358	0.0518
				0.1782	0.1894	0.1838	0.2472	0.2458	0.2465	0.0627
			Lime	0.2374	0.2480	0.2427	0.4054	0.3792	0.3923	0.1496
				0.2460	0.2520	0.2490	0.4720	0.4670	0.4695	0.2205
			Lime Plus Liquid Additive	0.2486	0.2782	0.2634	0.4665	0.4540	0.4603	0.1969
				0.2422	0.2628	0.2525	0.4526	0.4510	0.4518	0.1993
	Gravel/Limestone	12.5	None	0.1978	0.1978	0.1978	0.3298	0.3154	0.3226	0.1248
				0.2544	0.2544	0.2544	0.4844	0.4796	0.4820	0.2276
			Lime	0.2814	0.2814	0.2814	0.5092	0.5008	0.5050	0.2236
				0.2662	0.2662	0.2662	0.4496	0.4402	0.4449	0.1787
			Lime Plus Liquid Additive	0.2602	0.3066	0.2834	0.4852	0.4492	0.4672	0.1838
				0.2338	0.2464	0.2401	0.4224	0.4212	0.4218	0.1817
		19.0	None	0.2404	0.2470	0.2437	0.4080	0.4024	0.4052	0.1615
				0.2468	0.2558	0.2513	0.4620	0.4556	0.4588	0.2075
			Lime	0.2376	0.2574	0.2475	0.5078	0.4960	0.5019	0.2544
				0.2456	0.2526	0.2491	0.4680	0.4602	0.4641	0.2150
			Lime Plus Liquid Additive	0.2360	0.2646	0.2503	0.4274	0.4228	0.4251	0.1748
				0.2396	0.2582	0.2489	0.4832	0.4271	0.4552	0.2063

Table 4.9 Average Turbidity Ratio Difference (PG 76-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity Ratio (1)	Low Turbidity Ratio (2)	Average	High Turbidity Ratio (1)	High Turbidity Ratio (2)	Average	Difference
76	Gravel	12.5	None	0.2244	0.2242	0.2243	0.2838	0.2842	0.2840	0.0597
				0.2256	0.2330	0.2293	0.3390	0.3382	0.3386	0.1093
			Lime	0.2394	0.2490	0.2442	0.4908	0.4364	0.4636	0.2194
				0.2400	0.2496	0.2448	0.4188	0.4018	0.4103	0.1655
			Lime Plus Liquid Additive	0.2406	0.2622	0.2514	0.4448	0.4538	0.4493	0.1979
				0.2402	0.2610	0.2506	0.4752	0.4464	0.4608	0.2102
		19.0	None	0.2564	0.2490	0.2527	0.4814	0.4706	0.4760	0.2233
				0.2128	0.2242	0.2185	0.3656	0.3638	0.3647	0.1462
			Lime	0.2400	0.2506	0.2453	0.4800	0.4018	0.4409	0.1956
				0.2400	0.2688	0.2544	0.4708	0.4430	0.4569	0.2025
			Lime Plus Liquid Additive	0.2342	0.2504	0.2423	0.4658	0.4764	0.4711	0.2288
				0.2476	0.2580	0.2528	0.4716	0.4630	0.4673	0.2145
	Gravel/Limestone	12.5	None	0.2150	0.2244	0.2197	0.3996	0.3600	0.3798	0.1601
				0.2438	0.2510	0.2474	0.5052	0.4904	0.4978	0.2504
			Lime	0.2382	0.2510	0.2446	0.4548	0.4578	0.4563	0.2117
				0.2444	0.2532	0.2488	0.4438	0.4472	0.4455	0.1967
			Lime Plus Liquid Additive	0.2410	0.2552	0.2481	0.4904	0.4770	0.4837	0.2356
				0.2392	0.2424	0.2408	0.4710	0.4552	0.4631	0.2223
		19.0	None	0.2444	0.2528	0.2486	0.5008	0.5126	0.5067	0.2581
				0.2174	0.2238	0.2206	0.4266	0.4174	0.4220	0.2014
			Lime	0.2402	0.2636	0.2519	0.4788	0.4708	0.4748	0.2229
				0.2390	0.2534	0.2462	0.4626	0.4538	0.4582	0.2120
			Lime Plus Liquid Additive	0.2374	0.2536	0.2455	0.4762	0.4798	0.4780	0.2325
				0.2394	0.2606	0.2500	0.4576	0.4398	0.4487	0.1987

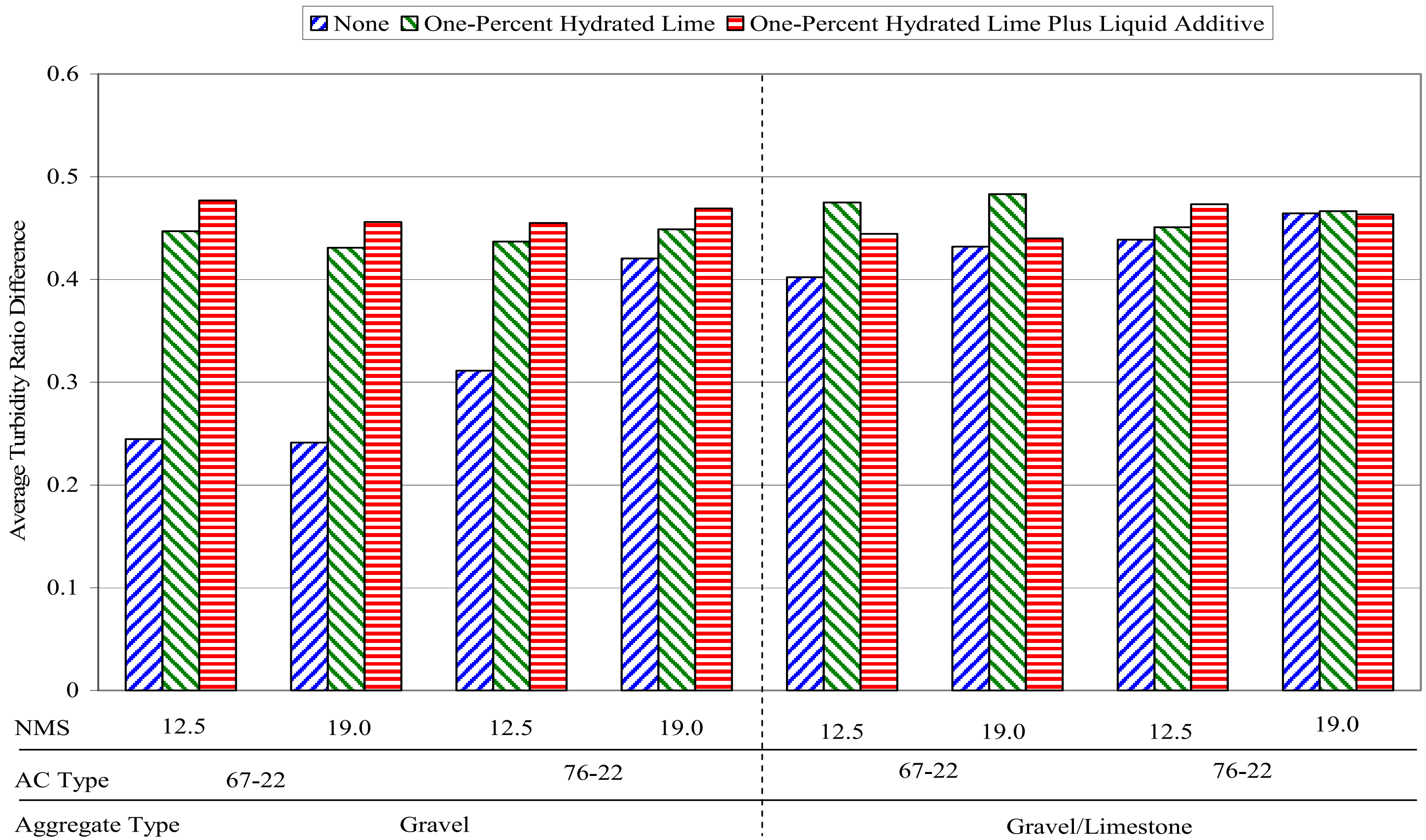


Figure 4.12 Average Turbidity Ratio Difference (PG 67-22 and 76-22)

Table 4.10 Average Turbidity Ratio Difference (SMA)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity Ratio (1)	Low Turbidity Ratio (2)	Average	High Turbidity Ratio (1)	High Turbidity Ratio (2)	Average	Difference
SMA[1]	Gravel	12.5	None	0.2484	0.2506	0.2495	0.4616	0.4572	0.4594	0.2099
				0.2390	0.2460	0.2425	0.4438	0.4656	0.4547	0.2122
			Lime	0.2390	0.2530	0.2460	0.4936	0.4810	0.4873	0.2413
				0.2414	0.2518	0.2466	0.4458	0.4422	0.4440	0.1974
			Lime Plus Liquid Additive	0.2402	0.2532	0.2467	0.4656	0.4692	0.4674	0.2207
				0.2416	0.2636	0.2526	0.4850	0.4748	0.4799	0.2273
		19.0	None	0.2470	0.2534	0.2502	0.4616	0.4556	0.4586	0.2084
				0.2554	0.2552	0.2553	0.4592	0.4578	0.4585	0.2032
			Lime	0.2424	0.2486	0.2455	0.4676	0.4604	0.4640	0.2185
				0.2432	0.2626	0.2529	0.4980	0.4882	0.4931	0.2402
			Lime Plus Liquid Additive	0.2478	0.2464	0.2471	0.4688	0.4568	0.4628	0.2157
				0.2428	0.2496	0.2462	0.4672	0.4488	0.4580	0.2118
	Gravel/Limestone	12.5	None	0.2464	0.2548	0.2506	0.4848	0.4800	0.4824	0.2318
				0.2420	0.2540	0.2480	0.4580	0.4568	0.4574	0.2094
			Lime	0.2362	0.2448	0.2405	0.4638	0.4530	0.4584	0.2179
				0.2396	0.2508	0.2452	0.4596	0.4460	0.4528	0.2076
			Lime Plus Liquid Additive	0.2426	0.2614	0.2520	0.4690	0.4636	0.4663	0.2143
				0.2374	0.2466	0.2420	0.4904	0.4856	0.4880	0.2460
		19.0	None	0.2466	0.2622	0.2544	0.4968	0.4902	0.4935	0.2391
				0.2462	0.2512	0.2487	0.4844	0.4780	0.4812	0.2325
			Lime	0.2438	0.2530	0.2484	0.4868	0.4786	0.4827	0.2343
				0.2382	0.2488	0.2435	0.4790	0.4696	0.4743	0.2308
			Lime Plus Liquid Additive	0.2476	0.2598	0.2537	0.4842	0.4826	0.4834	0.2297
				0.2466	0.2622	0.2544	0.4754	0.4564	0.4659	0.2115

[1] SMA = Fiber Plus PG 76-22

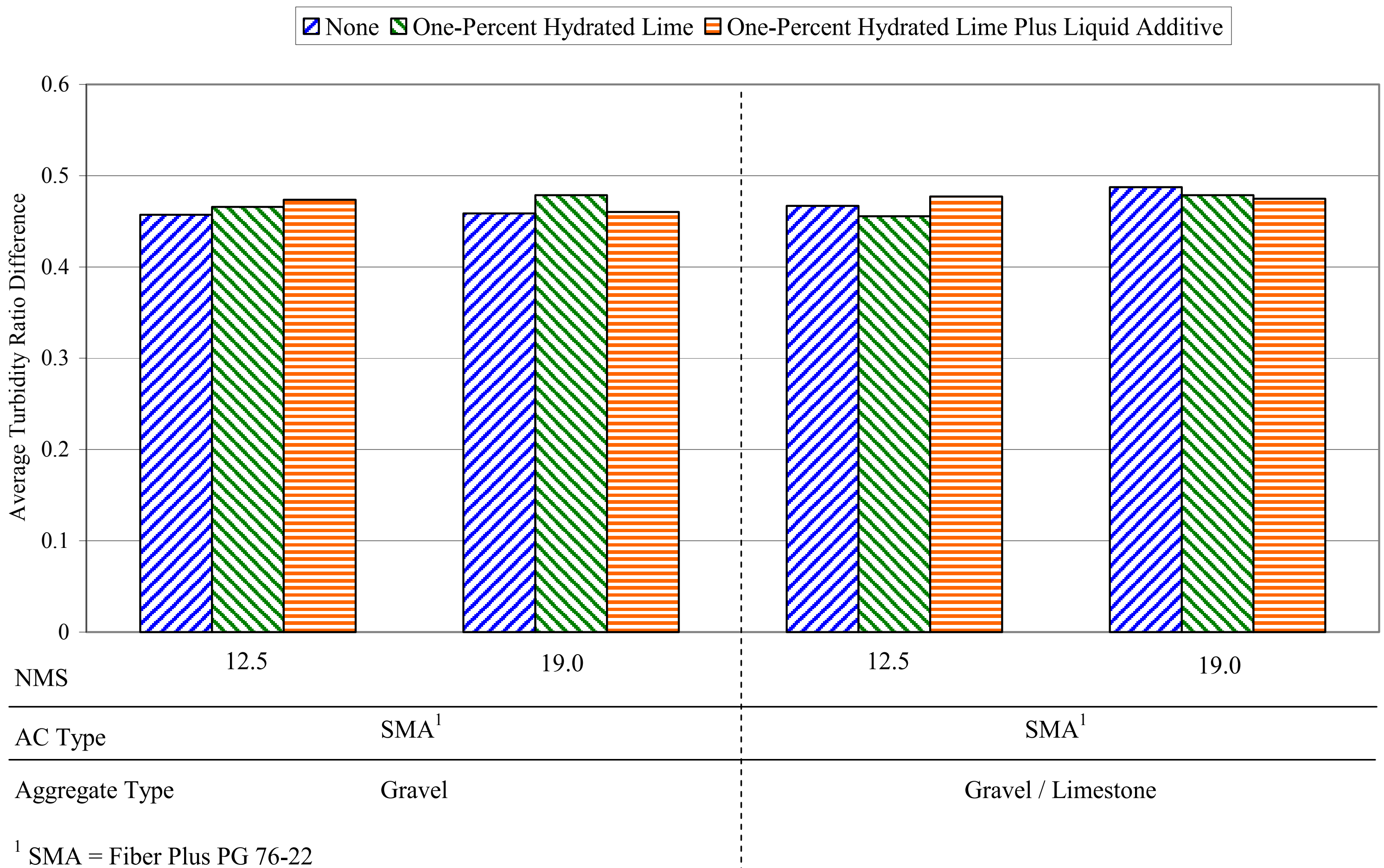


Figure 4.13 Average Turbidity Ratio Difference (SMA)

Table 4.11 Average Turbidity Difference (PG 67-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity (1) (NTU)	Low Turbidity (2) (NTU)	Average	High Turbidity (1) (NTU)	High Turbidity (2) (NTU)	Average	Difference
67	Gravel	12.5	None	0.40	0.40	0.40	3.50	3.40	3.45	3.05
				0.90	0.80	0.85	2.50	2.60	2.55	1.70
			Lime	0.69	0.73	0.71	1.80	1.60	1.70	0.99
				1.10	0.70	0.90	1.60	1.50	1.55	0.65
			Lime Plus Liquid Additive	0.65	0.55	0.60	4.30	3.60	3.95	3.35
				0.50	0.60	0.55	2.40	2.50	2.45	1.90
		19.0	None	0.30	0.40	0.35	1.40	1.10	1.25	0.90
				1.20	0.80	1.00	1.60	1.70	1.65	0.65
			Lime	1.30	1.30	1.30	5.40	4.50	4.95	3.65
				1.60	1.50	1.55	2.40	3.10	2.75	1.20
			Lime Plus Liquid Additive	0.60	0.60	0.60	1.80	1.90	1.85	1.25
				0.50	0.50	0.50	1.90	1.50	1.70	1.20
	Gravel/Limestone	12.5	None	0.60	0.70	0.65	2.10	2.20	2.15	1.50
				0.40	0.40	0.40	4.00	4.20	4.10	3.70
			Lime	0.80	0.90	0.85	3.50	3.20	3.35	2.50
				0.90	0.80	0.85	2.20	2.00	2.10	1.25
			Lime Plus Liquid Additive	0.80	0.43	0.62	1.70	1.60	1.65	1.04
				0.40	0.40	0.40	1.60	1.70	1.65	1.25
		19.0	None	1.10	0.80	0.95	2.30	2.30	2.30	1.35
				0.80	0.70	0.75	1.90	1.60	1.75	1.00
			Lime	0.90	0.80	0.85	2.20	2.00	2.10	1.25
				1.40	1.00	1.20	1.50	1.60	1.55	0.35
			Lime Plus Liquid Additive	0.50	0.40	0.45	1.60	1.80	1.70	1.25
				0.70	0.80	0.75	1.80	1.70	1.75	1.00

Table 4.12 Average Turbidity Difference (PG 76-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity (1) (NTU)	Low Turbidity (2) (NTU)	Average	High Turbidity (1) (NTU)	High Turbidity (2) (NTU)	Average	Difference
76	Gravel	12.5	None	0.60	0.80	0.70	2.60	2.50	2.55	1.85
				0.35	0.45	0.40	2.60	2.54	2.57	2.17
			Lime	0.50	0.60	0.55	4.00	4.00	4.00	3.45
				0.50	0.60	0.55	2.80	2.80	2.80	2.25
			Lime Plus Liquid Additive	0.50	0.60	0.55	1.20	0.90	1.05	0.50
				0.60	0.70	0.65	1.50	1.50	1.50	0.85
		19.0	None	0.60	0.70	0.65	1.97	2.11	2.04	1.39
				0.80	0.80	0.80	2.00	1.63	1.82	1.02
			Lime	0.80	0.60	0.70	1.40	1.30	1.35	0.65
				0.40	0.50	0.45	1.80	2.00	1.90	1.45
			Lime Plus Liquid Additive	0.80	0.60	0.70	1.70	1.50	1.60	0.90
				0.70	0.70	0.70	1.50	1.40	1.45	0.75
	Gravel/Limestone	12.5	None	0.90	0.90	0.90	2.00	1.80	1.90	1.00
				0.73	0.75	0.74	1.20	1.26	1.23	0.49
			Lime	0.50	0.50	0.50	1.70	1.50	1.60	1.10
				0.60	0.50	0.55	2.20	1.80	2.00	1.45
			Lime Plus Liquid Additive	0.70	0.60	0.65	2.30	2.10	2.20	1.55
				0.70	0.70	0.70	2.00	1.60	1.80	1.10
		19.0	None	0.50	0.47	0.49	1.70	1.50	1.60	1.12
				0.37	0.39	0.38	2.70	2.50	2.60	2.22
			Lime	0.50	0.70	0.60	1.10	1.20	1.15	0.55
				0.50	0.50	0.50	1.70	1.30	1.50	1.00
			Lime Plus Liquid Additive	0.90	1.00	0.95	1.40	1.20	1.30	0.35
				1.20	1.10	1.15	2.50	2.20	2.35	1.20

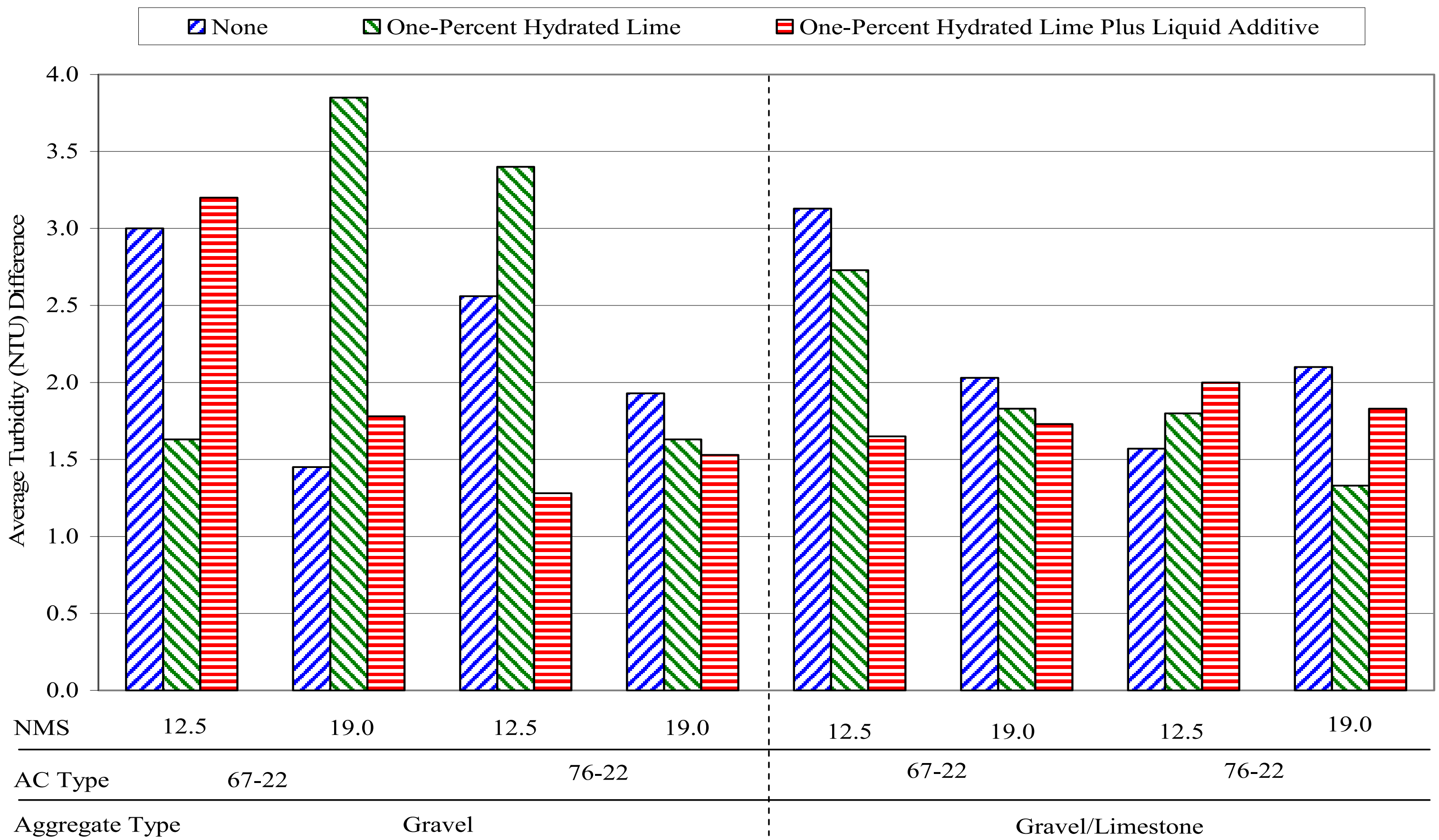
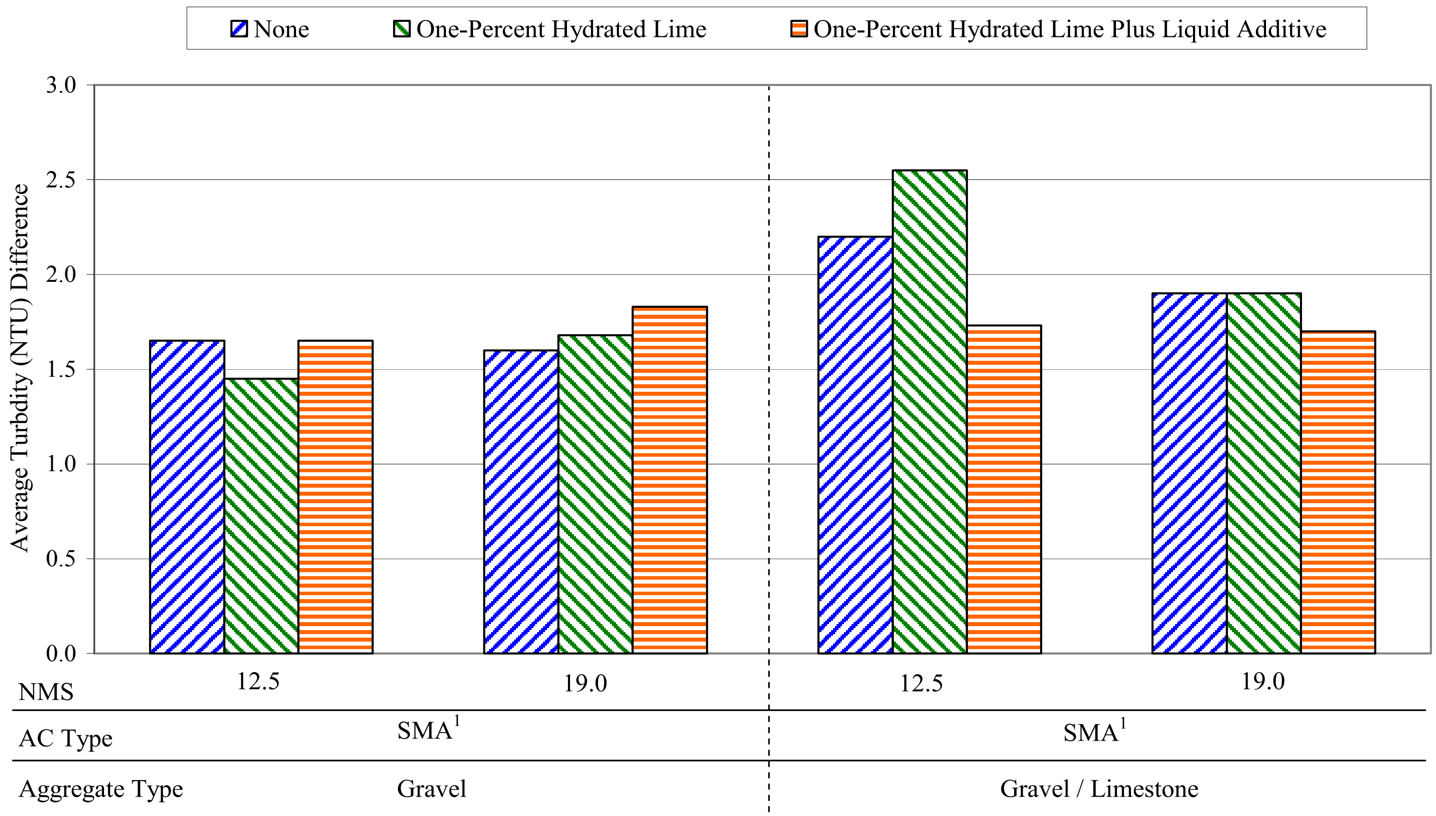


Figure 4.14 Average Turbidity Difference (PG 67-22 and 76-22)

Table 4.13 Average Turbidity Difference (SMA)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low Turbidity (1) (NTU)	Low Turbidity (2) (NTU)	Average	High Turbidity (1) (NTU)	High Turbidity (2) (NTU)	Average	Difference
SMA	Gravel	12.5	None	0.90	0.70	0.80	1.70	1.50	1.60	0.80
				0.70	0.80	0.75	1.70	1.70	1.70	0.95
			Lime	1.00	1.10	1.05	1.40	1.30	1.35	0.30
				0.70	0.80	0.75	1.80	1.30	1.55	0.80
			Lime Plus Liquid Additive	0.90	0.80	0.85	1.80	1.60	1.70	0.85
				0.90	1.00	0.95	1.60	1.60	1.60	0.65
		19.0	None	0.80	0.70	0.75	1.50	1.40	1.45	0.70
				0.70	0.60	0.65	1.90	1.60	1.75	1.10
			Lime	1.20	1.00	1.10	2.10	2.00	2.05	0.95
				0.70	0.80	0.75	1.30	1.30	1.30	0.55
			Lime Plus Liquid Additive	0.80	0.70	0.75	1.30	1.40	1.35	0.60
				0.80	0.70	0.75	2.60	2.00	2.30	1.55
	Gravel/Limestone	12.5	None	1.00	0.60	0.80	2.40	2.50	2.45	1.65
				0.70	0.60	0.65	2.40	1.50	1.95	1.30
			Lime	0.70	0.70	0.70	3.40	3.60	3.50	2.80
				1.00	1.10	1.05	1.70	1.50	1.60	0.55
			Lime Plus Liquid Additive	1.00	1.10	1.05	1.80	1.80	1.80	0.75
				1.00	0.60	0.80	1.90	1.40	1.65	0.85
		19.0	None	0.40	0.60	0.50	1.90	1.70	1.80	1.30
				1.20	1.20	1.20	2.40	1.60	2.00	0.80
			Lime	1.00	1.20	1.10	1.70	1.60	1.65	0.55
				0.70	0.70	0.70	2.20	2.10	2.15	1.45
			Lime Plus Liquid Additive	0.80	0.70	0.75	1.80	1.50	1.65	0.90
				0.80	0.90	0.85	1.80	1.70	1.75	0.90

[1] SMA = Fiber Plus PG 76-22



[1] SMA = Fiber Plus PG 76-22

Figure 4.15 Average Turbidity Difference (SMA)

Table 4.14 Average pH Difference (PG 67-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low pH (1)	Low pH (2)	Average	High pH (1)	High pH (2)	Average	Difference
67	Gravel	12.5	None	7.65	7.87	7.76	8.55	8.71	8.63	0.87
				7.79	7.81	7.80	7.90	7.85	7.88	0.08
			Lime	7.79	7.83	7.81	8.16	8.21	8.19	0.38
				7.89	7.80	7.85	8.30	8.27	8.29	0.44
			Lime Plus Liquid Additive	7.90	7.72	7.81	8.29	8.31	8.30	0.49
				7.85	7.75	7.80	8.35	8.30	8.33	0.52
		19.0	None	7.51	7.64	7.58	8.67	8.72	8.70	1.12
				7.78	7.70	7.74	7.98	7.99	7.99	0.25
			Lime	7.82	7.94	7.88	8.89	8.75	8.82	0.94
				7.80	7.70	7.75	8.10	8.15	8.13	0.38
			Lime Plus Liquid Additive	7.85	7.77	7.81	8.58	8.60	8.59	0.78
				7.78	7.60	7.69	8.41	8.38	8.40	0.71
	Gravel/Limestone	12.5	None	7.57	7.49	7.53	8.46	8.29	8.38	0.85
				7.68	7.74	7.71	8.38	8.65	8.52	0.81
			Lime	7.57	7.48	7.53	8.88	8.79	8.84	1.31
				7.96	7.93	7.95	8.21	8.18	8.20	0.25
			Lime Plus Liquid Additive	7.84	7.88	7.86	8.15	8.16	8.16	0.30
				7.77	7.60	7.69	8.65	8.64	8.65	0.96
		19.0	None	7.85	7.76	7.81	7.88	7.90	7.89	0.09
				7.95	7.80	7.88	7.91	7.99	7.95	0.08
			Lime	7.82	7.65	7.74	8.45	8.65	8.55	0.82
				7.82	7.68	7.75	8.93	8.90	8.92	1.17
			Lime Plus Liquid Additive	7.94	7.75	7.85	8.29	8.33	8.31	0.46
				7.85	7.69	7.77	8.93	8.94	8.94	1.17

Table 4.15 Average pH Difference (PG 76-22)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low pH (1)	Low pH (2)	Average	High pH (1)	High pH (2)	Average	Difference
76	Gravel	12.5	None	7.68	7.73	7.71	8.15	8.20	8.18	0.47
				7.84	7.62	7.73	8.56	8.43	8.50	0.77
			Lime	7.79	7.58	7.69	8.47	8.44	8.46	0.77
				7.77	7.66	7.72	8.37	8.36	8.37	0.65
			Lime Plus Liquid Additive	7.80	7.74	7.77	8.29	8.31	8.30	0.53
				7.82	7.70	7.76	8.68	8.65	8.67	0.90
		19.0	None	7.89	7.76	7.83	8.01	8.15	8.08	0.26
				7.94	7.95	7.95	8.91	8.95	8.93	0.98
			Lime	7.90	7.79	7.85	8.43	8.41	8.42	0.57
				7.97	7.83	7.90	8.30	8.30	8.30	0.40
			Lime Plus Liquid Additive	7.76	7.65	7.71	8.76	8.75	8.76	1.05
				7.91	7.87	7.89	8.45	8.45	8.45	0.56
	Gravel/Limestone	12.5	None	7.95	7.81	7.88	8.24	8.20	8.22	0.34
				7.66	7.85	7.76	8.26	8.41	8.34	0.58
			Lime	7.93	7.76	7.85	8.15	8.20	8.18	0.33
				7.83	7.68	7.76	8.73	8.74	8.74	0.98
			Lime Plus Liquid Additive	7.93	7.85	7.89	8.25	8.26	8.26	0.36
				7.72	7.73	7.73	8.08	8.11	8.10	0.37
		19.0	None	7.95	7.91	7.93	8.40	8.37	8.39	0.46
				7.86	7.69	7.78	8.88	8.74	8.81	1.04
			Lime	7.80	7.75	7.78	8.89	8.99	8.94	1.17
				7.84	7.79	7.82	8.37	8.37	8.37	0.56
			Lime Plus Liquid Additive	7.89	7.96	7.93	8.87	8.84	8.86	0.93
				7.93	7.88	7.91	8.41	8.37	8.39	0.49

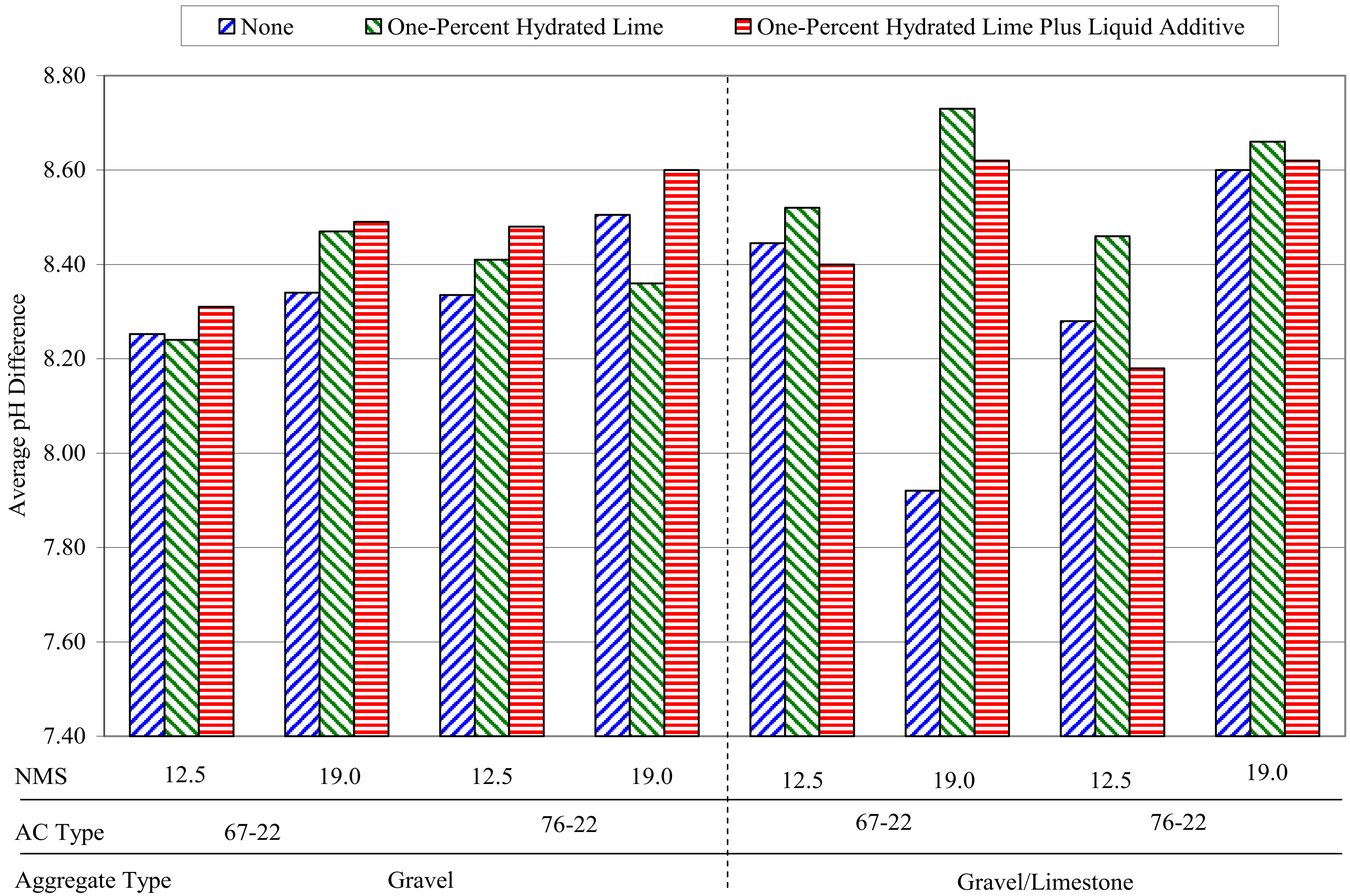
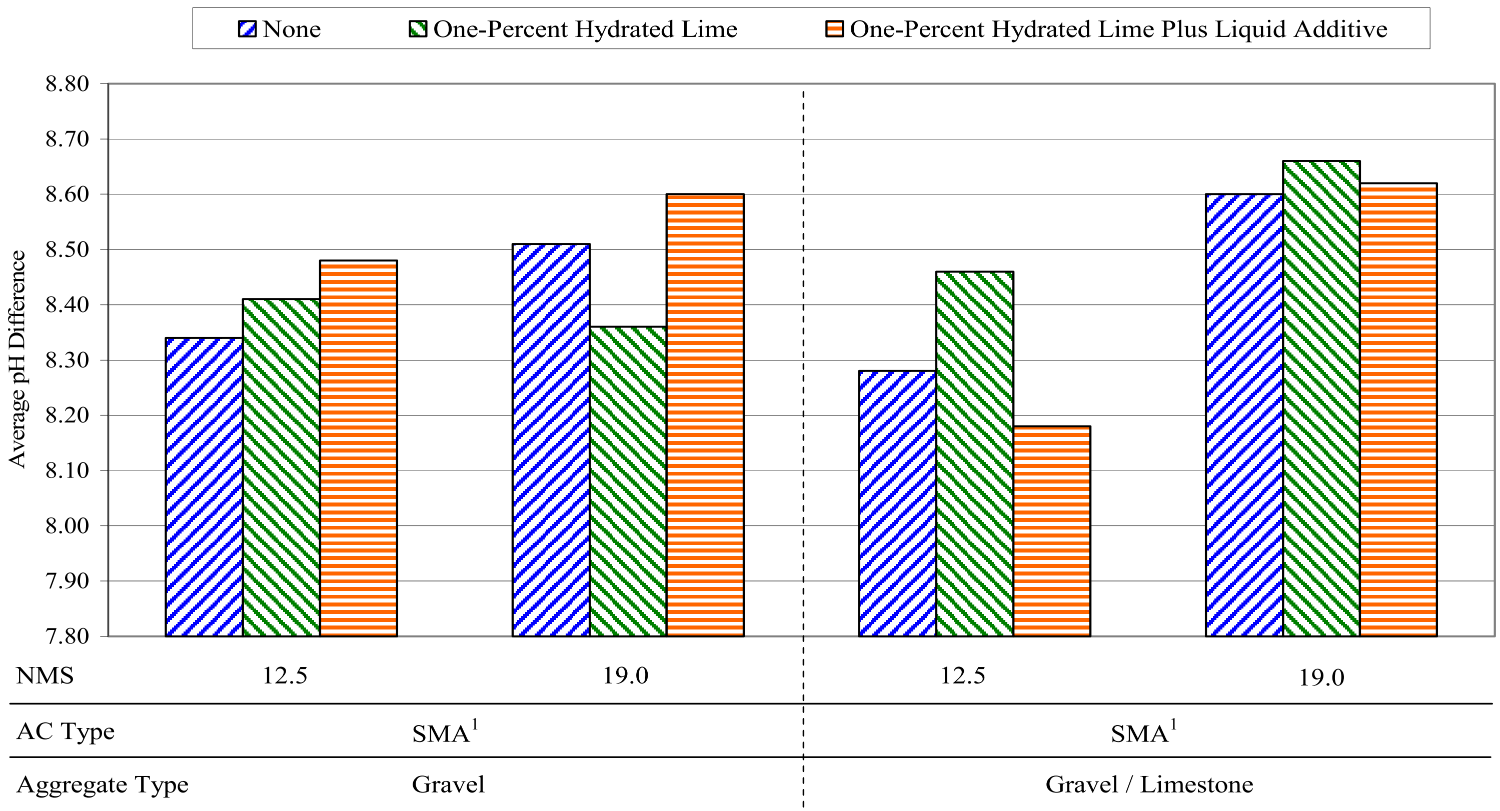


Figure 4.16 Average pH Difference (PG 67-22 and 76-22)

Table 4.16 Average pH Difference (SMA)

Asphalt Binder	Aggregate Type	Nominal Max Size (mm)	Antistripping Additive	Low pH (1)	Low pH (2)	Average	High pH (1)	High pH (2)	Average	Difference
SMA[1]	Gravel	12.5	None	7.86	7.93	7.90	7.94	7.96	7.95	0.06
				7.91	7.92	7.92	7.88	7.89	7.89	-0.03
			Lime	7.88	7.91	7.90	8.32	8.27	8.30	0.40
				7.90	7.88	7.89	7.94	7.97	7.96	0.06
			Lime Plus Liquid Additive	7.99	7.92	7.96	8.03	8.02	8.03	0.07
				7.93	7.87	7.90	8.57	8.61	8.59	0.69
		19.0	None	7.86	7.85	7.86	7.90	7.94	7.92	0.06
				7.91	7.87	7.89	7.89	7.88	7.89	-0.01
			Lime	7.91	7.89	7.90	8.07	8.09	8.08	0.18
				7.86	7.87	7.87	8.45	8.43	8.44	0.57
			Lime Plus Liquid Additive	7.88	7.84	7.86	8.60	8.71	8.66	0.80
				7.83	7.81	7.82	8.09	8.12	8.11	0.29
	Gravel/Limestone	12.5	None	7.83	7.87	7.85	7.89	7.91	7.90	0.05
				7.83	7.89	7.86	7.86	7.92	7.89	0.03
			Lime	7.92	7.89	7.91	7.91	8.02	7.97	0.06
				7.83	7.38	7.61	7.98	8.06	8.02	0.41
			Lime Plus Liquid Additive	7.93	7.84	7.89	8.11	8.20	8.16	0.27
				7.74	7.84	7.79	8.18	8.27	8.23	0.44
		19.0	None	7.91	7.92	7.92	7.82	7.88	7.85	-0.07
				7.82	7.66	7.74	7.82	7.88	7.85	0.11
			Lime	7.64	7.60	7.62	8.44	8.49	8.47	0.85
				7.97	7.92	7.95	8.08	8.07	8.08	0.13
			Lime Plus Liquid Additive	7.92	7.81	7.87	8.04	8.11	8.08	0.21
				7.89	7.88	7.89	8.15	8.15	8.15	0.27

1 SMA = Fiber Plus PG 76-22



[1] SMA = Fiber Plus PG 76-22

Figure 4.17 Average pH Difference (SMA)

4.7 MIST RESULTS STATISTICAL ANALYSIS

Statistical analyses were conducted for three dependent variables: turbidity ratio, manual turbidity, and pH. Variables were analyzed relative to four independent variables: aggregate size, aggregate type, asphalt binder type, and additive type. Analyses were conducted using Statistical Analysis System (SAS) software, version 8.12 (38). An analysis of variance (ANOVA) was performed to determine the significance of study factors and/or interaction of factors. Class level information is shown in Table 4.17. Independent variables were aggregate size (Size), aggregate type (AGG), asphalt binder type (AC), and additive type (Additive), evaluated at 2, 2, 3, and 3 levels, respectively.

Table 4.17 Class Level Information

Class	Levels	Values		
Aggregate Size (mm)	2	12.5		19.0
Aggregate Type	2	Gravel		Gravel/Limestone
Asphalt Binder Type	3	67-22	76-22	SMA[1]
Additive Type	3	None	Hydrated Lime	Hyd. Lime Plus Liquid Additive

[1] SMA = Fiber Plus PG 76-22

4.7.1. Analysis of Turbidity Ratio

A summary of the ANOVA analysis for turbidity ratio is shown in Table 4.19. The analysis indicated that main level factors of aggregate, asphalt binder, and additive type were significant. Significant interactions for turbidity ratio included aggregate type*additive type and asphalt binder type*additive type. The fact that aggregate type is significant is likely due to the different aggregates used with the limestone being hydrophobic and gravel being hydrophobic. The significance of binder and additive type is attributable due to the addition of polymers, fibers, and additives (hydrated lime and chemical agents), which likely increase adhesion strength between asphalt binder and aggregate.

Table 4.18 Summary of Statistical Analysis for Turbidity Ratio

Dependent Variable: Turbidity Ratio					
Source	df	SS	MS	F stat	Prob. > F
Model	35	0.1294	0.0037	3.55	0.0001
Error	36	0.0375	0.001		
Total	71	0.1669			
		R-Square	Adj. R-Square	Root MSE	Mean
		0.7756	16.2807	0.0323	0.1981
Source	df	Type I SS	MS	F stat	Prob. > F
Size	1	0.0024	0.0024	2.28	0.1396
AGG	1	0.0166	0.0166	15.98	0.0003
AC	2	0.028	0.014	13.47	0.0001
Additive	2	0.0244	0.0122	11.71	0.0001
Size*AGG	1	0.0001	0.0001	0.09	0.7684
Size*AC	2	0.0022	0.0011	1.08	0.3512
AGG*AC	2	0.0054	0.0027	2.61	0.0871
Size*Additive	2	0.0016	0.0008	0.76	0.473
AGG*Additive	2	0.0186	0.0093	8.92	0.0007
AC*Additive	4	0.0158	0.0039	3.79	0.0113
Size*AGG*AC	2	0.0022	0.0011	1.04	0.365
Size*AGG*Additive	2	0.005	0.0003	0.26	0.7739
Size*AC*Additive	4	0.0033	0.0008	0.79	0.5375
AGG*AC*Additive	4	0.0073	0.0018	1.74	0.1616
Size*AGG*AC*Additive	4	0.0011	0.0003	0.25	0.9048

A Tukey's Studentized Range test was performed to determine the significance of aggregate size, aggregate type, asphalt binder type, and additive type. Test results are shown in Tables 4.19 through 4.22. Results indicate average turbidity ratio change is significantly lower for gravel mixes than gravel/limestone mixes. The analysis indicates average turbidity ratio change is significantly lower for PG 67-22 specimens than PG 76-22 and SMA (fibers plus PG 76-22) mixes. The analysis also indicates average turbidity ratio is significantly lower for specimens with no lime than those with hydrated lime and hydrated lime plus liquid additive.

Results are contrary to expected results and are likely a result of the way the change in turbidity ratio was measured. MIST results may be somewhat inaccurate, relative to manual turbidity measurements, due to an intake of air bubbles or turbulence when conditioning water is measured. Air bubbles (turbulence) cause the turbidity ratio to increase by approximately twice the magnitude of a normal reading. Manual turbidity results are more accurate, relative to the MIST results, for two primary reasons: 1) no turbulence during measurements and 2) calibration capability between tests.

Table 4.19 Mean Comparison of Turbidity Ratio Change for Aggregate Size

Aggregate Size	Mean	N	Tukey Grouping[1]
19	0.2038	36	A
12.5	0.1924	36	A
Alpha = 0.05 df = 36 MSE = 0.0010 Critical Value of Studentized Range = 2.8682 Mininum Significant Difference = 0.0154			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.20 Mean Comparison of Ratio Change for Aggregate Type

Aggregate Type	Mean	N	Tukey Grouping[1]
Gravel/Limestone	0.2133	36	A
Gravel	0.1829	36	B
Alpha = 0.05			
df = 36			
MSE = 0.0010			
Critical Value of Studentized Range = 2.8682			
Mininum Significant Difference = 0.0154			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.21 Mean Comparison of Ratio Change for AC Type

AC Type	Mean	N	Tukey Grouping[2]
SMA[1]	0.2213	24	A
76	0.1999	24	A
67	0.1731	24	B
Alpha = 0.05			
df = 36			
MSE = 0.0010			
Critical Value of Studentized Range = 3.4568			
Mininum Significant Difference = 0.0228			

[1] SMA = Fibers Plus PG 76-22

[2]Means With the Same Letter Are Not Significantly Different

Table 4.22 Mean Comparison of Ratio Change for Additive Type

Additive Type	Mean	N	Tukey Grouping[1]
Lime	0.2118	24	A
Lime Plus Liquid	0.2104	24	A
None	0.1721	24	B
Alpha = 0.05 df = 36 Mininum Significant Difference = 0.0228			

[1]Means With the Same Letter Are Not Significantly Different

4.7.2 Analysis of Turbidity

A summary of the ANOVA analysis for turbidity is shown in Table 4.23. The analysis indicated that main level factors of aggregate type and asphalt binder type were significant. Interactions that were significant included: 1) aggregate type*asphalt binder type*additive type and 2) aggregate size*aggregate type*asphalt binder type*additive type. Asphalt binder type is significant primarily because PG 67-22 is an unmodified binder in contrast to the PG 76-22 and SMA (fibers plus PG 76-22). Polymers and stabilizing fibers likely improve adhesion between asphalt binder and aggregate. As discussed previously, aggregate type is significant due to limestone aggregate having a greater affinity for asphalt binder than water in contrast to the gravel aggregate.

Table 4.23 Summary of Statistical Analysis for Turbidity

Dependent Variable: Turbidity					
Source	df	SS	MS	F stat	Prob. > F
Model	35	27.78	0.7937	1.85	0.0354
Error	36	15.46	0.4294		
Total	71	43.24			
		R-Square	Adj. R-Square	Root MSE	Mean
		0.6425	50.4092	0.6553	1.3
Source	df	Type I SS	MS	F stat	Prob. > F
Size	1	0.1606	0.1606	0.37	0.5447
AGG	1	2.7222	2.7220	6.34	0.0164
AC	2	4.2658	2.1329	4.97	0.0124
Additive	2	1.0975	0.5488	1.28	0.2910
Size*AGG	1	0.0050	0.0050	0.01	0.9147
Size*AC	2	1.6769	0.8385	1.95	0.1567
AGG*AC	2	0.9603	0.4801	1.12	0.3380
Size*Additive	2	0.2853	0.1426	0.33	0.7196
AGG*Additive	2	0.3253	0.1626	0.38	0.6874
AC*Additive	4	0.9167	0.2292	0.53	0.7118
Size*AGG*AC	2	1.5258	0.7629	1.78	0.1837
Size*AGG*Additive	2	1.2475	0.6238	1.45	0.2474
Size*AC*Additive	4	3.1072	0.7768	1.81	0.1485
AGG*AC*Additive	4	4.5922	1.1481	2.67	0.0475
Size*AGG*AC*Additive	4	4.8917	1.2230	2.85	0.0378

Significance of aggregate size, aggregate type, asphalt binder type, and additive type was determined through a Tukey's Studentized Range test. The test results are shown in Tables 4.24 through 4.27. Results indicate the average turbidity change is significantly lower for gravel/limestone mixes than for gravel mixes. This again is due to limestone being a hydrophobic aggregate. Results indicate the average turbidity change is significant for different levels of asphalt binder, with SMA (fibers plus PG 76-22) having the lowest change likely due to polymer modification and fibers stiffening the asphalt binder. There is no statistical difference among aggregate sizes when testing loose specimens because the type of stripping occurring is not a result of internal void structure, but more due to developed film thickness.

Table 4.24 Mean Comparison of Turbidity Change for Aggregate Size

Aggregate Size	Mean	N	Tukey Grouping[1]
12.5	1.3472	36	A
19	1.2528	36	A
Alpha = 0.05 df = 36 MSE = 0.4294 Critical Value of Studentized Range = 2.8682 Mininum Significant Difference = 0.3133			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.25 Mean Comparison of Turbidity Change for Aggregate Type

Aggregate Type	Mean	N	Tukey Grouping[1]
Gravel	1.4944	36	A
Gravel/Limestone	1.1056	36	B
Alpha = 0.05 df = 36 MSE = 0.4294 Critical Value of Studentized Range = 2.8682 Mininum Significant Difference = 0.3133			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.26 Mean Comparison of Turbidity Change for AC Type

AC Type	Mean	N	Tukey Grouping[2]
67	1.6042	24	A
76	1.2875	24	A , B
SMA[1]	1.0083	24	B
Alpha = 0.05 df = 36 MSE = 0.4294 Critical Value of Studentized Range = 3.4568 Mininum Significant Difference = 0.4624			

[1] SMA = Fibers Plus PG 76-22

[2]Means With the Same Letter Are Not Significantly Different

Table 4.27 Mean Comparison of Turbidity Change for Additive Type

Additive Type	Mean	N	Tukey Grouping[1]
None	1.4167	24	A
Lime	1.3542	24	A
Lime Plus Liquid	1.1292	24	A
Alpha = 0.05 df = 36 MSE = 0.4294 Critical Value of Studentized Range = 3.4568 Mininum Significant Difference = 0.4624			

[1]Means With the Same Letter Are Not Significantly Different

4.7.3 Analysis of pH

A summary of the ANOVA analysis for pH change is shown in Table 4.28. Results indicated that aggregate size, aggregate type, and additive type had no significant effect on specimen pH. Asphalt type was the only factor to have a significant effect on pH. Asphalt binder type is significant primarily because SMA includes fibers in contrast to PG 67-22 and 76-22. Fibers likely increase adhesion strength between asphalt binder and aggregate.

Table 4.28 Summary of Statistical Analysis for pH Change

Dependent Variable: pH					
Source	df	SS	MS	F stat	Prob. > F
Model	35	5.02	0.14	1.3	0.2178
Error	36	3.97	0.11		
Total	71	8.99			
		R-Square	Adj. R-Square	Root MSE	Mean
		0.5585	65.21	0.33	0.51
Source	df	Type I SS	MS	F stat	Prob. > F
Size	1	0.0055	0.0055	0.05	0.8243
AGG	1	0.1258	0.1258	1.14	0.2924
AC	2	2.4955	1.2478	11.32	0.0002
Additive	2	0.5506	0.2753	2.5	0.0964
Size*AGG	1	0.0039	0.0039	0.04	0.8518
Size*AC	2	0.0758	0.0379	0.34	0.7114
AGG*AC	2	0.0115	0.0057	0.05	0.9494
Size*Additive	2	0.2818	0.1409	1.28	0.2907
AGG*Additive	2	0.1434	0.0717	0.65	0.5276
AC*Additive	4	0.2279	0.057	0.52	0.7237
Size*AGG*AC	2	0.3448	0.1724	1.56	0.223
Size*AGG*Additive	2	0.121	0.0605	0.55	0.5822
Size*AC*Additive	4	0.1486	0.0371	0.34	0.8511
AGG*AC*Additive	4	0.2789	0.0697	0.63	0.6424
Size*AGG*AC*Additive	4	0.2033	0.0508	0.46	0.7637

A Tukey's Studentized Range test was performed to determine the significance of aggregate size, aggregate type, asphalt binder type, and additive type. Results are shown in Tables 4.29 through 4.32. Results indicate average pH change is significantly lower for SMA (fibers plus PG 76-22) than for PG 67-22 and 76-22. This could be a result of polymer modified binder, stabilizing fibers, and higher asphalt content. Polymer and fiber addition stiffens asphalt binder which likely resulted in less asphalt binder emulsification.

Table 4.29 Mean Comparison of pH Change for Aggregate Size

Aggregate Size	Mean	N	Tukey Grouping[1]
19	0.5178	36	A
12.5	0.5002	36	A
Alpha = 0.05 df = 36 MSE = 0.1101 Critical Value of Studentized Range = 2.8682 Mininum Significant Difference = 0.1587			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.30 Mean Comparison of pH Change for Aggregate Type

Aggregate Type	Mean	N	Tukey Grouping[1]
Gravel/Limestone	0.5508	36	A
Gravel	0.4672	36	A
Alpha = 0.05 df = 36 MSE = 0.1102 Critical Value of Studentized Range = 2.8682 Mininum Significant Difference = 0.1587			

[1]Means With the Same Letter Are Not Significantly Different

Table 4.31 Mean Comparison of pH Change for AC Type

AC Type	Mean	N	Tukey Grouping[2]
76	0.6467	24	A
67	0.6346	24	A
SMA[1]	0.2458	24	B
Alpha = 0.05 df = 36 MSE = 0.1102 Critical Value of Studentized Range = 3.4568 Mininum Significant Difference = 0.2342			

[1]SMA = Fiber Plus PG 76-22

[2]Means With the Same Letter Are Not Significantly Different

Table 4.32 Mean Comparison of pH Change for Additive Type

Additive Type	Mean	N	Tukey Grouping[1]
Lime	0.5742	24	A
Lime Plus Liquid	0.5675	24	A
None	0.3854	24	A
Alpha = 0.05 df = 36 MSE = 0.1102 Critical Value of Studentized Range = 3.4568 Mininum Significant Difference = 0.2342			

[1]Means With the Same Letter Are Not Significantly Different

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

The study objective was to determine the ability of the Moisture Induced Stress Tester (MIST) to accurately predict HMA stripping and to develop associated test protocols. The MIST was designed to detect stripping of laboratory prepared loose/compacted HMA specimens and/or field cores, by simulating field stripping mechanisms (water, repeated trafficking, and elevated in-place service temperatures). Turbidity ratio increase was monitored and recorded by the MIST with use of a software program and personal computer.

Boil Test (MT-59) and Resistance of Bituminous Paving Mixtures to Stripping – Vacuum Saturation Method (MT-63) tests were incorporated into the study to determine if there was a correlation with MIST results.

The following conclusions from each test are offered forth.

5.1 MT-59 BOIL TEST

- Ineffective in measuring stripping.
- All mixes retained an asphalt binder coating greater than 95 percent.

5.2 MT 63 INDIRECT TENSILE STRENGTH (TSR) TEST

- For PG 67-22 asphalt binder mixes, one-percent hydrated lime plus liquid additive mixes had higher TSRs than mixes with no lime and mixes with one-percent hydrated lime.
- For PG 76-22 asphalt binder mixes, TSR for mixes with one-percent hydrated lime was higher than mixes with no lime and mixes with one-percent hydrated lime plus a liquid additive.
- Comparison of the SMA (fibers plus PG 76-22) mixes indicated TSR was not influenced by antistripping additives.
- TSR values for SMA mixes were generally higher than other mixes.

5.3 MIST TURBIDITY RATIO

- For PG 67-22 gravel mixes, average turbidity ratios were highest for mixes with one-percent hydrated lime plus liquid additive than for mixes with no lime and mixes with one-percent hydrated lime.
- Among PG 67-22 gravel/limestone mixes, mixes with one-percent hydrated lime had higher average turbidity ratios than mixes with no lime and mixes with one-percent hydrated lime plus liquid additive.
- Among PG 76-22 mixes, the average turbidity ratio was highest for mixes with one-percent hydrated lime and liquid additive than mixes with no lime and mixes with one-percent hydrated lime.
- Comparison among PG 67-22 and 76-22 mixes indicated the average turbidity ratio was approximately the same for all mixes.
- Among SMA (fibers plus PG 76-22) mixes, none of the antistripping agents had an influence on average turbidity ratio.

5.4 MIST CONDITIONED – MANUAL TURBIDITY

- Results indicated that there was not statistical difference among PG 67-22 mixes and PG 76-22 mixes or PG 76-22 mixes and SMA mixes. However, there was statistical difference among PG 67-22 mixes and SMA mixes. SMA mixes had the lowest change in average turbidity.
- Comparison among aggregate types indicated the gravel/limestone mixes had a lower average turbidity difference than the gravel mixes.

5.5 MIST CONDITIONED – pH

- Results among PG 67-22, PG 76-22, and SMA (fiber plus PG 76-22) gravel and gravel/limestone mixes indicate pH is not a reliable indicator for measuring stripping.
- Results are scattered indicating no conclusive evidence that pH is effected by the three levels of antistripping additives.

5.6 SUMMARY

In summary, MT-59 testing method is not an accurate test in identifying stripping of HMA mixes. The test is not severe enough to identify mixes that are known to be stripping susceptible.

Although MT-63 is one of the most commonly used tests, it is not always 100 percent accurate in identifying stripping susceptible mixes. MT-63 results tend be highly variable due to specified allowable saturation levels and air void levels. However, some trends that were evident through testing are: 1) addition of the polymer to the asphalt binder increases the TSR and 2) addition of hydrated lime and hydrated lime plus liquid additive increases TSR for PG 67-22 mixes. It does appear that SMA mixes have greater resistance to stripping that other PG 67-22 and PG 76-22 Superpave mixes in the study. This is likely due to the use of the PG 76-22 binder and the stabilizing fibers.

The MIST shows potential in its ability to measure stripping of HMA. The data taken from the change in turbidity ratio clearly indicates that some form of stripping is occurring during the test. Further MIST research must be performed before test parameters can be selected. However, before further research is continued, several MIST modifications should be to improve its operation and stripping evaluation capability.

5.7 SUGGESTED MIST MODIFICATIONS

Suggested MIST modifications are as follows:

- Air pressure capability should be increased from 480 kPa (70 psi) to 690 kPa (100 psi)
- Water volume evaluated during testing should be reduced as much as possible to improve test efficiency.
- A turbidity sensor for each individual specimen so turbidity measurements are independent of each other.
- Conditioning water should be forced directly through the HMA specimen, not allowed to flow around. This will increase the severity of the conditioning process and likely improve the test results.

- All conditioning water should circulate through turbidity sensor instead of a small sample being obtained.
- pH meter should be installed for real time monitoring.
- Digital thermostat is needed to allow small incremental temperature adjustments.
- Hydrocarbon sensor should be installed to detect emulsified asphalt binder in the conditioning water.
- Software used to collect the data should be Microsoft Excel format.
- Software should only collect data during turbidity measurements.

CHAPTER 6 REFERENCES

1. Roberts, F., P. Kandhall, E. Brown, D. Lee, and T. Kennedy. *Hot Mix Asphalt Materials, Mixture Design, and Construction, NAPA Education Foundation,* Lanham, Maryland, 1991

2. The Asphalt Institute. Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types. Manual Series No. 2, Fourth Edition, March 1974.

3. Hunter, E., and K. Ksaibati, *"Evaluating Moisture Susceptibility of Asphalt Mixes,"* Department of Civil and Architectural Engineering, Laramie, Wyoming, November 2002.

4. Pan, C. and T. White. *"Conditions for Stripping Using Accelerated Testing,"* Joint Transportation Research Program, Purdue University, West Lafayette, Indiana, Rep. FHWA/IN/JTRP-97/13, February 1999.

5. Kennedy, T., F. Roberts, and K. Lee. Evaluating Moisture Susceptibility of Asphalt Mixtures Using the Texas Boiling Test," *Transportation Research Record 968*, TRB, National Research Council, Washington, D.C., 1984, pp. 45-54.

6. Tunnicliff, D., and R. Root. "Antistripping Additives in Asphalt Concrete-State-of-the-Art 1981" P*roceedings of the Association of Asphalt Paving Technologists*, Vol. 51 (1982), pp. 265-289.

7. Pavement Management Systems Limited. Study of Asphalt Cement Additives and Extenders. *Roads and Transportation Association of Canada*, January 1993.

8. Taylor, M., and N. Khosla. "Stripping of Asphalt Pavements: State-of-the-Art," *Transportation Research Record 911,* National Research Council, TRB, Washington, D.C., 1983. pp. 150-158.

9. Yoon, H. and A. Tarrer. "Effect of Aggregate Properties on Stripping," *Transportation Research Record 1171,* TRB, National Research Council, Washington, D.C., 1988, pp. 37-43.

10. Barksdale, R. *The Aggregate Handbook,* Sheridan Books, Inc., Virginia, 2001.

11. ASTM. (2003). "Practice for Effect of Water on Bituminous-Coated Aggregate Using Boiling Water.", D3625, West Conshohocken, Pennsylvania.

12. AASHTO. (2000). "Coating and Stripping of Bitumen-Aggregate Mixtures.", T182-84, Washington, D.C.

13. AASHTO. (2000). "Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage.", T283, Washington, D.C.

14. AASHTO. (2000). "Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures.", T165, Washington, D.C.

15. Aschenbrener, T. "Evaluation of Hamburg Wheel-Tracking Device to Predict Moisture Damage in Hot-Mix Asphalt," *Transportation Research Record 1492*, TRB, National Research Council, Washington, D.C., 1995, pp. 193-201.

16. Tandon, V., N. Vemuri, S. Nazarian, and M. Tahmoressi. "A Comprehensive Evaluation of Environmental Conditioning System," P*roceedings of the Association of Asphalt Paving Technologists*, Vol. 66 (1997), pp. 187-210.

17. Stuart, K. *"Moisture Damage in Asphalt Mixtures – A State of the Art Report."* FHWA, Report FHWA-RD-90-019, August 1990.

18. Coplantz, J. and D. Newcomb. "Water Sensitivity Test Methods for Asphalt Concrete Mixtures: A Laboratory Comparison," *Transportation Research Record 1171,* TRB, National Research Council, Washington, D.C., 1988, pp. 44-50.

19. Parker, F., and F. Gharaybeh. "Evaluation of Tests to Assess Stripping Potential of Asphalt Concrete Mixtures," *Transportation Research Record 1171,* TRB, National Research Council, Washington, D.C., 1988, pp. 18-26.

20. Ishai, I., and S. Nesichi. "Laboratory Evaluation of Moisture Damage to Bituminous Paving Mixtures by Long-Term Hot Immersion," *Transportation Research Record 1171*, TRB, National Research Council, Washington, D.C., 1988, pp. 12-17.

21. Mahoney, J., and J. Stephens. *"Comparison of AASHTO Moisture Sensitivity Test with Connecticut Department of Transportation Modified Test Method,"* Connecticut Advanced Pavement Laboratory, University of Connecticut, Storrs, Connecticut, Rep. CAPLab 99-1, August 1999.

22. Aschenbrener, T., R. McGennis, and R. Terrel. "Comparison of Several Moisture Susceptibility Tests to Pavements of Known Field Performance," P*roceedings of the Association of Asphalt Paving Technologists*, Vol. 64 (1995), pp. 162-196.

23. Scherocman, J., K. Mesch, and J. Proctor. "The Effect of Multiple Freeze-Thaw Cycle Conditioning on the Moisture Damage in Asphalt Concrete Mixtures," *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 55 (1986), pp. 212-228.

24. Parker, F., and M. Wilson. "Evaluation of Boiling and Stress Pedestal Tests for Assessing Stripping Potential of Alabama Asphalt Concrete Mixtures," *Transportation Research Record 1096*, TRB, National Research Council, Washington, D.C., 1986, pp. 90-100.

25. Parker, F., and F. Gharaybeh. "Evaluation of Indirect Tensile Tests for Assessing Stripping of Alabama Asphalt Concrete Mixtures," *Transportation Research Record 1115*, TRB, National Research Council, Washington, D.C., 1988, pp. 113-124.

26. Akili, W. "The Effect of Moisture on Laboratory Prepared Asphalt Mixes, *Journal of Testing and Evaluation*, Vol. 21. No. 1, January 1993, pp. 73-83.

27. Maupin, G. "Evaluation of Stripping in Virginia's Pavements," *Transportation Research Record 1681*, National Research Council, TRB, Washington, D.C., 1999, pp. 37-42.

28. Choubane, B., G. Page, and J. Musselman. "Effects of Water Saturation Level on Resistance of Compacted Hot-Mix Asphalt Samples to Moisture-Induced Damage," *Transportation Research Record 1723*, National Research Council, TRB, Washington, D.C., 2001, pp. 97-106.

29. Izzo, R., and M. Tahmoressi, "Use of the Hamburg Wheel-Tracking Device for Evaluating Moisture Susceptibility for Hot-Mix Asphalt," *Transportation Research Record 1681*, National Research Council, TRB, Washington, D.C., 1999, pp. 76-85.

30. Alam, M., V. Tandon, S. Nazarian, and M. Tahmoressi. "Identification of Moisture-Susceptible Asphalt Concrete Mixes Using Modified Enviromental Conditioning System," *Transportation Research Record 1630*, TRB, National Research Council, Washington, D.C., 1998, pp. 106-116.

31. Mississippi Department of Transportation Standard Operating Procedure No. TMD-11-78-00-000: Volumetric Mix Design of Hot Mix Asphalt Mixtures Using the Superpave Gyratory Compactor, November 1, 2000.

32. Mississippi Department of Transportation Standard Operating Procedure No. TMD-11-80-00-000: Volumetric Mix Design Procedure for Stone Matrix Asphalt (SMA), November 1, 2000.

33. AASHTO. (2001). "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.", T166, Washington, D.C.

34. AASHTO. (2001). "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures.", T209, Washington, D.C.

35. Mississippi Department of Transportation Standard Operating Procedure No. TMD-11-63-00-000: Resistance of Bituminous Paving Mixtures to Stripping (Vacuum Saturation Method), November 1, 2000.

36. Mississippi Department of Transportation Standard Operating Procedure No. TMD-11-59-00-000: Determination of Loss of Coating of HMA (Boiling Water Test), November 1, 2000.

37. United States Geologic Survey, "Common Water Measurements," *Water Science for Schools*, <http://ga.water.usgs.gov/edu/characteristics.html#Turbidity> (May 2, 2004).

38. Statistical Analysis Software (SAS), Version 8.12, SAS Institute, Inc.

APPENDIX A
MIX DESIGN RESULTS

Table A.1 12.5 GRV – PG 67 and 76-22 Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**		
Apparent Specific Gravity (Gsa):	2.636	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.508	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.437	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	5.9			
Asphalt Binder Gravity (Gb)	1.027			
% Absorbed Asphalt (Pba)	1.19			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
C7	4.0	4465.0	2467.0	4550.0	2.144	2.371	9.6	15.6	38.3	2.9	2.1
C8	4.0	4470.9	2467.7	4549.6	2.148	2.371	9.4	15.4	38.8	2.9	2.1
AVG	4.0				2.146	2.371	9.5	15.5	38.6	2.9	2.1
C9	5.0	4501.3	2461.8	4530.9	2.175	2.339	7.0	15.2	54.0	3.9	1.5
C10	5.0	4532.6	2487.4	4562.7	2.184	2.339	6.6	14.9	55.4	3.9	1.5
AVG	5.0				2.180	2.339	6.8	15.0	54.7	3.9	1.5
C11	6.0	4506.2	2480.7	4513.6	2.217	2.308	4.0	14.5	72.7	4.9	1.2
C12	6.0	4560.7	2519.5	4568.8	2.225	2.308	3.6	14.2	74.8	4.9	1.2
AVG	6.0				2.221	2.308	3.8	14.3	73.7	4.9	1.2

Table A.2 19.0 GRV – PG 67 and 76-22 Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**	
Apparent Specific Gravity (Gsa):	2.622	Superpave Gyratory Compactor:	Pine
Effective Specific Gravity (Gse):	2.500	Ndesign, Gyrations:	96
Bulk Specific Gravity (Gsb):	2.435	Mold Diameter:	150 mm
Percent Passing 0.075 mm:	5.6		
Asphalt Binder Gravity (Gb)	1.027		
% Absorbed Asphalt (Pba)	1.10		

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
C21	4.0	4465.3	2468.3	4515.3	2.181	2.365	7.8	14.0	44.6	2.9	1.9
C22	4.0	4474.6	2464.2	4517.9	2.179	2.365	7.9	14.1	44.3	2.9	1.9
AVG	4.0				2.180	2.365	7.8	14.0	44.4	2.9	1.9
C23	5.0	4522.3	2509.6	4564.3	2.201	2.333	5.7	14.1	59.9	4.0	1.4
C24	5.0	4518.6	2486.6	4542.3	2.198	2.333	5.8	14.2	59.4	4.0	1.4
AVG	5.0				2.200	2.333	5.7	14.2	59.7	4.0	1.4
C25	6.0	4562.3	2511.5	4572.0	2.214	2.302	3.8	14.5	73.7	5.0	1.1
C26	6.0	4574.8	2524.3	4580.3	2.225	2.302	3.3	14.1	76.3	5.0	1.1
AVG	6.0				2.220	2.302	3.6	14.3	75.0	5.0	1.1

Table A.3 12.5 GRV/LMS – PG 67 and 76-22 Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**		
Apparent Specific Gravity (Gsa):	2.672	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.559	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.531	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	4.9			
Asphalt Binder Gravity (Gb)	1.027			
% Absorbed Asphalt (Pba)	0.44			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
C21	4.5	4458.1	2524.0	4485.4	2.273	2.398	5.2	14.2	63.5	4.1	1.2
C22	4.5	4482.9	2537.7	4506.7	2.277	2.398	5.0	14.1	64.2	4.1	1.2
AVG	4.5				2.275	2.398	5.1	14.2	63.8	4.1	1.2
C23	5.0	4494.1	2547.0	4506.9	2.293	2.381	3.7	13.9	73.5	4.6	1.1
	5.0	4456.0	2526.5	4471.4	2.291	2.381	3.8	14.0	73.0	4.6	1.1
AVG	5.0				2.292	2.381	3.7	14.0	73.3	4.6	1.1
C25	5.5	4500.6	2568.1	4507.2	2.321	2.365	1.8	13.3	86.2	5.1	1.0
C26	5.5	4517.3	2577.0	4522.7	2.322	2.365	1.8	13.3	86.4	5.1	1.0
AVG	5.5				2.321	2.365	1.8	13.3	86.3	5.1	1.0

Table A.4 19.0 GRV/LMS – PG 67 and 76-22 Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**	
Apparent Specific Gravity (Gsa):	2.676	Superpave Gyratory Compactor:	Pine
Effective Specific Gravity (Gse):	2.586	Ndesign, Gyrations:	96
Bulk Specific Gravity (Gsb):	2.546	Mold Diameter:	150 mm
Percent Passing 0.075 mm:	5.0		
Asphalt Binder Gravity (Gb)	1.027		
% Absorbed Asphalt (Pba)	0.62		

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
C50	3.5	4416.2	2533.2	4461.5	2.181	2.456	11.2	17.3	35.5	2.9	1.7
C51	3.5	4423.9	2541.0	4463.6	2.179	2.456	11.3	17.4	35.3	2.9	1.7
AVG	3.5				2.180	2.456	11.2	17.4	35.4	2.9	1.7
C52	4.0	4457.8	2572.4	4518.5	2.291	2.438	6.0	13.6	55.6	3.4	1.5
C53	4.0	4450.8	2548.8	4479.5	2.305	2.438	5.4	13.1	58.4	3.4	1.5
AVG	4.0				2.298	2.438	5.7	13.4	57.0	3.4	1.5
C54	4.5	4473.0	2561.1	4488.6	2.321	2.421	4.1	13.0	68.1	3.9	1.3
C55	4.5	4457.7	2561.7	4475.4	2.329	2.421	3.8	12.6	70.1	3.9	1.3
AVG	4.5				2.325	2.421	4.0	12.8	69.1	3.9	1.3

Table A.5 12.5 GRV – SMA Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**		
Apparent Specific Gravity (Gsa):	2.600	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.530	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.383	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	10.6			
Asphalt Binder Gravity (Gb)	2.027			
% Absorbed Asphalt (Pba)	4.94			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	VMA (%)	VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
K10	6.0	4558.8	2460.4	4666.1	2.067	2.326	11.1	18.5	39.7	1.4	7.8
K11	6.0	4547.9	2456.8	4671.0	2.054	2.326	11.7	19.0	38.4	1.4	7.8
AVG	6.0				2.060	2.326	11.4	18.7	39.0	1.4	7.8
K12	7.0	4590.6	2454.9	4667.2	2.075	2.295	9.6	19.0	49.6	2.4	4.4
K13	7.0	4582.8	2445.5	4648.8	2.080	2.295	9.4	18.8	50.2	2.4	4.4
AVG	7.0				2.078	2.295	9.5	18.9	49.9	2.4	4.4
K14	8.0	4628.5	2456.7	4665.9	2.095	2.265	7.5	19.1	60.8	3.5	3.1
K15	8.0	4633.2	2449.7	4669.5	2.087	2.265	7.8	19.4	59.6	3.5	3.1
AVG	8.0				2.091	2.265	7.7	19.3	60.2	3.5	3.1

Table A.6 19.0 GRV – SMA Mix Design Summary

Aggregate Blend and Binder Properties		Compaction Parameters		
Apparent Specific Gravity (Gsa):	2.623	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.456	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.410	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	10.6			
Asphalt Binder Gravity (Gb)	1.027			
% Absorbed Asphalt (Pba)	0.80			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
K10	6.0	4245.4	2306.8	4310.6	2.119	2.267	6.5	17.4	62.3	5.2	2.0
K11	6.0	4218.6	2290.3	4289.1	2.111	2.267	6.9	17.7	61.0	5.2	2.0
AVG	6.0				2.115	2.267	6.7	17.5	61.6	5.2	2.0
K12	7.0	4262.6	2299.1	4290.1	2.141	2.238	4.3	17.4	75.0	6.3	1.7
K13	7.0	4280.8	2318.9	4321.1	2.138	2.238	4.5	17.5	74.4	6.3	1.7
AVG	7.0				2.139	2.238	4.4	17.4	74.7	6.3	1.7
K14	8.0	4314.6	2325.5	4334.0	2.148	2.210	2.8	18.0	84.4	7.3	1.5
K15	8.0	4311.5	2330.7	4325.5	2.161	2.210	2.2	17.5	87.4	7.3	1.5
AVG	8.0				2.155	2.210	2.5	17.7	85.9	7.3	1.5

Table A.7 12.5 GRV/LMS – SMA Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**		
Apparent Specific Gravity (Gsa):	2.658	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.575	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.488	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	10.2			
Asphalt Binder Gravity (Gb)	1.027			
% Absorbed Asphalt (Pba)	1.40			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	VMA (%)	VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
L1	6.0	4226.4	2347.2	4312.9	2.150	2.362	9.0	18.8	52.3	4.7	2.2
L2	6.0	4218.1	2344.4	4294.5	2.163	2.362	8.4	18.3	54.0	4.7	2.2
AVG	6.0				2.157	2.362	8.7	18.5	53.2	4.7	2.2
L3	7.0	4265.1	2356.4	4318.5	2.174	2.329	6.7	18.7	64.4	5.7	1.8
L4	7.0	4278.3	2390.1	4364.5	2.167	2.329	7.0	19.0	63.3	5.7	1.8
AVG	7.0				2.170	2.329	6.8	18.9	63.8	5.7	1.8
L5	8.0	4313.9	2363.0	4338.2	2.184	2.298	5.0	19.2	74.2	6.7	1.5
L6	8.0	4317.7	2363.5	4337.0	2.188	2.298	4.8	19.1	74.9	6.7	1.5
AVG	8.0				2.186	2.298	4.9	19.2	74.6	6.7	1.5

Table A.8 19.0 GRV/LMS – SMA Mix Design Summary

Aggregate Blend and Binder Properties		**Compaction Parameters**		
Apparent Specific Gravity (Gsa):	2.707	Superpave Gyratory Compactor:	Pine	
Effective Specific Gravity (Gse):	2.633	Ndesign, Gyrations:	96	
Bulk Specific Gravity (Gsb):	2.579	Mold Diameter:	150	mm
Percent Passing 0.075 mm:	10			
Asphalt Binder Gravity (Gb)	1.027			
% Absorbed Asphalt (Pba)	0.81			

		AASHTO T166 Results									
Specimen Number	Asphalt Content (%)	Dry Weight (gm)	Submerged Weight (gm)	SSD Weight (gm)	Gmb @ Ndes	Gmm	Ndesign VTM (%)	Ndesign VMA (%)	Ndesign VFA (%)	% Effective Asphalt (Pbe)	Dust Proportion (DP)
S1	6.0	4249.3	2423.3	4286.9	2.280	2.407	5.3	16.9	68.8	5.2	1.9
S2	6.0	4242.1	2400.2	4282.1	2.254	2.407	6.3	17.8	64.4	5.2	1.9
AVG	6.0				2.267	2.407	5.8	17.4	66.6	5.2	1.9
S3	7.0	4304.5	2365.1	4252.6	2.281	2.373	3.9	17.8	78.0	6.2	1.6
S4	7.0	4310.6	2381.5	4266.4	2.287	2.373	3.6	17.5	79.3	6.2	1.6
AVG	7.0				2.284	2.373	3.8	17.6	78.7	6.2	1.6
S5	8.0	4283.6	2428.6	4292.6	2.298	2.340	1.8	18.0	90.0	7.3	1.4
S6	8.0	4293.8	2434.0	4299.2	2.302	2.340	1.6	17.9	90.9	7.3	1.4
AVG	8.0				2.300	2.340	1.7	18.0	90.5	7.3	1.4

APPENDIX B
TENSILE STENGTH RESULTS

Table B.1 12.5 GRV – PG 67-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	H1	H5	H6	H2	H3	H4
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3450.7	3456.5	3479.8	3473.1	3459.6	3457.2
(D) SSD Weight, gm	3492.3	3490.8	3515.3	3503.6	3495.3	3490.5
(E) Submerged Weight, gm	1869.5	1869.5	1899.5	1882.7	1877.2	1871.6
(F) Bulk Specific Gravity [A/(D - E)]	2.126	2.132	2.154	2.143	2.138	2.136
(G) Theoretical Maximum Gravity	2.311	2.311	2.311	2.311	2.311	2.311
(H) % Air Voids [100*(1-F/G)]	7.99	7.75	6.81	7.28	7.48	7.59
(I) Volume of Air Voids [H*(D - E)/100]	129.6	125.6	110.0	N / A		
55% Saturated	3522.0	3525.6	3540.3			
70% Saturated	3541.4	3544.4	3556.8			
80% Saturated	3554.4	3557.0	3567.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3545.9	3550.7	3557.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	95.2	94.2	77.8			
(L) % Saturation [100*(K/I)]	73.4	75.0	70.7			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4833	4994	5092	5848	6003	5886
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	165.90697	170.3043	166.98503
(R) Conditioned S*T*, psi [2P/(A*B*π)]	137.1	141.7	144.5	N/A	N/A	N/A
(S) Average S*T*, psi	141.1			167.7		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				84		

Table B.2 12.5 GRV – PG 67-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L33	L35	L38	L34	L36	L37
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3507.1	3511.5	3487.2	3505.4	3511.8	3503.1
(D) SSD Weight, gm	3551.1	3548.8	3530.7	3548.3	3550.9	3546.0
(E) Submerged Weight, gm	1969.1	1968.5	1952.7	1964.5	1968.8	1966.3
(F) Bulk Specific Gravity [A/(D - E)]	2.217	2.222	2.210	2.213	2.220	2.218
(G) Theoretical Maximum Gravity	2.380	2.380	2.380	2.380	2.380	2.380
(H) % Air Voids [100*(1-F/G)]	6.85	6.64	7.15	7.00	6.73	6.82
(I) Volume of Air Voids [H*(D - E)/100]	108.4	104.9	112.8	N / A		
55% Saturated	3566.7	3569.2	3549.2			
70% Saturated	3583.0	3584.9	3566.2			
80% Saturated	3593.8	3595.4	3577.4			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3584.9	3590.9	3572.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	77.8	79.4	85.0			
(L) % Saturation [100*(K/I)]	71.8	75.7	75.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3290	3608	3341	3664	3804	3547
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	103.9	107.9	100.6
(R) Conditioned S*T*, psi [2P/(A*B*π)]	93.3	102.4	94.8	N/A	N/A	N/A
(S) Average S*T*, psi	96.8			104.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				93		

Table B.3 12.5 GRV – PG 67-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	C37	C38	C42	C39	C40	C41
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3395.5	3415.7	3408.7	3398.9	3416.9	3404.7
(D) SSD Weight, gm	3426.5	3442.9	3435.3	3427.6	3445.8	3431.0
(E) Submerged Weight, gm	1830.7	1840.7	1837.6	1832.8	1842.3	1834.4
(F) Bulk Specific Gravity [A/(D - E)]	2.128	2.132	2.134	2.131	2.131	2.132
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.77	7.59	7.52	7.62	7.63	7.57
(I) Volume of Air Voids [H*(D - E)/100]	124.0	121.6	120.2	N / A		
55% Saturated	3463.7	3482.6	3474.8			
70% Saturated	3482.3	3500.8	3492.8			
80% Saturated	3494.7	3513.0	3504.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3481.6	3499.5	3504.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	86.1	83.8	95.5			
(L) % Saturation [100*(K/I)]	69.4	68.9	79.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	2940	3156	3036	4200	3720	4080
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	119.15343	105.5359	115.74905
(R) Conditioned S*T*, psi [2P/(A*B*π)]	83.4	89.5	86.1	N/A	N/A	N/A
(S) Average S*T*, psi	86.4			113.5		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				76		

Table B.4 19.0 GRV – PG 67-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	C37	C38	C42	C39	C40	C41
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3395.5	3415.7	3408.7	3398.9	3416.9	3404.7
(D) SSD Weight, gm	3426.5	3442.9	3435.3	3427.6	3445.8	3431.0
(E) Submerged Weight, gm	1830.7	1840.7	1837.6	1832.8	1842.3	1834.4
(F) Bulk Specific Gravity [A/(D - E)]	2.128	2.132	2.134	2.131	2.131	2.132
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.77	7.59	7.52	7.62	7.63	7.57
(I) Volume of Air Voids [H*(D - E)/100]	124.0	121.6	120.2	N / A		
55% Saturated	3463.7	3482.6	3474.8			
70% Saturated	3482.3	3500.8	3492.8			
80% Saturated	3494.7	3513.0	3504.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3481.6	3499.5	3504.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	86.1	83.8	95.5			
(L) % Saturation [100*(K/I)]	69.4	68.9	79.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	2940	3156	3036	4200	3720	4080
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	119.15343	105.5359	115.74905
(R) Conditioned S*T*, psi [2P/(A*B*π)]	83.4	89.5	86.1	N/A	N/A	N/A
(S) Average S*T*, psi	86.4			113.5		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				76		

Table B.5 19.0 GRV – PG 67-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	E20	E23	E24	E19	E21	E22
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3431.5	3414.2	3421.2	3407.7	3404.9	3424.2
(D) SSD Weight, gm	3455.5	3437.6	3444.9	3430.2	3429.9	3447.4
(E) Submerged Weight, gm	1855.3	1837.7	1840.2	1838.2	1834.0	1848.1
(F) Bulk Specific Gravity [A/(D - E)]	2.144	2.134	2.132	2.141	2.134	2.141
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.05	7.50	7.59	7.22	7.52	7.19
(I) Volume of Air Voids [H*(D - E)/100]	112.8	120.0	121.7	N / A		
55% Saturated	3493.5	3480.2	3488.2			
70% Saturated	3510.4	3498.2	3506.4			
80% Saturated	3521.7	3510.2	3518.6			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3510.3	3497.6	3506.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	78.8	83.4	85.1			
(L) % Saturation [100*(K/I)]	69.9	69.5	69.9			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3204	3372	3348	4215	3391	4261
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	119.6	96.2	120.9
(R) Conditioned S*T*, psi [2P/(A*B*π)]	90.9	95.7	95.0	N/A	N/A	N/A
(S) Average S*T*, psi	93.8			112.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				84		

Table B.6 19.0 GRV – PG 67-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	C88	C91	C92	C87	C89	C90
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3413.9	3409.7	3391.8	3409.5	3405.4	3407.3
(D) SSD Weight, gm	3438.8	3439.5	3418.9	3436.9	3430.3	3435.7
(E) Submerged Weight, gm	1837.3	1836.6	1821.2	1836.8	1830.2	1830.5
(F) Bulk Specific Gravity [A/(D - E)]	2.132	2.127	2.123	2.131	2.128	2.123
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.60	7.79	7.98	7.64	7.75	7.99
(I) Volume of Air Voids [H*(D - E)/100]	121.7	124.9	127.5	N / A		
55% Saturated	3480.8	3478.4	3461.9			
70% Saturated	3499.1	3497.1	3481.0			
80% Saturated	3511.3	3509.6	3493.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3496.3	3495.8	3487.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	82.4	86.1	95.9			
(L) % Saturation [100*(K/I)]	67.7	68.9	75.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3460	3250	3330	3650	3960	3760
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	103.6	112.3	106.7
(R) Conditioned S*T*, psi [2P/(A*B*π)]	98.2	92.2	94.5	N/A	N/A	N/A
(S) Average S*T*, psi	94.9			107.5		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				88		

Table B.7 12.5 GRV/LMS – PG 67-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A37	A39	A40	A36	A38	A41
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3609.5	3597.5	3600.3	3621.8	3587.5	3600.3
(D) SSD Weight, gm	3640.7	3632.3	3628.3	3649.5	3618.0	3633.1
(E) Submerged Weight, gm	2020.1	2013.9	2013.5	2029.0	2001.6	2014.5
(F) Bulk Specific Gravity [A/(D - E)]	2.227	2.223	2.230	2.235	2.219	2.224
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	6.57	6.76	6.48	6.25	6.90	6.70
(I) Volume of Air Voids [H*(D - E)/100]	106.5	109.4	104.6	N / A		
55% Saturated	3668.1	3657.7	3657.8			
70% Saturated	3684.1	3674.1	3673.5			
80% Saturated	3694.7	3685.0	3684.0			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3683.1	3680.8	3675.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	73.6	83.3	75.3			
(L) % Saturation [100*(K/I)]	69.1	76.2	72.0			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3480	3036	3360	5480	5076	5419
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	155.46686	144.00544	153.7363
(R) Conditioned S*T*, psi [2P/(A*B*π)]	98.7	86.1	95.3	N/A	N/A	N/A
(S) Average S*T*, psi	93.4			151.1		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				62		

Table B.8 12.5 GRV/LMS – PG 67-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	D13	D15	D18	D14	D16	D17
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3589.1	3603.0	3586.0	3592.7	3586.5	3598.9
(D) SSD Weight, gm	3630.3	3633.3	3619.9	3621.1	3623.8	3629.0
(E) Submerged Weight, gm	2007.5	2018.6	2004.6	2007.8	2007.2	2009.9
(F) Bulk Specific Gravity [A/(D - E)]	2.212	2.231	2.220	2.227	2.219	2.223
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	7.23	6.40	6.88	6.59	6.94	6.76
(I) Volume of Air Voids [H*(D - E)/100]	117.3	103.4	111.1	N / A		
55% Saturated	3653.6	3659.9	3647.1			
70% Saturated	3671.2	3675.4	3663.8			
80% Saturated	3682.9	3685.7	3674.9			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3680.8	3681.6	3674.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	91.7	78.6	88.0			
(L) % Saturation [100*(K/I)]	78.2	76.0	79.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4574	4951	4585	5945	5562	5581
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	168.7	157.8	158.3
(R) Conditioned S*T*, psi [2P/(A*B*π)]	129.8	140.5	130.1	N/A	N/A	N/A
(S) Average S*T*, psi	133.4			161.6		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				83		

Table B.9 12.5 GRV/LMS – PG 67-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	C94	C97	C98	C93	C95	C96
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3600.1	3597.2	3599.4	3606.9	3590.1	3594.3
(D) SSD Weight, gm	3631.9	3628.1	3630.3	3637.8	3619.5	3628.9
(E) Submerged Weight, gm	2012.6	2005.6	2008.4	2015.0	2005.3	2005.4
(F) Bulk Specific Gravity [A/(D - E)]	2.223	2.217	2.219	2.223	2.224	2.214
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	6.74	7.00	6.91	6.77	6.71	7.13
(I) Volume of Air Voids [H*(D - E)/100]	109.2	113.6	112.1	N / A		
55% Saturated	3660.2	3659.7	3661.0			
70% Saturated	3676.5	3676.7	3677.9			
80% Saturated	3687.5	3688.1	3689.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3686.1	3687.0	3685.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	86.0	89.8	85.8			
(L) % Saturation [100*(K/I)]	78.8	79.0	76.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4431	4340	4516	5100	4990	5241
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	144.7	141.6	148.7
(R) Conditioned S*T*, psi [2P/(A*B*π)]	125.7	123.1	128.1	N/A	N/A	N/A
(S) Average S*T*, psi	125.7			145.0		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				87		

Table B.10 19.0 GRV/LMS – PG 67-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A44	A46	A47	A42	A43	A45
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3625.9	3637.1	3605.4	3610.1	3639.5	3601.4
(D) SSD Weight, gm	3654.9	3668.8	3638.4	3639.6	3666.5	3635.7
(E) Submerged Weight, gm	2044.0	2052.3	2030.4	2035.2	2055.3	2024.2
(F) Bulk Specific Gravity [A/(D - E)]	2.251	2.250	2.242	2.250	2.259	2.235
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.03	7.06	7.39	7.06	6.70	7.69
(I) Volume of Air Voids [H*(D - E)/100]	113.2	114.2	118.8	N / A		
55% Saturated	3688.2	3699.9	3670.7			
70% Saturated	3705.1	3717.0	3688.5			
80% Saturated	3716.5	3728.4	3700.4			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3702.5	3718.3	3688.5	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	76.6	81.2	83.1			
(L) % Saturation [100*(K/I)]	67.7	71.1	70.0			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3451	3747	3520	4980	5820	5280
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	141.28193	165.11261	149.79289
(R) Conditioned S*T*, psi [2P/(A*B*π)]	97.9	106.3	99.9	N/A	N/A	N/A
(S) Average S*T*, psi	101.4			152.1		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				67		

Table B.11 19.0 GRV/LMS – PG 67-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	D19	D20	D23	D21	D22	D24
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3618.3	3621.8	3611.2	3607.2	3621.3	3635.1
(D) SSD Weight, gm	3647.4	3655.7	3646.7	3647.3	3656.7	3664.8
(E) Submerged Weight, gm	2037.3	2046.1	2033.7	2030.2	2040.5	2052.2
(F) Bulk Specific Gravity [A/(D - E)]	2.247	2.250	2.239	2.231	2.241	2.254
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.18	7.06	7.53	7.86	7.45	6.89
(I) Volume of Air Voids [H*(D - E)/100]	115.6	113.6	121.4	N / A		
55% Saturated	3681.9	3684.3	3678.0			
70% Saturated	3699.2	3701.3	3696.2			
80% Saturated	3710.7	3712.7	3708.3			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3704.2	3697.0	3693.1	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	85.9	75.2	81.9			
(L) % Saturation [100*(K/I)]	74.3	66.2	67.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4562	4784	4369	5265	5463	5378
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	149.4	155.0	152.6
(R) Conditioned S*T*, psi [2P/(A*B*π)]	129.4	135.7	123.9	N/A	N/A	N/A
(S) Average S*T*, psi	129.7			152.3		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				85		

Table B.12 19.0 GRV/LMS – PG 67-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	C99	C100	C104	C101	C102	C103
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3620.2	3619.7	3615.9	3613.2	3614.0	3619.6
(D) SSD Weight, gm	3650.8	3649.5	3647.1	3651.3	3644.1	3651.8
(E) Submerged Weight, gm	2040.5	2042.0	2031.2	2042.5	2038.3	2039.9
(F) Bulk Specific Gravity [A/(D - E)]	2.248	2.252	2.238	2.246	2.251	2.246
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.14	6.99	7.57	7.23	7.04	7.25
(I) Volume of Air Voids [H*(D - E)/100]	115.0	112.4	122.3	N / A		
55% Saturated	3683.4	3681.5	3683.2			
70% Saturated	3700.7	3698.4	3701.5			
80% Saturated	3712.2	3709.6	3713.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3698.0	3698.2	3698.5	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	77.8	78.5	82.6			
(L) % Saturation [100*(K/I)]	67.7	69.9	67.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4151	4427	4562	4979	5103	5053
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	141.3	144.8	143.4
(R) Conditioned S*T*, psi [2P/(A*B*π)]	117.8	125.6	129.4	N/A	N/A	N/A
(S) Average S*T*, psi	124.3			143.1		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				87		

Table B.13 12.5 GRV – PG 76-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	H1	H5	H6	H2	H3	H4
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3450.7	3456.5	3479.8	3473.1	3459.6	3457.2
(D) SSD Weight, gm	3492.3	3490.8	3515.3	3503.6	3495.3	3490.5
(E) Submerged Weight, gm	1869.5	1869.5	1899.5	1882.7	1877.2	1871.6
(F) Bulk Specific Gravity [A/(D - E)]	2.126	2.132	2.154	2.143	2.138	2.136
(G) Theoretical Maximum Gravity	2.311	2.311	2.311	2.311	2.311	2.311
(H) % Air Voids [100*(1-F/G)]	7.99	7.75	6.81	7.28	7.48	7.59
(I) Volume of Air Voids [H*(D - E)/100]	129.6	125.6	110.0	N / A		
55% Saturated	3522.0	3525.6	3540.3			
70% Saturated	3541.4	3544.4	3556.8			
80% Saturated	3554.4	3557.0	3567.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3545.9	3550.7	3557.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	95.2	94.2	77.8			
(L) % Saturation [100*(K/I)]	73.4	75.0	70.7			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4833	4994	5092	5848	6003	5886
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	165.90697	170.3043	166.98503
(R) Conditioned S*T*, psi [2P/(A*B*π)]	137.1	141.7	144.5	N/A	N/A	N/A
(S) Average S*T*, psi	141.1			167.7		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				84		

Table B.14 12.5 GRV – PG 76-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	J2	J3	J5	J1	J4	J6
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3453.9	3479.2	3471.3	3483.5	3476.6	3459.8
(D) SSD Weight, gm	3486.6	3501.8	3494.5	3508.9	3499.5	3485.2
(E) Submerged Weight, gm	1863.7	1879.4	1880.2	1882.4	1882.2	1869.2
(F) Bulk Specific Gravity [A/(D - E)]	2.128	2.144	2.150	2.142	2.150	2.141
(G) Theoretical Maximum Gravity	2.311	2.311	2.311	2.311	2.311	2.311
(H) % Air Voids [100*(1-F/G)]	7.91	7.21	6.95	7.33	6.98	7.36
(I) Volume of Air Voids [H*(D - E)/100]	128.4	116.9	112.2	N / A		
55% Saturated	3524.5	3543.5	3533.0			
70% Saturated	3543.7	3561.0	3549.9			
80% Saturated	3556.6	3572.7	3561.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3546.8	3559.8	3552.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	92.9	80.6	81.0			
(L) % Saturation [100*(K/I)]	72.4	68.9	72.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4800	4850	4900	5275	5197	5333
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	149.7	147.4	151.3
(R) Conditioned S*T*, psi [2P/(A*B*π)]	136.2	137.6	139.0	N/A	N/A	N/A
(S) Average S*T*, psi	137.6			149.5		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				92		

Table B.15 12.5 GRV – PG 76-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A91	A92	A93	A88	A89	A90
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3461.1	3471.6	3460.3	3474.5	3461.9	3474.0
(D) SSD Weight, gm	3486.1	3495.5	3490.6	3497.3	3488.9	3496.5
(E) Submerged Weight, gm	1866.7	1874.4	1872.3	1872.3	1870.9	1876.3
(F) Bulk Specific Gravity [A/(D - E)]	2.137	2.142	2.138	2.138	2.140	2.144
(G) Theoretical Maximum Gravity	2.311	2.311	2.311	2.311	2.311	2.311
(H) % Air Voids [100*(1-F/G)]	7.52	7.33	7.48	7.48	7.42	7.22
(I) Volume of Air Voids [H*(D - E)/100]	121.7	118.9	121.0	N / A		
55% Saturated	3528.1	3537.0	3526.8			
70% Saturated	3546.3	3554.8	3545.0			
80% Saturated	3558.5	3566.7	3557.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3544.9	3551.9	3542.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	83.8	80.3	82.5			
(L) % Saturation [100*(K/I)]	68.8	67.5	68.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (ST) Calculations						
(P) Failure Load, lbs	4754	4750	4399	5854	5484	5877
(Q) Dry ST, psi [2P/(A*B*π)]	N/A	N/A	N/A	166.1	155.6	166.7
(R) Conditioned ST, psi [2P/(A*B*π)]	134.9	134.8	124.8	N/A	N/A	N/A
(S) Average ST, psi	131.5			162.8		
Tensile Strength Ratio [Avg Conditioned ST / Avg Dry ST]:				81		

Table B.16 19.0 GRV – PG 76-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	H7	H10	H11	H8	H9	H12
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3420.9	3417.4	3394.0	3413.0	3426.1	3387.5
(D) SSD Weight, gm	3465.0	3456.4	3440.1	3460.2	3463.5	3436.4
(E) Submerged Weight, gm	1858.3	1863.5	1848.8	1861.2	1864.7	1847.7
(F) Bulk Specific Gravity [A/(D - E)]	2.129	2.145	2.133	2.134	2.143	2.132
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.71	7.00	7.55	7.48	7.11	7.57
(I) Volume of Air Voids [H*(D - E)/100]	123.9	111.6	120.1	N / A		
55% Saturated	3489.0	3478.8	3460.1			
70% Saturated	3507.6	3495.5	3478.1			
80% Saturated	3520.0	3506.7	3490.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3504.2	3494.7	3478.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	83.3	77.3	84.8			
(L) % Saturation [100*(K/I)]	67.3	69.3	70.6			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4365	4930	4350	5650	5742	5286
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	160.28974	162.89977	149.96311
(R) Conditioned S*T*, psi [2P/(A*B*π)]	123.8	139.9	123.4	N/A	N/A	N/A
(S) Average S*T*, psi	129.0			157.7		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				82		

Table B.17 19.0 GRV – PG 76-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	J7	J9	J10	J8	J11	J12
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3410.6	3407.4	3408.6	3414.4	3393.6	3435.4
(D) SSD Weight, gm	3446.3	3440.4	3447.7	3448.1	3437.6	3462.7
(E) Submerged Weight, gm	1845.9	1841.4	1845.8	1843.8	1838.7	1868.7
(F) Bulk Specific Gravity [A/(D - E)]	2.131	2.131	2.128	2.128	2.122	2.155
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.62	7.63	7.77	7.75	8.00	6.58
(I) Volume of Air Voids [H*(D - E)/100]	122.0	122.0	124.4	N / A		
55% Saturated	3477.7	3474.5	3477.0			
70% Saturated	3496.0	3492.8	3495.7			
80% Saturated	3508.2	3505.0	3508.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3498.6	3494.9	3497.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	88.0	87.5	88.6			
(L) % Saturation [100*(K/I)]	72.1	71.7	71.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4462	4555	4611	4811	5629	5468
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	136.5	159.7	155.1
(R) Conditioned S*T*, psi [2P/(A*B*π)]	126.6	129.2	130.8	N/A	N/A	N/A
(S) Average S*T*, psi	128.9			150.4		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				86		

Table B.18 19.0 GRV – PG 76-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A95	A96	A98	A94	A97	A99
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3401.0	3420.7	3415.2	3419.8	3399.0	3407.4
(D) SSD Weight, gm	3437.1	3456.0	3441.7	3455.9	3438.1	3452.6
(E) Submerged Weight, gm	1841.1	1855.7	1846.1	1854.9	1849.7	1857.7
(F) Bulk Specific Gravity [A/(D - E)]	2.131	2.138	2.140	2.136	2.140	2.136
(G) Theoretical Maximum Gravity	2.307	2.307	2.307	2.307	2.307	2.307
(H) % Air Voids [100*(1-F/G)]	7.63	7.35	7.22	7.41	7.24	7.39
(I) Volume of Air Voids [H*(D - E)/100]	121.8	117.6	115.2	N / A		
55% Saturated	3468.0	3485.4	3478.6			
70% Saturated	3486.3	3503.0	3495.9			
80% Saturated	3498.4	3514.7	3507.4			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3484.0	3505.1	3490.1	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	83.0	84.4	74.9			
(L) % Saturation [100*(K/I)]	68.1	71.8	65.0			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4431	4343	4221	5035	5044	5428
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	142.8	143.1	154.0
(R) Conditioned S*T*, psi [2P/(A*B*π)]	125.7	123.2	119.7	N/A	N/A	N/A
(S) Average S*T*, psi	122.9			146.6		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				84		

Table B.19 12.5 GRV/LMS – PG 76-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	G2	G3	G6	G1	G5	G4
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3567.4	3578.8	3588.8	3550.6	3599.8	3597.6
(D) SSD Weight, gm	3618.4	3623.9	3634.8	3612.9	3638.2	3640.0
(E) Submerged Weight, gm	2003.5	2008.6	2015.0	1995.2	2024.9	2015.8
(F) Bulk Specific Gravity [A/(D - E)]	2.209	2.216	2.216	2.195	2.231	2.215
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	7.34	7.07	7.06	7.93	6.40	7.09
(I) Volume of Air Voids [H*(D - E)/100]	118.5	114.1	114.4	N / A		
55% Saturated	3632.6	3641.6	3651.7			
70% Saturated	3650.4	3658.7	3668.9			
80% Saturated	3662.2	3670.1	3680.3			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3672.0	3677.0	3675.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	104.6	98.2	86.2			
(L) % Saturation [100*(K/I)]	88.3	86.0	75.3			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4308	4696	4400	5173	5613	5987
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	146.75731	159.24005	169.85038
(R) Conditioned S*T*, psi [2P/(A*B*π)]	122.2	133.2	124.8	N/A	N/A	N/A
(S) Average S*T*, psi	126.8			158.6		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				80		

Table B.20 12.5 GRV/LMS – PG 76-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	I1	I3	I6	I2	I4	I5
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3588.8	3594.6	3597.2	3588.8	3588.2	3599.4
(D) SSD Weight, gm	3619.6	3624.1	3631.6	3626.5	3624.0	3632.0
(E) Submerged Weight, gm	2001.2	2009.8	2015.3	2006.5	2007.0	2016.2
(F) Bulk Specific Gravity [A/(D - E)]	2.217	2.227	2.226	2.215	2.219	2.228
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	6.98	6.60	6.65	7.08	6.92	6.56
(I) Volume of Air Voids [H*(D - E)/100]	113.0	106.5	107.4	N / A		
55% Saturated	3651.0	3653.2	3656.3			
70% Saturated	3667.9	3669.1	3672.4			
80% Saturated	3679.2	3679.8	3683.1			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3672.2	3674.1	3681.9	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	83.4	79.5	84.7			
(L) % Saturation [100*(K/I)]	73.8	74.6	78.9			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	5312	5291	5249	5743	5954	6078
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	162.9	168.9	172.4
(R) Conditioned S*T*, psi [2P/(A*B*π)]	150.7	150.1	148.9	N/A	N/A	N/A
(S) Average S*T*, psi	149.9			168.1		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				89		

Table B.21 12.5 GRV/LMS – PG 76-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A76	A80	A81	A77	A78	A79
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3592.8	3595.0	3589.9	3591.7	3587.1	3598.2
(D) SSD Weight, gm	3633.7	3636.8	3633.9	3634.3	3629.0	3634.8
(E) Submerged Weight, gm	2012.7	2018.9	2015.8	2014.0	2008.8	2019.2
(F) Bulk Specific Gravity [A/(D - E)]	2.216	2.222	2.219	2.217	2.214	2.227
(G) Theoretical Maximum Gravity	2.384	2.384	2.384	2.384	2.384	2.384
(H) % Air Voids [100*(1-F/G)]	7.03	6.79	6.94	7.02	7.13	6.58
(I) Volume of Air Voids [H*(D - E)/100]	114.0	109.9	112.3	N / A		
55% Saturated	3655.5	3655.5	3651.6			
70% Saturated	3672.6	3672.0	3668.5			
80% Saturated	3684.0	3682.9	3679.7			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3682.9	3681.5	3679.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	90.1	86.5	89.1			
(L) % Saturation [100*(K/I)]	79.1	78.7	79.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4455	4656	4460	5452	5737	5540
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	154.7	162.8	157.2
(R) Conditioned S*T*, psi [2P/(A*B*π)]	126.4	132.1	126.5	N/A	N/A	N/A
(S) Average S*T*, psi	128.3			158.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				81		

Table B.22 19.0 GRV/LMS – PG 76-22 – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	G7	G9	G11	G8	G10	G12
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3608.9	3606.1	3621.4	3597.6	3591.8	3610.9
(D) SSD Weight, gm	3655.7	3652.6	3661.7	3636.5	3641.5	3654.7
(E) Submerged Weight, gm	2043.3	2037.1	2044.2	2039.5	2029.7	2040.4
(F) Bulk Specific Gravity [A/(D - E)]	2.238	2.232	2.239	2.253	2.228	2.237
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.55	7.80	7.52	6.95	7.95	7.61
(I) Volume of Air Voids [H*(D - E)/100]	121.7	126.0	121.7	N / A		
55% Saturated	3675.9	3675.4	3688.3			
70% Saturated	3694.1	3694.3	3706.6			
80% Saturated	3706.3	3706.9	3718.7			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3714.0	3699.8	3713.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	105.1	93.7	92.2			
(L) % Saturation [100*(K/I)]	86.3	74.4	75.7			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4271	4305	4198	5933	5472	5801
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	168.31841	155.2399	164.57359
(R) Conditioned S*T*, psi [2P/(A*B*π)]	121.2	122.1	119.1	N/A	N/A	N/A
(S) Average S*T*, psi	120.8			162.7		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				74		

Table B.23 19.0 GRV/LMS – PG 76-22 – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	I7	I8	I12	I9	I10	I11
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3614.1	3610.0	3613.3	3633.4	3616.6	3612.2
(D) SSD Weight, gm	3650.2	3653.5	3651.3	3665.1	3655.0	3654.7
(E) Submerged Weight, gm	2042.0	2037.5	2046.1	2060.2	2042.9	2037.2
(F) Bulk Specific Gravity [A/(D - E)]	2.247	2.234	2.251	2.264	2.243	2.233
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.17	7.73	7.02	6.49	7.34	7.76
(I) Volume of Air Voids [H*(D - E)/100]	115.4	124.9	112.7	N / A		
55% Saturated	3677.6	3678.7	3675.3			
70% Saturated	3694.9	3697.4	3692.2			
80% Saturated	3706.4	3709.9	3703.5			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3695.9	3700.6	3691.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	81.8	90.6	78.0			
(L) % Saturation [100*(K/I)]	70.9	72.5	69.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4913	4997	5090	6476	6158	5980
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	183.7	174.7	169.7
(R) Conditioned S*T*, psi [2P/(A*B*π)]	139.4	141.8	144.4	N/A	N/A	N/A
(S) Average S*T*, psi	141.8			176.0		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				81		

Table B.24 19.0 GRV/LMS – PG 76-22 – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	A82	A85	A87	A83	A84	A86
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3603.9	3595.9	3606.1	3601.4	3617.8	3586.8
(D) SSD Weight, gm	3647.6	3643.4	3650.3	3655.2	3656.7	3634.9
(E) Submerged Weight, gm	2042.4	2032.3	2041.0	2040.3	2050.0	2034.8
(F) Bulk Specific Gravity [A/(D - E)]	2.245	2.232	2.241	2.230	2.252	2.242
(G) Theoretical Maximum Gravity	2.421	2.421	2.421	2.421	2.421	2.421
(H) % Air Voids [100*(1-F/G)]	7.26	7.81	7.44	7.88	6.99	7.41
(I) Volume of Air Voids [H*(D - E)/100]	116.6	125.8	119.8	N / A		
55% Saturated	3668.0	3665.1	3672.0			
70% Saturated	3685.5	3684.0	3690.0			
80% Saturated	3697.2	3696.5	3701.9			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3691.9	3691.1	3700.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	88.0	95.2	94.5			
(L) % Saturation [100*(K/I)]	75.5	75.7	78.9			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4492	4483	4141	5531	5896	5578
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	156.9	167.3	158.2
(R) Conditioned S*T*, psi [2P/(A*B*π)]	127.4	127.2	117.5	N/A	N/A	N/A
(S) Average S*T*, psi	124.0			160.8		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				77		

Table B.25 12.5 GRV – SMA – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K25	K29	K30	K26	K27	K28
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3210.2	3199.5	3211.4	3188.5	3218.2	3203.9
(D) SSD Weight, gm	3262.1	3257.0	3253.8	3247.2	3266.5	3252.0
(E) Submerged Weight, gm	1683.3	1683.2	1690.0	1675.0	1694.4	1688.9
(F) Bulk Specific Gravity [A/(D - E)]	2.033	2.033	2.054	2.028	2.047	2.050
(G) Theoretical Maximum Gravity	2.188	2.188	2.188	2.188	2.188	2.188
(H) % Air Voids [100*(1-F/G)]	7.07	7.09	6.14	7.31	6.44	6.32
(I) Volume of Air Voids [H*(D - E)/100]	111.6	111.5	96.1	N / A		
55% Saturated	3271.6	3260.8	3264.2			
70% Saturated	3288.3	3277.6	3278.6			
80% Saturated	3299.5	3288.7	3288.3			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3298.0	3287.5	3285.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	87.8	88.0	74.3			
(L) % Saturation [100*(K/I)]	78.7	78.9	77.3			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	2817	3079	3149	3248	3285	3439
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	92.145322	93.195007	97.563966
(R) Conditioned S*T*, psi [2P/(A*B*π)]	79.9	87.4	89.3	N/A	N/A	N/A
(S) Average S*T*, psi	85.5			94.3		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				91		

Table B.26 12.5 GRV – SMA – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K38	K39	K41	K37	K40	K42
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3209.9	3207.8	3225.6	3222.3	3210.0	3216.0
(D) SSD Weight, gm	3263.4	3259.1	3280.9	3269.7	3260.9	3268.0
(E) Submerged Weight, gm	1678.6	1673.5	1687.6	1685.0	1672.8	1678.6
(F) Bulk Specific Gravity [A/(D - E)]	2.025	2.023	2.024	2.033	2.021	2.023
(G) Theoretical Maximum Gravity	2.188	2.188	2.188	2.188	2.188	2.188
(H) % Air Voids [100*(1-F/G)]	7.43	7.54	7.47	7.07	7.62	7.52
(I) Volume of Air Voids [H*(D - E)/100]	117.8	119.5	119.1	N / A		
55% Saturated	3274.7	3273.5	3291.1			
70% Saturated	3292.3	3291.5	3309.0			
80% Saturated	3304.1	3303.4	3320.9			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3303.2	3297.5	3309.4	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	93.3	89.7	83.8			
(L) % Saturation [100*(K/I)]	79.2	75.1	70.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	74.9			N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	-3135.0					
(O) % Saturation [100*(N/I)]	-325276.5					
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3201	3248	3496	3903	3697	3720
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	110.7	104.9	105.5
(R) Conditioned S*T*, psi [2P/(A*B*π)]	90.8	92.1	99.2	N/A	N/A	N/A
(S) Average S*T*, psi	94.0			107.0		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				88		

Table B.27 12.5 GRV – SMA – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K49	K51	K53	K50	K52	K54
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3217.6	3230.6	3204.3	3224.8	3218.0	3219.4
(D) SSD Weight, gm	3275.1	3271.2	3256.7	3279.2	3265.0	3274.3
(E) Submerged Weight, gm	1685.5	1692.6	1677.0	1691.0	1692.4	1684.8
(F) Bulk Specific Gravity [A/(D - E)]	2.024	2.046	2.028	2.030	2.046	2.025
(G) Theoretical Maximum Gravity	2.188	2.188	2.188	2.188	2.188	2.188
(H) % Air Voids [100*(1-F/G)]	7.49	6.47	7.29	7.20	6.48	7.43
(I) Volume of Air Voids [H*(D - E)/100]	119.0	102.1	115.2	N / A		
55% Saturated	3283.1	3286.8	3267.7			
70% Saturated	3300.9	3302.1	3284.9			
80% Saturated	3312.8	3312.3	3296.5			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3305.2	3306.2	3290.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	87.6	75.6	85.7			
(L) % Saturation [100*(K/I)]	73.6	74.1	74.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	2859	3060	2658	3224	3402	3388
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	91.5	96.5	96.1
(R) Conditioned S*T*, psi [2P/(A*B*π)]	81.1	86.8	75.4	N/A	N/A	N/A
(S) Average S*T*, psi	81.1			94.7		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				86		

Table B.28 19.0 GRV– SMA – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K31	K34	K36	K32	K33	K35
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3221.8	3203.1	3219.9	3189.9	3215.9	3229.7
(D) SSD Weight, gm	3282.3	3254.1	3270.8	3244.3	3270.1	3280.7
(E) Submerged Weight, gm	1718.8	1713.6	1725.1	1706.1	1724.7	1728.5
(F) Bulk Specific Gravity [A/(D - E)]	2.061	2.079	2.083	2.074	2.081	2.081
(G) Theoretical Maximum Gravity	2.229	2.229	2.229	2.229	2.229	2.229
(H) % Air Voids [100*(1-F/G)]	7.55	6.72	6.54	6.96	6.64	6.65
(I) Volume of Air Voids [H*(D - E)/100]	118.1	103.5	101.2	N / A		
55% Saturated	3286.8	3260.0	3275.5			
70% Saturated	3304.5	3275.5	3290.7			
80% Saturated	3316.3	3285.9	3300.8			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3315.2	3285.1	3298.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	93.4	82.0	78.4			
(L) % Saturation [100*(K/I)]	79.1	79.2	77.5			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3000	3037	3524	3556	3304	3954
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	100.88324	93.734034	112.17445
(R) Conditioned S*T*, psi [2P/(A*B*π)]	85.1	86.2	100.0	N/A	N/A	N/A
(S) Average S*T*, psi	90.4			102.3		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				88		

Table B.29 19.0 GRV – SMA – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K45	K46	K48	K43	K44	K47
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3235.8	3237.3	3231.3	3224.1	3226.9	3225.3
(D) SSD Weight, gm	3291.5	3284.5	3285.6	3271.3	3279.3	3273.3
(E) Submerged Weight, gm	1724.4	1722.2	1716.1	1713.3	1713.1	1717.5
(F) Bulk Specific Gravity [A/(D - E)]	2.065	2.072	2.059	2.069	2.060	2.073
(G) Theoretical Maximum Gravity	2.229	2.229	2.229	2.229	2.229	2.229
(H) % Air Voids [100*(1-F/G)]	7.37	7.04	7.64	7.16	7.57	7.00
(I) Volume of Air Voids [H*(D - E)/100]	115.4	109.9	119.8	N / A		
55% Saturated	3299.3	3297.8	3297.2			
70% Saturated	3316.6	3314.3	3315.2			
80% Saturated	3328.1	3325.3	3327.2			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3321.6	3313.6	3315.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	85.8	76.3	84.0			
(L) % Saturation [100*(K/I)]	74.3	69.4	70.1			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	71.3			N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	-3164.5					
(O) % Saturation [100*(N/I)]	-327994.0					
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	2897	4174	3893	4399	4029	4460
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	124.8	114.3	126.5
(R) Conditioned S*T*, psi [2P/(A*B*π)]	82.2	118.4	110.4	N/A	N/A	N/A
(S) Average S*T*, psi	114.4			121.9		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				94		

Table B.30 19.0 GRV – SMA – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	K55	K58	K59	K56	K57	K60
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3238.3	3220.8	3231.1	3231.9	3231.1	3233.7
(D) SSD Weight, gm	3284.8	3269.1	3278.6	3278.0	3284.6	3273.1
(E) Submerged Weight, gm	1727.0	1716.8	1715.5	1719.2	1720.9	1727.6
(F) Bulk Specific Gravity [A/(D - E)]	2.079	2.075	2.067	2.073	2.066	2.092
(G) Theoretical Maximum Gravity	2.229	2.229	2.229	2.229	2.229	2.229
(H) % Air Voids [100*(1-F/G)]	6.74	6.92	7.26	6.98	7.30	6.13
(I) Volume of Air Voids [H*(D - E)/100]	105.0	107.3	113.5	N / A		
55% Saturated	3296.0	3279.8	3293.5			
70% Saturated	3311.8	3295.9	3310.6			
80% Saturated	3322.3	3306.7	3321.9			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3312.7	3302.9	3318.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	74.4	82.1	87.1			
(L) % Saturation [100*(K/I)]	70.9	76.5	76.7			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3512	3430	3874	3954	4080	4357
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	112.2	115.7	123.6
(R) Conditioned S*T*, psi [2P/(A*B*π)]	99.6	97.3	109.9	N/A	N/A	N/A
(S) Average S*T*, psi	102.3			117.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				87		

Table B.31 12.5 GRV/LMS – SMA – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L15	L19	L20	L16	L17	L18
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3384.8	3364.5	3375.8	3390.4	3379.4	3390.2
(D) SSD Weight, gm	3427.7	3418.0	3422.0	3433.7	3425.5	3436.2
(E) Submerged Weight, gm	1835.5	1822.7	1832.0	1835.3	1835.8	1838
(F) Bulk Specific Gravity [A/(D - E)]	2.126	2.109	2.123	2.121	2.126	2.121
(G) Theoretical Maximum Gravity	2.282	2.282	2.282	2.282	2.282	2.282
(H) % Air Voids [100*(1-F/G)]	6.84	7.58	6.96	7.05	6.84	7.04
(I) Volume of Air Voids [H*(D - E)/100]	108.9	120.9	110.7	N / A		
55% Saturated	3444.7	3431.0	3436.7			
70% Saturated	3461.1	3449.2	3453.3			
80% Saturated	3472.0	3461.2	3464.3			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3469.3	3460.0	3464.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	84.5	95.5	88.4			
(L) % Saturation [100*(K/I)]	77.6	79.0	79.9			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (ST) Calculations						
(P) Failure Load, lbs	2995	2635	3023	3252	2985	3365
(Q) Dry ST, psi [2P/(A*B*π)]	N/A	N/A	N/A	92.258801	84.684047	95.464596
(R) Conditioned ST, psi [2P/(A*B*π)]	85.0	74.8	85.8	N/A	N/A	N/A
(S) Average ST, psi	81.8			90.8		
Tensile Strength Ratio [Avg Conditioned ST / Avg Dry ST]:				90		

Table B.32 12.5 GRV/LMS – SMA – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L27	L28	L31	L29	L30	L32
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3381.9	3399.2	3386.0	3386.0	3387.1	3396.8
(D) SSD Weight, gm	3419.7	3436.1	3426.0	3423.2	3425.0	3431.4
(E) Submerged Weight, gm	1821.0	1835.4	1830.6	1821.7	1826.5	1835.9
(F) Bulk Specific Gravity [A/(D - E)]	2.115	2.124	2.122	2.114	2.119	2.129
(G) Theoretical Maximum Gravity	2.282	2.282	2.282	2.282	2.282	2.282
(H) % Air Voids [100*(1-F/G)]	7.30	6.94	7.00	7.35	7.15	6.71
(I) Volume of Air Voids [H*(D - E)/100]	116.7	111.1	111.6	N / A		
55% Saturated	3446.1	3460.3	3447.4			
70% Saturated	3463.6	3477.0	3464.1			
80% Saturated	3475.3	3488.1	3475.3			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3470.2	3476.2	3468.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	88.3	77.0	82.3			
(L) % Saturation [100*(K/I)]	75.7	69.3	73.7			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (ST) Calculations						
(P) Failure Load, lbs	3065	3789	2954	3748	3589	3669
(Q) Dry ST, psi [2P/(A*B*π)]	N/A	N/A	N/A	106.3	101.8	104.1
(R) Conditioned ST, psi [2P/(A*B*π)]	86.9	107.5	83.8	N/A	N/A	N/A
(S) Average ST, psi	92.7			104.1		
Tensile Strength Ratio [Avg Conditioned ST / Avg Dry ST]:				89		

Table B.33 12.5 GRV/LMS – SMA – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L41	L42	L43	L39	L40	L44
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3392.9	3394.7	3384.3	3405.3	3396.2	3407.6
(D) SSD Weight, gm	3422.9	3424.7	3420.3	3434.6	3428.1	3435.1
(E) Submerged Weight, gm	1826.1	1831.4	1824.3	1834.4	1828.3	1831.8
(F) Bulk Specific Gravity [A/(D - E)]	2.125	2.131	2.120	2.128	2.123	2.125
(G) Theoretical Maximum Gravity	2.282	2.282	2.282	2.282	2.282	2.282
(H) % Air Voids [100*(1-F/G)]	6.89	6.63	7.08	6.75	6.97	6.86
(I) Volume of Air Voids [H*(D - E)/100]	110.0	105.7	113.0	N / A		
55% Saturated	3453.4	3452.8	3446.4			
70% Saturated	3469.9	3468.7	3463.4			
80% Saturated	3480.9	3479.3	3474.7			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3478.6	3472.8	3465.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	85.7	78.1	80.7			
(L) % Saturation [100*(K/I)]	77.9	73.9	71.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3140	2789	3074	3884	3940	4001
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	110.2	111.8	113.5
(R) Conditioned S*T*, psi [2P/(A*B*π)]	89.1	79.1	87.2	N/A	N/A	N/A
(S) Average S*T*, psi	85.1			111.8		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				76		

Table B.34 19.0 GRV/LMS – SMA – None TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L21	L22	L23	L24	L25	L26
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3514.9	3498.2	3522.2	3518.3	3524.8	3514.7
(D) SSD Weight, gm	3552.1	3539.7	3565.1	3558.3	3577.3	3553.7
(E) Submerged Weight, gm	1980.0	1968.6	1979.9	1985.1	1990.1	1978.8
(F) Bulk Specific Gravity [A/(D - E)]	2.236	2.227	2.222	2.236	2.221	2.232
(G) Theoretical Maximum Gravity	2.380	2.380	2.380	2.380	2.380	2.380
(H) % Air Voids [100*(1-F/G)]	6.06	6.45	6.64	6.03	6.69	6.23
(I) Volume of Air Voids [H*(D - E)/100]	95.3	101.3	105.3	N / A		
55% Saturated	3567.3	3553.9	3580.1			
70% Saturated	3581.6	3569.1	3595.9			
80% Saturated	3591.1	3579.2	3606.4			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3580.3	3572.6	3599.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	65.4	74.4	77.1			
(L) % Saturation [100*(K/I)]	68.7	73.5	73.2			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	71.8			N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	-3443.1					
(O) % Saturation [100*(N/I)]	-353836.5					
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	4042	3786	3453	4291	4090	4408
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	121.73509	116.03275	125.05437
(R) Conditioned S*T*, psi [2P/(A*B*π)]	114.7	107.4	98.0	N/A	N/A	N/A
(S) Average S*T*, psi	106.7			120.9		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				88		

Table B.35 19.0 GRV/LMS – SMA – One-Percent Hydrated Lime TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L33	L35	L38	L34	L36	L37
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3507.1	3511.5	3487.2	3505.4	3511.8	3503.1
(D) SSD Weight, gm	3551.1	3548.8	3530.7	3548.3	3550.9	3546.0
(E) Submerged Weight, gm	1969.1	1968.5	1952.7	1964.5	1968.8	1966.3
(F) Bulk Specific Gravity [A/(D - E)]	2.217	2.222	2.210	2.213	2.220	2.218
(G) Theoretical Maximum Gravity	2.380	2.380	2.380	2.380	2.380	2.380
(H) % Air Voids [100*(1-F/G)]	6.85	6.64	7.15	7.00	6.73	6.82
(I) Volume of Air Voids [H*(D - E)/100]	108.4	104.9	112.8	N / A		
55% Saturated	3566.7	3569.2	3549.2			
70% Saturated	3583.0	3584.9	3566.2			
80% Saturated	3593.8	3595.4	3577.4			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3584.9	3590.9	3572.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	77.8	79.4	85.0			
(L) % Saturation [100*(K/I)]	71.8	75.7	75.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3290	3608	3341	3664	3804	3547
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	103.9	107.9	100.6
(R) Conditioned S*T*, psi [2P/(A*B*π)]	93.3	102.4	94.8	N/A	N/A	N/A
(S) Average S*T*, psi	96.8			104.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				93		

Table B.36 19.0 GRV/LMS – SMA – One-Percent Hydrated Lime Plus Liquid Additive TSR Summary

	Conditioned Samples			Unconditioned Samples		
Sample Number	L45	L48	L49	L46	L47	L50
(A) Diameter, in	6	6	6	6	6	6
(B) Height, in	3.74	3.74	3.74	3.74	3.74	3.74
(C) Weight in Air, gm	3508.9	3497.7	3492.1	3513.4	3517.9	3511.5
(D) SSD Weight, gm	3545.9	3534.5	3525.7	3551.3	3545.0	3541.3
(E) Submerged Weight, gm	1965.6	1960.8	1965.3	1969.1	1970.4	1967.0
(F) Bulk Specific Gravity [A/(D - E)]	2.220	2.223	2.238	2.221	2.234	2.231
(G) Theoretical Maximum Gravity	2.380	2.380	2.380	2.380	2.380	2.380
(H) % Air Voids [100*(1-F/G)]	6.71	6.61	5.97	6.70	6.13	6.28
(I) Volume of Air Voids [H*(D - E)/100]	106.0	104.1	93.1	N / A		
55% Saturated	3567.2	3554.9	3543.3			
70% Saturated	3583.1	3570.6	3557.3			
80% Saturated	3593.7	3581.0	3566.6			
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3589.2	3569.8	3560.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	80.3	72.1	68.1			
(L) % Saturation [100*(K/I)]	75.8	69.3	73.1			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm				N / A		
(N) Vol. Of Absorbed Water, cc [M - C]						
(O) % Saturation [100*(N/I)]						
Tensile Strength (S*T*) Calculations						
(P) Failure Load, lbs	3861	3608	3697	4002	4768	4679
(Q) Dry S*T*, psi [2P/(A*B*π)]	N/A	N/A	N/A	113.5	135.3	132.7
(R) Conditioned S*T*, psi [2P/(A*B*π)]	109.5	102.4	104.9	N/A	N/A	N/A
(S) Average S*T*, psi	105.6			127.2		
Tensile Strength Ratio [Avg Conditioned S*T* / Avg Dry S*T*]:				83		