LABORATORY REFINEMENT OF 4.75 mm SUPERPAVE DESIGNED ASPAHLT MIXTURES

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LABORATORY REFINEMENT OF 4.75 mm SUPERPAVE DESIGNED ASPAHLT MIXTURES

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LABORATORY REFINEMENT OF 4.75 mm SUPERPAVE DESIGNED ASPAHLT MIXTURES

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David Michael Rausch, son of David and Laura Rausch, was born August 3, 1972, in Santa Clara, California. He graduated with a Bachelors of Science Degree in Geology from Idaho State University in 1997. Upon graduation he moved to Salt Lake City, Utah, were he studied Civil Engineering at the University of Utah. He was also employed with Granite Construction for 7 years while in Utah. In the summer of 2004 he began his studies as a graduate student at Auburn University in pursuit of a Masters of Science degree in Civil Engineering. He is married to Ruth Norma Tovar Rausch, and is Father to David Michael Rausch Jr. and Patrick Arthur Rausch.

THESIS ABSTRACT

LABORATORY REFINEMENT OF 4.75 mm SUPERPAVE DESIGNED ASPAHLT MIXTURES

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In 2004 a pooled fund study was initiated to refine mix design criteria for 4.75mm NMAS Superpave designed mixes and field validate design criteria. Nine states were participants in this study, Alabama, Connecticut, Florida, Minnesota, Missouri, New Hampshire, Tennessee, Virginia, and Wisconsin. Twenty nine 4.75 mm NMAS mix designs have been performed on material from the nine participating states. Each designed mix was tested for permanent deformation, permeability, tensile strength ratio and durability. Also, four plant produced mixtures were evaluated and served as a baseline for performance. The objective of this research was to refine the current procedures and criteria for 4.75mm NMAS Superpave designed mixtures.

Based on the results of this study it has been found that 4.75 mm NMAS mixtures can be designed in the laboratory to meet current AASHTO specifications. However based on performance testing, special care should be taken when using these mixtures for higher traffic volume applications. Generally, it was determined that lowering the volume of effective asphalt (Vbe) was the most effective way to control permanent deformation. Since, all the blend gradations were fine graded, the best way to control VMA was to use coarser blends or increase the dust content. The 4.75 mm NMAS mixtures were found to be durable based on fracture energy testing. Permeability is low for these mixtures even at relatively high air void contents.

It is recommended that the limit on the percent passing the 0.075 mm sieve be increased to allow for higher dust content, but maintain the current maximum dust to binder ratio of 2.0 to ensure durability. Also, it is recommended that a range of 4.0 to 6.0 design air voids be permitted and VMA and VFA criteria be replaced with maximum and minimum Vbe requirements.

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1.0 Introduction

Until recently, 9.5 mm was the smallest nominal maximum aggregate size (NMAS) used in the Superpave mix design system. In 2002, the National Center for Asphalt Technology (NCAT) completed a research study to develop Superpave mix design criteria for 4.75mm NMAS mixtures (1). With the help of this research, the Superpave Mixture/ Aggregate Expert Task Group recommended to AASHTO the addition of 4.75mm NMAS mixes to the Superpave mix design system.

Since the adoption of Superpave mix design by many states, there has been the belief that coarse graded mixtures (those below the restricted zone) should be used for high volume roadways. To satisfy the requirements of coarse graded asphalt mixtures, large portions of coarse aggregate have been used in these mixtures. As a result, the percent of screenings (manufactured fine aggregate) in these mixtures was reduced. This has lead to an excess of screenings in a number of quarries across the nation. The realization of the growing abundance of fine aggregate material led to research, such as that performed by NCAT (2), into the utilization of screenings as the sole material stockpile in asphalt mixtures. The NCAT research (2) showed that some screenings could be successfully used as the only material stockpile in asphalt mixtures.

Many state agencies have expressed an interested in using 4.75mm NMAS Superpave designed mixtures for thin lift applications, leveling courses, to decrease construction time, to provide a use for screening stockpiles, to provide an economical surface mix for low volume roads, and to be used for maintenance.

Although the original NCAT study on 4.75 mm mixes (1) provided an initial standard and criteria for 4.75mm NMAS Superpave mixes based on laboratory results, it was recommended that the mix design criteria be refined further in the laboratory and field validated. Laboratory refinement of the procedure was recommended in the following areas:

1) Minimum VMA criteria and dust ratio requirements,
2) Maximum VMA requirements,
3) %G_{mm} @N_{ini} criteria,
4) Aggregate properties,
5) Binder contents and design air void level (e.g., 4%) and
6) Enhanced performance with the use of polymer modified binders.

Since the original study (1) was performed with two aggregate sources, it was also recommended that the refinement study incorporate materials from various states to obtain a larger range of aggregate types.

In 2005, a pooled fund study was initiated to refine mix design criteria for 4.75mm NMAS Superpave designed mixes and field validate design criteria. Nine states were participants in this study, Alabama, Connecticut, Florida, Minnesota, Missouri, New Hampshire, Tennessee, Virginia and Wisconsin. Research began at NCAT in the winter of 2005 for the laboratory refinement phase of this project.

1.1 Objective

The main objective of this study was to refine the current procedures and criteria for 4.75mm NMAS Superpave designed mixtures. Specifically the criteria to be refined were:

- Minimum VMA requirements and a workable range for VFA (Voids Filled with Asphalt)
- $\%G_{mm}$ $@N_{ini}$ Requirements
- Aggregate characteristics such as Sand Equivalent and Fine Aggregate Angularity of mixture
- Appropriate design air void content for a given compaction effort
- Dust to binder ratio requirements
- A recommendation on the usage of modified binders to enhance performance of 4.75 NMAS asphalt mixtures

1.2 Scope

A literature review was completed to understand the history and practical use of 4.75mm NMAS Superpave designed mixtures. Next, a laboratory test plan was created. This test plan included performing numerous Superpave mix designs for material provided by each state. For each material and mix design, aggregate properties were measured, optimum asphalt content was determined for a given compaction effort and design air void percent, and performance tests were conducted to determine how well the mixtures performed for a given set of properties. The results of these mix designs were compared with the current

AASHTO specification for 4.75mm NMAS Superpave mixtures. These comparisons coupled with the results of the performance tests are used to evaluate the appropriateness of the current specifications and to make improvement recommendations.

The study in this thesis only reports the findings of the laboratory phase of the pooled fund 4.75mm Superpave refinement project and does not include how these mixes will perform in the field validation phase of study.

2.0 Background

2.1 History of Superpave

The Superpave mix design method was developed under the Strategic Highway Research Program (SHRP), which was initiated in the late 1980's. The primary goal of this research was to develop an improved mix design method. Before Superpave, the Marshall Mix design method was the most widely used procedure in the United States and the world. Asphalt mixtures designed under the Marshall system have performed well for many years. However, it became evident that with increasing traffic and heavier loads an improved mix design system was needed.

The SHRP program was started in 1988 and completed in 1993. This program focused primarily on new methods for evaluating asphalt binders, new mix design procedures, and tests for evaluating performance of asphalt mixtures. The Superpave design method has been undergoing constant refinement since its adoption and in-place performance continues to be monitored.

2.2 Aggregate Characteristics and Gradations in Superpave

During the development of aggregate specifications in Superpave it was felt that not only was engineering data and theory needed, but the subjective knowledge of experts was imperative. Fourteen experts were selected by SHRP to form a consensus opinion on aggregate specifications in Superpave. The panel of experts was known as the Aggregate Expert Task Group (ETG).

To avoid problems that may arise from group dynamics in face to face panel meetings, an alternative committee process know as the Delphi method was used. In this method, negative effects of face to face meetings are removed while retaining the strengths of joint decisions. Participants in the Delphi method never meet; instead questionnaires are used and administered by a coordinator to arrive at a consensus opinion. In SHRP a modified Delphi process was used. The modified process retains some anonymity but, allows a little face to face contact with several rounds of meetings. Results from the modified Delphi Method were used to develop aggregates and mix characteristics to be included in the specifications. As outlined in SHRP-A-408(3) the aggregate characteristics evaluated were;

1. Gradation Controls
2. Coarse Aggregate Angularity
3. Fine Aggregate Angularity
4. Aggregate Toughness
5. Aggregate Soundness
6. Aggregate Deleterious Materials
7. Clay Content
8. Thin and Elongated Particles

Mix characteristics to be evaluated;

1. Air Voids
2. Voids in Mineral Aggregate

3. Voids Filled with Asphalt
4. Dust to Asphalt Ratio

Originally, in Superpave, gradation was controlled using gradation control points and a restricted zone. Research (4) has shown the use of a restricted zone for Superpave designed mixes is unnecessary and it has since been removed from AASHTO Superpave mix design specifications. Also important in gradation control is the Nominal Maximum Aggregate Size (NMAS) which is defined as one sieve size larger than the first sieve to retain more than 10% (5). SHRP chose not to include criteria for selecting NMAS for different pavement layers or applications. It was determined that specifying agencies would select NMAS according to their specific requirements.

A discussion of aggregate toughness, soundness, deleterious materials, coarse aggregate angularity, and thin and elongated particles is not presented in this thesis. Toughness, soundness, and deleterious materials are source-specific properties and as such are not specified in the Superpave mix design specifications. These properties are left to individual agencies to specify based on local experience. Particle elongation and coarse aggregate angularity are important indicators of an asphalt mixtures performance. However, since these tests are performed on the coarse fraction (plus 4.75mm) of an aggregate blend, they are not applicable to this study.

On the other hand, fine aggregate angularity (FAA) may be one of the more important aggregate factors when designing a 4.75 mm NMAS asphalt mixture. Excessive amounts of rounded material can increase rutting susceptibility and decrease stability. The FAA test (AASHTO T-304) is an indirect method of measuring angularity of minus #8

(2.36mm) material by determining the void content in a loosely compacted state. This test method is based on the National Aggregate Association Flow Test Method A. Material with higher void content is assumed to have higher angularity and rougher texture.

Recently, NCHRP report 539 (6) has presented and summarized research findings on fine aggregate texture and angularity. Some of the points that pertain to this research are as follows.

- The results of studies relating the uncompacted voids content from AASHTO T-304 Method A to performance are mixed. Generally, studies indicated a trend between uncompacted voids content and improved rutting performance, but in some cases the trend was weak. Subtle differences in uncompacted voids content can be overwhelmed by the effect of the coarse aggregate or other HMA properties. Several studies supported the 45% uncompacted voids criteria for high traffic, but several also indicated performance was unclear between 43% and 45% (or higher) uncompacted voids. There is clear evidence that good-performing mixes can be designed with uncompacted void contents between 43% and 45%, but evaluations of these mixes using some type of rutting performance test is recommended.
- Higher uncompacted void contents generally resulted in higher VMA and lower densities at N_{ini}
- The variability of AASHTO T304 method A appears to be larger than reported in the test method. Much of this variability appears to be related to variability in the fine aggregate specific gravity measurements used to calculate the uncompacted

voids. Ongoing research to improve fine aggregate specific gravity measurements may also benefit AASHTO T304.

- The current Superpave consensus aggregate properties do not address the angularity of the material that passes the No. 4 sieve but retained on the No. 8 sieve. It is doubtful that the current AASHTO T304 apparatus could accommodate material of this size fraction.

In AASHTO Superpave specifications, clay content is measured using the sand equivalent test. The sand equivalent test is used to show the relative proportions of dust or clay like material in fine aggregates. Clay like fine particles in asphalt mixtures can weaken the mixture which could lead to performance problems such as rutting and stripping. Since 4.75 mm NMAS asphalt mixtures are composed entirely of fine aggregate, the sand equivalent test may provide an important indication of performance. The lower the sand equivalent value, the higher the percent of clay size material there is in the aggregate blend. Current minimum values of sand equivalent specified in AASHTO are 40% or 45% depending on design equivalent single axle loads (ESALs) and depth from surface. advantages to this test are that it is quick and straightforward to perform, and the equipment is simple and inexpensive. According to NCHRP 539 (6) the test method generally gives good results. However, research has shown that there are concerns that warrant further investigation. Research by Sroup-Gardiner et al. (7) found that the sand equivalent test values were not sensitive to either the general mineralogy or the percentage passing the 0.075mm sieve. Also, there was no significant relationship between sand equivalent and tensile strength ratio (TSR) or VMA. Kandhal et al. (8) also showed that no significant relationship existed between sand equivalent test values and

TSR or Hamburg wheel tracking device test results. Generally, if a sand equivalent test is satisfactory, it is unlikely that the clay size particles will lead to performance problems. However, if a sand equivalence test is unsatisfactory the aggregate blend may be rejected or adjusted to meet the sand equivalent minimum.

2.3 Performance Testing

2.3.1 Permanent Deformation

For permanent deformation testing the Material Verification Tester (MVT) was used in this study. The MVT is a compact version of the asphalt pavement analyzer (APA). Like the APA, the MVT shown in Figure (2.1) is a wheel tracking device used to rut laboratory compacted samples or 6 inch diameter cores. Unlike the APA, the MVT only has the capability of testing two Superpave gyratory specimens or one beam specimen. The benefits of the MVT are that it is smaller and lighter than the APA, which makes it more convenient for QC/QA applications in smaller laboratories. The MVT was used in this project since the amounts of material were limited and the number of specimens required to perform the MVT test was reduced from six to two.

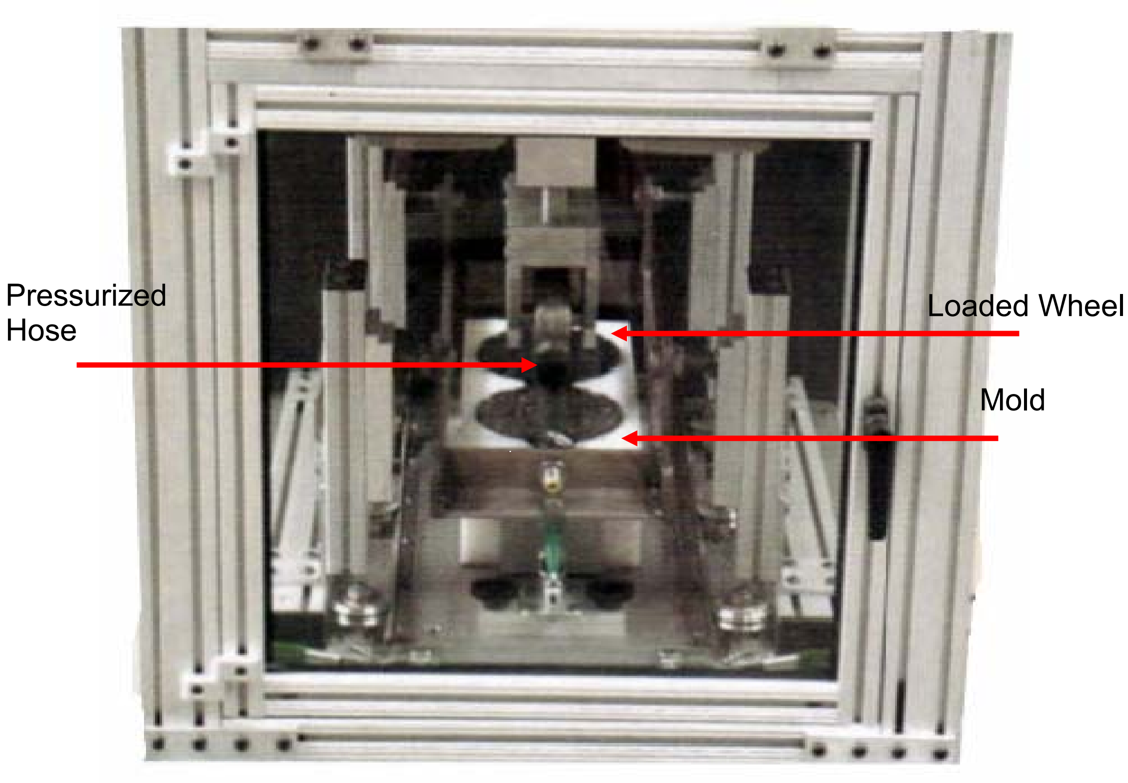


Figure 2.1 Material Verification Tester

NCHRP report 508 (9) documented a research program targeted at the evaluation of the APA to determine its suitability as a general method of predicting rut potential. In this study, 10 mixes of known field performance were tested to compare APA results with actual field performance. The test plan was designed to evaluate several factors thought to influence APA rut depths. These factors are as follows:

- Specimen type: Beam samples versus cylindrical
- Hose diameter: 25mm versus 38mm outside diameter
- Test temperature: High temperature of standard performance grade based on climate; 6°C higher than high temperature of standard performance grade.

- Air void content: 4.0±0.5 percent; 7.0±0.5 percent.

Based on a comparison of laboratory results and field performance the researchers made several conclusions (9). A few of the significant conclusions are presented here.

- Cylindrical samples compacted to 4 percent air voids and beam samples compacted to 5 percent air voids resulted in APA laboratory test results that were more closely related to field performance than did cylindrical and beam samples compacted to 7 percent air voids.
- Samples tested in the APA at test temperatures corresponding to the high temperature for the standard performance grade for a project location better predicted field rutting performance than did samples tested at 6^0C higher than the high temperature of the standard performance grade.
- Beam and cylindrical samples predicted field rutting performance about equally well.
- APA-measured rut depths were collectively higher with beam samples than with cylindrical samples.
- It is generally not possible to predict field rut depths from APA rut depths on a specific project using relationships developed on other projects with different geographical locations and traffic.

Research comparing MVT rutting to APA rutting is scarce. However, some work by Moore and Prowell (10) at NCAT developed a correlation between the APA and MVT. Asphalt mixtures from the NCAT test track were used to compare the two devices.

It was found that the MVT generally had rut depths greater than those generated by the APA. This relationship is shown in Figure 2.2.

Cooley et al (1) conducted APA testing on 4.75mm NMAS mixes. A statistical analysis of the APA rut depth data was performed by conducting an analysis of variance (ANOVA) to evaluate the effect of four main factors (aggregate type, gradation shape, dust content and design air voids) and interactions between these four main factors. Table 2.1 shows the results of this analysis.

Two aggregate types were used, a granite and a limestone, three gradation curves were used fine, medium and coarse shown in Figure 2.3. Three dust contents were analyzed (6%, 9%, and 12%) and each aggregate mixture was designed for 4% and 6% air voids at a N_{design} of 75 gyrations.

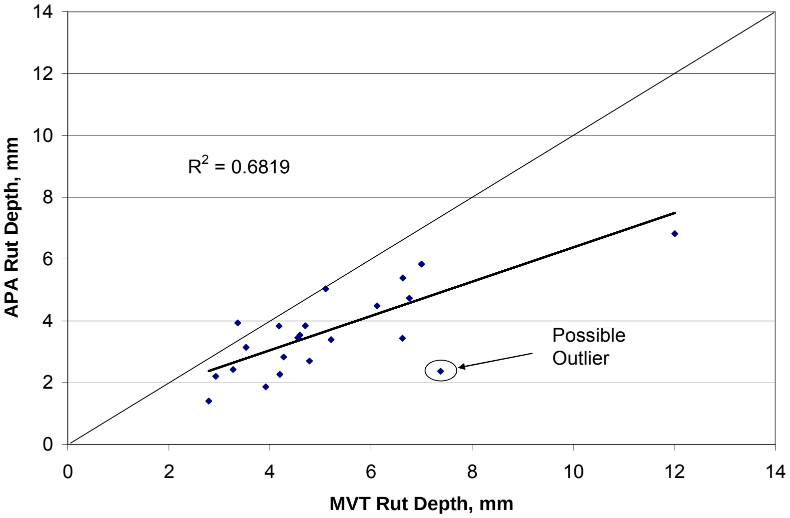


Figure 2.2 APA Rut Depths versus MVT Rut depths

Table 2.1 Results of Analysis of Variance for Rut Depth, Cooley et al. (1)

Source	F-statistic	p-value	Significant?[1]
Aggregate	18.35	0.000	Yes
Gradation	166.09	0.000	Yes
Dust	94.62	0.000	Yes
Design Air Voids (VTM)	19.14	0.000	Yes
Aggregate*Gradation	264.36	0.000	Yes
Aggregate*Dust	22.49	0.000	Yes
Aggregate*VTM	10.37	0.002	Yes
Gradation*Dust	68.49	0.000	Yes
Gradation*VTM	0.85	0.433	No
Dust*VTM	1.42	0.249	No
Aggregate*Gradation*Dust	22.57	0.000	No
Aggregate*Gradation*VTM	0.60	0.552	No
Aggregate*Dust*VTM	16.06	0.000	Yes
Gradation*Dust*VTM	11.43	0.000	Yes
Aggregate*Gradation*Dust*VTM	1.30	0.278	No

[1] Level of Significance of 95 percent

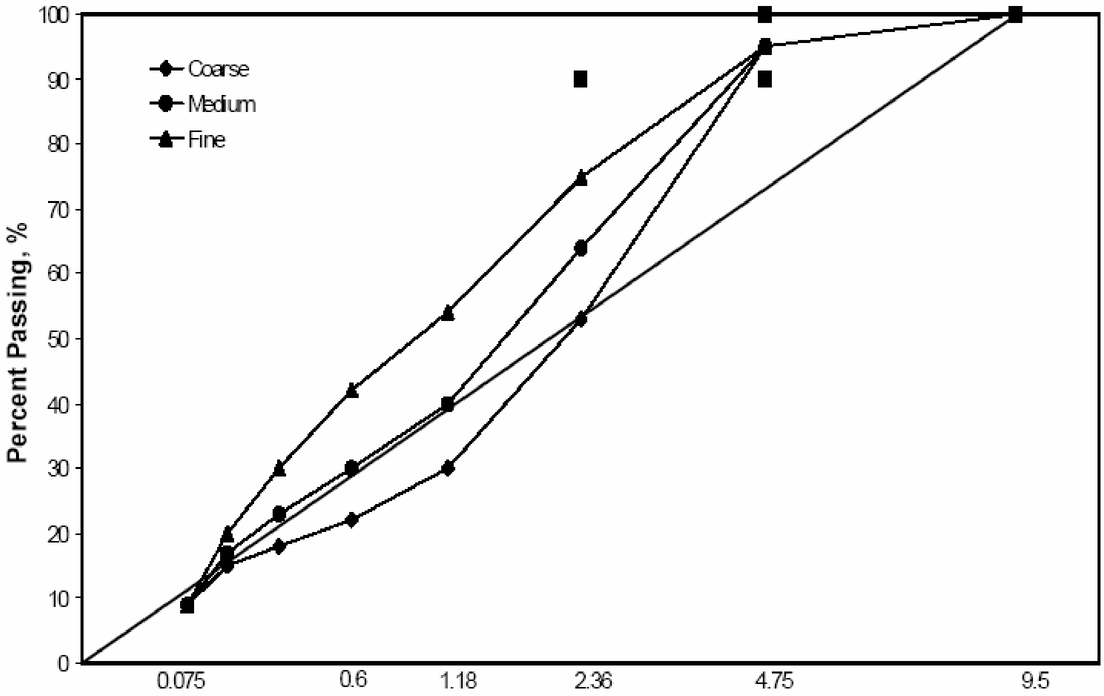


Figure 2.3 General Gradation Shapes Used by Cooley et al (1)

All four of the main factors shown in Table 2.1 had a significant affect on APA rut depths. The granite mixes on average had greater rut depths than did limestone mixes. Coarser gradations usually had greater rut depths than fine or medium gradations. Decreasing dust contents led to greater rut depths. On average, mixes designed at 4 % air voids had greater rut depths than mixes designed at 6% air voids.

There were several two factor interactions that were significant. The interaction between aggregate type and gradation was shown to be significant. For coarse gradations the difference in surface texture seemed to be the controlling factor. For medium gradations rut depths were similar for both aggregate types. Fine gradations showed a large difference in rut depths between aggregate types due to higher optimum asphalt contents for the granite mixtures.

Another two way interaction shown to be significant was between aggregate type and dust contents. For higher dust contents (12%), the increased surface texture of the granite (FAA= 49%) provided lower rut depths than the limestone mixes (FAA=46%). The lowest dust content of 6.0% had extremely high rut depths for the granite mixtures even with higher surface texture because of elevated asphalt contents compared to the limestone mixes.

The interaction between aggregate type and design air voids content was significant. Differences in average rut depths between the granite mixtures at 4.0% and 6.0% design air voids (1.7mm) was higher than the average difference between the limestone mixtures at 4% and 6% (0.2mm). This is due to the high optimum asphalt content of 8.0% for the granite fine graded mixtures designed at 4.0% air voids and 6.0% dust which is a 3.0 to 1.0 percent higher optimum asphalt content than any other mixture prepared for this study. If the granite mixtures designed at 4.0% air voids and 6.0% dust are removed from the averages then the differences in rut depth between the design air voids becomes 0.1mm which is similar to that of the limestone mix.

Finally, the interaction between gradation and dust content was significant. For coarse and medium gradations, different dust contents changed rut depths very little, for coarse gradations the difference in rut depths was 0.1mm and for medium gradations the difference was 1.5mm. Fine gradations, however had large differences in rut depths (8.5mm) at the different dust contents.

2.3.2 Moisture Susceptibility

Although there are several tests available for moisture susceptibility the most commonly used is the modified Lottman test (AASHTO T 283). This method is a combination of the Tunnicliff - Root and Lottman tests. AASHTO T 283 has shown to be reliable and is commonly specified by most DOTs. Tensile strength ratios of 0.7 or 0.8 are the typical values used as criteria indicateing mixtures prone to moisture damage.

2.3.3 Permeability

In dense-graded asphalt mixtures permeability is an important property to minimize. Asphalt pavements with high permeabilities are susceptible to moisture damage. The factors that affect permeability are gradation, NMAS, optimum asphalt content, and relative density. In-place density after compaction may be the most important factor influencing permeability. It is generally accepted that in-place air void contents for HMA should be between 3 to 8 percent. Air voids lower than 3 percent will tend to have problems with rutting and shoving in the pavement. Air voids over 8 percent will cause high permeability (5).

NMAS has a direct influence on permeability. As NMAS increases, the size of the voids increase, and thus the interconnectivity of air voids increase. This relationship was shown by Mallik et al. (11). Figure (2.4) clearly shows permeability increasing with increasing NMAS and in-place air voids.

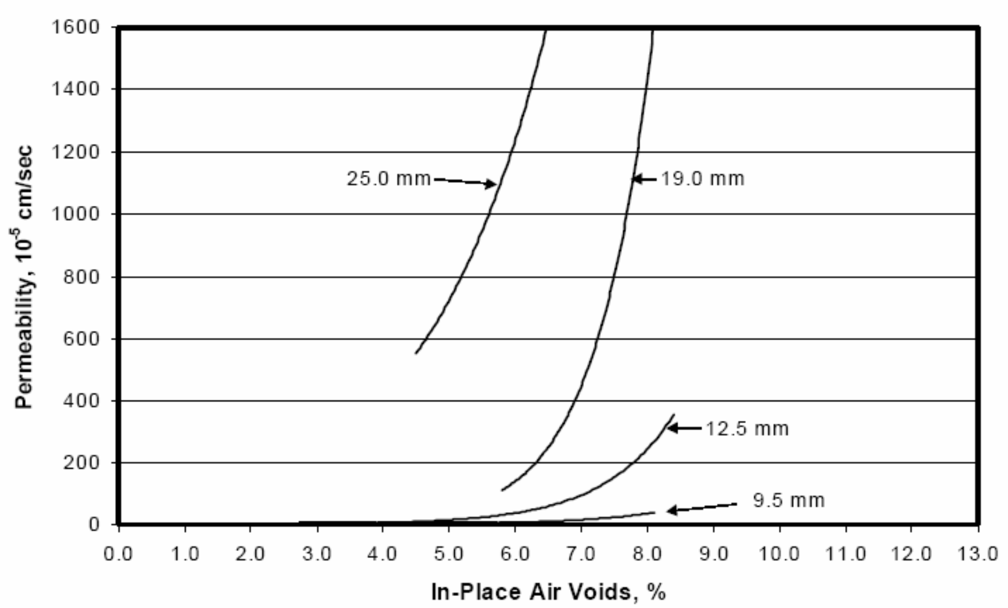


Figure 2.4 Best fit curves for In-Place Air Voids Versus Permeability for Different NMAS (11)

Gradation shape is also an important factor that controls permeability. In general, coarse-graded mixtures have higher permeability than similar fine-graded mixtures. This is probably due to more interconnection of voids in coarse graded mixtures. Fine-graded mixtures tend to have smaller voids which are not as interconnected compared to coarse graded mixtures of the same NMAS.

Permeability testing for this research was accomplished using a falling head test (ASTM PS 121). This provisional standard is no longer in use by ASTM; however it is similar to Florida Method (FM5-565). Cooley et al. (12) showed that laboratory permeability, using the Florida method, had almost a 1 to 1 correlation with NCAT field permeability device for permeability's less than 500E^{-5}cm/sec, shown in Figure (2.5). For 4.75 mm NMAS asphalt mixtures it may be assumed that permeability values will be representative of values that will occur in the field because of the low permeabilities and high air void content (9 %) tested in the laboratory.

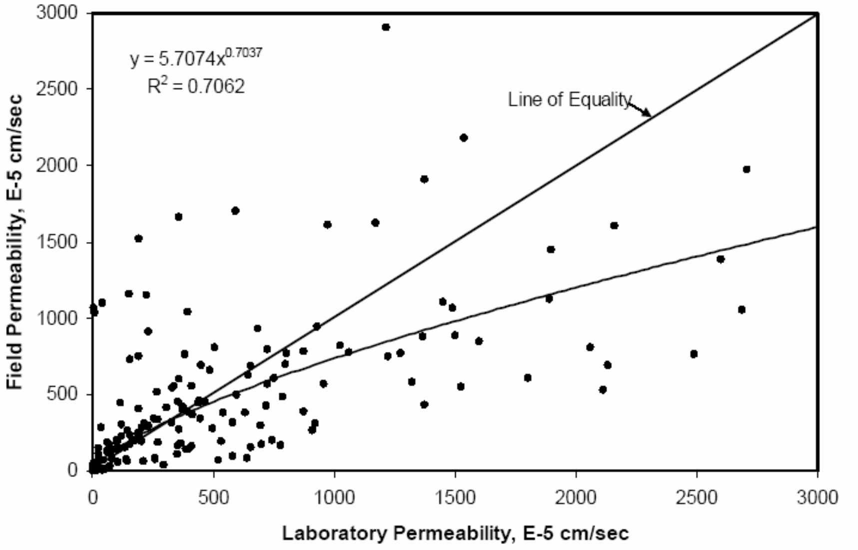


Figure 2.5 Relationship between Field and Laboratory Permeability, Cooley et al (12)

2.3.4 Fracture Energy Density

One method for evaluating resistance to cracking is the indirect tension test (IDT). There are several tests for fatigue cracking and thermal cracking that can be performed on an indirect tension tester, such as creep compliance and indirect tension (IDT) strength testing. Fracture energy is one parameter that can be evaluated by indirect tensile strength testing. Kim et al.(13) suggest that fracture energy, which is the sum of strain energy and damage energy, may be a proper indicator for the resistance of asphalt concrete to fatigue cracking. This claim is based on the observation that resistance of asphalt concrete to fatigue may be quantified by considering both resistance to deformation and resistance to damage. Fracture energy density of a medium such as asphalt concrete is found by integrating the area under the tensile stress-strain curve up to the point of fracture, a diagram of this relationship was created and presented in Figure 2.6. According to Birgisson et al (14), fracture in a specimen is detected by monitoring the deformation differential and marking the location at which the deformation differential starts to deviate from a smooth curve, as illustrated in Figure 2.7.

Kim et al. (13) compared several engineering parameters derived from IDT creep and strength tests, to observe fatigue performance data on cores from WesTrack. These parameters included (1) creep compliance at 200 sec, (2) n-value, (3) indirect tensile strength, (4) horizontal center strain at peak stress, and (5) fracture energy. Of these five parameters, fracture energy had the best correlation with the percentage of fatigue cracking. This relationship is seen in Figure 2.8. Kim suggests that based on this research, fracture energy at 20^{o}C is an excellent indicator of resistance of the mixture to fatigue cracking based on IDT testing of WesTrack cores. Also, he proposed IDT testing at 20^{o}C as a simple performance test for fatigue cracking.

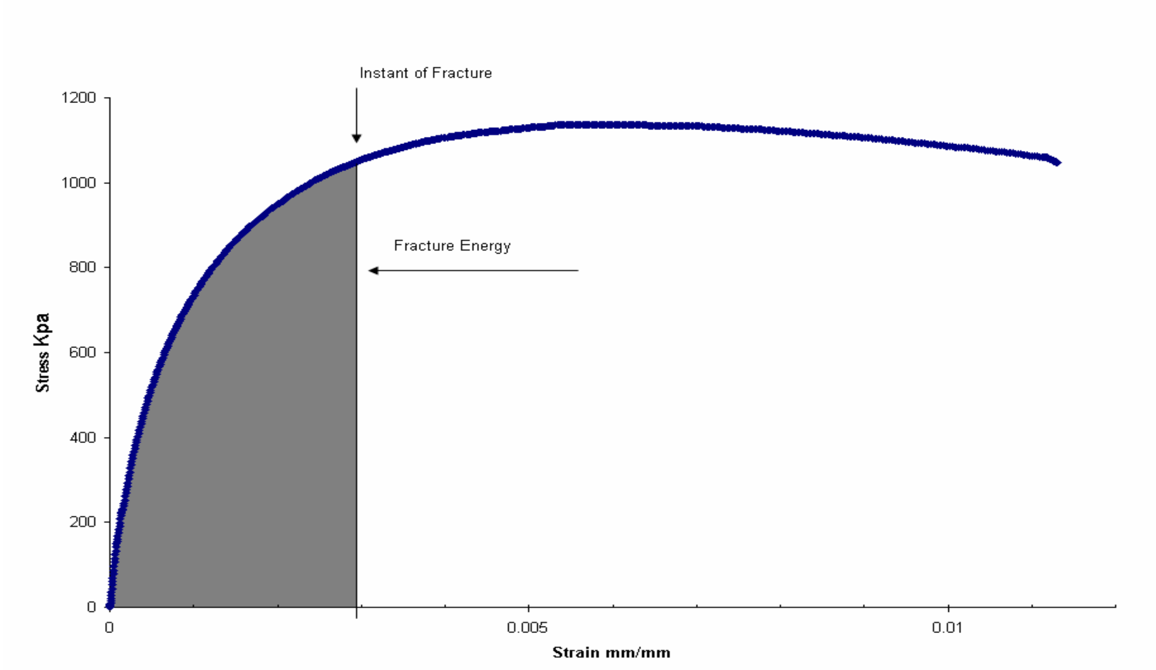


Figure 2.6 Area Under Stress Strain Curve at Point of Fracture

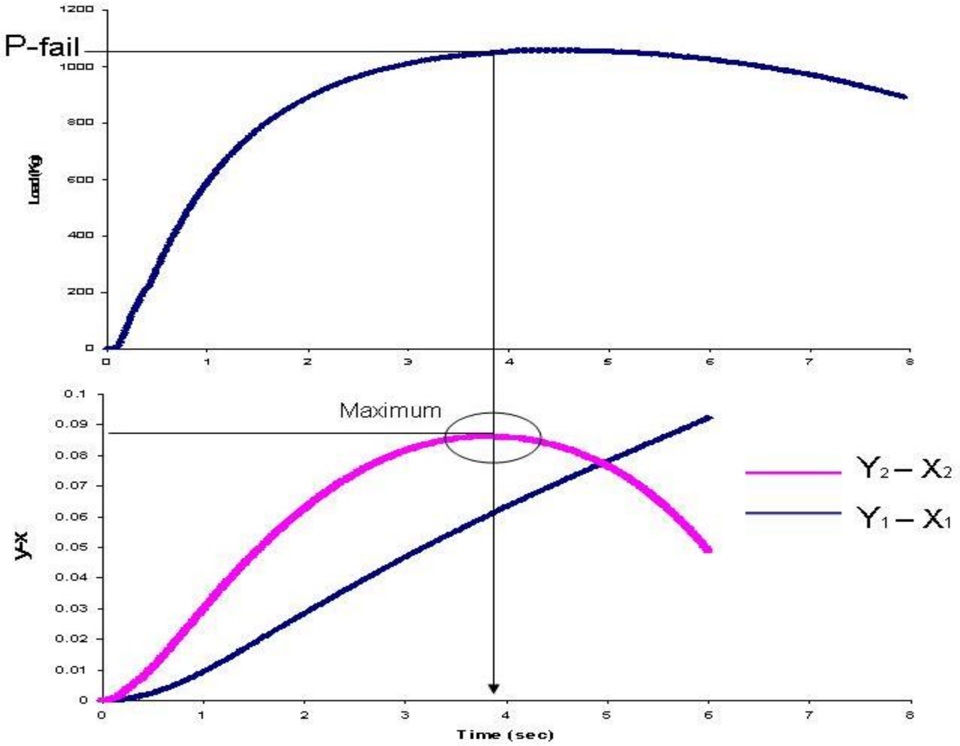


Figure 2.7 Determination of Point of Fracture (14)

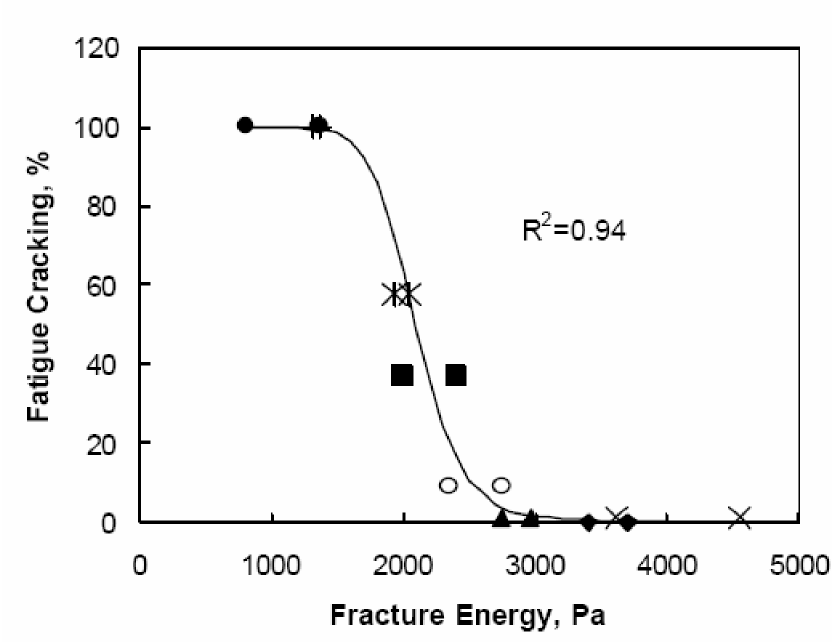


Figure 2.8 Relationship between Field Fatigue Performance and Fracture Energy

Roque et al. (15) found that crack growth parameters in laboratory samples did not correlate well with observed field performance of the same asphalt mixtures. Also, it was found that fracture energy density correlated well with field performance. However, it did not correlate well with measured crack growth rates in the laboratory. To explain this contradiction it was noted how the loading and temperature conditions are different in the field compared to the laboratory. Laboratory tests are conducted in such a way that failure is forced to occur under repeated loading after a relatively short period of time. In the field the mixture is exposed to a wide range of stresses, depending upon wheel load magnitudes and position. Also, temperature changes and times between loadings in the field may result in a significant amount of healing that is not allowed to occur in the laboratory. If damage to the asphalt mixture occurs as micro-cracks, healing of the mixture may occur if loading is discontinued and/or temperature increases such that healing is allowed to occur before a macro-crack develops.

Based on the idea of asphalt healing as it relates to micro and macro cracking Roque introduced the threshold concept. The threshold is defined as a materials state between micro-damage and macro-crack development. If the threshold is not reached, micro-damage in the specimen may be healable, thus the crack might not propagate. However, once the threshold is exceeded, the crack will grow. It appears that the threshold is not related to the rate of crack propagation, Roque finds that mixtures with low threshold may exhibit relatively low crack growth rates and mixtures with high thresholds, once cracked may exhibit high crack growth rates. It is suggested that fracture energy may be a value used as a threshold.

2.4 Development of Mix Design Criteria for 4.75mm Superpave Mixes

In 2002, Cooley et al. (1), published research conducted at The National Center for Asphalt Technology on the topic of specifications for 4.75mm Superpave mixtures. The objective of this study was to develop mix design criteria for 4.75mm NMAS mixture. Criteria targeted in the research were gradation controls and volumetric property requirements.

Based on the findings of this study the following recommendations were made for mix design criteria:

- Gradations for 4.75mm NMAS mixes should be controlled on the 1.18mm and 0.075mm sieves.
- On the 1.18mm sieve, the gradation control points are recommended as 30 to 54 percent based on the range of gradations used in the study.

- On the 0.075mm sieve, the control points are recommended as 6 to 12 percent.
- A target designed air void content of 4.0 percent should be used.
- For all traffic levels, minimum VMA criteria should be utilized.
- Although 50 gyrations were not performed in the study it was recommended that mixes designed at 50 gyrations should have no maximum VMA criteria should be utilized.
- For mixes designed at 75 gyrations and above, VFA criteria should be 75 to 78 percent.
- Percent G_{mm} at N_{ini} values currently specified in AASHTO MP2-01 for the different traffic levels are recommended.
- Criteria for dust to effective binder ratio are recommended as 0.9 to 2.2

Cooley provided a draft mix design system for 4.75 mm NMAS Superpave mixtures. It was recommended that mix design procedures be refined in the laboratory. Refinements of the procedure were recommended in the following areas:

1. Minimum VMA criteria and $P_{0.075}/P_{be}$-Ratio Requirements: Laboratory work is needed to evaluate the aging characteristics of 4.75 mm NMAS mixes designed with the draft mix design system. The minimum criteria of 16 percent was selected based upon Maryland and Georgia minimum binder contents and gradation specifications on similar mixes. Included within this work should be an evaluation of the maximum $P_{0.075}/P_{be}$ ratio requirement.

2. Maximum VMA criteria: High optimum binder contents were identified as the primary cause of excessive laboratory rutting. For this reason, a maximum VMA criteria of 18 percent was recommended. This value needs to be validated in the laboratory by designing numerous mixes with a wide range of aggregate types to further evaluate the relationship between VMA and rut resistance.

3. $\%G_{mm}@N_{ini}$ criteria: Within this study, two high quality aggregates were utilized. None of the 36 mixes designed failed the $\%G_{mm}@N_{ini}$ criteria for a 75 gyration design (90.5 percent). Additional work needs to be conducted that incorporates various percentages of natural, rounded sand to evaluate the applicability of $\%G_{mm}@N_{ini}$ requirements within the mix design system.

4. Aggregate Properties: Both of the aggregates used in this study had FAA values in excess of 45 percent. Additional refinement needs to be conducted to evaluate the desired FAA values for different design levels. Research is also needed to quantify an acceptable aggregate toughness and resistance to abrasion.

5. To avoid excessive binder contents, field work should verify if 4.75 mm NMAS mixes can be designed at a single air void level (e.g., 4 percent) and result in satisfactory performance or if a design air voids range criteria is needed.

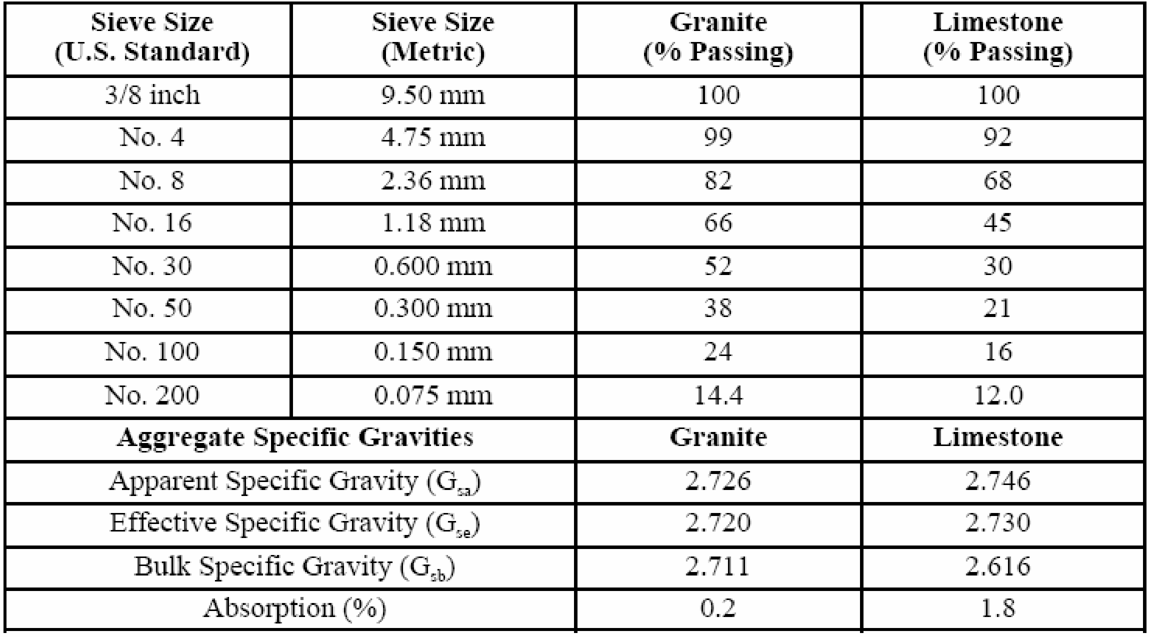
6. Use of Polymer Modified Binders: Within a refinement study, some polymer modified binders should be included to evaluate any enhanced performance.

2.5 Use of Screenings to Produce HMA mixtures

Historically, some agencies have specified coarse-graded Superpave mixtures, because it is thought that coarse graded mixtures are less susceptible to rutting. This has led to a large amount of screenings that are not being utilized. In 2002, Cooley et al. (2) presented research concerning the use of screenings to produce HMA mixtures. The main objective of this study was to determine if rut resistant HMA mixtures could be attained with the aggregate portion of the mixture consisting solely of manufactured aggregate screenings. Secondary objectives were to determine what effect both a modified asphalt binder and a fiber additive might have on rutting.

Two fine aggregates were used which consisted of a granite and a limestone. Table 2.2 shows the gradation for these aggregates. The limestone mixture meets current AASHTO gradation specifications for 4.75 mm NMAS mixtures, the granite does not meet current AASHTO gradation specifications since it is over the specified limits passing the 1.180 and 0.075 mm sieves. Two asphalt grades were used; PG 64-22 and PG 76-22. Each mixture was designed at three different air void contents (4.0, 5.0, and, 6.0 percent). There were eight mixture combinations of aggregate type, binder grade and, fiber additive. For each combination a mix design was performed with 100 gyrations to determine the optimum asphalt content at three air void contents. The asphalt pavement analyzer was used as a performance test to evaluate rutting potential within this study.

Table 2.2 Gradations and Properties of Screenings (1)



Sieve Size (U.S. Standard)	Sieve Size (Metric)	Granite (% Passing)	Limestone (% Passing)
3/8 inch	9.50 mm	100	100
No. 4	4.75 mm	99	92
No. 8	2.36 mm	82	68
No. 16	1.18 mm	66	45
No. 30	0.600 mm	52	30
No. 50	0.300 mm	38	21
No. 100	0.150 mm	24	16
No. 200	0.075 mm	14.4	12.0
Aggregate Specific Gravities		**Granite**	**Limestone**
Apparent Specific Gravity (G_{sa})		2.726	2.746
Effective Specific Gravity (G_{se})		2.720	2.730
Bulk Specific Gravity (G_{sb})		2.711	2.616
Absorption (%)		0.2	1.8

Analysis of variance (ANOVA) was used in analyzing the results of this research to evaluate the main factors affecting optimum asphalt content, VMA, %Gmm@ Nini, and APA rut depths. In summary, it was found the main factors significantly affecting optimum asphalt content were: aggregate type, use of fibers, and design air voids. The two factors that significantly affected VMA were aggregate type and the presences of fibers. %Gmm @ Nini was affected by aggregate type and design air voids. Several factors that affected APA rut depths were aggregate type, design air voids, and binder grade. Also, there were several significant two and three factor interactions that affected rut resistance. They were (1) aggregate type and design air voids, (2) aggregate type and binder grade, (3) fiber addition and design air voids, (4) design air voids and binder grade, (5) aggregate type, addition of fiber and binder grade, and (6) aggregate type, design air voids and binder grade. The following conclusions were obtained from this research:

- Mixes having screenings as the sole aggregate portion can be successfully designed in the laboratory for some screenings but may be difficult for others.
- Screenings type and the existence of cellulose fiber significantly affected optimum binder content. Of these factors, screenings type had the largest impact on optimum binder content, with a 2.7 percent difference in average optimum asphalt content between the two aggregate types. The existence of cellulose fiber on average increased optimum binder content by 0.7 percent.
- Screening type, design air voids, and the existence of cellulose fiber significantly affected voids in mineral aggregate. Screenings type had a larger impact on VMA, granite mixtures produced an average of 8.0 percent more VMA. Mixtures containing fibers had 1.4 percent higher VMA than did mixes without fibers.
- Screenings type significantly affected % Gmm @ Nini results.
- Screenings type and binder type significantly affected laboratory rut depths. Of these, binder type had the largest impact followed by screenings material. Mixes containing a PG 76-22 binder had significantly lower rut depths than mixes containing a PG 64-22. Mixes designed at 4.0 percent air voids had significantly higher rut depths than mixes designed at 5.0 or 6.0 percent air voids.

Based upon the conclusions of the study, the following recommendations were provided:

- Mixes utilizing a screening stockpile as the sole aggregate portion and having a gradation that meets the requirements for 4.75 mm Superpave mixes should be designed in accordance with the recommended Superpave mix design system.

- Mixes Utilizing a screenings stockpile as the sole aggregate portion but with gradations not meeting the requirements for 4.75 mm Superpave Mixes should be designed using the following criteria

Property	Criteria
Design Air Void Content, %	4 to 6
Effective Volume of Binder, %	12 min.
Voids Filled with Asphalt, %	67-80

The preceding recommendation was based on the performance of the granite screenings mixtures which had a finer gradation than the current gradation limits for 4.75 mm NMAS Superpave mixtures. A finer gradation for the granite stockpile probably contributed to the higher VMAs and optimum asphalt contents compared to mixtures prepared with the limestone stockpile. It can be seen in Figure 2.9 that reducing optimum binder content by increasing design air voids improved the rutting performance of the granite screenings. Fine-graded mixtures composed of a single screening stockpile can be designed to be rut resistant by allowing for a range of design air voids. However, based on the current AASHTO specified minimum of 16 percent VMA and 4.0 percent air voids it was recommended that a minimum of 12 percent volume of effective asphalt be maintained to preserve durability. By lowering the asphalt content by designing at higher air voids and placing a 12 percent minimum Vbe requirement for screening stockpiles that do not meet gradation limits for 4.75 mm Superpave mixes should produce asphalt mixtures are rut and crack resistant.

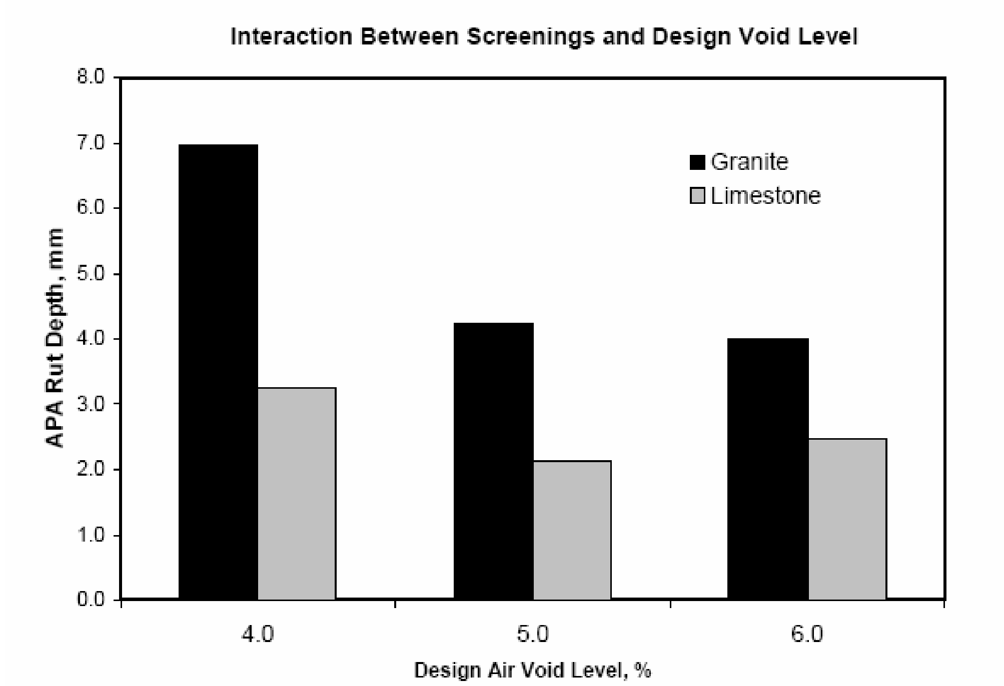


Figure 2.9 Interaction Between Screenings Type and Design Air Voids on Rut Depths (2)

2.6 Low Volume Applications

Since the development of the Superpave mix design system, most of the Superpave designed asphalt mixtures placed have been designed for high traffic volume applications. One proposed use of 4.75 mm NMAS mixtures is low traffic volume applications. 4.75 mm NMAS mixtures will generally have a surface with minimal surface voids which creates a surface texture that is impermeable. These properties would be ideal for use in subdivisions and recreational paths where there is high pedestrian and low vehicle traffic. Although the definition of a low volume road may differ between agencies, it may generally be considered as one with less than 1 million design ESALs.

Several states have already had successful experiences using 4.75 mm NMAS like mixes for years. Alabama, Maryland, and Georgia have used these mixtures for thin overlays and preventative maintenance with good results. However, Superpave designed mixtures are not commonly used in low traffic applications throughout the United States. This may be due in part to the belief by some county and city agencies that costs involved with using Superpave designed mixtures are prohibitive. Also, there is concern that Superpave designed mixtures will result in lower optimum asphalt contents that will lead to reduced durability. It is important for a long lasting low volume mixture that it be resistant to fatigue and thermal cracking. Since requirements for low volume roads may be quite different than their high volume counterparts, a literature review on Superpave designed mixtures for low volume applications is provided.

To determine if Superpave could be utilized successfully for low traffic volume applications, a number of agencies have carried out research to compare traditional Marshall designed mixtures with Superpave design methods (16) (17) (18). The general concern was that a Superpave designed mixture would adversely affect mixture durability with lower optimum asphalt content. Although, different approaches were used by different agencies, researchers tried to determine the design gyration level that would provide asphalt contents and volumetric properties similar to Marshall designed mixtures that have a good performance history. Prowell et al. (16) found that a N_{des} of 68 gyrations provided similar designed binder contents to a 50 blow Marshall with optimum binder content selected at 6.0 percent air voids. Mogawer et al. (17) recommends a N_{des} of 50 gyrations for low volume roads in New England. Habib et al.(18) suggested that N_{des} values used in Superpave mix design are about 20 % higher than what is required. Habib concludes that lowering N_{des} would result in increased asphalt contents for Superpave mixtures. Prowell and Habib both found that VFA Superpave requirements for these types of mixtures may be to restrictive.

E.J. Engle (19) conducted a study of 8 projects paved in 1998 to evaluate the performance of Superpave designed asphalt mixtures for low volume roads. The final report was published in October 2004. Of the eight mixtures three were 19 mm NMAS, four were 12.5 mm NMAS, and one was a 9.5 mm NMAS. All mixtures used a performance graded 58-22 binder. The objective of this research was to evaluate what issues affected the use of Superpave designed mixtures on low volume roads. Issues that were evaluated included, economics, performance, and resources with regard to material and equipment. This research found that after six years all the pavements investigated exhibited excellent cracking resistance, except one project that had reflective cracks that began to appear a few weeks after placement. However, the authors did not relate the cracking to the use of Superpave designed mixtures but, attributed it to the expected reflective cracking of a thin overlay on top of a PCC pavement. Rutting on all involved projects was well within the range of acceptable values, under 0.1 inch. The researchers found that it became impossible to get an objective measure of project costs and material resources compared to paving with conventional mixtures. However, it was the opinion of engineers and contractors involved in the projects, that costs involved with the projects did not significantly increase.

In a 2004 article published in Asphalt (20), three county engineers were interviewed about their experience with Superpave designed mixtures for low volume county roads. The interviews were from Blue Earth County, Minnesota, Stearns County, Minnesota, and St. Louis County, Missouri. All three county engineers found that

Superpave was effective for county roads. However, Stearns County found that costs were prohibitive for use of Superpave designed mixture on low volume roads, but Stearns County planned to continue its use on arterials and higher traffic roads.

2.7 Leveling and Patching

Two possible uses for 4.75 mm NMAS Superpave mixture are as a leveling course or as a patching mix. A leveling course is defined as (21), a HMA layer of variable thickness used to eliminate irregularities in the contour of an existing surface prior to superimposed treatment or construction. According to Watson (22) the Georgia State Department of Transportation found that a smaller aggregate size mixture is beneficial for leveling applications where very thin lifts are needed to correct surface defects.

Patches are needed to repair weak areas in pavements, pot holes, or utility cuts. Structural patches should be designed and constructed with full depth asphalt concrete to ensure strength equal to or exceeding that of the surrounding pavement structure.

Generally, there are three types of asphalt patching mixtures used (23); (a) hot mixed, hot laid, (b) hot mixed, cold laid, or (c) cold mixed, cold laid. Dense graded aggregates are used primarily for hot mixed, hot laid patching mixtures. Typical gradations of dense graded patching mixtures are presented in Table 2.3 (23). It can be seen that the current AASHTO gradation limits for 4.75 mm NMAS Superpave mixtures would fall within the limits of gradation C. The majority of all patching mixtures use 9.5 mm or 12.5 mm mixes (23). However, some agencies do specify a 4.75 mm NMAS mixture for patching. Larger NMAS mixtures seem to be preferred, because they provide better stability, especially in deeper patches. When shallow holes are to be filled, a smaller NMAS mixture is beneficial, especially when the mixture must be feathered at the edges of the hole. Small size asphalt mixtures also tend to be less permeable and less prone to segregation which may be and advantage for patching mixtures.

Table 2.3 Typical Gradations of Dense-Graded Patching Mixtures (23)

Sieve Size	Percent Passing		
	A	B	C
19.0 mm	100		
12.5 mm	90-100	100	
9.5 mm	75-90	90-100	100
4.75 mm	47-68	60-80	80-100
2.36 mm	35-52	35-65	65-100
1.18 mm	24-40	-	40-80
0.600 mm	14-30	-	20-65
0.300 mm	9-20	6-25	7-40
0.075 mm	2-9	2-10	2-10

2.8 Thin Overlays and Surface Mixtures

4.75 mm NMAS mixtures may be ideal for thin overlays and surface mixtures. Hansen (24) stated that hot-mix asphalt overlays are probably the most versatile pavement preservation techniques available. They can improve structural capacity, improve ride, enhance skid resistance, reduce noise, and improve drainage. However, in the case of thin overlays, they should only be placed on structurally sound pavements that exhibit surface distresses such as low severity cracking and raveling. According to NCHRP report 531 (25), lift thickness should be at least three to four times the NMAS. For the case of a overlays less than one inch a 4.75mm NMAS asphalt mixture would meet a lift thickness to NMAS ratio of 3 to 4.

The main function of a thin overlay of hot-mix asphalt may not be necessarily to provide strength to the pavement structure, but to protect a deteriorating pavement. If a thin overlay of 4.75 mm NMAS dense-graded HMA is used as a surface mixture it may provide a smooth, durable, watertight surface. However, one possible concern for applying this type of mixture as surface mix is producing low surface texture. A low macro texture might lead to poor skid resistance, especially with a wet pavement surface.

2.9 NCAT Survey

As part of the initial portion of this study a survey of the current usages and possible future applications of this type of mix were sent out to all US state highway agencies. Of the 50 states 21 responded as shown in Figure 2.10. Table 2.4 summarizes some of the individual responses from the survey. The questions included in the survey were:

- Do you currently have a specification for a mixture type designated as a 4.75 mm NMAS mixture or a mixture that would likely fit in this general size range?
- What are the typical aggregate components in this mixture?
- What are the primary uses of the mixture?
- What is the spread rate typically used for this mix type?
- What method do you use for the mix design of this mix type?
- What is an in-place density requirement for this mix type?
- What are the advantages of this mix type compared to competing products?
- What problems or disadvantages are associated to this mix type?
- What is the approximate usage of this mixture type for your agency?

- Is this quantity expected to change over the next year?
- What potential uses of this type of mixture should be further developed?

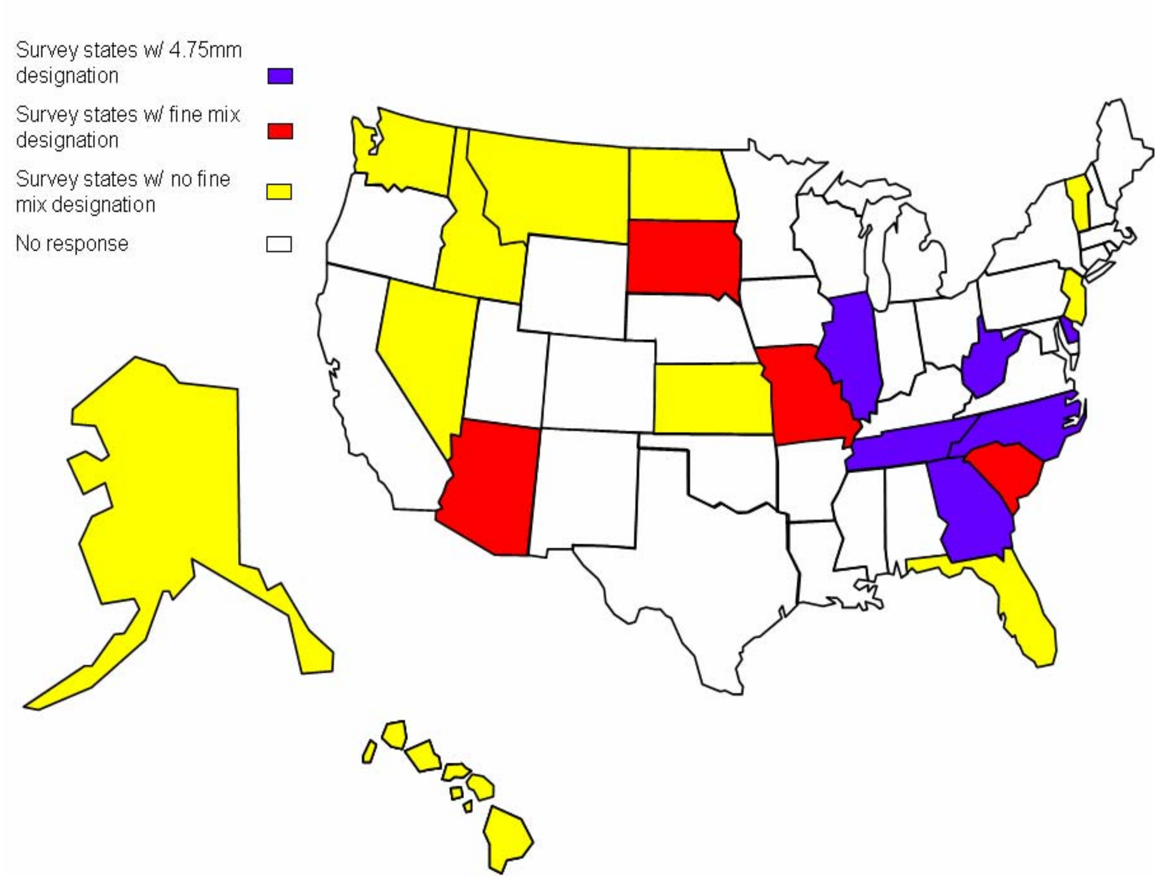


Figure 2.10 Map of Respondents to NCAT survey

Table 2.4 Summarized Survey

State	Do you specify a 4.75mm like mix?	Mix Design Method	Spread Rates	Inplace density requirement ?	Production is expected to?	Primary Uses
Alaska	no					
Arizona	yes	Arizona Method	50lb/sqy	no	decrease	Surface mix
Delaware	yes	Superpave	Varies	no	increase	Leveling course
Florida	no					
Georgia	yes	Superpave	85lb/sqy	no	N/A	Leveling course
Hawaii	no					
Idaho	no					
Illinois	yes	Superpave	3/4" thick	94%	increase	Leveling course
Kansas	no					
Missouri	yes	Marshall	1"-1.75"	no	remain steady	Surface, leveling,
Montana	no					
Nevada	no					
New Jersey	no					
North Dakota	no					
North Carolina	yes	N/A	1"	85%or90%	remain steady	N/A
South Carolina	yes	Marshall	125lb/sqy	no	remain steady	Surface mix
South Dakota	yes	Marshall	150 Ton/mile	no	remain steady	Leveling mix
Tennessee	yes	Marshall	35lb/sqy	no	remain steady	Leveling mix
Vermont	no					
Washington	yes	N/A	N/A	N/A	N/A	N/A
West Virginia	yes	Marshall	70lb/sqy	92%	increase	Surface mix

Generally, three types of aggregates are used in these 4.75 mm mixtures; (1) small size rock or chip (0 to 30%), (2) screenings (0-50% typical), and (3) natural sand (0-30% typical). The most common grade of asphalt used was a performance grade 64-22. Hydrated lime mixed at 1% is commonly used as an additive. Also mentioned were cement and liquid anti-strip additives. There was a large range of spread rates reported, the average was 80 lb/sy with the range being (35 -125 lb/sy). Superpave and Marshall mix design methods are both used to design 4.75 mm NMAS asphalt mixtures, for Superpave mixtures an Ndes of 50 gyrations was typical. For the states that use Marshall designed mixtures, only Missouri disclosed the compaction effort used for their design (35 blows). Most states do not have current in-place density requirements; however three states do have minimum in-place density requirements. North Carolina has minimum in-place density requirements of 90% or 85% for the two types of small aggregate mixtures specified in that state, Illinois specifies 94%, and West Virginia specifies 92%.

Common uses for these types of mixtures were: leveling or scratch course, surface mixtures for low volume roads, and thin overlays for pavement maintenance. Better appearance and performance compared to competing products and lower initial costs were cited as the most common advantages of this type of mixture. Other advantages that were listed were; can be placed in lifts less than one inch, relieve abundance of quarry fines, helps retard reflective cracking, and noise reduction. Generally, the disadvantages mentioned were that this type of mixture does not provide enough strength to the pavement structure and it can be susceptible to rutting.

When asked how the production quantity was expected to change over the next two years most states believed the quantity would remain steady or increase. Individual responses for production rate are given in Table 2.5.

Table 2.5 Approximate Production of 4.75 mm NMAS Mixtures

Delaware	<1000 tons
Georgia:	320,000 tons for FY 2004
Illinois:	Not yet adopted as common practice (N/A)
Tennessee:	225,000 tons
West Virginia:	15,000 – 20,000 tons
Arizona:	250,000 – 350,000 tons
South Carolina:	Low tonnage approximately 5% of total tonnage
South Dakota:	75,000 tons
Missouri:	1.7 million Surface level, and 750 thousand BP-2
North Carolina(SF9.5A):	1,000,000 tons
North Carolina(S4.75A):	75,000 tons

The final question posed in the survey was, what further developments of this type of mixture are needed. The individual responses are shown in Table 2.6.

Table 2.6 Further Developments of 4.75 mm NMAS Mixtures

Florida:	Leveling, thin overlays (maintenance/local agency)
New Jersey:	They anticipate using a 4.75mm mix for leveling on a concrete pavement overlay on an upcoming project. Right now they are planning on using the 4.75mm mix in AASHTO M323.
Vermont:	It's use for low ESAL Superpave ability to resist rutting, and cold weather climate capabilities.
Hawaii:	Thin overlay for preventive maintenance.
Nevada:	They attempted to use a similar material in the past to fill substantial cracking. After failed attempts and problems, use was discontinued.
North Dakota:	Bike trails.
Washington:	Thin wearing surfaces over structurally sound pavement.
Delaware:	They are looking at the material for subdivision overlay work.
Georgia:	For low volume local roads, parking lots, etc.
Illinois:	Explore ways to add macro texture to allow as a surface course.
Tennessee:	None. They are in the pooled fund study and hope to have a 4.75mm in place soon. They are currently working hard on SMA and OGFC.
South Dakota:	Specifications for all types of roads (surface mix)
Missouri:	Long lasting surfaces mixtures for low volume roadways.
Iowa:	4.75 mm mixtures may have an application as scratch course mix, but would not be specified for conventional HMA mixture (surface, intermediate, base)
Idaho:	Unknown at this time.
North Carolina:	No response

An important finding from this survey was that 4.75 mm NMAS mixtures are being specified and used as surface mixtures, leveling courses and thin overlays. There are some benefits in using this type of mixture for these applications. Most states agreed that 4.75mm NMAS mixes should be developed further to increase the mixtures overall structural capabilities and rutting resistance to increase performance as a mixture to be used for low volume roads and thin overlays.

3.0 Research Plan

In the spring of 2005 a panel meeting was conducted at NCAT and representatives from the nine participating states were present. The objective of this panel meeting was to ratify a test plan for the 4.75mm Superpave refinement pooled fund study. Items discussed at this meeting included:

1. Expected applications for 4.75mm mixes
2. Mix design issues
3. Construction and performance concerns
4. Development of a mix design matrix
5. Performance test issues (i.e. air void content for performance testing, type of test used for durability testing, and load and tire pressure used for rut testing)

From this meeting a comprehensive test plan was created. The mix test matrix is shown in Table 3.1. This matrix shows that a 4.75 mm mix design was planned for all participating states using 50 gyrations and a design air void content of 4.0 percent. Variations of those mix designs were planned by changing the design gyrations and the design air void contents. Additional variations were planned to evaluate changes in other mix factors such as dust content and binder grade. These are referred to as blend adjustment mixtures.

The first task was to obtain materials form each state. Participating states were required to submit a proposed 4.75mm blend representing a source and general gradation from their state. Also, included in this study were four plant produced baseline 4.75mm mixtures with known field performance that had been successfully used. The baseline mixtures were obtained from Mississippi, Maryland, Georgia, and Michigan. These baseline mixtures served as bench marks for comparing the results of the laboratory mix designs using the materials from the participating states.

When the materials were received from participating states, gradations and specific gravity tests were performed. Alternative trial blends were then developed in addition to the blends submitted by the participating states.

Table 3.1 Original Design Matrix

Ndesign Gyrations =	50		75	
Air Voids =	4%	6%	4%	6%
Mixture Material				
Florida	X		X	X
Wisconsin	X	X		
Virginia	X		X	
Missouri	X	X		
Minnesota	X		X	X
Alabama	X	X		
Tennessee	X		X	
Connecticut	X	X		
New Hampshire	X		X	X
Virginia Adjustment	X	X		
Florida Adjustment	X		X	
Wisconsin Adjustment	X	X		
Tennessee GM	X		X	
Georgia Baseline	X			
Mississippi Baseline	X			
Maryland Baseline	X			
Michigan Baseline	X			

Table 3.1 shows the final mix design matrix. Thirteen aggregate blends from the participating states were designed at 4.0 percent air voids using 50 gyrations. Six of the thirteen aggregate blends were also designed at 4.0 percent air voids using 75 gyrations.

An additional seven of the thirteen aggregate blends were designed at 6.0 percent air voids using 50 gyrations. Finally, three of the blends were designed at 6.0 percent air voids and 75 gyrations. The 50 and 75 gyration compaction levels were selected because 4.75mm mixes will likely be used for lower volume traffic applications (less than 3 million ESALs). Four and six percent design air voids were used to examine the concern of the mixes being over-asphalted due to high VMA values. A possible solution to mixes with high asphalt contents would be to increase the design air void content to between 4.0 percent and 6.0 percent. However, this may lead to durability and moisture susceptibility problems.

For each mix design and baseline mixture, a suite of performance tests was conducted. The performance tests were selected for analysis of permanent deformation, durability, permeability, and moisture sensitivity. For very thin lift applications and light traffic pavements with low speed limits, rutting may not be a major concern. However, tests for permanent deformation were included to evaluate how stable these mixes will be in other applications. Durability testing was conducted to verify volumetric criteria (e.g., VMA and VFA). Permeability tests were conducted to help evaluate possible in-place density requirements in the field. Testing was performed on all the mixtures to evaluate their susceptibility to moisture damage.

3.1 Test Methods

3.1.1 Aggregate Tests

Aggregate analysis for gradation and specific gravity was performed on all virgin aggregate materials sent to NCAT for this study. Gradations were performed in accordance with AASHTO T 27, *Sieve Analysis of Fine and Coarse Aggregate*, and AASHTO T 11, *Materials Finer Than 75µm (No.200) Sieve in Mineral Aggregate by Washing.* Specific Gravities were determined by AASHTO T 84, Specific *Gravity and Absorption of Fine Aggregate*; and AASHTO T 85, *Specific Gravities and Absorption of Coarse Aggregate.* For the final blended aggregate determined from the mix design, AASHTO T 304 *Uncompaced Void Content of Fine Aggregate* and AASHTO T 176 *Plastic Fines in Graded Aggregates and Soils by use of the Sand Equivalent Test* were performed.

3.1.2 Mix Designs

The AASHTO standard practice R 35-3, *Superpave Volumetric Design for Hot Mix Asphalt (HMA)*, was followed during the mix design phase of the study. This standard practice was used to verify specifications for 4.75mm NMAS in AASHTO (M 323-04), *Standard Specifications for Superpave Volumetric Mix Design*.

Three aggregate blend gradations were evaluated for each of the eight participating state's aggregate stockpiles. One of the three blends used in the aggregate trials was the blend proportion submitted by each state for their materials. The current gradation specification for 4.75 mm mixes shown in Table 3.2, was used to set control points in the blending process. Control points for the 4.75mm sieve (100-90% passing) were strictly observed in the blending process to maintain a true 4.75mm NMAS mix. However, the controls on the #16 (1.18mm) and #200 (0.075mm) sieves were given some flexibility. Since only two to three aggregate stockpiles were provided by most states, it was not always possible to develop reasonable alternative blends by proportioning the stockpile percentages. Therefore some gradations were allowed outside the control points. Figure 3.1 shows all the gradations used in this study plotted on a 0.45 power chart. Most of these mixtures tend to be fine graded.

Table 3.2 4.75mm Superpave Control Points

Sieve	Min.	Max.
12.5	100	
9.5	95	100
4.75	90	100
2.36	-	-
1.18	30	60
0.075	6	12

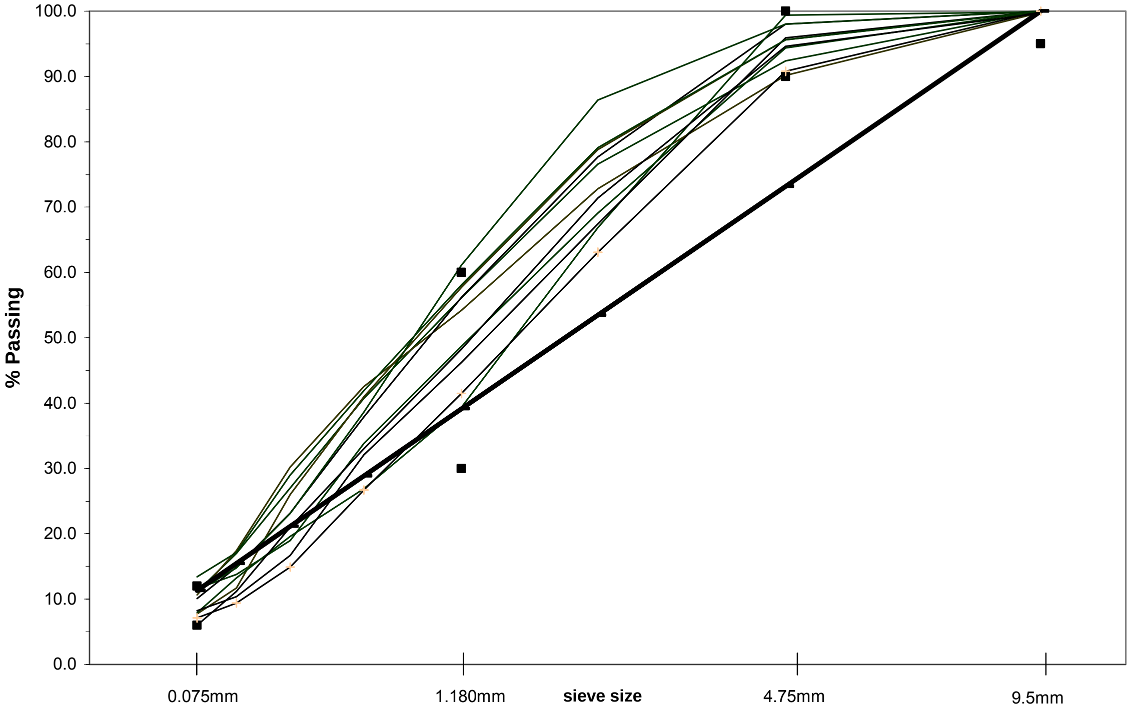


Figure 3.1 Gradations for State Mixtures

Once three aggregate blends were determined, an initial asphalt content was estimated for each blend. Two replicate samples prepared for each blend were mixed and conditioned in accordance with AASHTO R 30. Specimens were compacted in a Superpave Gyratory Compactor (Pine Instruments model AFG1A) following procedures in AASHTO T 312. This Superpave Gyratory Compactor was calibrated to provide an external angle of 1.25 degrees. The internal angle, measured with the Pine model AFLS1 Rapid Angle Measurement kit, was 1.215 degrees. Compaction results may vary for compactors that have internal angles different than 1.215 degrees. The bulk specific gravity of each compacted sample was determined by AASHTO T 166. Two samples for each blend were prepared for determination of the theoretical maximum specific gravity of the asphalt mixture using AASHTO T 209. Voids in mineral aggregate (VMA), percent air voids, voids filled with asphalt (VFA), dust to binder ratio, and Gmm @ Nini were calculated for each trial blend. The volumetric properties of each blend were considered in determining which of the three blends was selected for the final mix design. In general, mixtures with the lowest estimated optimum asphalt content at the design air void contents were selected, which is a common practice, as long as VMA, VFA, and dust to binder rations were reasonable.

From the trial blend series one blend was selected for each state. A binder series was run for the selected blend. In this part of the mix design process, three pairs of specimens were prepared and mixed at differing asphalt contents. The three asphalt contents were at the estimated optimum, at estimated optimum minus 0.5%, and at estimated optimum plus 0.5%. The volumetric properties of the mixtures were determined as mentioned above for the trial blend series and a better estimate of the optimum asphalt at the desired air void content was determined.

Finally, a set of two specimens was prepared with the selected aggregate blend and mixed at optimum asphalt content to verify the mix design. If the asphalt mixture compacted to the design air voids and the volumetric properties were reasonable then the mix design was accepted for the study and samples were then prepared for performance tests.

3.1.3 Performance Tests

Moisture susceptibility testing was performed following AASHTO T-283, *Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage*. At the panel meeting to discuss the testing plan for this study, representatives from the participating states decided that a higher air void percent should be used for some performance tests. AASHTO T-283 states specimens should be compacted to 7.0% +/-1% air voids. The panel decided that the in-place air void content after construction for 4.75mm mixes would likely be in the range of 8 to 10%. For this reason, specimens molded for moisture susceptibility in this study were targeted at 9.0 +/- 0.5% air voids.

Permeability testing was conducted following the former ASTM provisional standard 129. The target air void content was 9.0 +/- 0.5% for the reasons mentioned above. The specimens were compacted in a Pine Superpave Gyratory Compactor to a height of 55mm then saw cut in half to obtain two samples about one inch in thickness.

Permanent deformation testing was completed using a Mixture Verification Tester (MVT). The MVT is a compact version of the Asphalt Pavement Analyzer. MVT testing followed AASHTO TP63-03 *Rutting Susceptibility of Asphalt Pavements Using the Asphalt Pavement Analyzer*. All specimens were tested using 100 lb wheel load and 100 psi hose pressure. For this study all specimen tests were conducted at 64° C. The specimens from the mix design verification were used in the MVT test. Therefor the air void contents in the MVT test specimens were either close to 4.0 or 6.0 percent air voids

Durability was analyzed by means of fracture energy testing. The basic procedure for *Strength of Hot-Mix Asphalt (HMA) Using Indirect Tensile Test Device*, AASHTO T 322-03, was followed when determining the fracture energy of the test specimens.

Testing was performed on an Instron Indirect Tension Tester at 20°C, Figure 3.2, with a ram displacement rate of 50 mm per minute. Samples were molded in a Superpave Gyratory Compactor (diameter = 150 mm) and then saw cut on both sides to a height of between 38 mm and 50 mm. Horizontal and vertical linear variable differential transducers (LVDTs) were mounted to both sides of the sample using a gauge length of 38.1 mm. Load was applied to the specimens until a peak load was reached and then began to decrease. A data acquisition system recorded load and LVDT data every 0.01 seconds. These data were then used to generate stress-strain curves. Procedures discussed in *Fracture Energy from Indirect Tension Testing*, Kim (14), were used in the calculation of fracture energy. Fracture energy was calculated as the area under the stress-strain curve to the point of fracture as illustrated in Figure 2.6. The point of fracture was determined by plotting the difference between the vertical and horizontal LVDTs on each side of the specimen. The point at which the first side reached a maximum on this plot was taken as the time of fracture. This procedure was presented in Figure 2.7.

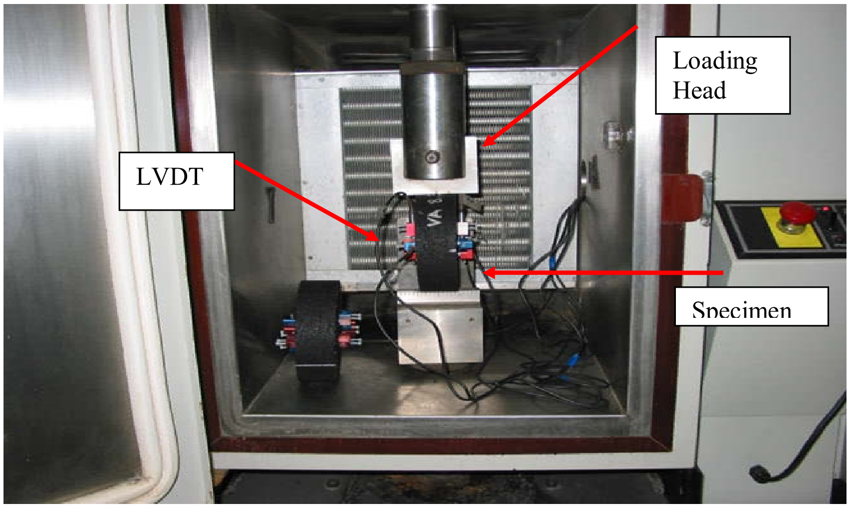


Figure 3.2 Instron Indirect Tension Tester

All specimens were compacted so the air void content after the top and bottom had been cut would be 9.0 ± 0.5 percent. Horizontal and vertical LVDTs were mounted on both sides of the specimens. After mounting the LVDTs the specimens were then place in an environmental chamber set at 20ºC for two hours.

After two hours at 20ºC the specimens were then tested on the Instron Indirect Tension Tester. The LVDTs recorded to a data acquisition system every 0.01 second. The data that were recorded were:

1. Time
2. Load (Kg)
3. Horizontal and Vertical deformation (mm)

Once the load reached a maximum the test was terminated. The fracture energy is the area of the stress strain curve up to the point of fracture. To determine the point of fracture the deformation differential is plotted and the location on this curve which the deformation differential starts to deviate from a smooth curve was considered the point of fracture. This was illustrated in Figure 2.7.

Strain was calculated by using equation (1) for center strain found in Kim et al. (13). Poisson's ratio was assumed at 0.35. Parameters for a gauge length of 38.1 mm were determined and are shown in Table (3.3).

$$\varepsilon_{x=0} = U(t)\frac{\gamma_1 + \gamma_2 \nu}{\gamma_3 + \gamma_4 \nu} \qquad \text{Equation 1}$$

Where,

U(t) = Average Horizontal Displacement

ν = Poisson's Ratio

γ_1 γ_2 γ_3 and γ_4 = Parameters

Table 3.3 Parameters

Coefficient	
γ_1	8.48
γ_2	25.6
γ_3	0.288
γ_4	0.931

After the point of fracture was determined the area under the curve was calculated by multiplying the change in strain for each time increment by the stress at that point and summing those values up to the point of fracture.

4.0 Results and Analysis

Twenty nine mix designs were performed with aggregate from nine participating states. As seen in the test matrix, Table 3.1, the research design variables were Ndesign (50 and 75) and design air voids (4 and 6 percent). Table 4.1 shows the volumetric and aggregate properties of these mix designs.

The code used in this text to describe the mix designs is defined as follows; the first two letters are used to define the state of origin, i.e. AL = Alabama. The following numbers are the number of design gyrations and the third number is design air voids, i.e. AL-50-6 = Alabama materials designed at 50 gyrations and 6.0 percent air voids. In the case of blend adjustments extra letters are given to describe the difference, TNGM is used to denote Tennessee gravel mix which is material from Tennessee but a different source aggregate than the TN mix design from Tennessee limestone. To describe blend adjustments mixtures the letters “adj.” have been attached, i.e. FL adj = Florida blend adjusted. Table 4.2 shows a description of materials used for each state and stockpile percentages for each blend. Table 4.3 provides percent passing used for each mixture. Figure 3.1 is the gradation plot for all 13 aggregate blends.

Table 4.1 Mix Design Volumetric Properties

State(mix)-Ndes-Va%	*%A.C.*	*VMA*	*VFA*	*% G_{mm} @ N_{ini}*	*Dust$_{ratio}$*	*film thickness (microns)*	*Sand Equivalence*	*FAA*
AL-50-4	7.4	18.5	78.4	89.0	1.8	6.1	67	46.3
AL-50-6	6.9	18.8	68.1	87.2	2.0	5.4	67	46.3
TN-50-4	7.3	16.9	76.8	87.8	2.0	6.3	69	44.8
TN-75-4	6.8	16.0	74.8	87.2	2.2	5.7	69	44.8
MO-50-4	6.9	18.2	78.2	88.8	1.7	5.9	74	49.0
MO-50-6	6.2	18.4	66.7	86.9	2.0	5.1	74	49.0
VA-50-4	8.8	16.8	75.8	89.0	1.7	6.3	76	45.0
VA-75-4	8.3	15.8	74.9	88.5	1.9	5.8	76	45.0
FL-50-4	11.8	24.2	82.8	88.9	0.8	11.8	88	44.1
FL-75-4	11.0	22.6	81.8	88.4	0.9	10.8	88	44.1
FL-75-6	10.1	22.5	73.7	86.4	1.0	9.6	88	44.1
CT-50-4	8.8	19.9	80.9	86.6	1.2	8.9	79	46.1
CT-50-6	7.2	19.0	68.5	85.1	1.4	7.1	79	46.1
MN-50-4	8.8	21.1	80.4	87.5	1.6	7.4	67	46.2
MN-75-4	8.3	20.1	79.8	86.9	1.7	6.9	67	46.2
MN-75-6	7.4	19.7	70.1	85.3	1.9	5.8	67	46.2
NH-50-4	9.7	23.8	83.6	89.8	0.7	12.8	85	51.0
NH-75-4	9.3	22.9	84.0	89.4	0.7	12.1	85	51.0
NH-75-6	8.6	23.1	75.0	87.4	0.8	10.9	85	51.0
WI-50-4	7.5	18.0	77.4	87.7	1.2	8.9	81	43.7
WI-50-6	6.7	17.8	66.9	86.7	1.4	7.7	81	43.7
TNGM-50-4	9.7	20.9	80.7	88.1	1.0	9.2	70	42.2
TNGM-75-4	9.3	17.5	76.5	87.5	1.3	8.6	70	42.2
VA adj-50-4	9.0	16.8	76.4	88.5	1.7	6.5	76	45.0
VA adj-75-4	8.7	16.5	75.6	88.0	1.7	6.1	76	45.0
FL adj-50-4	10.0	20.6	81.1	88.9	1.7	7.9	79	44.5
FL adj-75-6	9.1	20.6	71.0	86.7	1.9	6.4	79	44.5
WI adj-50-4	6.8	16.1	74.4	87.1	1.9	6.8	81	45.8
WI adj-50-6	6.3	16.5	64.4	85.3	2.1	6.3	81	45.8

Table 4.2 Materials and Stockpile Percentages for Laboratory Mixtures

	Stockpile 1			Stockpile 2			Stockpile 3			Stockpile 4		
State(mix)	Name	Type	%	Name	Type	%	Name	Type	%	Name	Type	%
AL	M-10	GN	75%	89s	GN	10%	Shorter sand	NS	15%			
TN	#10 hard	LM	63%	Natural	NS	20%	#10 soft	LM	17%			
MO	MO14	DM	65%	MO15	DM	20%	MO13	DM	15%			
VA	#10	GN	75%	Sand	NS	25%						
FL	Screenings	LM	92%	Sand	NS	8%						
CT	Stone Sand	TR	80%	Screenings	TR	20%						
MN	Minntac	TL	87%	Minntac fine	TL	13%						
NH	WMS	TR	69%	D-Dust	TR	16%	RAP	---	15%			
WI	Man.Sand	LM	65%	Screen 1/4"	LM	20%	Natural	NS	15%			
TNGM	# 10	GV	57%	Sand	NS	19%	#10 soft	LM	18%	Agg lime	LM	6%
Fladj	Screenings	LM	91%	Sand	NS	3%	Fine	F	6%			
WI adj	Man.Sand	LM	56%	Screen 1/4"	LM	44%						

Rock type description

GN= Granite	TR= Trap Rock
LM= Limestone	GV= Gravel
DM= Dolomite	TL= Tailings
NS= Natural Sand	F= Bag house

Table 4.3 Blend Gradation for Laboratory Mixtures

	Percent Passing							
State(mix)	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm	0.075 mm
AL	100.0	92.4	76.6	56.1	40.7	27.0	17.0	11.1
TN	100.0	94.4	69.1	48.7	33.8	19.0	13.8	11.6
MO	99.8	90.2	72.8	54.2	42.5	30.2	17.4	10.6
VA	100.0	98.0	77.7	56.2	37.9	23.2	14.9	10.1
FL	100	95.6	78.8	57.7	41	26	11.7	7.7
CT	99.9	99.4	66.9	39.4	26.9	19.6	13.2	7.9
MN	100	98	86.4	61.1	38.6	23.1	14.8	11.2
NH	99.7	94.6	71.4	48.3	33.0	21.0	11.2	6.0
WI	100	90.8	63.1	41.5	26.7	14.9	9.4	7.1
TNGM	100	95.9	67.4	46.2	32.1	16.7	10.4	8.2
Fladj	100	95.6	79.1	58.1	41.9	29	17.1	13.4
WI adj	100	89.6	58.1	37.3	24.7	16.7	12.3	9.5

4.1 Mix Design Results

4.1.1 Optimum Asphalt Content

Optimum asphalt contents for the mixtures prepared in this study were relatively high compared to traditional Superpave designed mixtures. The average asphalt content for all twenty nine mixtures was 8.4 percent, and the average effective asphalt content was 6.6 percent this was expected since VMA for 4.75 mm mixtures are generally high. The average asphalt absorption was 1.8 percent. FL-50-4 had the highest asphalt content and effective asphalt contents at 11.8 and 9.8 respectively. MO-50-6 had the lowest optimum asphalt content at 6.2 percent. WIadj-50-6 had the lowest effective asphalt content at 4.6 percent. New Hampshire aggregate had the lowest asphalt absorption at 0.60 percent, whereas the Virginia aggregate had the highest amount of asphalt absorption between 2.9 and 3.0 percent.

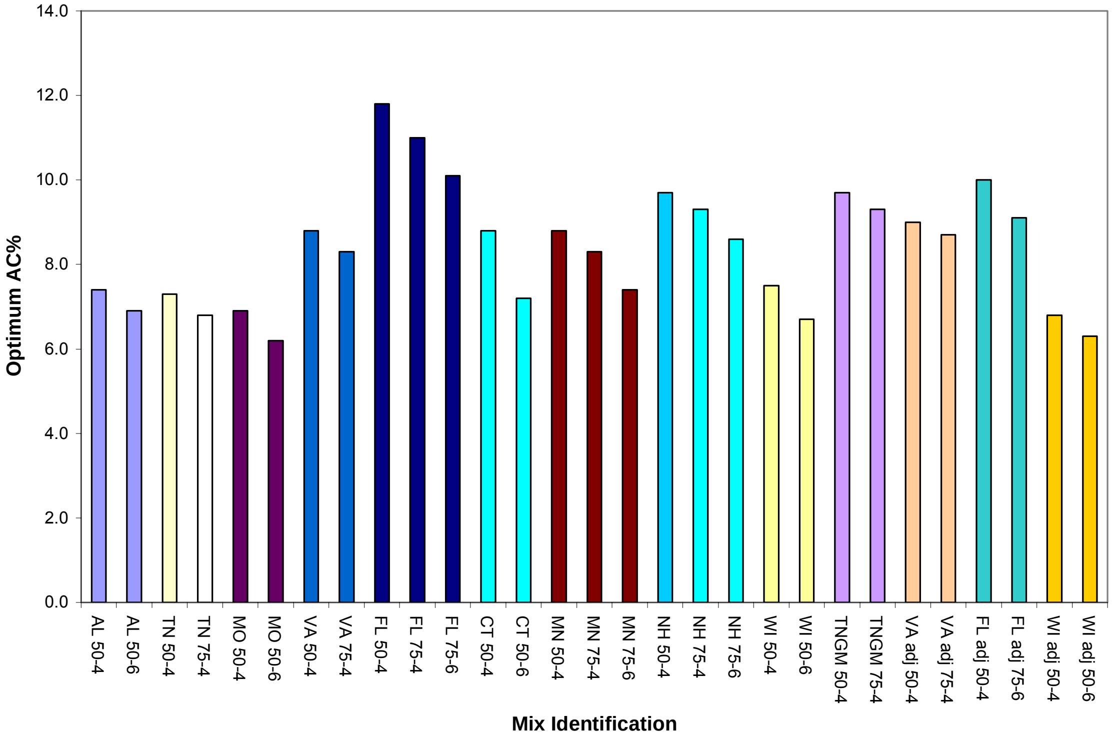


Figure 4.1 Optimum Asphalt Contents

Figure 4.1 shows optimum asphalt content for each mix design. It can be seen that increasing from 50 to 75 gyrations or increasing design air voids from 4.0 to 6.0 percent lowers optimum asphalt content. The same trend can be seen in Figure 4.2 for effective asphalt content. The statistical software package MINITAB was employed to conduct an Analysis of Variance (ANOVA) to determine which design factors had a significant effect on effective asphalt content. Three factors were used in this analysis; Ndesign, design air voids and material source. Results of this analysis are shown in Table 4.4.

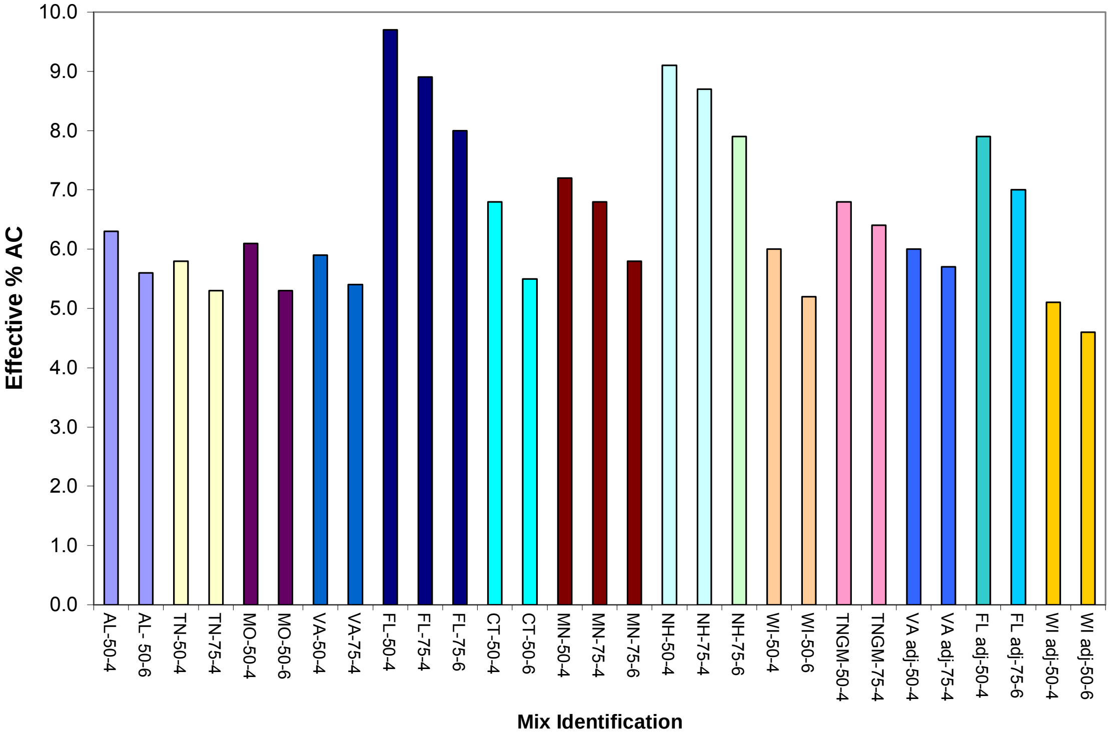


Figure 4.2 Effective Asphalt Content

The ANOVA results for effective asphalt show that there is strong evidence to support the conclusion that Ndesign, design air voids, and materials source all influence asphalt content.

Table 4.4 Analysis of Variance for Effective Asphalt Content

Source	DF	Seq SS	Adj SS	Adj MS	Fstat	P
Ndesign	1	1.9892	0.8149	0.8149	29.93	0.000
Air voids(design)	1	2.9622	3.1157	3.1157	114.42	0.000
Material source	15	48.3621	48.3621	3.2241	118.40	0.000
Error	14	0.3812	0.3812	0.0272		
Total	31	53.6947				

S = 0.165017   R-Sq = 99.29%   R-Sq(adj) = 98.43%

To analyze the effect of design air voids and Ndesign, mix designs were separated into groups that had matching mix designs for each comparison. The comparisons were as follows:

50 gyrations (4%Va and 6%Va)
4%Va (50 and 75 gyrations)
75 gyrations (4%Va and 6%Va)

The mix design groupings are shown in Tables 4.5 to 4.7 and will be used in comparison evaluations in subsequent sections. Figures 4.3 to 4.5 show the mean asphalt contents for each grouping and the mean difference for each comparison. It can be seen in Figures 4.3 and 4.5 that changing from 4.0 to 6.0 percent design air voids decreases the effective asphalt content by 0.9 percent on average. Figure 4.4 shows that changing from 50 to 75 gyrations decrease the effective asphalt content by 0.5 percent. This may indicate that increasing design air voids may be more effective in reducing asphalt content than increasing gyrations.

Table 4.5 Mix Designs Comparisons for Ndes = 50 (4-6 Percent Air voids)

State Id	*Air voids (design)*	*Ndesign*	*%A.C.*	*Eff AC%*	*VMA*	*VFA*	*%Gmm @Nini*	*Dust$_{ratio}$*	*SE*	*FAA*	*film thickness (microns)*
AL	4.0	50	7.4	6.30	18.5	78.4	89.0	1.8	67	46.3	6.1
CT	4.0	50	8.8	6.80	19.9	80.9	86.6	1.2	79	40.7	8.9
MO	4.0	50	6.9	6.10	18.2	78.2	88.8	1.7	74	49.0	5.9
WI	4.0	50	7.5	6.00	18.0	77.4	87.7	1.2	81	43.7	8.9
WI2	4.0	50	6.8	5.1	16.1	74.4	87.1	1.9	81	45.8	6.8
		ave =	7.5	6.1	18.1	77.9	87.8	1.6			7.3
		stdev =	0.8	0.6	1.4	2.3	1.0	0.3			1.5
AL	6.0	50	6.9	5.60	18.8	68.1	87.2	2.0	67	46.3	5.4
CT	6.0	50	7.2	5.50	19.0	68.5	85.1	1.4	79	40.7	7.1
MO	6.0	50	6.2	5.30	18.4	66.7	86.9	2.0	74	49.0	5.1
WI	6.0	50	6.7	5.20	17.8	66.9	86.7	1.4	81	43.7	7.7
WI2	6.0	50	6.3	4.6	16.5	64.4	85.3	2.1	81	45.8	6.3
		ave =	6.7	5.2	18.1	66.9	86.2	1.8			6.3
		stdev =	0.4	0.4	1.0	1.6	1.0	0.3			1.1
		Diff =	0.8	0.8	0.0	10.9	1.6	-0.2			1.0

Table 4.6 Mix Design Comparison for 4% Air voids (50 -75 Gyrations)

State Id	*Air voids (design)*	*Ndesign*	*%A.C.*	*Eff AC%*	*Binder*	*VMA*	*VFA*	*%Gmm @Nini*	*Dust*$_{ratio}$	*SE*	*FAA*	*film thickness (microns)*
FL	4.0	50	11.8	9.70	64-22	24.2	82.8	88.9	0.8	88	44.1	11.8
MN	4.0	50	8.8	7.20	64-22	21.1	80.4	87.5	1.6	67	46.2	7.4
NH	4.0	50	9.7	9.10	64-22	23.8	83.6	89.8	0.7	85	51.0	12.8
TN	4.0	50	7.3	5.80	64-22	16.9	76.8	87.8	2.0	69	44.8	6.3
TNGM	4.0	50	9.7	6.8	64-22	20.9	80.7	88.1	1.0	70	42.2	9.2
VA	4.0	50	8.8	5.90	64-22	16.8	75.8	89.0	1.7	76	45.0	6.3
VA2	4.0	50	9.0	6.0	70-22	16.8	76.4	88.5	1.7	76	45.0	6.5
		ave =	9.3	7.2		20.1	79.5	88.5	1.4			8.6
		stdev =	1.4	1.6		3.3	3.2	0.8	0.5			2.7
FL	4.0	75	11.0	8.90	64-22	22.6	81.8	88.4	0.9	88	44.1	10.8
MN	4.0	75	8.3	6.80	64-22	20.1	79.8	86.9	1.7	67	46.2	6.9
NH	4.0	75	9.3	8.70	64-23	22.9	84.0	89.4	0.7	85	51.0	12.1
TN	4.0	75	6.8	5.30	64-22	16.0	74.8	87.2	2.2	69	44.8	5.7
TNGM	4.0	75	9.3	6.4	64-22	17.5	76.5	87.5	1.3	70	42.2	8.6
VA	4.0	75	8.3	5.40	64-22	15.8	74.9	88.5	1.9	76	45.0	5.8
VA2	4.0	75	8.7	5.7	70-22	16.5	75.6	88.0	1.7	76	45.0	6.1
		ave =	8.8	6.7		18.8	78.2	88.0	1.5			8.0
		stdev =	1.3	1.5		3.1	3.7	0.9	0.5			2.6
		Diff =	0.49	0.47		1.3	1.3	0.5	-0.1			0.6

Table 4.7 Mix Designs Comparisons for Ndes = 75 (4-6 Percent Air voids)

State Id	*Air voids (design)*	*Ndesign*	*%A.C.*	*Eff AC%*	*Binder*	*VMA*	*VFA*	*%Gmm @Nini*	*Dust*$_{ratio}$	*SE*	*FAA*	*film thickness (microns)*
FL	4.0	75	11.0	8.90	64-22	22.6	81.8	88.4	0.9	88	44.1	10.8
MN	4.0	75	8.3	6.80	64-22	20.1	79.8	86.9	1.7	67	46.2	6.9
NH	4.0	75	9.3	8.70	64-23	22.9	84.0	89.4	0.7	85	51.0	12.1
		ave =	9.5	8.1		21.9	81.9	88.2	1.1			9.9
		stdev =	1.4	1.2		1.5	2.1	1.3	0.5			2.7
FL	6.0	75	10.1	8.00	64-22	22.5	73.7	86.4	1.0	88	44.1	9.6
MN	6.0	75	7.4	5.80	64-22	19.7	70.1	85.3	1.9	67	46.2	5.8
NH	6.0	75	8.6	7.90	64-24	23.1	75.0	87.4	0.8	85	51.0	10.9
		ave =	8.7	7.2		21.8	72.9	86.4	1.2			8.8
		stdev =	1.4	1.2		1.8	2.5	1.1	0.6			2.7
		Diff =	0.8	0.9		0.1	8.9	1.9	-0.1	0.0	0.0	1.2

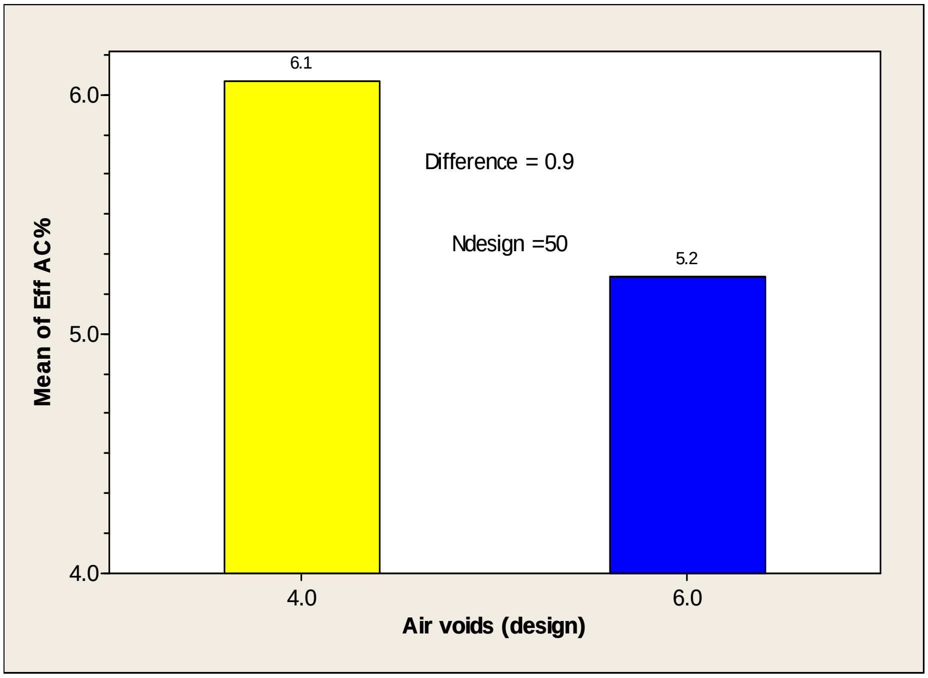


Figure 4.3 Mean Effective Asphalt for 4 and 6 % Air Voids (Ndes = 50)

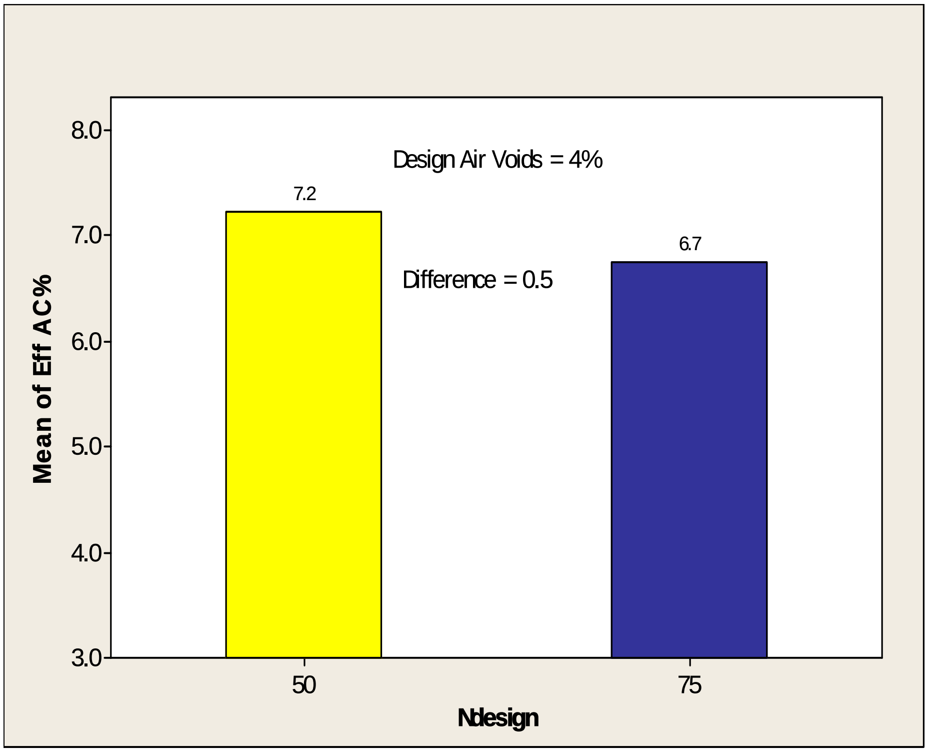


Figure 4.4 Mean Effective Asphalt Content for Ndes =50 and 75 (4% Air Voids)

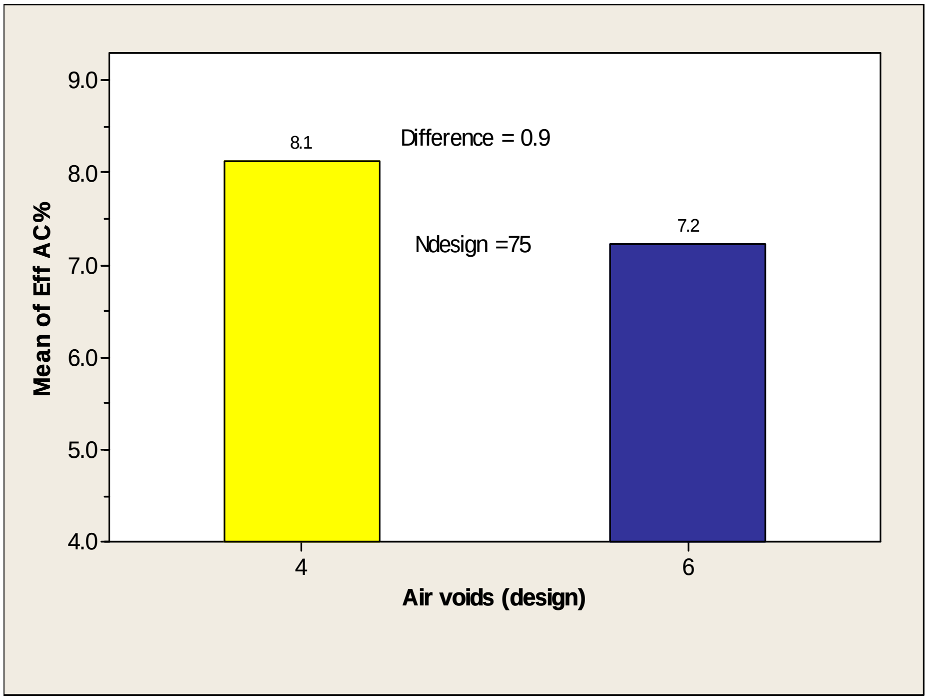


Figure 4.5 Mean Effective Asphalt Content for 4 and 6 % Air Voids (Ndes = 75)

4.1.2 VMA

The minimum VMA currently specified in AASHTO for 4.75 mm NMAS Superpave designed mixture is 16.0 percent. For all mix designs prepared for this research the average VMA was 19.3 percent. Only one mixture (VA-75-4) failed to meet the current minimum VMA criterion. The maximum value was 24.2 percent (FL-50-4). Figure 4.6 shows all VMA values determined for the mix designs performed in this research.

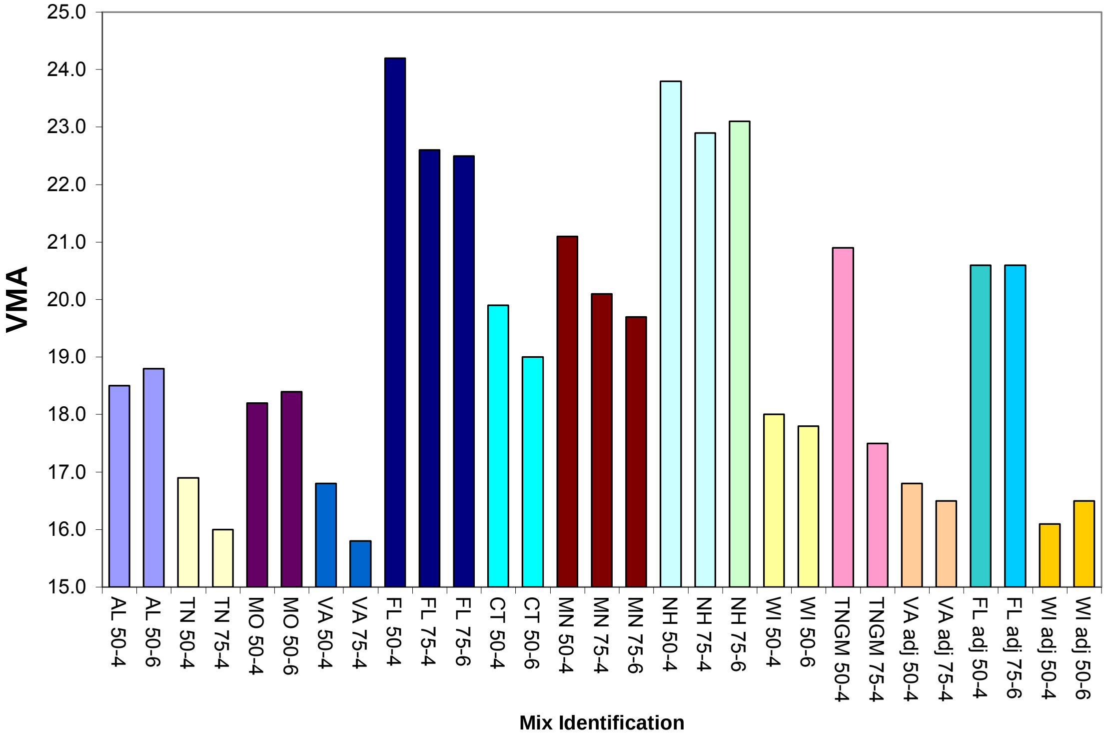


Figure 4.6 VMA Results for Each Mix Design

It is seen in Figure 4.6 that the largest change in VMA occurs when the compaction level is increased from 50 to 75 gyrations. This is expected since the aggregate will be forced into tighter packing when the compaction energy is increased. As is well known when designing asphalt mixtures, the addition of asphalt binder will decrease VMA until a minimum is reached, any additional asphalt binder past this minimum will begin to push the aggregate structure open increasing VMA. This effect explains why some mixtures had a slight increase or decrease in VMA when increasing the design air voids from 4 to 6 percent which lowers the optimum asphalt content.

To analyze the effect of Ndesign, design air voids, and material source on VMA, MINITAB was used to perform ANOVA. The results of this analysis are presented in

Table 4.8. As with effective asphalt content, one can see that material type has the most significant effect on VMA. Ndesign also had a significant effect on VMA. Design air voids however, did not significantly influence VMA.

To illustrate the results of the ANOVA, the groupings presented as comparison groups in Tables 4.5 to 4.7 were used to show the differences in VMA due to changes in design air voids and Ndesign. Figure 4.7 shows that there is no mean difference in VMA for mixtures designed with 50 gyrations at 4.0 and 6.0 percent air voids. For Ndesign of 75 the mean difference in VMA between 4.0 and 6.0 percent design air voids, shown in Figure 4.8, is very slight at 0.1 percent. On the other hand, mixtures designed at 50 and 75 gyrations have a significant mean difference in VMA (1.3%), as illustrated in Figure 4.9.

Table 4.8 Analysis of Variance for VMA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Source Material	12	170.023	171.551	14.296	44.44	0.000
Air voids (design)	1	0.43	0.017	0.017	0.05	0.821
Ndesign	1	5.673	5.673	5.673	17.64	0.001
Error	14	4.503	4.503	0.322		
Total	28	180.63				

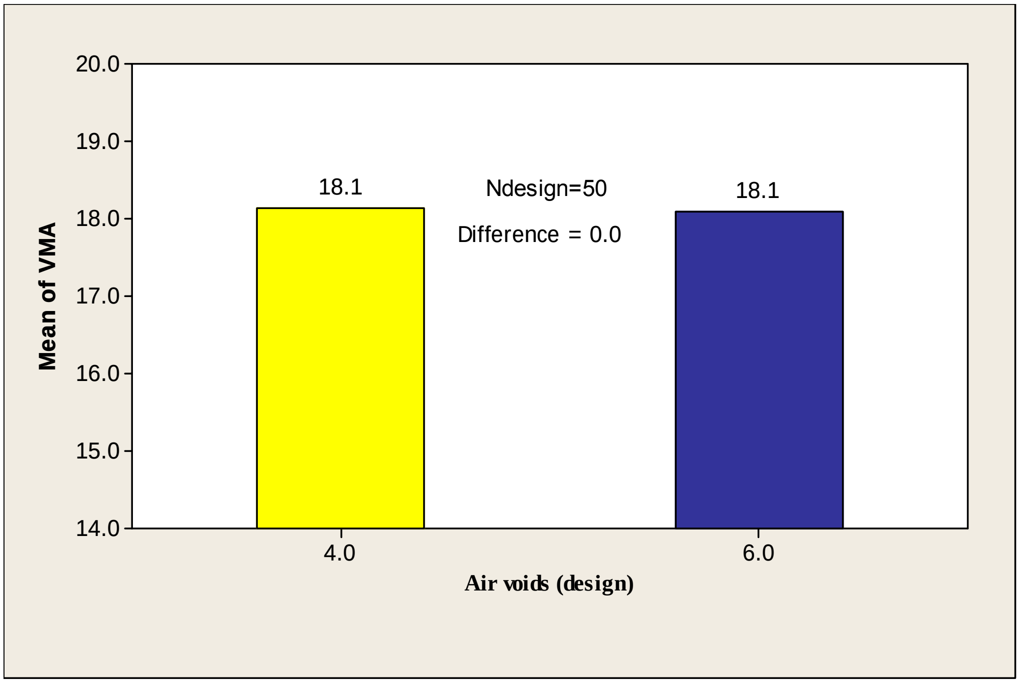


Figure 4.7 Mean VMA for 4% and 6 % Air Voids (Ndes = 50)

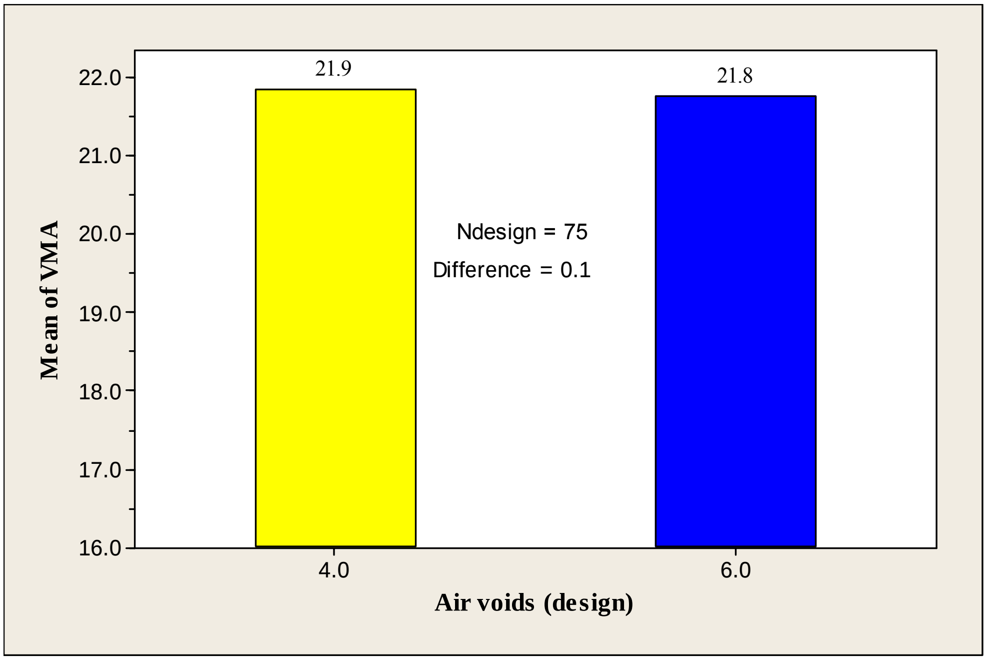


Figure 4.8 Mean VMA for 4% and 6 % Air Voids (Ndes = 75)

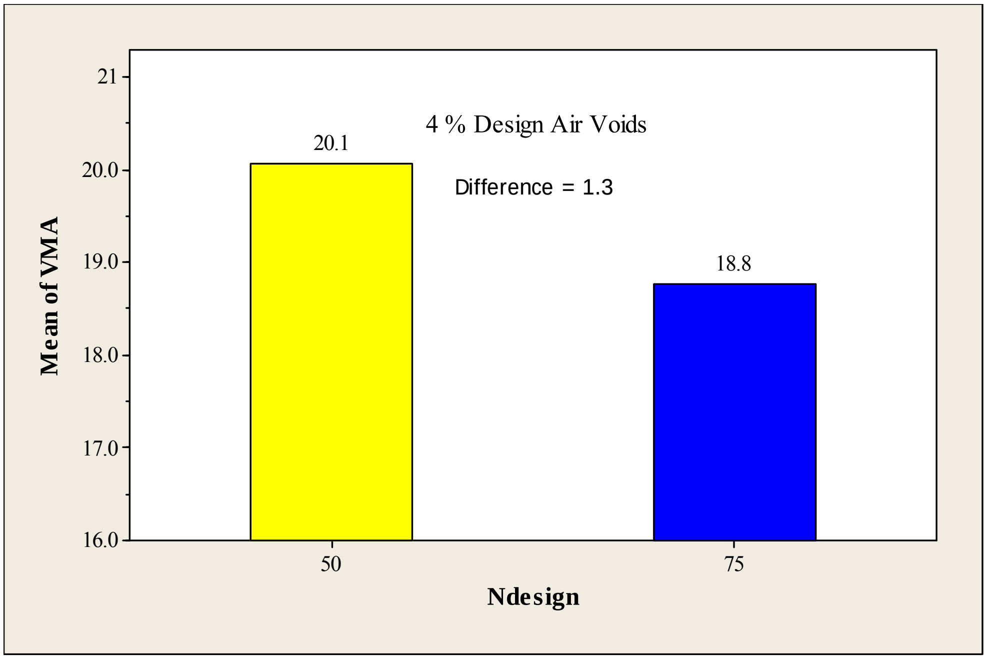


Figure 4.9 Mean VMA for Ndesign =50 and 75 at 4% design Air Voids

4.1.3 VFA

There are three VFA ranges currently specified in the AASHTO specifications for 4.75 mm NMAS mixtures as shown in Table 4.9. The average VFA for all mix designs in this study was 75.8 percent. However, only six mix designs in this study meet the tightest VFA criteria which apply to mixes used on projects with over three million ESALs. A maximum VFA observed was 84 percent for NH-75-4 and the minimum VFA was 64.4 percent for WI adj-50-6. Seventeen mix designs meet the VFA range for 0.3 to 3 million ESALs. Sixteen mix designs meet the VFA range for less than 0.3 million ESALs. Eight mixtures had VFA over 80 percent and one was under 65 percent. Generally, mixtures over the maximum are over asphalted and may be susceptible to rutting.

To analyze the effects of the experimental factors an analysis of variance was performed using MINITAB. The results of this analysis are presented in Table 4.10. Design air voids had the most significant effect on VFA, with material source also being a significant factor. Ndesign was shown to have the least significant influence on VFA.

Table 4.9 AASHTO Specifications for 4.75mm NMAS Superpave Mixtures

<table>
<tr><th rowspan="2">Design ESALs (Millions)</th><th rowspan="2">Ndes</th><th colspan="2">Min.FAA
Depth from Surface</th><th rowspan="2">Min.Sand Equivalent</th><th rowspan="2">Min VMA</th><th rowspan="2">VFA</th><th rowspan="2">Nini</th></tr>
<tr><th>≤ 100 mm</th><th>≥ 100 mm</th></tr>
<tr><td><0.3</td><td>50</td><td>-</td><td>-</td><td>40</td><td>16</td><td>70-80%</td><td>≤91.5</td></tr>
<tr><td>0.3 to <3.0</td><td>75</td><td>40</td><td>40</td><td>40</td><td>16</td><td>65-78%</td><td>≤90.5</td></tr>
<tr><td>3.0 to<10</td><td>100</td><td>45</td><td>40</td><td>45</td><td>16</td><td>75-78%</td><td>≤89.0</td></tr>
<tr><td>Sieve size</td><td>Min.</td><td>Max.</td><td colspan="5">Air voids = 4.0%</td></tr>
<tr><td>12.5 mm</td><td>100</td><td></td><td colspan="5">Dust Proportion: 0.9 to 2.0</td></tr>
<tr><td>9.5 mm</td><td>95</td><td>100</td></tr>
<tr><td>4.75 mm</td><td>90</td><td>100</td></tr>
<tr><td>1.18 mm</td><td>30</td><td>60</td></tr>
<tr><td>0.075 mm</td><td>6</td><td>12</td></tr>
</table>

Table 4.10 Analysis of Variance for VFA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Source Material	12	282.136	246.366	20.53	18.45	0.000
Air voids(Design)	1	513.422	438.519	438.519	394.04	0.000
Ndesign	1	3.083	3.083	3.083	2.77	0.118
Error	14	15.58	15.58	1.113		
Total	28	814.221				

S = 1.05493   R-Sq = 98.09%   R-Sq(adj) = 96.17%

The comparison groups presented in Tables 4.5 to 4.7 were used to illustrate the results of the analysis of variance. Figure 4.10 shows the difference in VFA for mixtures with a Ndesign = 50 at 4.0 and 6.0 percent design air voids. Since both groups had an average VMA of 18.1 percent for both design air voids the difference of 11 percent VFA is expected. Figure 4.11 shows a slight decrease in voids filled due to increasing Ndesign from 50 to 75 gyrations at 4 percent air voids. The mean difference in VMA for this comparison set was 1.3 percent. Figure 4.12 shows the decrease in VFA by increasing design air voids from 4.0 to 6.0 percent for 75 gyrations mixes.

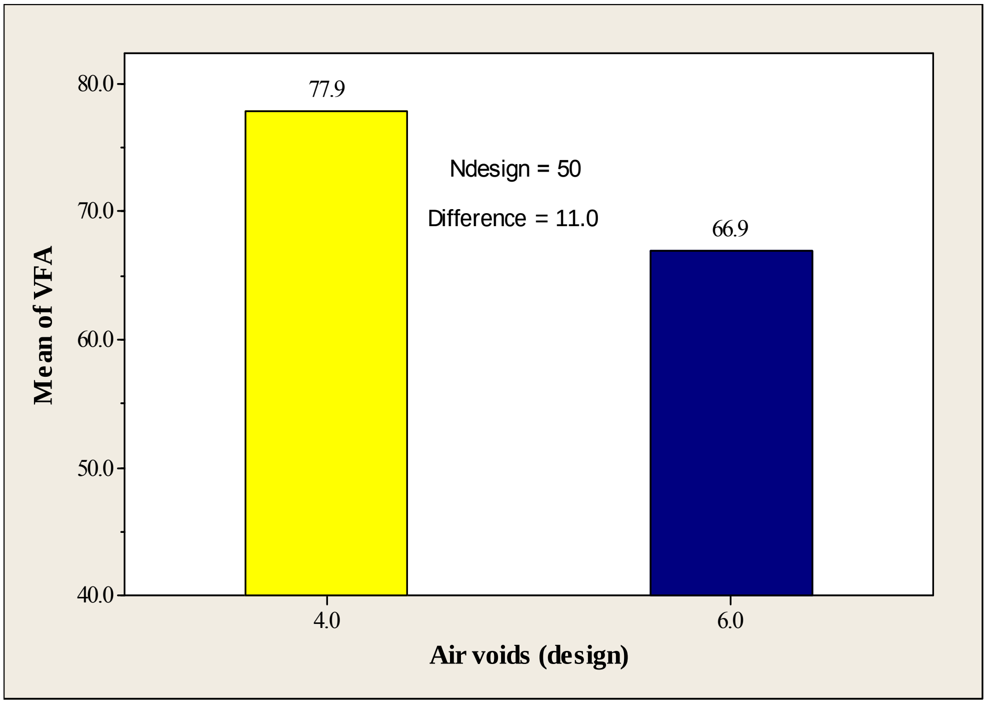


Figure 4.10 Mean VFA for 4% and 6 % Air Voids (Ndes = 50)

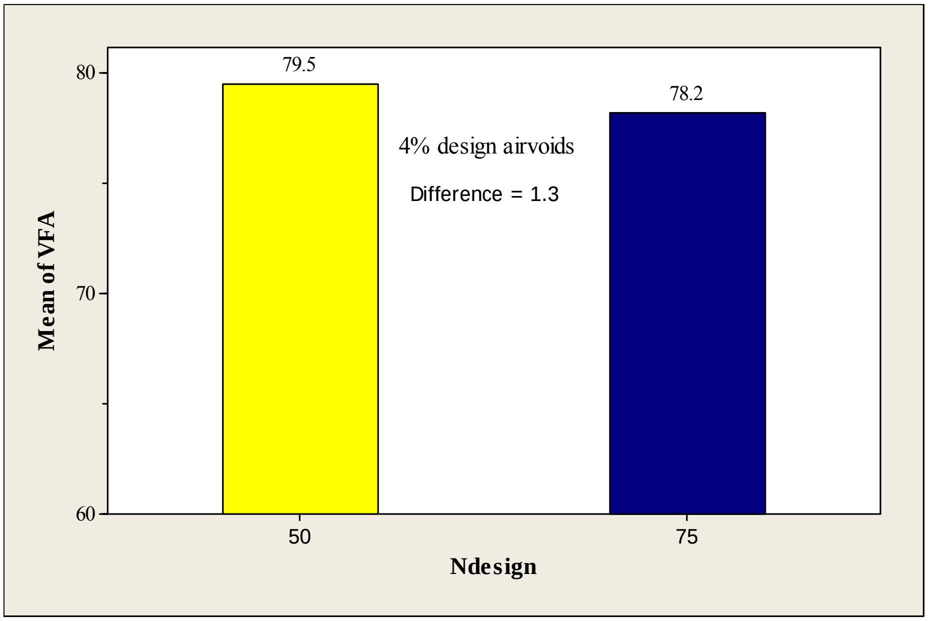


Figure 4.11 Mean VFA for 4% (Ndes = 50 and 75)

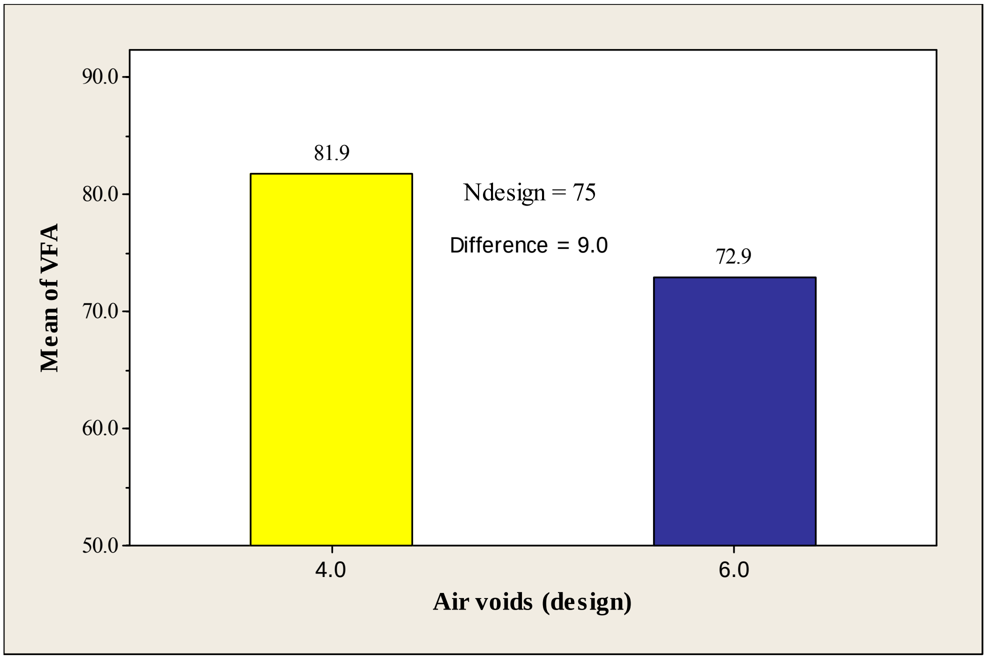


Figure 4.12 Mean VFA for 4% and 6 % Air Voids (Ndes = 75)

4.1.4 %Gmm@Nini

Table 4.9 shows the current AASHTO required relative density at Nini. For the two compaction levels evaluated in this study (50 and 75), the corresponding Nini values are 6 and 7 respectively. The descriptive statistics for each Nini level are provided in Table 4.11. All mixtures prepared for this research meet the specification limits for %Gmm@Nini for the lowest two traffic levels displayed in Table 4.9. Two mixtures (NH-50-4 and NH-75-4) did not meet the more restrictive %Gmm@Nini requirement of ≤ 89% for traffic levels greater than three million ESALs. Mixtures that do not meet %Gmm@Nini requirements tend to be tender which may lead to problems during field compaction.

Table 4.11 Descriptive Statistics for %Gmm @ Nini

Ndesign	N	Mean	StDev	Minimum	Median	Maximum
50	18	87.7	1.3	85.1	87.8	89.8
75	11	87.4	1.1	85.3	87.4	89.4

The analysis of variance table, Table 4.12, shows that all three design factors had a significant effect on %Gmm@Nini. The most significant effect is due to changes in design air voids. This is probably caused by a reduction in optimum asphalt content and the percent relative density required at Ndesign when increasing design air voids from 4.0 to 6.0 percent. Figures 4.13 to 4.15 show the differences in %Gmm@Nini for the comparison groups. Increasing design air voids has a substantial influence on %Gmm@Nini. The average decrease in %Gmm@Nini when increasing design air voids from 4.0 to 6.0 percent was 1.75 percent. Whereas changing Ndesign from 50 to 75 gyrations the average decrease in %Gmm@Nini was only 0.5 percent.

Table 4.12 Analysis of Variance for Gmm@Nini

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ndesign	1	0.5718	1.2686	1.2686	44.12	0.000
Air voids (design)	1	20.7127	12.9861	12.9861	451.66	0.000
Source Material	12	20.3516	20.3516	1.696	58.99	0.000
Error	14	0.4025	0.4025	0.0288		
Total	28	42.0386				

S = 0.169563   R-Sq = 99.04%   R-Sq(adj) = 98.08%

Table 4.13 shows Pearson correlation coefficients of linear relationships for % Gmm@Nini and effective asphalt content, VFA, VMA, film thickness and dust to asphalt ratio. The strongest relationship was between %Gmm@Nini and VFA (R=0.737, p-value 0.000 at a 95% confidence level). Also, shown to be significant is the relationship between % Gmm@Nini and effective asphalt content. Although the R-value is low, it was expected to see a trend of increasing % Gmm@Nini with increasing asphalt content since asphalt binder acts as a lubricant at compaction temperatures that facilitates compaction. Film thickness has a similar relationship with % Gmm@Nini which seems reasonable since film thickness is a function of effective asphalt content and gradation.

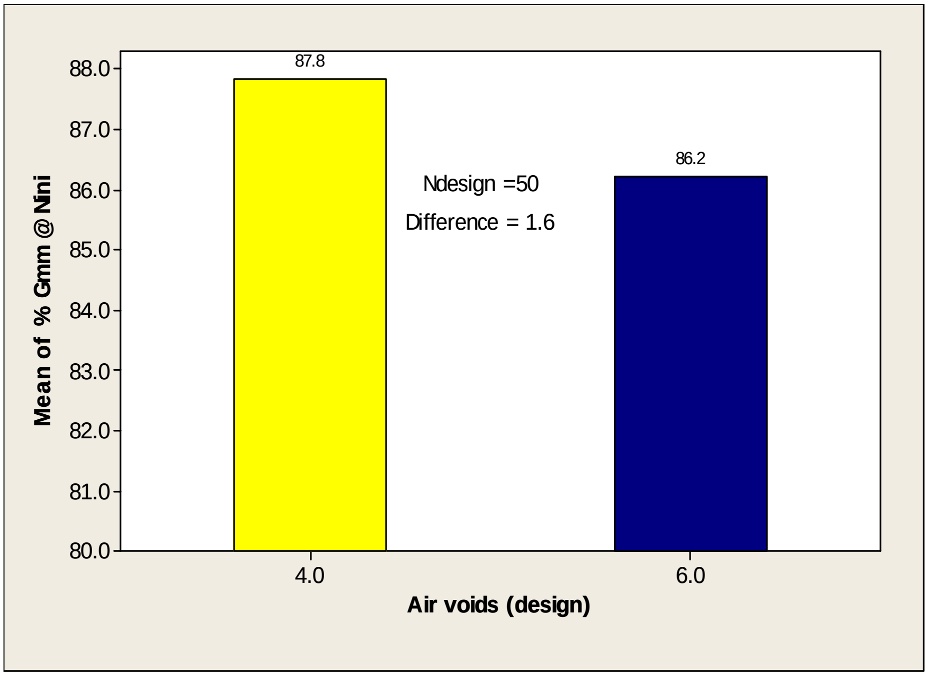


Figure 4.13 Mean %Gmm@Nini for 4% and 6% air voids Ndesign = 50

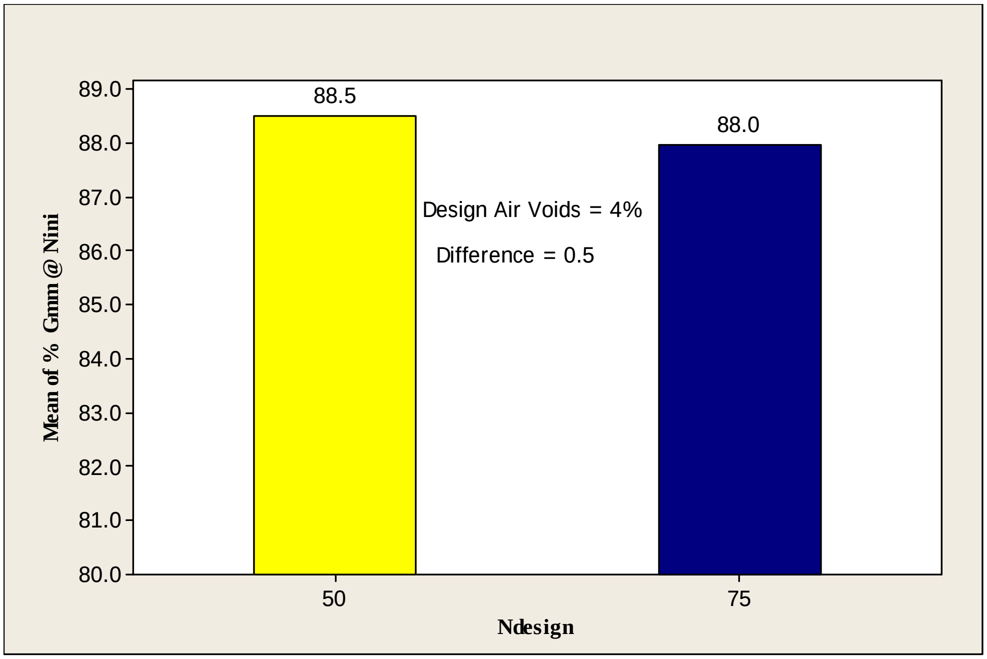


Figure 4.14 Mean %Gmm@Nini for 4% Air Voids at Ndesign = 50 and 75

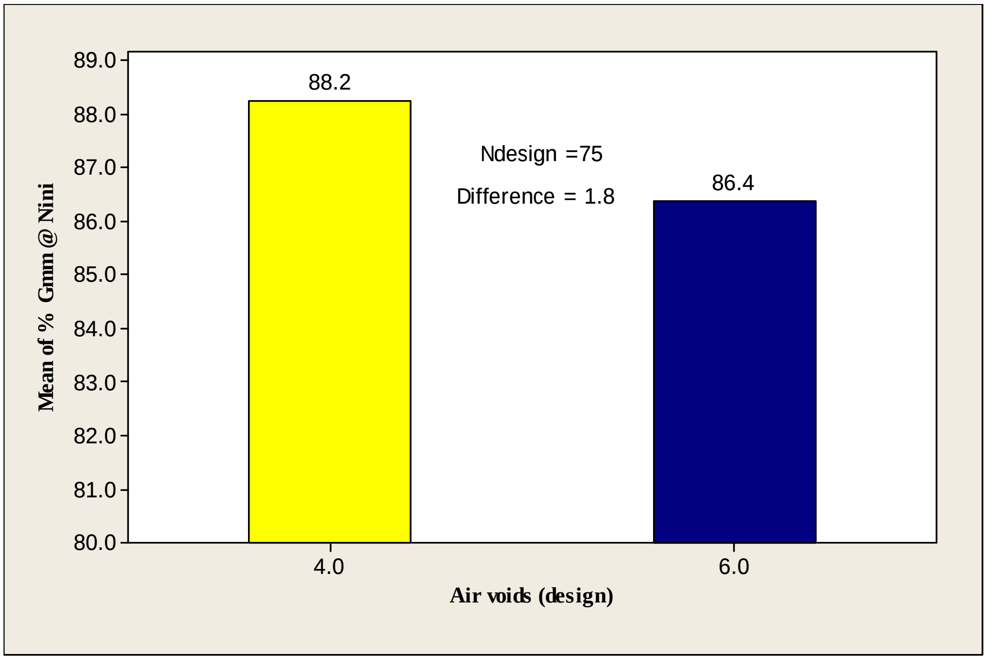


Figure 4.15 Mean Gmm@Nini for 4% and 6% Air Voids at Ndesign = 75

Table 4.13 Pearson Coefficients of Linear Relationships with Gmm@Nini

	VFA	VMA	Eff. AC%	Film Thickness	$Dust_{ratio}$
R	0.737	0.221	0.484	0.381	-0.341
p-value	0.000	0.249	0.008	0.041	0.07

4.1.5 Dust to Asphalt Proportion and Film Thickness

The dust to asphalt proportion range currently specified in AASHTO for 4.75 mm NMAS mixtures is 0.9 to 2.0. For the mix designs prepared in this study the average was 1.5. The maximum was 2.2 for TN-75-4, the minimum was 0.7 for NH-50-4 and NH-75-4. Two mixtures were above 2.0 and three were below 0.9. Since dust to asphalt ratio is a function of effective asphalt content it is clear that lowering asphalt content by increasing design air voids and/or Ndesign will increase the dust to asphalt proportion.

It has been suggested by some asphalt mix technologists that film thickness could be possible alternative to specifying minimum and maximum values for VMA and VFA. For this reason film thickness has been calculated for each mixture in this study. Film thickness is simply the volume of effective asphalt divided by the estimated surface area of the aggregate shown by equation (1). Surface area factors presented by Roberts et al (6) were used in this research for the calculation of film thickness. The average film thickness was 7.8 microns, the maximum was 12.8 for NH-50-4, and the minimum was 5.1 for MO-50-6.

$$TF = \frac{V_{be}}{SA \times W} 1000 \qquad \text{Equation (1)}$$

Where,

TF= Average film thickness, microns

Vbe = Effective Volume of Asphalt, liters

SA = Surface area of aggregate, m^2 per kg of aggregate

W = Weight of aggregate, kg

4.1.6 Aggregate Properties

Aggregate size distribution in an asphalt mixture is the most important factor in establishing the amount of voids in mineral aggregate (VMA) created in the aggregate structure. As VMA increases the asphalt needed to fill voids is increased. Since VMA is dependent on gradation, an understanding of how gradation parameters influenced the VMA of asphalt mixtures prepared for this study was necessary.

Fineness modulus (FM) was calculated for each blend in this study to examine the influence of gradation on VMA. The fineness modulus expresses how fine or coarse an aggregate blend is, the larger the fineness modulus the coarser the gradation. To examine the effect of gradation on VMA only the thirteen mixtures designed at 50 gyrations and 4.0% air voids were used to remove factors which have already been shown to affect VMA. Figure 4.16 shows two plots of fineness modulus versus VMA, one for mixtures with over 10 percent dust and one for mixtures with less than 10 percent dust. Fines Modulus does not take into account the percent passing the 0.075 mm sieve. Since all the mixtures presented in this study are fine-graded it was expected that coarser blends would have lower VMA as seen in Figure 4.16 for both curves. Also, by separating mixtures into two groups (over and under 10% dust) it is evident that dust content is probably the biggest factor affecting VMA.

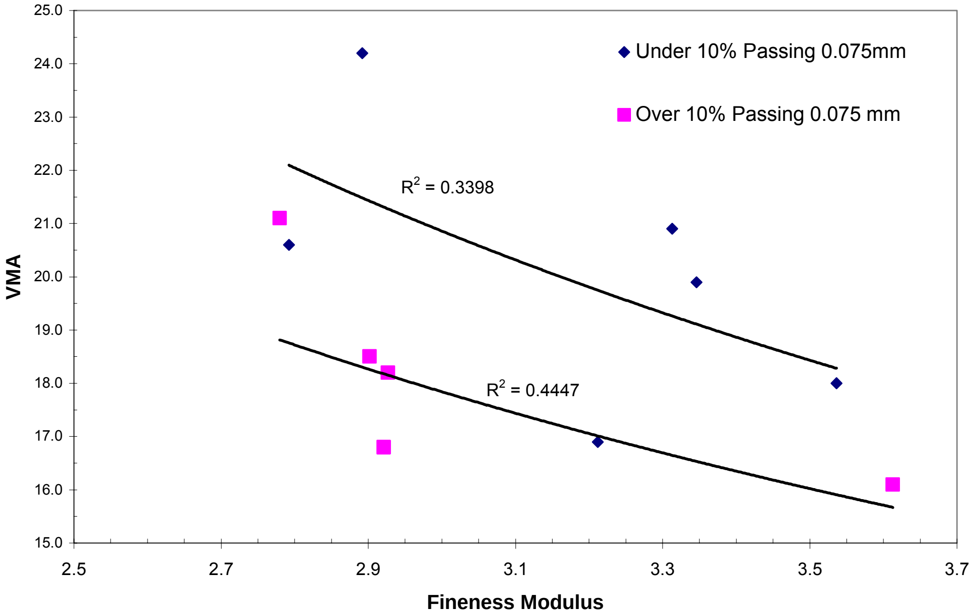


Figure 4.16 Fineness Modulus versus VMA

The 1.18 mm sieve was used as a primary control sieve in the gradation curve where the material retained above this sieve is coarse portion of the blend and the material passing is the fine portion. For fine-graded mixtures as the coarse portion increases, and the gradation curve moves closer to the maximum density line, VMA should also decrease. Figure 4.17 is presented to illustrate that as the fine portion of the blend increases VMA increases. Here again, the data are broken up into groups (over and under 10% dust). This shows that VMA can be controlled with higher dust contents and/or by adjusting the coarseness of the aggregate blend. There may be some potential problems for using higher dust contents to control VMA, such as higher dust to asphalt ratios and lower film thicknesses which could lead to durability problems.

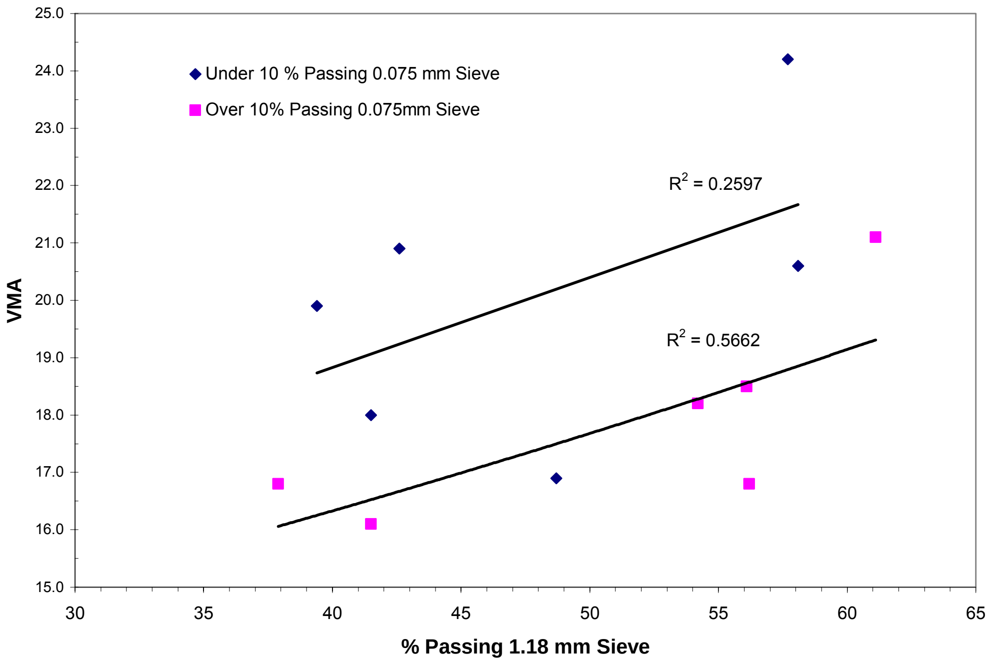


Figure 4.17 VMA versus Percent Passing 1.180 mm Sieve for Over and Under 10 percent Passing the 0.075 mm Sieve

The gradation distributions have been presented in Table 4.3 and plotted in Figure 3.1. All gradations used for mix design are considered fine graded. The average percent passing the control sieves (4.75mm, 1.18 mm, and 0.075 mm) was 94.9 50.4 and 9.5, respectively. One mixture was below the 90% minimum percent pass the 4.75 mm sieve (WI –adj). This was the coarsest gradation of the studied mixtures and it had one of the lowest VMAs in this research. One mix had over the 60% percent passing the 1.18 mm sieve, (MN). Even with a fairly high dust content of 11.2 percent, this blend had a VMA that was well above the 16 percent minimum. The blend adjustment from Florida (FL-adj) was the only mix with a gradation blend that was outside the current specification range for passing the 0.075 mm sieve. Baghouse fines were added to the first Florida mix (FL) to create the FL-adj aggregate blend in an attempt to reduce excessive VMA. Increasing the dust content from 7.7 to 13.4% reduced the VMA from 24.2 percent to

20.6 percent. This is probably due to the fine grading of the blend, (58.1% passing the 1.18 mm sieve and a fineness modulus of 2.792).

For mix designs below 0.3 million ESALs there are no requirement for fine aggregate angularity because mixture requirements are generally not as restrictive for lower ESAL ranges. Between 0.3 to 3 million ESALs the minimum is 40. Over 3 million ESALs, the FAA minimum is 45 for mixtures used within 100 mm of the pavement surface, and 40 for mixes used deeper than 100 mm from the pavement surface. For all the mix designs, the average FAA value was 45.2. The highest FAA was 51 for the New Hampshire mix and the lowest was 42.2 for the Tennessee gravel mix. Every blend met the 40 minimum FAA. Seven of the thirteen blends met the 45 minimum value.

Figure 4.18 shows that FAA does not correlate with VMA. This is counterintuitive it seem logical that high FAA values probably increase VMA. For 4.75 mm NMAS mixtures it would seem that since 100% of the blend is fine aggregate. This may be because other factors such as gradation are dominating VMA for this group of mixes. It also seems logical to assume that as FAA increases the relative density at Nini would decrease. Although it is a weak relationship the opposite trend was observed. Figure 4.19 shows that for the blends in this study as FAA increased a trend of increasing relative density developed at Nini. Since all the blends had FAA values above 40, and the average was 45.2, it is not possible to determine how blends with FAA below 40 would affect mixture properties and performance.

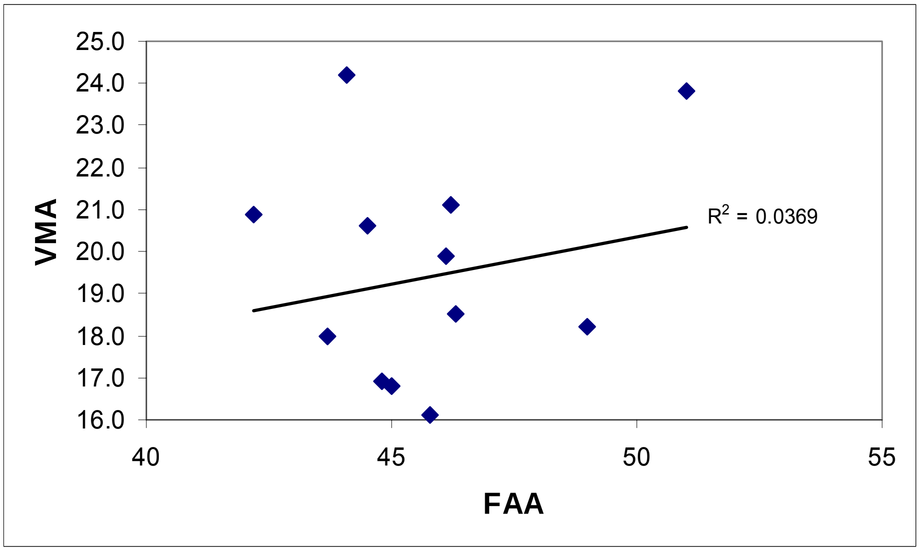


Figure 4.18 FAA versus VMA for Ndesign =50 and Design Air Voids =4%

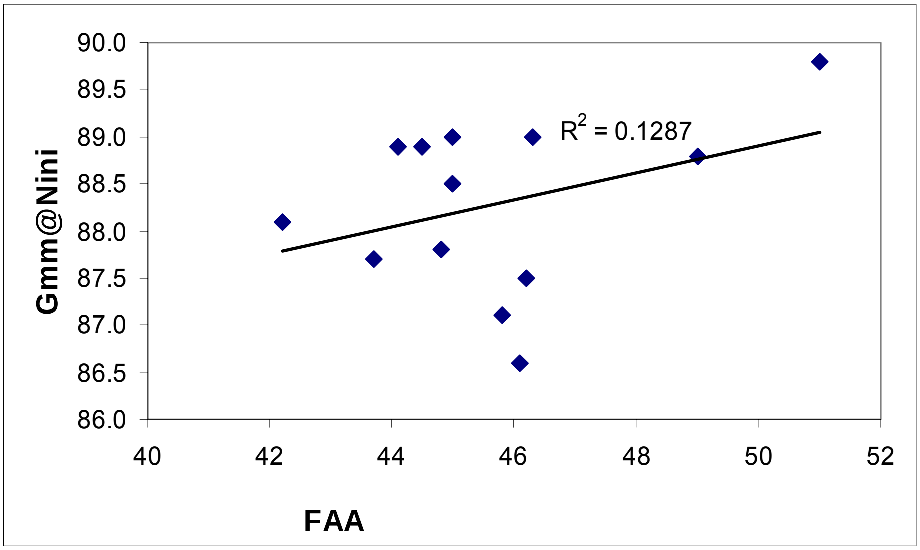


Figure 4.19 FAA versus Gmm@Nini for Ndesign =50 and Design Air Voids =4%

For asphalt mixtures designed for over 3 million ESALs, the minimum sand equivalent value is 45, for less than three million ESALs the minimum is 40. All blends are well above these minimum values. The average was 76, the minimum was 67 for Alabama and Minnesota blends, the maximum was 88 for the FL Florida blend. Since the amount of clay size particles are related to the amount of dust in the blend, sand equivalent is related to the amount passing the 0.075mm sieve, dust to asphalt ratio, and film thickness. These relationships are shown in Table 4.14, where Pearson correlation coefficients and p-values are presented for each relationship. Since all the sand equivalent values for blends presented in this study are well above the minimum specified values, its effect on performance may not be clear based on the results of this study. No direct relationship was found between sand equivalence and volumetric properties or performance.

Table 4.14 Pearson Coefficients for Sand Equivalent

	P-200	**$\text{Dust}_{\text{ratio}}$**	**film thickness**
R	-0.577	-0.57	0.679
p-value	0.039	0.042	0.011

4.2 Performance Tests

4.2.1 MVT Rut Depths

The Material Verification Tester was used to perform permanent deformation testing on all 29 mixtures. The specimens used for this particular performance test were prepared at the design air voids and compacted to Ndesign. Rutting was so severe for many of the mixtures that it is difficult to determine the effect of changes in air void, compaction level, and percent binder. All rut depths presented in this report were measured manually. Since the MVT is programmed to shut off if the automatic rut depth measurements exceed 15 mm, many tests were automatically terminated before 8000 cycles.

Table 4.15 gives the rut depths for all 29 blends and the number of cycles the test completed before termination. The average rut depth was 13.3 mm for those samples that completed 8000 cycles. An interesting comparison is to look at the average VMA for those mixtures that completed 8000 cycles to those that did not complete 8000 cycles. This comparison is shown in Figure 4.20. The average VMA for mixtures that completed 8000 cycles was 18.2 percent and 21.5 percent for those that were terminated before 8000. VMA results were ranked and plotted versus cycles to termination in Figure 4.21 for all mixtures. It is seen that over 20 percent VMA, rutting generally becomes so severe that the MVT test prematurely ended. There are some exceptions, one being VA-50-4 which has a relatively low VMA yet, did not complete 8000 cycles, this may be partly due to high percent natural sand (25%). The other exception that stands out is NH -75-6, which has a high VMA (23.1%) yet completed 8000 cycles and had a reasonable rut depth. This is probably explained by the mixtures high FAA value (51).

Based on the number of mixtures with over 20 percent VMA that did not complete a full 8000 cycles on the MVT device it is evident that limiting the VMA to under 20 percent in 4.75 NMAS mixtures will be important in designing rut resistant mixtures. To analyze all the MVT data including those mixtures that did not finish 8000 cycles on the MVT, rut depth was divided by the number of cycles for each mix to determine the total rutting rate in mm/cycle. When rutting rate is plotted against VMA shown in Figure 4.22 it can be seen that there are two separate trends for 4.0 and 6.0 percent air voids. The 6.0 percent design air void line plots beneath the 4.0 percent air void line and the lines diverge for higher VMA values. Thus 6.0 percent air void mixtures are more rutting resistant since the asphalt content is lower.

Table 4.15 Rut Depth and Mixture Properties for All Mix Designs

State(mix)	Air voids (design)	Ndesign	%Nat. Sand	Vbe	VMA	VFA	DP	FAA	film thickness (microns)	Rut depth (mm)	cycles	Rutting Rate mm/cycle
WI	4.0	50	0.0	12.0	16.1	74.4	1.9	45.8	6.8	5.3	8000	0.00066
WI	6.0	50	0.0	10.6	16.5	64.4	2.1	45.8	6.3	7.5	8000	0.00093
VA	4.0	50	0.0	12.8	16.8	76.4	1.7	45.0	6.5	9.8	8000	0.00123
VA	4.0	75	0.0	12.5	16.5	75.6	1.7	45.0	6.1	11.1	8000	0.00139
MO	6.0	50	0.0	12.3	18.4	66.7	2.0	49.0	5.1	11.3	8000	0.00141
FL	6.0	75	3.0	14.6	20.6	71.0	1.9	44.5	6.4	11.8	8000	0.00148
MO	4.0	50	0.0	14.2	18.2	78.2	1.7	49.0	5.9	12.1	8000	0.00151
CT	6.0	50	0.0	13.0	19.0	68.5	1.4	46.1	7.1	12.7	8000	0.00159
NH	6.0	75	0.0	17.3	23.1	75.0	0.8	51.0	10.9	13.1	8000	0.00164
WI	4.0	50	15.0	13.9	18.0	77.4	1.2	43.7	8.9	13.1	8000	0.00164
TN	4.0	75	20.0	12.0	16.0	74.8	2.2	44.8	5.7	13.5	8000	0.00169
VA	4.0	75	25.0	11.8	15.8	74.9	1.9	45.0	5.8	13.7	8000	0.00171
WI	6.0	50	15.0	11.9	17.8	66.9	1.4	43.7	7.7	14.0	8000	0.00175
FL	4.0	50	3.0	16.7	20.6	81.1	1.7	44.5	7.9	14.3	8000	0.00178
AL	4.0	50	15.0	14.5	18.5	78.4	1.8	46.3	6.1	15.4	8000	0.00192
AL	6.0	50	15.0	12.8	18.8	68.1	2.0	46.3	5.4	16.5	8000	0.00207
CT	4.0	50	0.0	16.1	19.9	80.9	1.2	46.1	8.9	17.2	8000	0.00215
TN	4.0	50	20.0	13.0	16.9	76.8	2.0	44.8	6.3	17.7	8000	0.00221
MN	6.0	75	0.0	13.8	19.7	70.1	1.9	46.2	5.8	13.9	5074	0.00273
TNGM	4.0	75	19.0	13.4	17.5	76.5	1.3	42.2	8.6	22.7	8000	0.00284
MN	4.0	75	0.0	16.0	20.1	79.8	1.7	46.2	6.9	15.8	5256	0.00301
VA	4.0	50	25.0	12.7	16.8	75.8	1.7	45.0	6.3	19.6	6228	0.00315
MN	4.0	50	0.0	17.0	21.1	80.4	1.6	46.2	7.4	19.1	5724	0.00334
NH	4.0	50	0.0	19.9	23.8	83.6	0.7	51.0	12.8	14.5	3595	0.00403
NH	4.0	75	0.0	19.2	22.9	84.0	0.7	51.0	12.1	17.2	4220	0.00408
FL	6.0	75	8.0	16.6	22.5	73.7	1.0	44.1	9.6	14.6	2425	0.00602
FL	4.0	75	8.0	18.5	22.6	81.8	0.9	44.1	10.8	15.4	2047	0.00752
TNGM	4.0	50	19.0	16.9	20.9	80.7	1.0	42.2	9.2	21.3	2795	0.00761
FL	4.0	50	8.0	20.1	24.2	82.8	0.8	44.1	11.8	19.5	1205	0.01614

Figure 4.23 is a plot of effective asphalt content by volume (Vbe) versus rutting rate and is separated by 4.0 and 6.0 percent air voids. It can be seen in Figure 4.23 that the 6.0 and 4.0 percent air void curves are much closer together than in Figure 4.22 which indicates that rutting for these laboratory mixtures is more dependent on the amount of asphalt not just the total VMA.

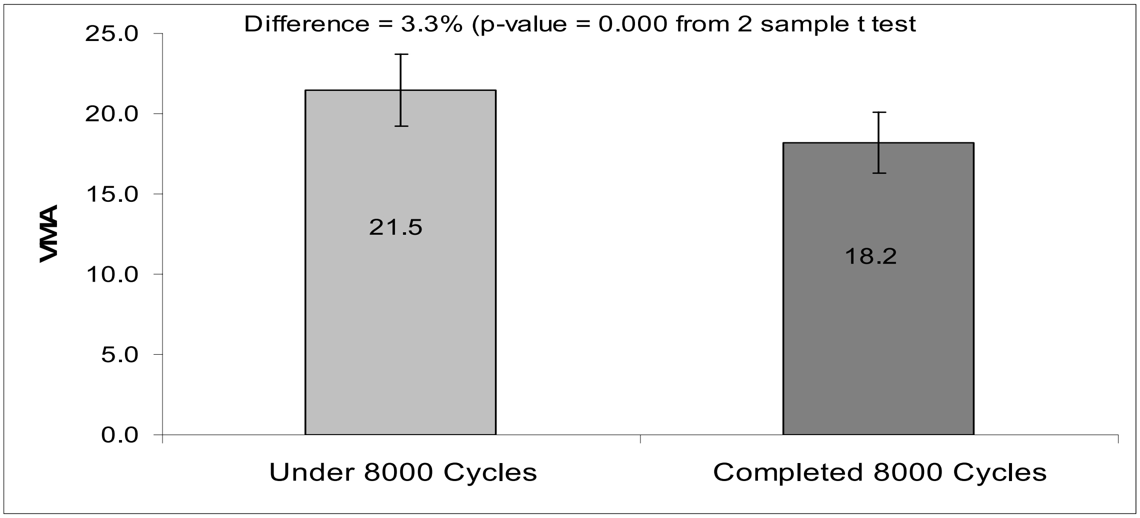


Figure 4.20 Mean Difference in VMA for Mixtures that Terminated early and Completed 8000 cycles on MVT

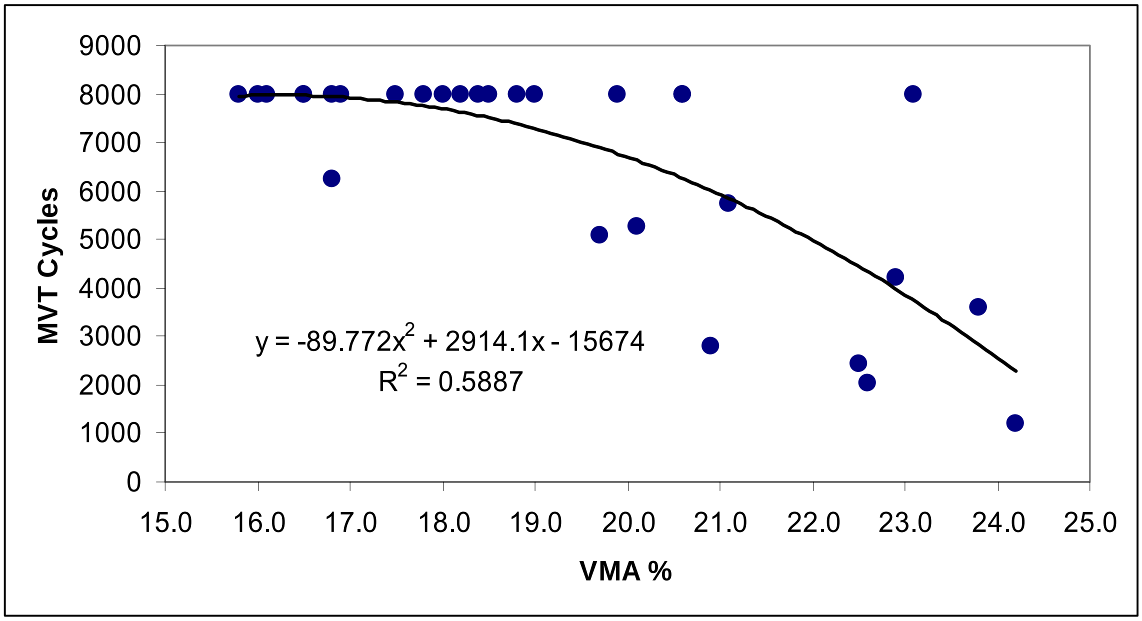


Figure 4.21 VMA versus Cycles to Termination

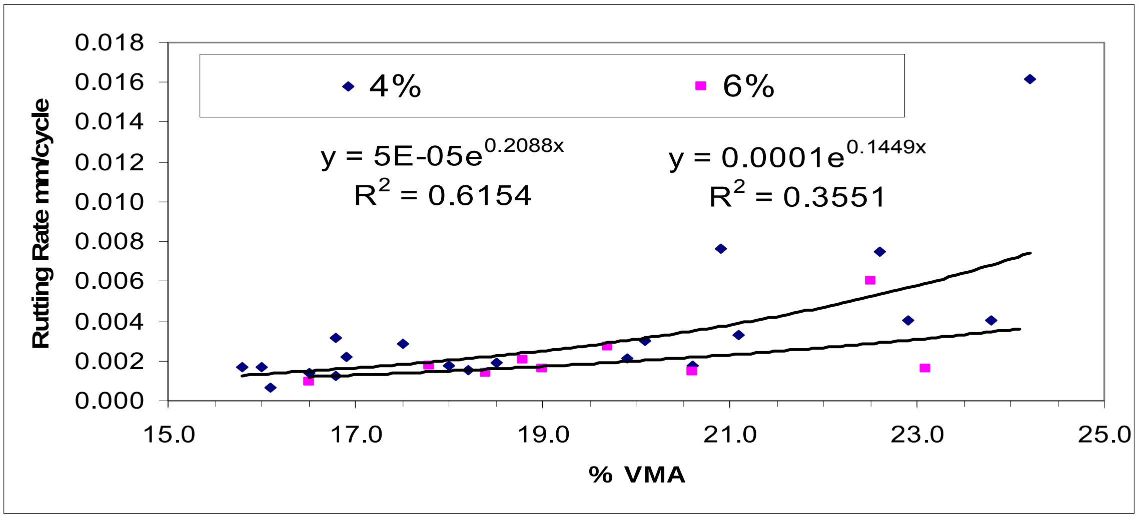


Figure 4.22 VMA versus Rutting Rate Asphalt Content by Design Air Voids

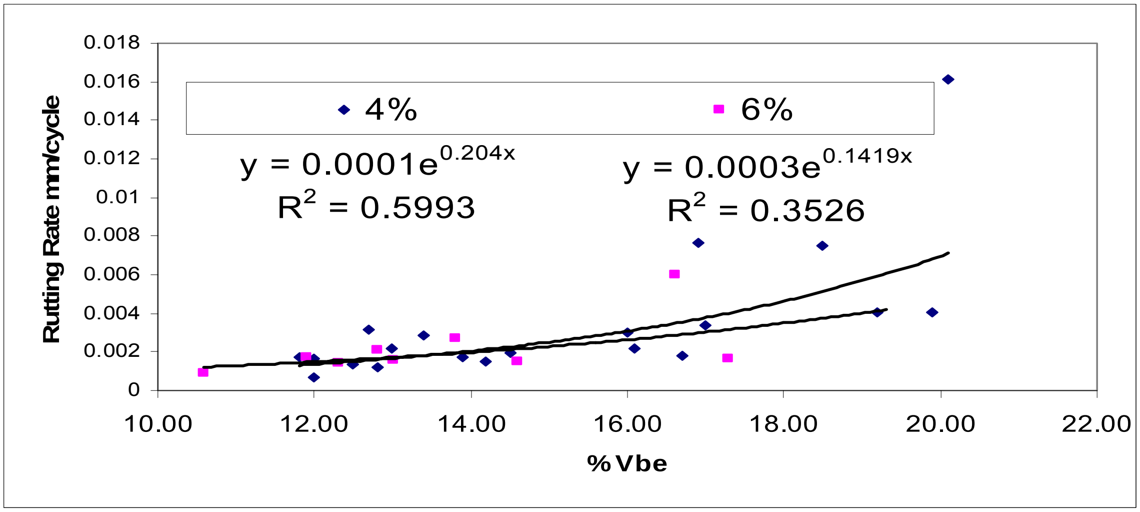


Figure 4.23 Volume of Effective Asphalt versus Rutting Rate by Design Air Voids

When volume of effective asphalt is plotted versus rutting rate for all mixtures, Figure 4.24, the relationship is reasonable with an $R^2 = 0.57$ considering the large range of materials and gradations used in this research. When the data is sorted in groups according to the amount of natural sand in each mixture, as seen in Figure 4.25, it is clear that as the percent natural sand is increased rutting rate also increases and the correlations improve. This is expected since rounded material is known to increase rutting susceptibility of asphalt mixtures. It appears that if the volume of effective asphalt is low the effect of natural sand is minimized. However, if Vbe is over 13 to 14 percent then natural sand can be detrimental to rutting performance. Based on the steep slope of the regression line for the over 15 percent natural sand mixtures, it may be beneficial to limit the amount of natural sand to less than 15 percent in mixtures designed for higher traffic volumes where rutting resistance is important.

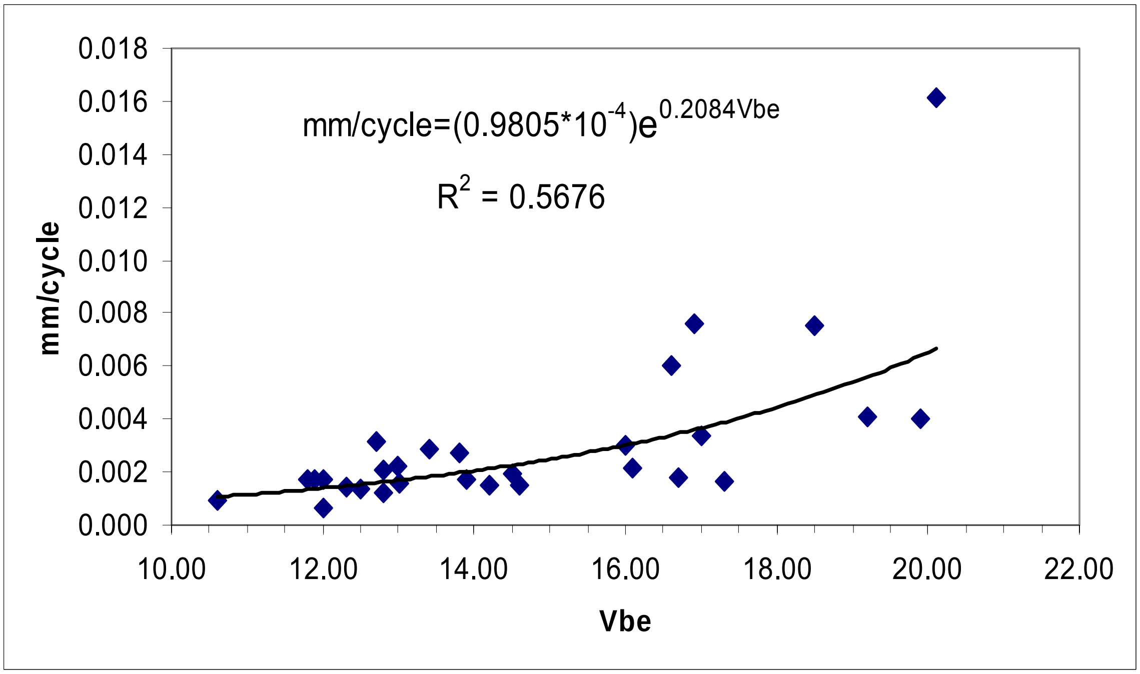


Figure 4.24 Vbe versus Rut Depths for all Mixtures

Recall from section 2.0 it was hypothesized that FAA may be an important indicator of a mixtures rutting resistance since the majority of the aggregate in 4.75 mm mixtures pass the 4.75 mm sieve. Figure 4.26 shows Vbe versus rutting rate for mixtures with FAA of over 45 and FAA under 45. It can be seen that for aggregate blends with an FAA of over 45, rutting rate increased with a linear relationship with increasing asphalt content. The curve is much steeper for aggregate blends with a FAA of less than 45.

Figures 4.25 and 4.26 indicate that natural sand and aggregate angularity can influence a mixtures rutting susceptibility especially at asphalt contents of over 14 percent by volume.

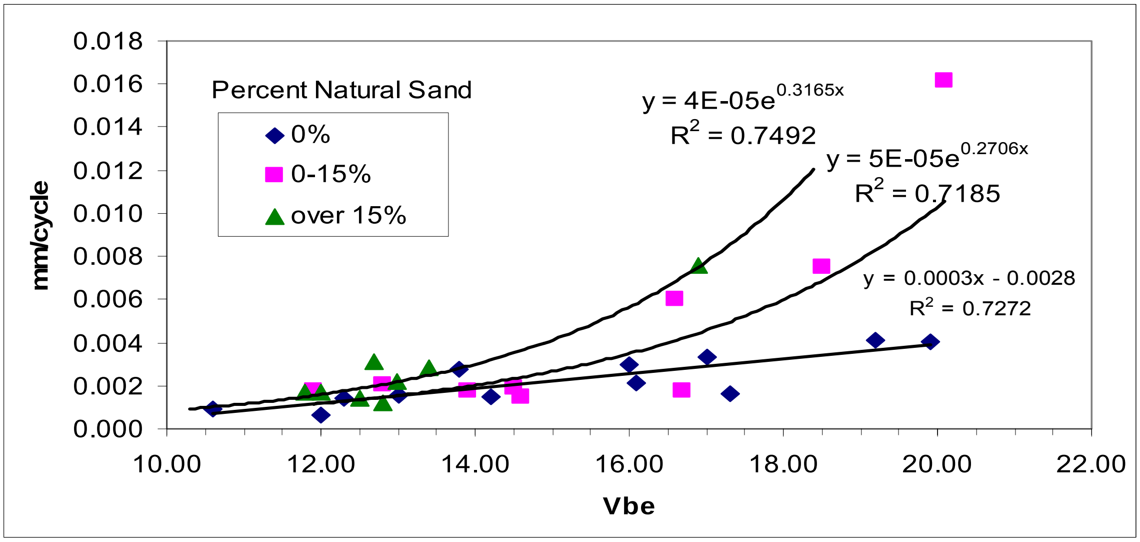


Figure 4.25 Vbe versus Rut Depths for all Mixtures Sorted by Percent Natural Sand

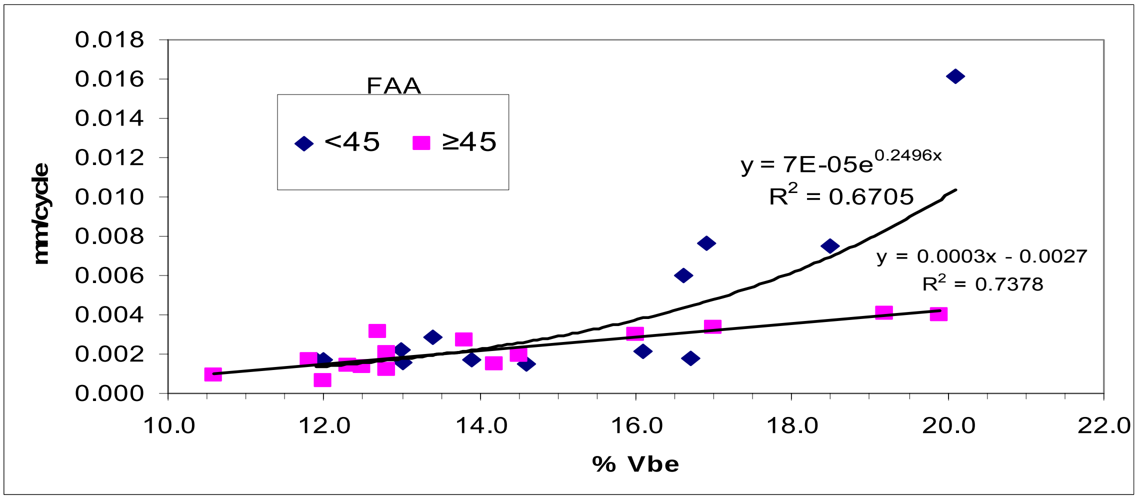


Figure 4.26 Vbe versus Rut Depth for All Mixtures Sorted by FAA

It has been shown for the mixtures prepared in this study that asphalt content, percent natural sand, and aggregate angularity all influence the rutting susceptibility of a 4.75 mm NMAS asphalt mixture. The question becomes what is an acceptable amount of rutting for 4.75 mm NMAS mixtures. Recall that Cooley et al (1) used a limiting APA rut depth of 9.5mm from NCHRP 9-17. Although, the APA was not used in testing specimens for this research a similar approach was used for this study. Using the relationship shown in Figure 2.2 where MVT rut depths were plotted against APA rut depths with cores from the NCAT test track, an equivalent MVT limiting rut depth is found to be 15.7 mm. However, the MVT was conducted at a hose pressure of 100 psi and wheel load of 100 lb. This presents another problem in comparing the MVT rut testing data to Cooley's APA limit since NCHRP 9-17 used 120 psi hose pressure and 120 lb wheel load. Using relationships established by Prowell and Moore (11) at NCAT shown in Figure 4.27, an equivalent critical rut depth for MVT was found to be 13.1 mm. Converting this critical rut depth to rutting rate and using the regression equation between Vbe and rutting rate (13.1 mm /8000 cycles = 0.00164 mm/cycle) shown in Figure 4.24, a maximum Vbe is determined to be 13.5 percent.

Based on 13.5 percent Vbe determined from a critical rutting rate of 0.00164 mm/cycle, the maximum VMA or VFA should be specified depending on the design air voids. For 4.0 percent design air voids the maximum VMA would be 17.5 percent and a maximum VFA would be 77 percent. If a mixture were to be designed at 6.0 percent air voids, the maximum VMA would be 19.5 percent and VFA would be 69 percent.

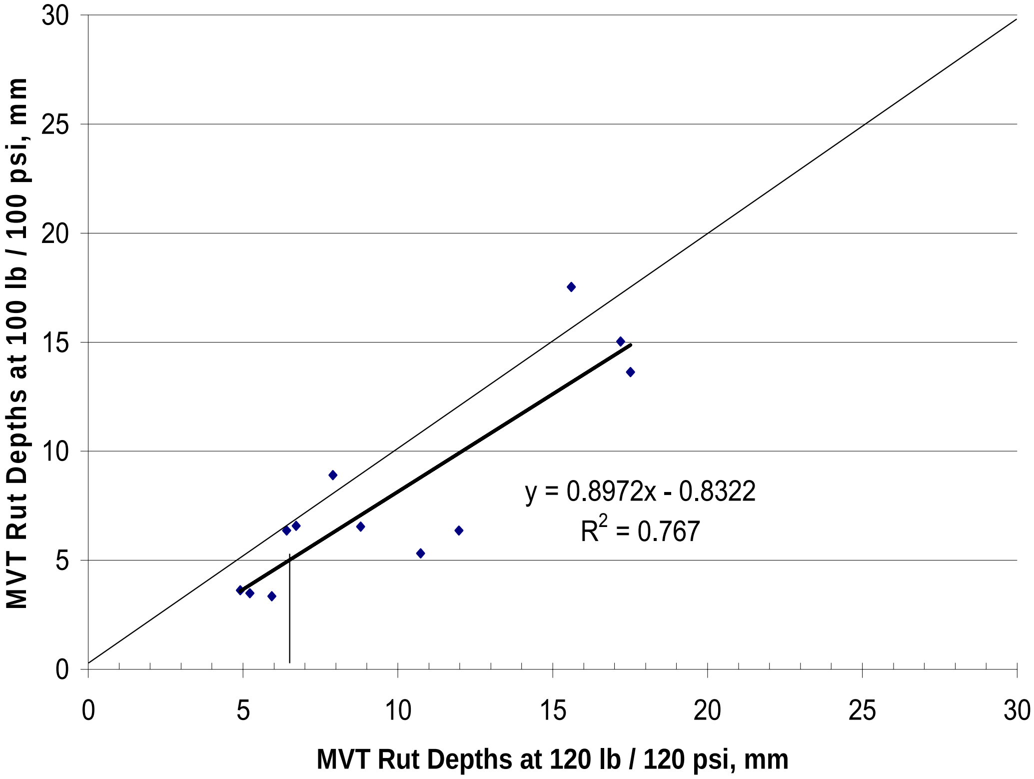


Figure 4.27 Relationship between MVT Rut Depths at 120 lb, 120 psi to MVT Rut Depths at 100 lb, 100 psi (11)

4.2.2 Tensile Strength Ratio

For all 29 mixtures designed in the study, Tensile Strength Ratios (TSR) were determined as per AASHTO T-283. During a panel meeting of participating states it was established that performance tests would be conducted at 9.0 percent air voids, since this is a likely in-place air void content after compaction for a 4.75 mm NMAS mixture. Thus, all samples were compacted to 9±0.5% air voids.

Figure 4.28 shows a plot of TSR for all 29 mixtures. The average TSR was 0.65 with a standard deviation of 0.19. The highest TSR was 0.99 for FLadj-75-6 and the lowest was 0.23 for VA-50-6. If 0.70 is used as a minimum TSR which is a common criteria for many specifying agencies, only 12 of the 29 mixtures meet this minimum criterion. No aintistripping additives were used in preparing the mix samples. It was noted during the saturation process of the conditioned samples that the vacuum pressure had to be reduced and the time to saturate generally needed to be increased compared to other asphalt mixtures with larger NMAS. It is believed that for 4.75 mm mixtures the void spaces are small and less interconnected. Low vacuum pressures and long saturation times may have caused some damage to specimens by expanding void spaces and pushing apart aggregate. On the other hand the low permeability results and difficulty in obtaining saturation of specimens lends some evidence that 4.75 mm mixtures may be resistant to moisture damage even at air void contents of 9.0 percent.

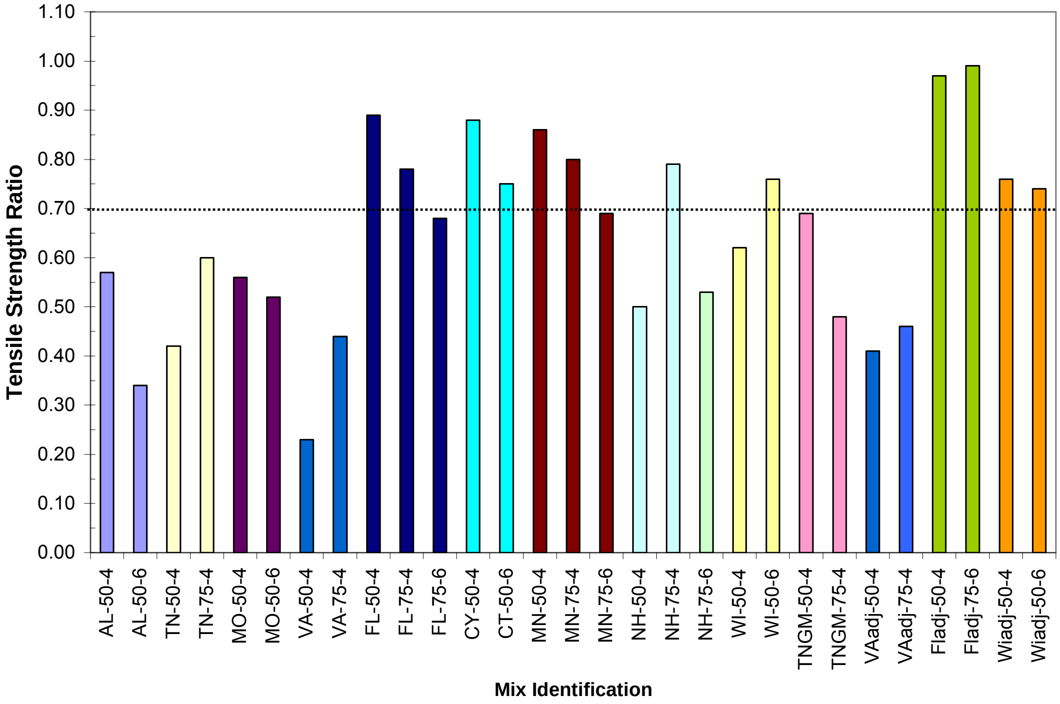


Figure 4.28 Tensile Strength Ratios for 29 Mix Designs

Decreasing the asphalt content caused a slight increase in moisture damage susceptibility as indicated by lower tensile strength ratios. In Figure 4.29 dry and wet tensile strengths are plotted for each blend, it can be seen that wet strengths tend to increase with increasing dry strength but not proportionally. This tends to indicate that wet strength may be more a function of the asphalt –aggregate bond strength than the amount of asphalt in the mixture. Asphalt-aggregate bond strength adhesion is obviously important to moisture susceptibility. This was not addressed in the experimental research plan for this study, so it is difficult to ascertain how the aggregate mineralogy affects the stripping potential of these mixtures.

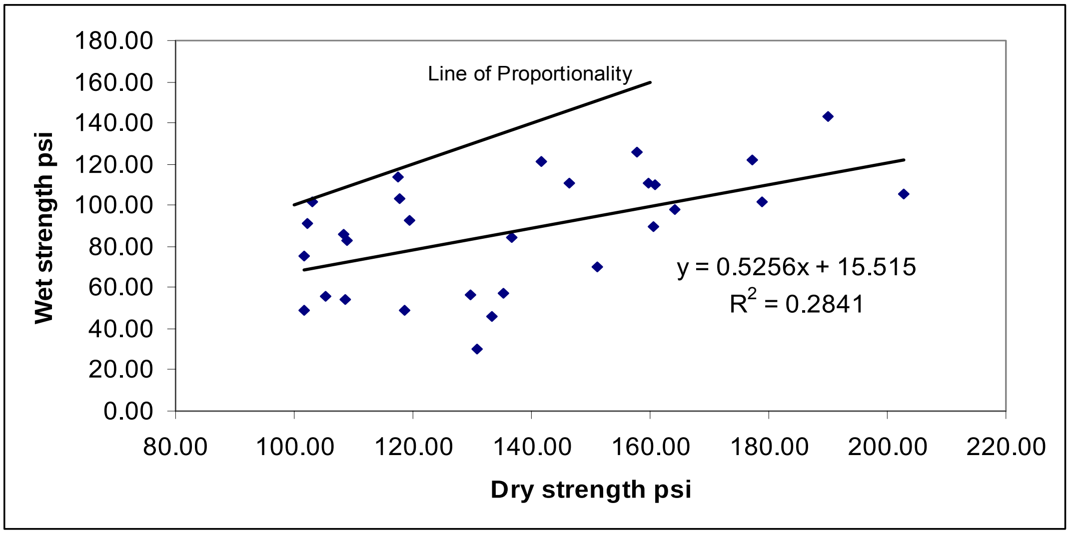


Figure 4.29 Wet versus Dry Strength

There is a weak relationship (R^2=0.21, p-value=0.013) between VMA and TSR as shown in Figure 4.30 and a weak relationship (R^2=0.17, p-value=0.025) between volume of effective asphalt shown in Figure 4.31.Although these relationships are confounded by other variables the general trend of increasing TSR with increasing VMA and effective asphalt content was expected due to thicker asphalt films at higher asphalt contents.

Natural sand content is one of the factors that may affect TSR for these mixtures as shown in Figure 4.32. Figure 4.32 is plotted with only the mixtures designed at 50 gyrations and 4.0 percent air voids to illustrate the influence natural sand has on sand asphalt mixtures.

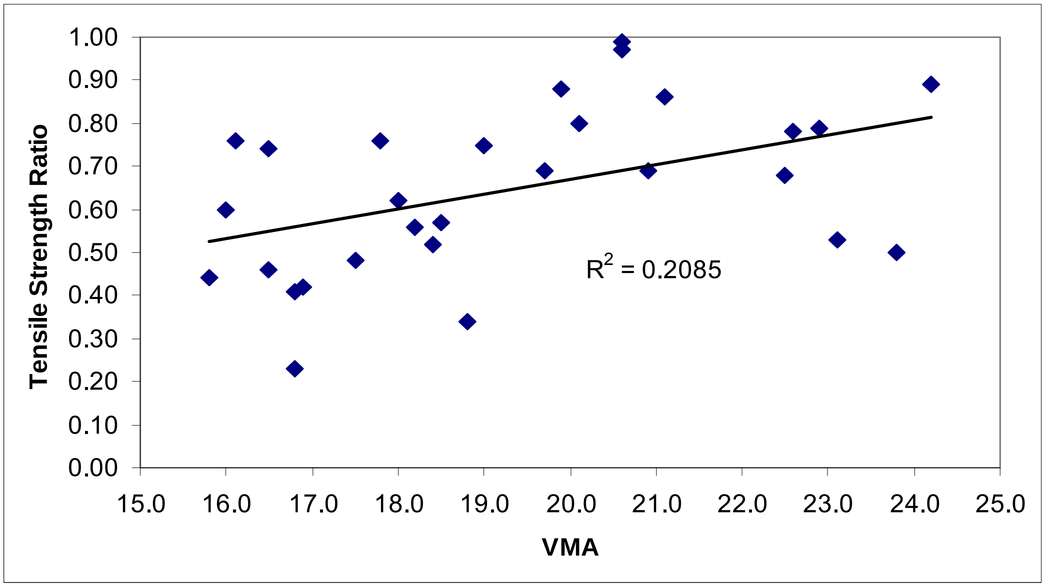


Figure 4.30 VMA versus Tensile Strength Ratio

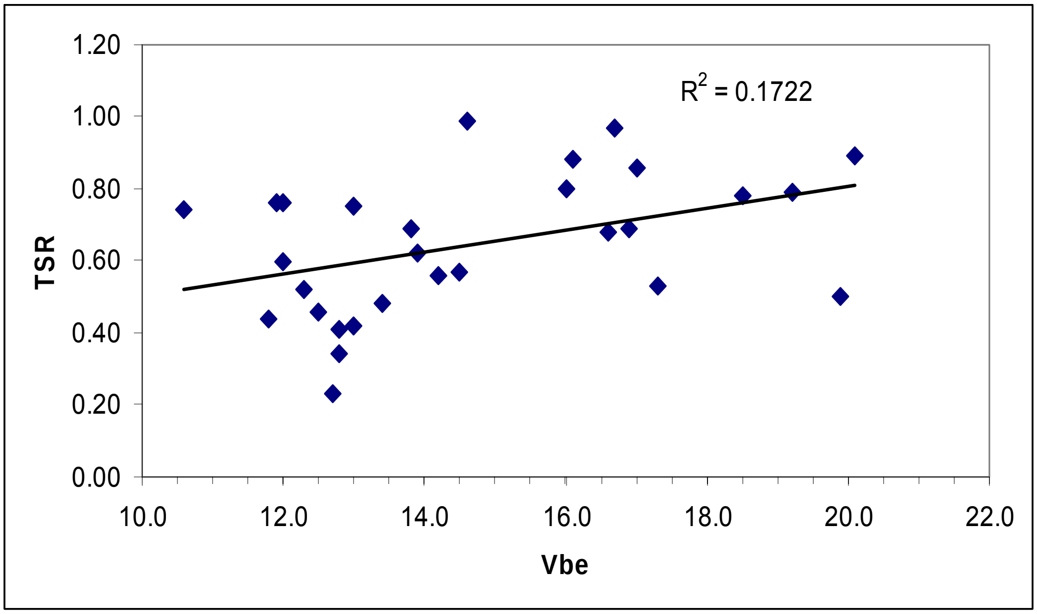


Figure 4.31 Effective Asphalt Content by Volume versus Tensile Strength Ratio

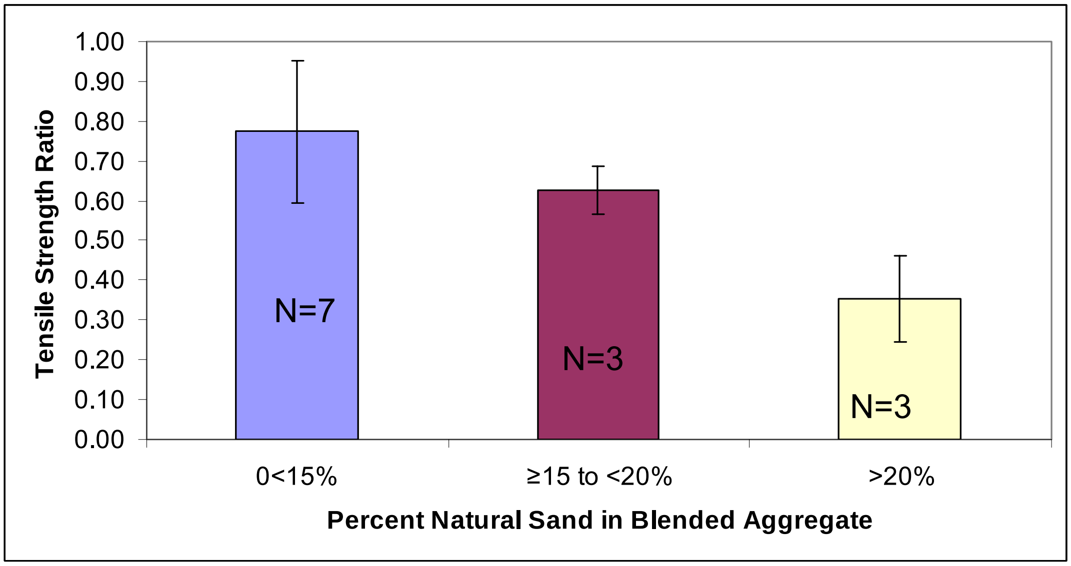


Figure 4.32 Relationship with Percent Natural Sand in Blended Aggregate and TSR for 50 Gyration 4.0% Air Void Mix Designs

It was thought that film thickness may be a good indicator of TSR; however for the blends in this study the relationship was weak (R^2=0.09, p-value=0.12). Dry strength seems to have a reasonable relationship (R^2=0.24, p-value=0.008) with film thickness, shown in Figure 4.33. No reasonable regression models could be determined for wet tensile strength of the asphalt mixtures in this study.

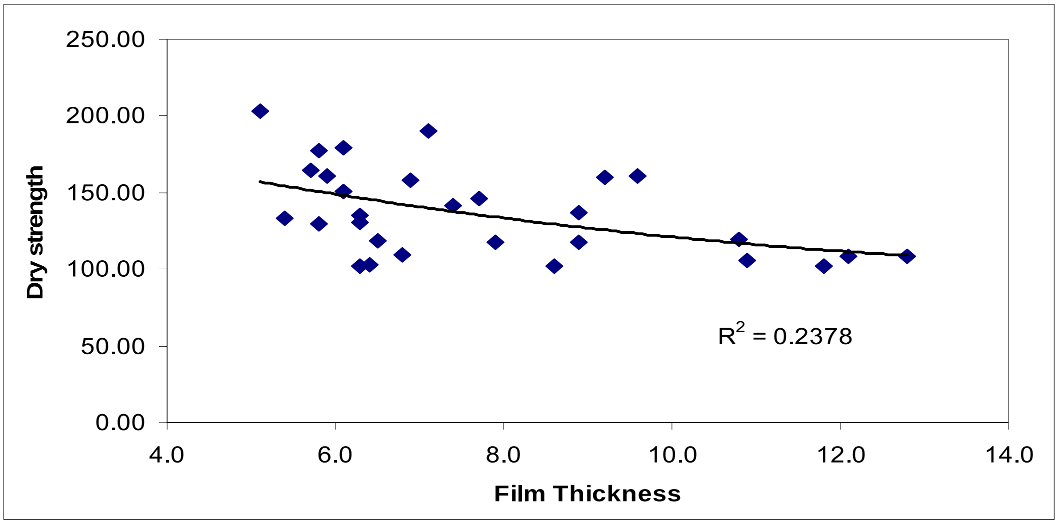


Figure 4.33 Dry Strength versus Film Thickness

4.2.3 Fracture Energy Density Ratio

All 29 laboratory designed mixtures and three baseline mixtures were tested for fracture energy density. For each mixture two sets of specimens were prepared, the first set of specimens were tested with no aging. The second set was oven aged at 85ºC for six days then tested. A ratio of the aged fracture energy density to the un-aged fracture energy density was then calculated. A hypothesis of this study was mixes with lower fracture energy ratios would be more prone to aging and cracking over time. Although the aged fracture energy values may not be below a threshold value where cracking will occur, a low ratio might identify a mixture that in certain field conditions could be more susceptible to cracking over time compared to mixtures with a higher ratio.

Table 4.16 shows fracture energy ratios with aged and un-aged values for the twenty nine laboratory designed mixtures. The average ratio is 96.2 percent with an average aged fracture energy density of 5.399 kJ/m^3 and an un-aged average of 5.574 kJ/m^3. The high average for fracture energy ratio indicates that small aggregate mixtures with high VMA and asphalt contents may be highly resistant to cracking over time. Fracture energy ratios were plotted in Figure 4.34 sorted by state. Generally fracture energy ratio tends to decrease with decreasing asphalt contents which results from an increase in design air voids and/or decrease in number of gyrations. For each source of material the 50 gyration and 4.0 percent air void mixture (50-4) had the highest asphalt content. However, there are several exceptions to decreasing ratio that stand out (TN, MO, and VA), where the ratio increases with decreasing asphalt content. Figure 4.35 shows a weak relationship (R^2=0.29 p-value= 0.002) between effective asphalt content and fracture energy ratio, but there is a general trend of decreasing ratio with decreasing effective asphalt content and the p-value of 0.002 indicates the trend is significant at α=0.05. This trend was expected since higher asphalt contents generally provide good cracking resistance.

MINITAB was employed to determine Pearson correlation coefficients with fracture energy ratio to aggregate and mixture volumetric properties. The significant relationships are shown in Table 4.17. Table 4.17 shows that there are also significant relationships between fracture energy ratio and VMA, VFA, film thickness and dust content, illustrated in Figures 4.37, 4.38 and 4.39. These relationships indicate that long term cracking resistance for 4.75 mm mixtures are affected to some degree by volumetric or mass proportions. Film thickness is known to influence cracking resistance of asphalt mixtures. There are two properties that effect film thickness, one being Vbe and the other being dust content, so it was expected that both dust and effective asphalt content would affect fracture energy ratio.

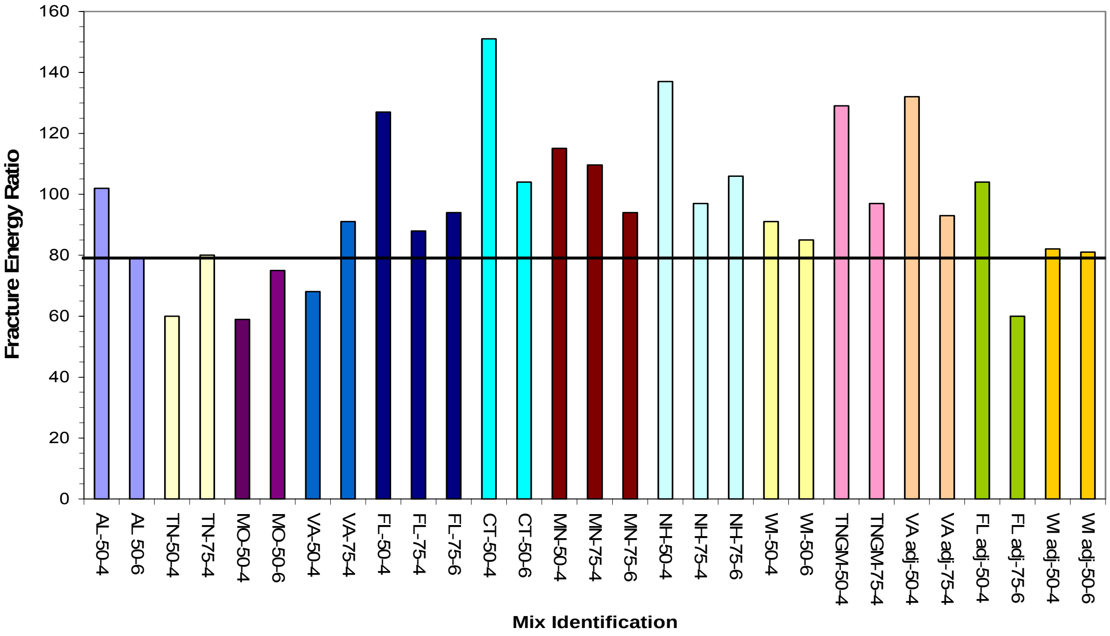


Figure 4.34 Fracture Energy Ratios for Laboratory Mixtures

Table 4.16 Fracture Energy Data for Laboratory Mixtures

State(mix)	*Pbe*	*VMA*	*VFA*	*DP*	*film thickness (microns)*	*F-E_{ratio} %*	*Fe ini*	*Fe cure*	*p-value**	*Significant*
AL-50-4	6.30	18.5	78.4	1.8	6.1	102	3.57	3.65	0.93	no
AL 50-6	5.60	18.8	68.1	2.0	5.4	79	6.10	4.84	0.32	no
TN-50-4	5.80	16.9	76.8	2.0	6.3	60	3.70	2.20	0.07	no
TN-75-4	5.30	16.0	74.8	2.2	5.7	80	2.86	2.29	0.19	no
MO-50-4	6.10	18.2	78.2	1.7	5.9	59	5.84	3.45	0.03	yes
MO-50-6	5.30	18.4	66.7	2.0	5.1	75	4.76	3.51	0.02	yes
VA-50-4	5.90	16.8	75.8	1.7	6.3	68	4.54	3.07	0.16	no
VA-75-4	5.40	15.8	74.9	1.9	5.8	91	6.37	5.79	0.51	no
FL-50-4	9.70	24.2	82.8	0.8	11.8	127	4.50	5.72	0.24	no
FL-75-4	8.90	22.6	81.8	0.9	10.8	88	5.07	4.47	0.32	no
FL-75-6	8.00	22.5	73.7	1.0	9.6	94	5.67	5.35	0.61	no
CT-50-4	6.80	19.9	80.9	1.2	8.9	151	5.60	8.48	0.02	yes
CT-50-6	5.50	19.0	68.5	1.4	7.1	104	6.90	7.15	0.89	no
MN-50-4	7.20	21.1	80.4	1.6	7.4	115	7.80	8.94	0.26	no
MN-75-4	6.80	20.1	79.8	1.7	6.9	110	7.38	8.08	0.26	no
MN-75-6	5.80	19.7	70.1	1.9	5.8	94	6.48	6.07	0.62	no
NH-50-4	9.10	23.8	83.6	0.7	12.8	137	5.45	7.45	0.02	yes
NH-75-4	8.70	22.9	84.0	0.7	12.1	97	5.90	5.72	0.84	no
NH-75-6	7.90	23.1	75.0	0.8	10.9	106	7.06	7.48	0.50	no
WI-50-4	6.00	18.0	77.4	1.2	8.9	91	5.51	5.04	0.69	no
WI-50-6	5.20	17.8	66.9	1.4	7.7	85	6.05	5.17	0.16	no
TNGM-50-4	6.8	20.9	80.7	1.0	9.2	129	5.46	6.62	0.029	yes
TNGM-75-4	6.4	17.5	76.5	1.3	8.6	97	5.06	4.88	0.882	no
VA adj-50-4	6.0	16.8	76.4	1.7	6.5	132	5.75	7.57	0.056	no
VA adj-75-4	5.7	16.5	75.6	1.7	6.1	93	5.68	5.31	0.065	no
FL adj-50-4	7.9	20.6	81.1	1.7	7.9	104	5.10	5.27	0.749	no
FL adj-75-6	7.0	20.6	71.0	1.9	6.4	60	5.89	3.54	0.037	yes
WI adj-50-4	5.1	16.1	74.4	1.9	6.8	82	6.80	5.57	0.164	no
WI adj-50-6	4.6	16.5	64.4	2.1	6.3	81	4.78	3.85	0.158	no
					Average	96.2	5.574	5.399		
					Stdev	23.4	1.1	1.8		
					COV	24%	20%	33%		

* p-values determined from two sample t-test
mean (Fe ini –Fe cure) $\neq 0$, $\alpha = 0.05$, $n = 8$

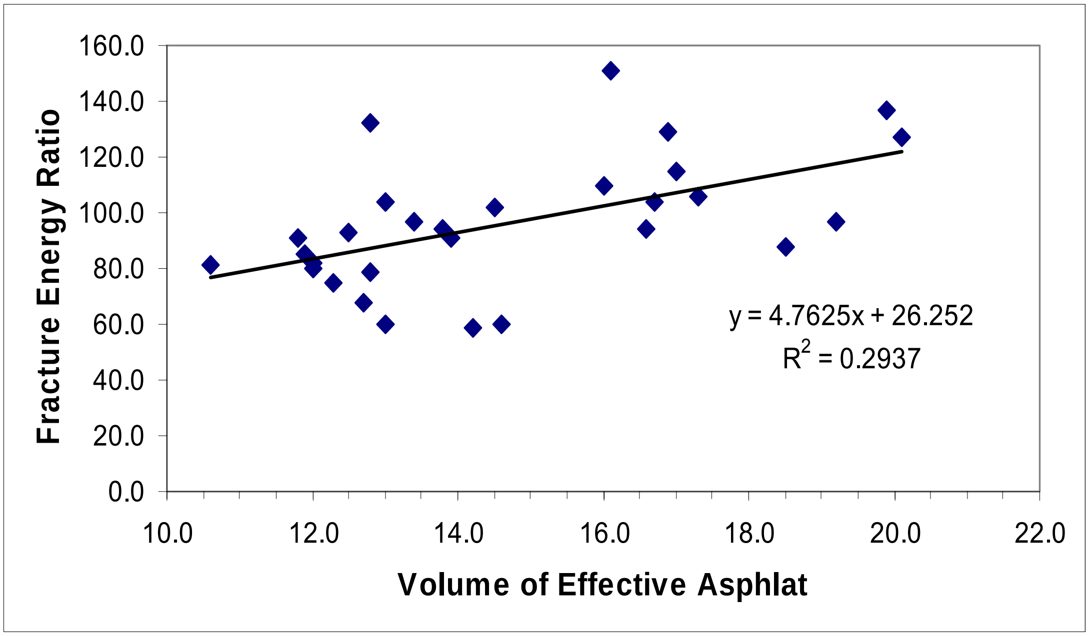


Figure 4.35 Fracture Energy Ratios versus Vbe

Table 4.17 Pearson Correlation Coefficients and p-values for Linear Relationships with Fracture Energy Ratio

	Film Thickness	Dp	VFA	VMA	P-200
R	0.532	-0.552	0.506	0.453	-0.418
p-value	0.003	0.002	0.005	0.013	0.024

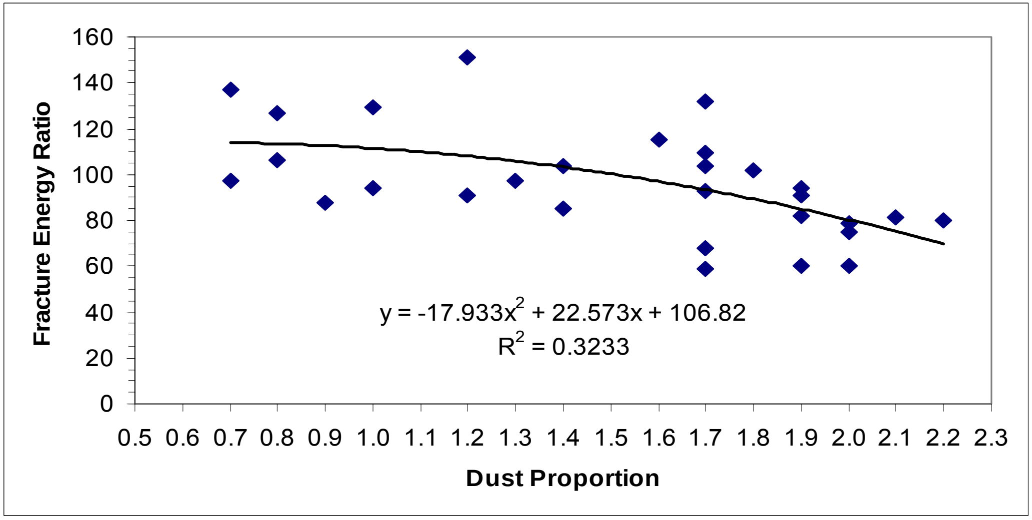


Figure 4.36 Fracture Energy Ratio versus Dust Proportion

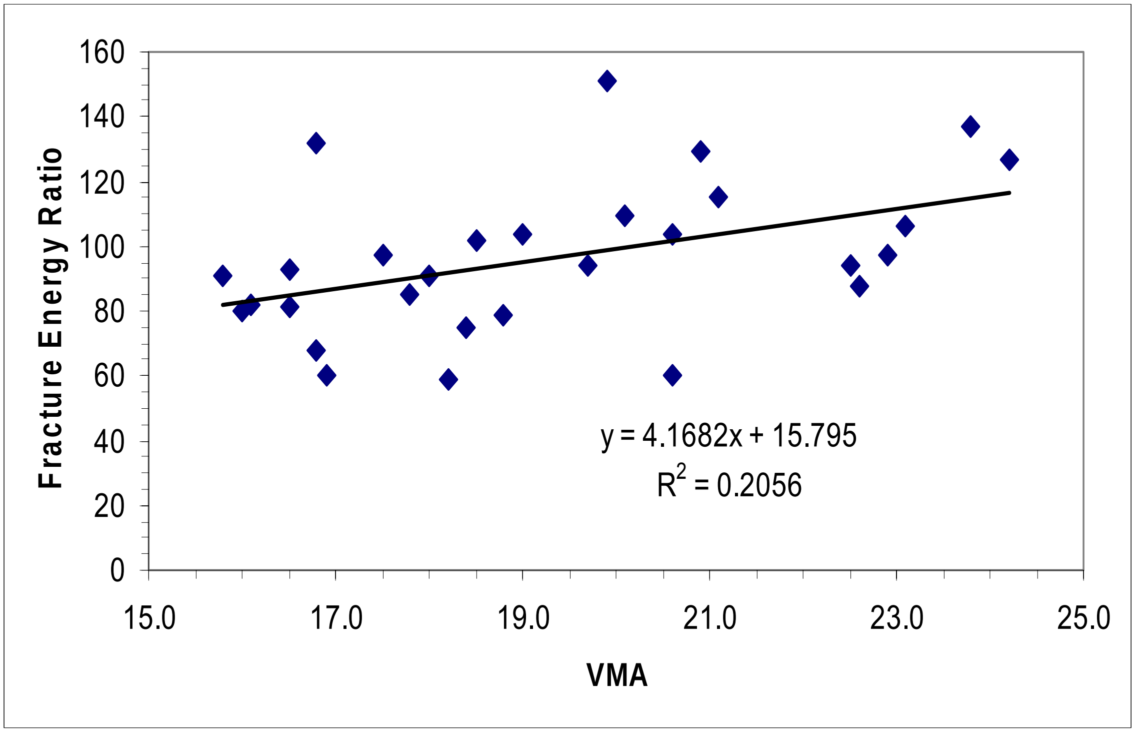


Figure 4.37 Fracture Energy Ratio versus VMA

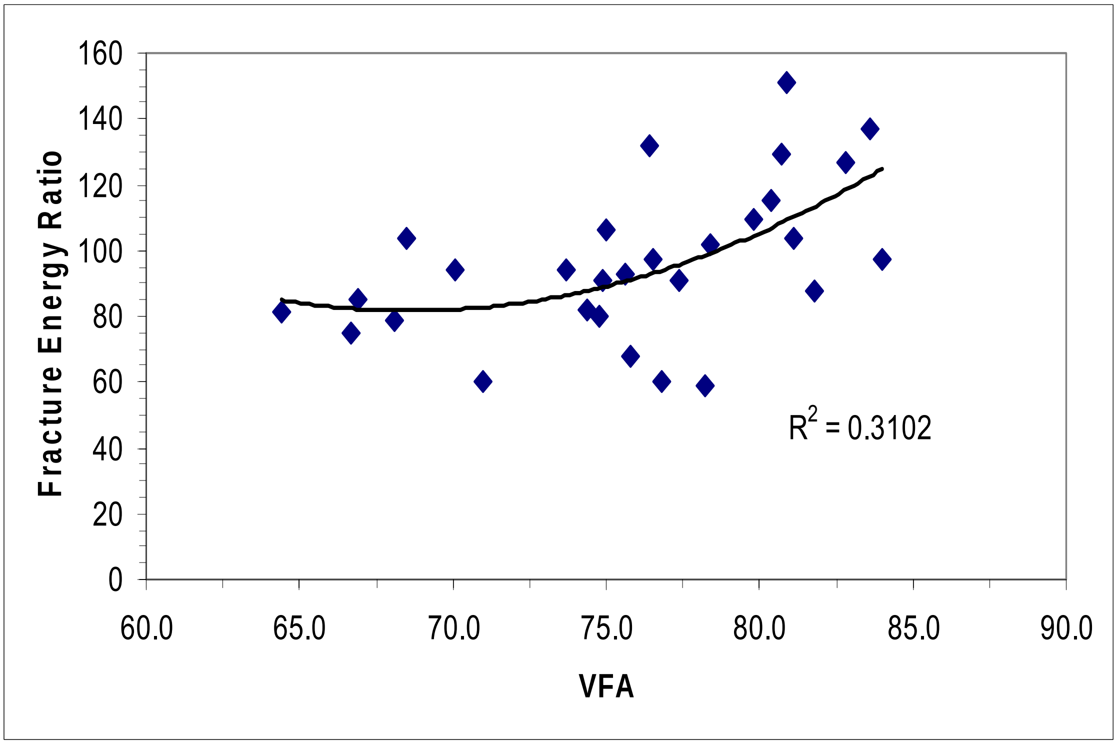


Figure 4.38 Fracture Energy Ratio versus VFA

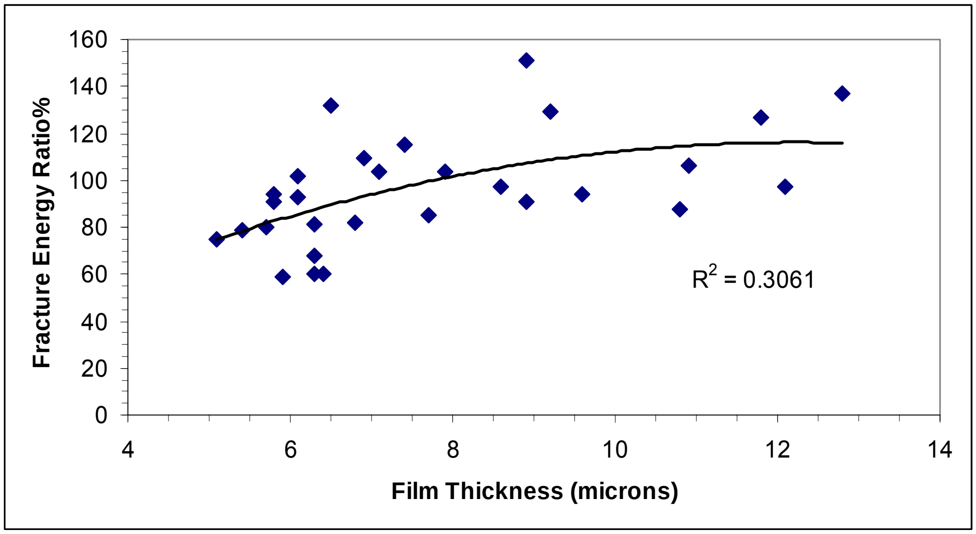


Figure 4.39 Fracture Energy Ratio versus Film Thickness

Establishing a fracture energy density threshold is needed to discern if cracking could be a concern for these mixtures. Recall, Figure 2.8 where Kim et al. (13) plotted fracture energy density for specimens from WesTrack. The regression indicates that fatigue cracking begins to occur at 3.0 kJ/m^3. If this number is taken as a threshold where, below cracking is expected to take place in the pavement, then most of the mixtures presented in Table 4.16 would have performed satisfactorily. However, this conclusion would not be valid due to the fact that the aging between the field conditions at WesTrack and the long term oven aging used in the research presented here are not the same.

Fracture energy ratio is used here to describe a mixtures ability to retain cracking resistance over time. However, it is unclear what an appropriate value of this ratio should be. For this reason the fracture energy ratios of the baseline mixtures presented in Table 4.18 were used as a bench mark to establish a reasonable limit for fracture energy ratios. Due to a lack of material, fracture energy density testing could not be performed for the baseline mixture from Mississippi. The mixtures from Georgia, Maryland, and Michigan are reported to be in service with good performance history. The mean FE ratio for the baseline mixtures is 76 percent and the median is 80 percent. To serve as a benchmark for durability performance, the baseline median was chosen as a conservative estimate of a minimum value to compare with the laboratory prepared mixes. Figure 4.34 shows that only 6 mixtures failed to meet the 80 percent minimum. From the regressions shown in Figures 4.35 a fracture energy ratio of 80 percent corresponds to a Vbe of 11.5 and from Figure 4.36 the 80 percent fracture energy ratio corresponds to a maximum dust to asphalt ratio of 2.0. Recommending only a minimum Vbe may not be sufficient with regard to assuring resistance to cracking, it can be seen in Figures 4.36 and 4.39 that dust to asphalt ratio and film thickness give slightly more significant relationships than Figure 4.35. Since film thickness and dust to asphalt ratio are both related to Vbe and dust content, it is clear that the ability to maintain cracking resistance for the 4.75 mm NMAS asphalt mixtures prepared for this study is dependent on asphalt and dust contents. The current specified dust to asphalt ratio of 2.0 appears to be a reasonable based on Figure 4.36.

Table 4.18 Fracture Energy Density Data for Baseline Mixtures

State(mix)	*Air voids (design)*	*Ndesign*	*%A.C.*	*Binder*	*VMA*	*VFA*	*$Dust_{ratio}$*	*film thickness (microns)*	*$F\text{-}E_{ratio}$ %*	*un-aged KJ/M^3*	*aged KJ/M^3*
Mississippi	4.0	50	5.9	76-22	17.7	66.6	2.0	5.4	N/A	N/A	N/A
Maryland	3.5	75	6.5	64-22	16.3	80.9	1.6	7.3	80	5.582	4.442
Georgia	6.0	50	6.0	64-22	16.7	76.4	1.5	6.7	81	4.887	3.949
Michigan	4.0	60	7.5	52-28	17.0	69.4	1.4	7.1	68	7.242	4.937
								Mean =	76	5.904	4.443
								Stdev=	7.1	1.210	0.494
								Median=	80	5.582	4.442

4.2.4 Permeability

Laboratory permeability, test method ASTM PS 121, was performed on 27 of the 29 mix designs. Mixtures TNGM-50-4 and VAadj-50-4 were not tested for permeability due to insufficient material. Permeability test results are shown in Table 4.19 and in Figure 4.40. Mixtures with permeability less than 125 E^{-5} cm/sec are generally considered impermeable. As seen in Figure 4.40 twenty one out of the twenty seven mixtures are below this threshold. The maximum was 210.75 E^{-5}cm/sec for WI-50-4 and the minimum was 7.55 cm/sec E^{-5}. It was thought that there would be a trend of increasing permeability with decreasing asphalt content; however as seen in Figure 4.41, this was not the case. Again, confounding effects due to the large range of material and gradations may explain why this relationship was not observed.

The results for this research provided no clear relationships between mixture permeability and volumetric properties or gradation. There may be several reasons for this. First, according to the test procedure used (ASTM PS 121); a vacuum pressure of 525 mm Hg is applied to the specimen for five minutes to achieve saturation. However, for these mixtures due to low permeability, specimens were saturated at a lower pressure (50-100 mm Hg) to increase vacuum for ten minutes until saturation a of 85 to 95 percent was accomplished. This high level of saturation was used, because it was observed that consistent readings on the permeameter were only achieved at about 90 percent saturation. It is possible that during the saturation process, the test specimens were damaged which increased permeability due to expansion of internal voids.

Table 4.19 Permeability and Mixture Data for Laboratory Mixtures

State(mix)	P-200	Pb	VMA	VFA	DP	SE	FAA	film thickness (microns)	k (cm/s)E^{-5}
AL-50-4	11.1	7.4	18.5	78.4	1.8	67	46.3	6.1	49.32
AL 50-6	11.1	6.9	18.8	68.1	2.0	67	46.3	5.4	50.19
TN-50-4	11.6	7.3	16.9	76.8	2.0	69	44.8	6.3	67.36
TN-75-4	11.6	6.8	16.0	74.8	2.2	69	44.8	5.7	75.25
MO-50-4	10.6	6.9	18.2	78.2	1.7	74	49.0	5.9	21.47
MO-50-6	10.6	6.2	18.4	66.7	2.0	74	49.0	5.1	38.14
VA-50-4	10.1	8.8	16.8	75.8	1.7	76	45.0	6.3	44.80
VA-75-4	10.1	8.3	15.8	74.9	1.9	76	45.0	5.8	30.37
FL-50-4	7.7	11.8	24.2	82.8	0.8	88	44.1	11.8	154.20
FL-75-4	7.7	11.0	22.6	81.8	0.9	88	44.1	10.8	126.47
FL-75-6	7.7	10.1	22.5	73.7	1.0	88	44.1	9.6	79.34
CT-50-4	7.9	8.8	19.9	80.9	1.2	79	46.1	8.9	91.35
CT-50-6	7.9	7.2	19.0	68.5	1.4	79	46.1	7.1	111.40
MN-50-4	11.2	8.8	21.1	80.4	1.6	67	46.2	7.4	8.39
MN-75-4	11.2	8.3	20.1	79.8	1.7	67	46.2	6.9	17.32
MN-75-6	11.2	7.4	19.7	70.1	1.9	67	46.2	5.8	7.55
NH-50-4	6.0	9.7	23.8	83.6	0.7	85	51.0	12.8	34.23
NH-75-4	6.0	9.3	22.9	84.0	0.7	85	51.0	12.1	52.38
NH-75-6	6.0	8.6	23.1	75.0	0.8	85	51.0	10.9	14.92
WI-50-4	7.1	7.5	18.0	77.4	1.2	81	43.7	8.9	210.75
WI-50-6	7.1	6.7	17.8	66.9	1.4	81	43.7	7.7	178.78
TNGM-75-4	8.2	9.3	17.5	76.5	1.3	70	42.2	8.6	162.4
VA adj-75-4	10.1	8.7	16.5	75.6	1.7	76	45.0	6.1	33.87
FL adj-50-4	13.4	10.0	20.6	81.1	1.7	79	44.5	7.9	177.21
FL adj-75-6	13.4	9.1	20.6	71.0	1.9	79	44.5	6.4	123.82
WI adj-50-4	9.5	6.8	16.1	74.4	1.9	81	45.8	6.8	30.95
WI adj-50-6	9.5	6.3	16.5	64.4	2.1	81	45.8	6.3	78.13
								Average=	76.68
								Stdev=	58.94
								COV=	77%

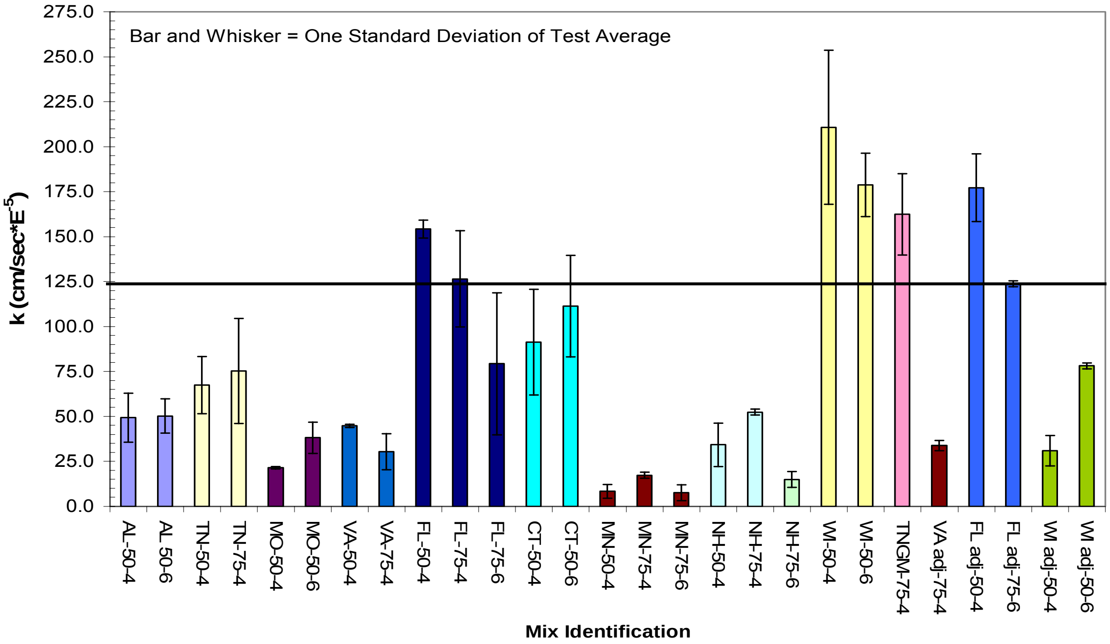


Figure 4.40 Permeability for Laboratory Mixtures

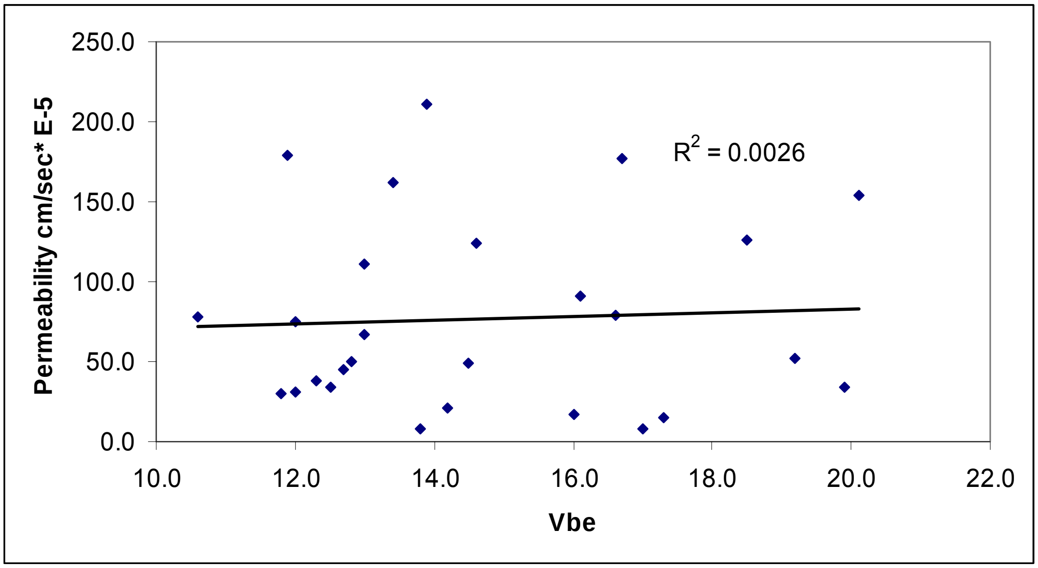


Figure 4.41 Permeability versus Volume of Effective Asphalt

A second concern is the precision of the test procedure. ASTM PS 121 provides no precision statement, so it is difficult to say if differences in permeability between mixtures using the same aggregate and gradation at different asphalt contents are appreciably different.

One aggregate property that may influence mixtures permeability is FAA. Figure 4.42 shows decreasing permeability with increasing FAA. Although, it would be logical to assume that aggregate blends with higher FAA would be more permeable. Figure 4.42 shows FAA versus permeability sorted by the percent natural sand in the aggregate blend. It can be seen that aggregate blends with FAA values under 45 contain natural sand. Crushed sand will generally have more flat and elongated particles compared to natural sand. During compaction the crushed particles may align perpendicularly to the applied load closing off flow paths. There may be a difference in the way aggregate particles align during compaction when a rounded material is present in the aggregate blend which creates a more dispersed structure allowing more flow paths through the compacted specimen.

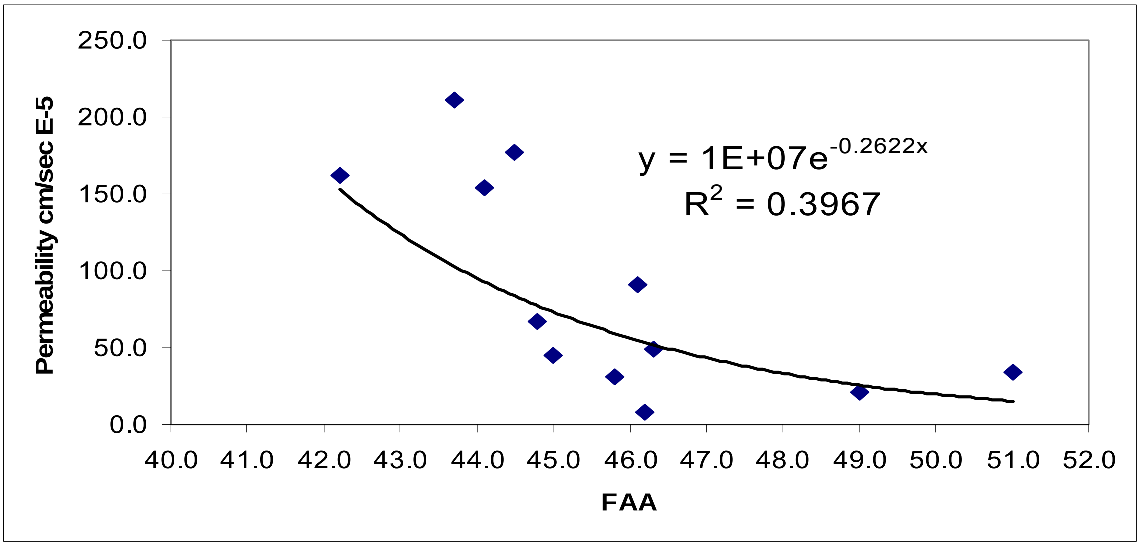


Figure 4.42 FAA versus Permeability Sorted by Percent Natural Sand

It is clear that most of the mixtures prepared for this research are impermeable even at high air voids. It was mentioned in section 2.3.3 that mixtures over 8.0 percent air voids are generally considered permeable. 4.75 mm NMAS mixtures are shown to be impermeable even at 9.0 percent air voids, because smaller aggregate size mixtures tend to have small air voids that are not as interconnected compared to larger NMAS asphalt mixture.

4.3 Baseline Mixtures

Four plant produced mixtures were used as a baseline to compare 4.75 mm NMAS mixtures that are currently being produced and have good performance history. Plant produced mixtures from Mississippi, Maryland, Georgia, and Michigan were introduced as baseline mixtures. The mixture properties and averages are given in Table 4.20. The mixture from Georgia is not a 4.75 mm NMAS blend based on the percent passing the 4.75 mm sieve, however it provides a good comparison to similar small aggregate size asphalt mixtures.

Generally, compared to the laboratory mixtures, baseline mixes are coarser-graded, have lower optimum asphalt contents, contain lower VMAs, produce lower rut depths, have higher TSR values, and produce lower average fracture energy ratios. Figure 4.43 shows gradations for the baseline mixtures highlighted over the 13 aggregate blends used for the laboratory mix designs, it can be seen that the baseline mixtures are generally coarser graded thus closer to the maximum density line. So, even with a lower percent passing the 0.075 mm sieve the baseline mixtures have lower VMA due to coarser gradations.

The baseline mixture from Mississippi had the lowest MVT rut depth for all mixtures in the study. This was expected since this mix contained a polymer modified PG 76-22 binder. The average MVT rut depth for the baseline mixtures was 9.4 mm. This average is below the 13.1mm rut depth that is assumed in this thesis as a critical rut depth for 4.75 mm NMAS mixtures. The baseline mixture from Michigan had a 15.7 mm in the MVT tester. This is probably due to the use of a PG 58-22 binder. Although the mix contained with the softer asphalt grade, the MVT test was conducted at 64ºC, as were all mixtures in this study.

Table 4.20 Mixture Properties and Performance Data for Baseline Mixtures.

State(mix)	*Air voids (design)*	*Va actual*	*Ndesign*	*Passing 0.075 mm*	*Passing 1.18mm*	*Passing 4.75mm*	*%Nat. sand*
Mississippi	4.0	5.9	50	10.7	50.0	98.0	10.9
Maryland	3.5	3.1	75	8.1	42.8	95.6	15.0
Georgia	6.0	3.9	50	8.5	43.1	79.5	0.0
Michigan	4.0	5.2	60	7.1	54.6	92.5	0.0
Average=	4.4	4.5	58.8	8.6	47.6	91.4	6.5
Stdev=	1.11	1.26	11.81	1.52	5.72	8.25	7.66

State(mix)	*%A.C.*	*Eff AC%*	*Binder*	*VMA*	*VFA*	*% Gmm @ Nini*	*Dust$_{ratio}$*
Mississippi	5.9	5.3	76-22	17.7	66.6	86	2.0
Maryland	6.5	5.7	64-22	16.3	80.9	89.1	1.6
Georgia	6.0	5.5	64-22	16.7	76.4	90.2	1.5
Michigan	7.5	6.0	58-22	17	69.4	88.5	1.4
Average=	6.5	5.6		16.9	73.3	88.5	1.6
Stdev=	0.73	0.30		0.59	6.52	1.78	0.26

State(mix)	*SE*	*FAA*	*film thickness (microns)*	*Rut depth (mm)*	*F-E$_{ratio}$ %*	*TSR*	*k (cm/s)E^{-5}*
Mississippi	N/A	N/A	5.4	3.8	N/A	0.85	48.13
Maryland	67	45.7	7.3	9.5	80	0.78	61.40
Georgia	N/A	N/A	6.7	8.6	81	0.92	107.15
Michigan	87	44.6	7.1	15.7	68	0.78	95.85
Average=	77.0	45.2	6.6	9.4	76.2	0.83	78.1
Stdev=	14.14	0.78	0.85	4.90	7.08	0.07	27.90

State(mix)	*Dry TS*	*Wet TS*	*Fe Un-aged*	*Fe aged*
Mississippi	220.1	187.9	N/A	N/A
Maryland	164.4	129	5.582	4.442
Georgia	137.1	126.3	4.887	3.949
Michigan	209.4	164.1	7.242	4.937
Average=	182.8	151.8	5.904	4.443
Stdev=	38.84	29.58	1.21	0.49

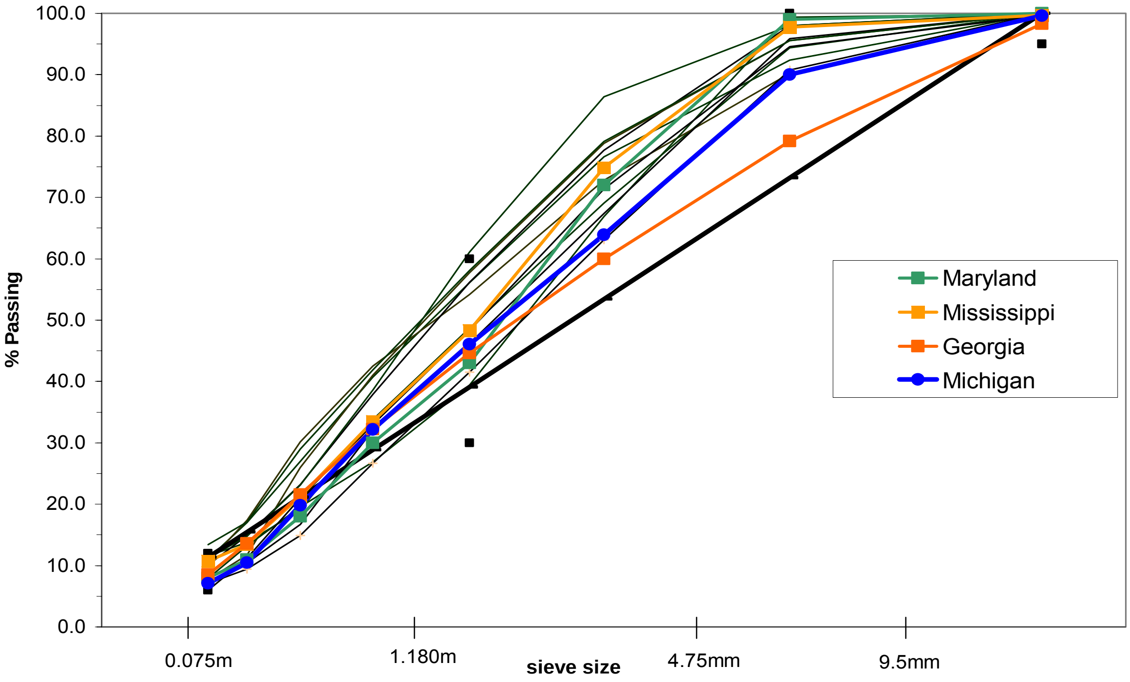


Figure 4.43 Gradations for Baseline Mixtures.

Tensile strength ratios for the baseline mixtures appear to be reasonable. The average was 0.83, however if 0.80 is used as a minimum which is common for many specifying agencies, the mixtures from Michigan and Maryland are slightly below this minimum. All baseline mixtures contained about 1.0 percent hydrated lime which may explain the higher tensile strength ratios compared to the laboratory mixtures.

One performance concern with these mixtures may be cracking resistance. Fracture energy ratios for baseline mixtures are low compared to most of the laboratory mixtures. There may be several reasons for lower ratios. Lower film thicknesses, lower VMAs and lower effective asphalt content probably contribute to the baseline mixtures reduced ability to resist cracking after oven aging compared to the laboratory prepared mix designs. Also, it is not clear if the softer binder used in the Michigan baseline mixture contributed to a lower fracture energy ratio, which is noticeably lower at 68 percent compared to 80 and 81 percent for baseline mixtures from Maryland and Georgia.

As with the laboratory designed mixtures, permeability was low even at high air voids. The average permeability for baseline mixtures was 78.1 cm/sec E^{-5} at 9.0 percent air voids, which is practically the same as the average for the laboratory mixtures at 76.7 cm/sec E^{-5} at 9.0 percent air voids.

4.4 AASHTO Specifications

The AASHTO specifications for 4.75 mm NMAS Superpave designed asphalt mixtures are presented in Table 4.21. The main objective for this research is to refine the current procedures and criteria for 4.75mm NMAS Superpave designed mixtures, so a comparison to current AASHTO criterion is presented in this section.

Table 4.21 AASHTO Criteria For 4.75mm NMAS Superpave Asphalt Mixtures.

Design ESALs (Millions)	**Ndes**	**Minimum FAA Depth from Surface**		**Minimum Sand Equivalent**	**Min. VMA**	**VFA**	**Nini**
		≤ 100 mm	≥ 100 mm				
<0.3	50	-	-	40	16.0	70-80%	≤91.5
0.3 to <3.0	75	40	40	40	16.0	65-78%	≤90.5
3.0 to<10	100	45	40	45	16.0	75-78%	≤89.0
Sieve size	**Min.**	**Max.**	Air voids = 4.0%				
12.5 mm	100		Dust Proportion: 0.9 to 2.0				
9.5 mm	95	100					
4.75 mm	90	100					
1.18 mm	30	60					
0.075 mm	6	12					

4.4.1 AASHTO Gradation Limits

Most of the laboratory prepared mixtures and baseline mixtures meet current gradation limits specified in AASHTO shown in Table 4.21. There are two mixes however, that are outside current limits. FLadj has 13.4 percent passing the 0.075mm sieve; which exceeds the maximum of 12.0 percent to lower the high VMA seen in the FLmix. Six percent baghouse fines were added to the FL blend to increase fines and lower VMA. For this mixture, adding fines had a beneficial effect. VMA was lowered, TSR values were increased, and dust to asphalt ratio was increased to meet current specifications. This indicates that increasing the maximum limit on 0.075 sieve may allow for 4.75 mm NMAS mix designs to have slightly higher dust contents as a way to control volumetric properties.

The MN mix was finer than the current limits specified for the 1.18 mm sieve. The maximum percent passing the 1.18 mm sieve can be currently 60 percent; MN has 61.1 percent passing. This gradation was found to give the lowest optimum asphalt content from the aggregate trial portion of the MN mix design. The final mixtures prepared with the MN aggregate blend did have high VMA (19.7 to 21.1); this is thought to be due to the fineness of the gradation.

The 1.18 mm sieve is used to divide a 4.75 mm NMAS mixture into two fractions where the material above this sieve is the coarse fraction and below is the fine fraction of the aggregate blend. Increasing the coarse fraction of the gradation should make a fine-graded mixture move closer to the maximum density line. Figure 4.44 indicates that two ways can be used to decrease effective asphalt content, one way being to increase the dust content the second being to decrease the fine fraction of the gradation. It is recommended that the current gradation limits be adjusted to limit the amount of material passing the 1.18 mm to 55 percent to force gradations closer to the maximum density line, and that the maximum amount of material passing the 0.075 mm sieve be increased to 13.0 percent.

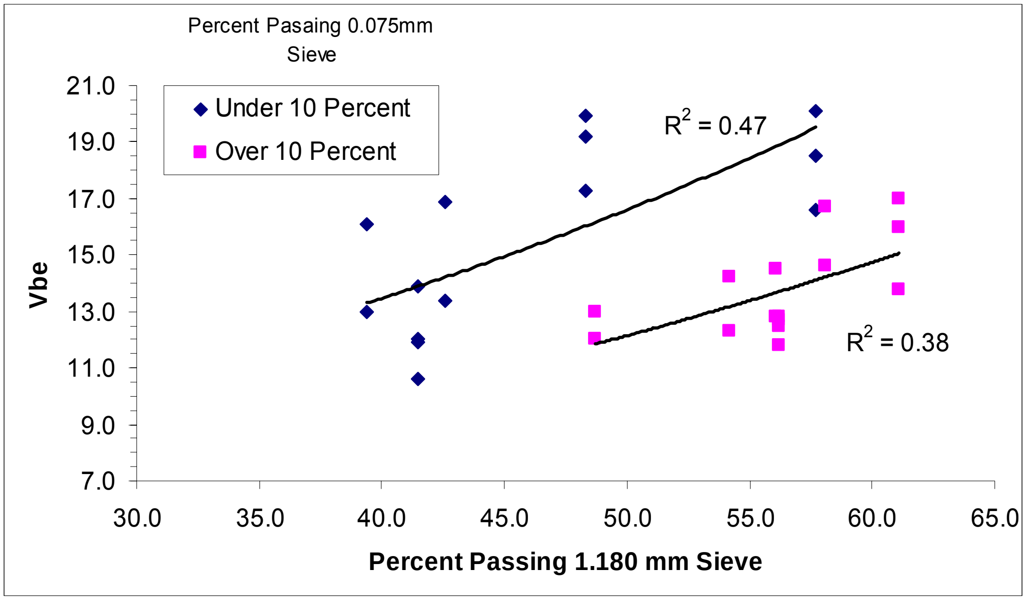


Figure 4.44 Vbe versus Percent Passing 1.18 mm Sieve Sorted by Dust Content

4.4.2 Criteria for Sand Equivalent

All of the aggregate blends in this study were well above the minimum specified limit for Sand Equivalent. The maximum sand equivalent result was 88 for the Florida blends, the minimum was 67 for the Minnesota and Alabama blends. An average SE for all the aggregate blends in this study was 77. Since all aggregate blends were well above the current minimum specified sand equivalence values shown in Table 4.21 there was no evidence to support changing sand equivalent criteria.

4.4.3 Criteria for Dust to Asphalt Ratio

As discussed in section 4.1.5 there were five mix designs that fell outside of the current specified range for dust to asphalt ratio. It was determined from the relationship shown in Figure 4.36 that the current specified maximum of 2.0 appears to be reasonable.

However, the minimum dust to asphalt ratio may be slightly too low. Figure 4.45 shows a plot of the average and median rutting rates for mixtures sorted by ranges of dust to asphalt ratio. It can be seen that higher dust to asphalt ratios tends to increase rutting resistance for these mixtures. In section 4.2.1 a minimum allowable MVT rut depth was determined to be 13.1 mm which is equivalent to a 0.0016 mm/cycle rutting rate at 8000 cycles. It can be seen in Table 4.15 that for mixtures with a rutting rate of less than 0.0016 mm/cycle, the average dust to asphalt ratio was 1.8 with only one mixture under 1.5 dust to asphalt ratio. Based on the high average rutting and variability for mixtures with less than 1.0 dust to asphalt ratio seen in Figure 4.45, it is recommended that the minimum dust to asphalt ratio be change to 1.0 percent and that for the ESAL range of over 3.0 million ESALs a minimum of 1.5 is recommended.

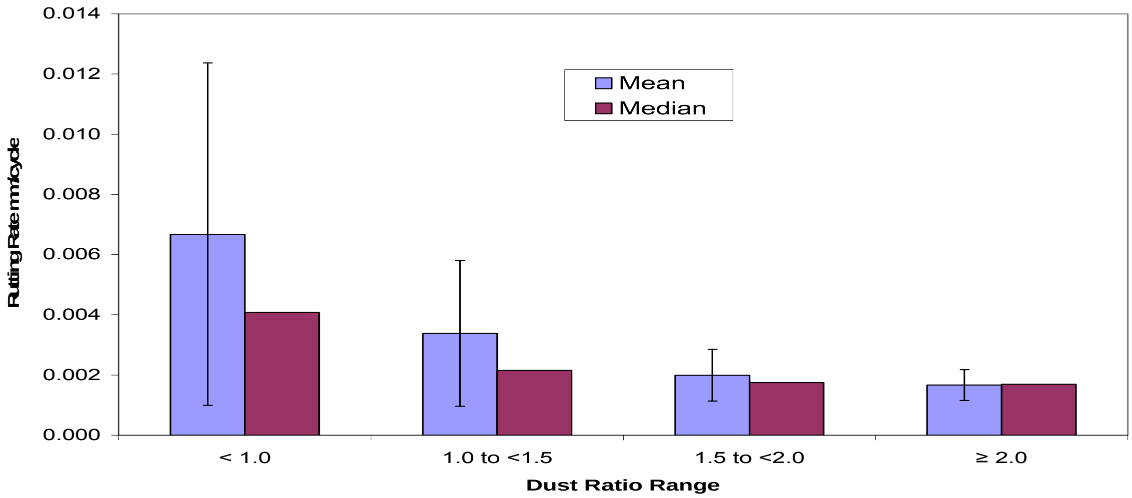


Figure 4.45 Rutting Rate versus Dust to Asphalt Ratio

4.4.4 Fine Aggregate Angularity

It was mentioned in section 4.1.6 that there was no clear relationship between FAA and the volumetric properties of the mix designs prepared for this study. However, it was found that FAA did influence some of the performance tests conducted for this research. In section 4.2.1 it was shown that an FAA over 45 reduced rutting at higher asphalt contents. Also, it was found in section 4.2.4 that FAA over 45 may lower permeability. Based on these results, a FAA of over 45 may be appropriate for mixtures designed to higher ESAL ranges.

4.4.5 %Gmm@ Nini

As mentioned in section 4.1.4 there were only two mix designs that failed to meet the most restrictive criteria for %Gmm@Nini (≤ 89.0 percent). The two mixtures that failed to meet this criterion also had relatively high rutting rates (0.004 mm/cycle), which may indicate that they would be unstable when subjected to traffic. At this time there is no recommendation on modifying the current %Gmm@Nini maximum. It was shown in Figures 4.13 and 4.15 that Gmm@Nini for 6.0 percent design air void mixtures were on average 1.7 percent lower than mixtures designed at 4.0 percent air voids. However if rutting rate is used as a measure of mixture stability as shown in Figure 4.46 there is no justification to lower the %Gmm@Nini maximum for 6.0 percent design air voids.

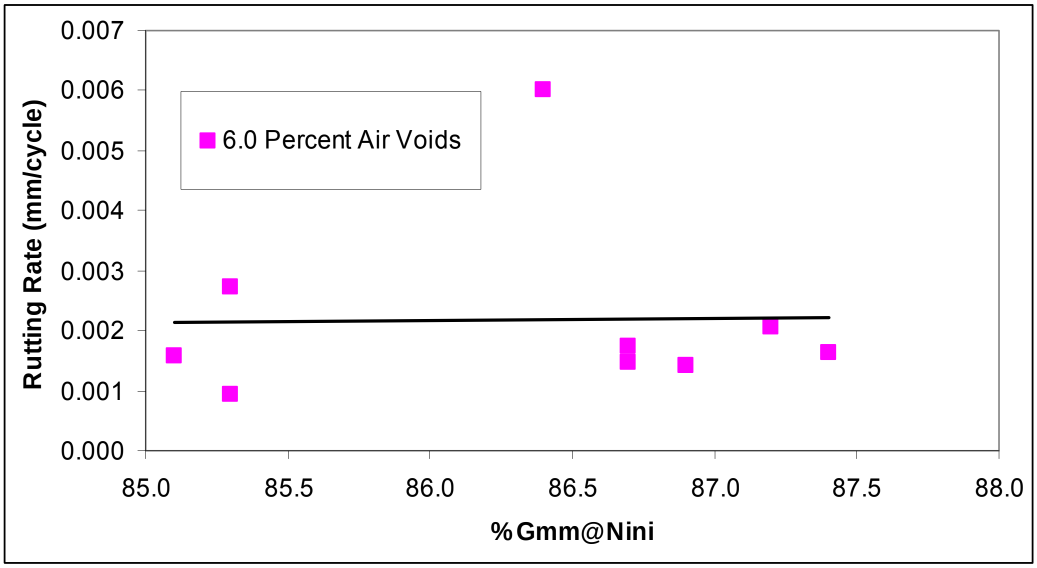


Figure 4.46 Gmm@Nini versus Rutting Rate for 6.0 Percent Design Air Voids

4.4.6 Volumetric Requirements

Currently only 4.0 percent air voids is permitted by AASHTO for all NMAS mixtures. Relationships shown in section 4.2 indicate that mixtures designed at 6.0 percent and 4.0 percent air voids can be designed to perform satisfactorily. Relationships shown in section 4.2.1 show that mixtures designed at 6.0 percent air voids can have lower rutting at higher VMA than mixtures designed at 4.0 percent air voids. It was found that rutting was more a function of effective asphalt content than VMA. The mixtures prepared for this study with aggregates from many different sources tended to have high VMA and therefore high asphalt contents. One way shown to reduce asphalt content was to design these mixes at higher air void contents. This allows aggregate blends with a high VMA to be used, yet maintains realistic asphalt contents. For this reason, a range of design air void contents of 4.0 to 6.0 percent should be specified.

A minimum of VMA of 16 percent is currently specified in AASHTO for 4.75 mm NMAS mixtures. This appears to be reasonable, but specifying a minimum Vbe may be a more sensible approach if a range of design air voids of 4.0 to 6.0 percent is adopted. Based on Figure 4.35, a minimum Vbe of 11.5 was found to be appropriate based on the results of fracture energy testing. Currently based on a minimum VMA of 16.0 percent and design air voids of 4.0 percent the minimum Vbe is 12.0 percent.

Most of the mix designs prepared for this study would not meet the current VFA criteria for over 3.0 million ESALs. It is proposed that a maximum Vbe requirement be used to allow for a range of design air voids. This would replace the criteria for maximum VFA. Based on Figure 4.27 a maximum Vbe of 13.5 percent is proposed for over 3.0 million design ESALs to limit the potential for rutting. This would, in effect, lower the current VFA maximum requirement of 78 percent to 77 for mixtures designed at 4.0 design air voids, while permitting lower maximum VFA for higher design air voids.

5.0 Conclusions and Recommendations

5.1 Conclusions

Twenty nine 4.75 mm NMAS Superpave mix designs were prepared in the laboratory with material from nine states. Each mix design was tested for permanent deformation, permeability, Tensile Strength Ratio and fracture energy. Also, four plant produced mixtures were evaluated and served as a baseline for performance. The objective of this research was to refine the current procedures and criteria for 4.75mm NMAS Superpave designed mixtures. Based on the results of this research several conclusions were made:

- Material source properties and gradation largely control optimum asphalt contents.
- It was shown for 4.75 mm mixtures a change in design air voids at a given gyration level does not significantly increase or decrease VMA, since the volume of asphalt is replaced by volume of air.
- Increasing the compaction from 50 to 75 gyrations will significantly decrease VMA by an average of 1.3 percent for a given mixture.
- All aggregate blends in this study would be considered fine-graded. It was found that coarser gradations, those closer to the maximum density line, had lower VMA.
- Increasing the dust content is the simplest way to lower VMA for these mixtures.
- VFA was reduced by an average of 11.0 percent by increasing design air voids from 4.0 to 6.0 percent. With a difference of only 1.3 percent, increasing

compaction effort from 50 to 75 gyrations did not significantly change VFA at 4.0 percent design air voids.

- High VMA for many 4.75 mm NMAS asphalt mixtures, resulted in elevated asphalt contents and excessive MVT rut depths (mean =14.6 mm).
- Mixtures with dust to asphalt ratios of less than 1.5 have a higher average rutting rate (mean = 0.00475mm/cycle) than mixtures over a 1.5 dust to asphalt ratio (mean = 0.00189 mm/cycle).
- With a difference in average rutting rate of 0.00235 mm/cycle between mixtures with a Vbe of less than 13.5 percent and over 13.5 percent indicates that mixtures with under 13.5 percent Vbe performed better in rutting than mixtures with over 13.5 percent Vbe for both 6.0 and 4.0 design air void mixtures.
- It was thought that 4.75 mm NMAS mixtures with optimum asphalt contents over 6.0 percent would achieve 70 to 80 percent retained tensile strength. So, the average tensile strength ratio of 0.65 was lower than expected. However, low permeability at typical in-place air void contents may help reduce exposure to moisture in the field.
- There is a general trend of increasing fracture energy ratio with increasing asphalt content. Based on the plots of fracture energy versus film thickness and dust ratio it is concluded that a 4.75 mm NMAS mixtures ability to maintain resistance to cracking is a function of film thickness which is related to both asphalt and dust content.
- The average permeability of 76.7 cm/sec $*E^{-5}$ at 9.0 percent air voids for the mix designs prepared in this study indicates 4.75 mm NMAS Superpave designed

asphalt mixtures are practically impermeable even at higher assumed in-place air voids.

- Mix designs containing natural sand adversely affected performance by decreasing the average TSR by 10 percent, increasing the average rutting rate by 0.001450 mm/cycle, and increasing average permeability by 62 cm/sec $*E^{-5}$.
- Mixtures with FAA values over 45 lowered rutting by an average of 0.00248 mm/cycle and lowered permeability by an average of 93 cm/sec $*E^{-5}$.

5.2 Recommendations

Based on the results of this study and the conclusions presented above several recommendations and guidelines are presented:

- It is recommended that AASHTO specifications be modified to allow a range for design air voids of 4.0 to 6.0 percent for 4.75 mm NMAS asphalt mixtures. Asphalt mixtures designed for surface applications on low traffic roadways a design air voids 4.0 percent maybe more appropriate. For high traffic applications where rutting is a concern increasing design air voids will lower asphalt contents which will decrease rutting potential.
- Criteria for VMA and VFA should be replaced with minimum and maximum Vbe requirements. This is a more sensible approach when a range of design air voids is adopted.
- Based on fracture energy and MVT rutting data a minimum Vbe of 11.5 percent and a maximum Vbe of 13.5 percent is recommended for 4.75 mm NMAS

Superpave asphalt mixtures designed for over 3.0 million ESALs. For less than 3.0 million design ESALs a range of 12.0 to 15.0 percent Vbe is recommended.

- The maximum %Gmm@Nini requirement appears appropriate for both 4.0 and 6.0 percent design air voids. At this time it is recommended that current Gmm@Nini criteria be maintained.
- For aggregate blends designed for over 0.3 million ESALs a FAA of 45 is recommended.
- For 4.75 mm NMAS asphalt mixtures designed for under 3.0 million ESALs the minimum dust to asphalt ratio should be increased slightly from current 0.9 to 1.0. Mixtures designed for over 3.0 million ESALs a minimum dust to asphalt ratio of 1.5 is recommended.
- The current maximum dust to asphalt ratio of 2.0 is appropriate based on the results of fracture energy testing. It is recommended that the maximum dust to asphalt ratio of 2.0 be maintained.
- No evidence was found that suggested the current sand equivalence minimum be adjusted. At this time it is recommended that minimum sand equivalent criteria for each design ESAL range be maintained.
- It is recommended that current gradation limits on the 1.180 mm and 0.075 mm sieve be adjusted. Limits placed on percent passing the 1.180 sieve should be 30-55 percent. Limits placed on percent passing the 0.075 mm sieve should be 6 to 13 percent
- It is recommended that 4.75 mm NMAS Superpave designed mixtures not contain more than 15 percent natural sand with a FAA under 45 percent.

Based on the recommendations provided in this report a proposed set of design criteria is given in Table 5.1.

Table 5.1 Proposed Design Criteria for 4.75 mm NMAS Superpave Design Mixtures

Design ESAL Range (Millions)	Ndes	Minimum FAA	Minimum Sand Equivalent	Minimum Vbe	Maximum Vbe	Gmm@Nini	Dust Proportion
<0.3	50	40	40	12.0	15.0	≤91.5	1.0 to 2.0
0.3 to ≤ 3.0	75	45	40	12.0	14.5	≤90.5	1.0 to 2.0
3.0 to ≤ 10	100	45	45	11.5	13.5	≤89.0	1.5 to 2.0

Gradation Limits

Sieve Size	Max.	Min.
12.5 mm	---	100
9.5 mm	100	95
4.75 mm	100	90
1.18 mm	30	55
0.075 mm	13	6

Design Air Void Range = 4.0 to 6.0 Percent

The laboratory research has shown that small aggregate size mixtures with high VMA tend to maintain resistance to fracture after long term oven aging, generally have low permeability and can be designed to be rut resistant. Based on these findings several possible applications are recommended:

- 4.75 mm NMAS mixtures may be best suited for low traffic volume applications (less than 3 million design ESALs) as a thin overlay where mixture durability is important.
- Small aggregate size and low permeability would produce good mixtures for very thin lift surface applications used as preventative maintenance on existing pavements.
- Surface course on parking lots and residential streets.
- Small aggregate size mixtures would be ideal for thin leveling courses.
- Patching mixtures on low volume roadways.

This thesis was based on Phase 1 of the pooled fund study to refine the current AASHTO specifications on 4.75 mm NMAS Superpave mixtures. In the second phase of this research, it is hoped that a number projects will be available to conduct field studies on production and construction issues relevant to 4.75 mm NMAS mixtures. It is recommended that for the field research phase of this study the following issues be addressed:

- In-place densities after compaction
- Appropriate spread rates and lift thicknesses
- Workability of the mixture during construction
- Variability in mixture volumetric and aggregate properties during production and construction
- Friction of in-place mixtures
- Stability of the mixture during compaction.
- Permeability of in-place mixtures
- A typical ultimate density of these mixtures should be determined, however this will require testing on a project that has been in service for more than two to three years

6.0 References

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Appendix A

Laboratory Mix Designs

A1.1 Mix Design for Alabama Materials

Alabama Trial Blends

Aggregate

	Stockpile		
sieve size	M-10	89s	Shorter
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	100
#4	99.7	27.0	99.1
#8	83.5	2.0	91.4
#16	58.9	1.0	78.5
#30	43.5	0.4	53.4
#50	32.0	0.4	19.8
#100	22.0	0.4	3.4
#200	14.5	0.4	1.4
Gsb	2.578	2.643	2.634
Gsa	2.651	2.693	2.669
Absorption%	1.20	0.70	0.50

Trial Blend Proportions

Blend	M-10	89s	Shorter
1	60%	10%	30%
2	87%	13%	0%
3	75%	10%	15%

Trial Blend Results

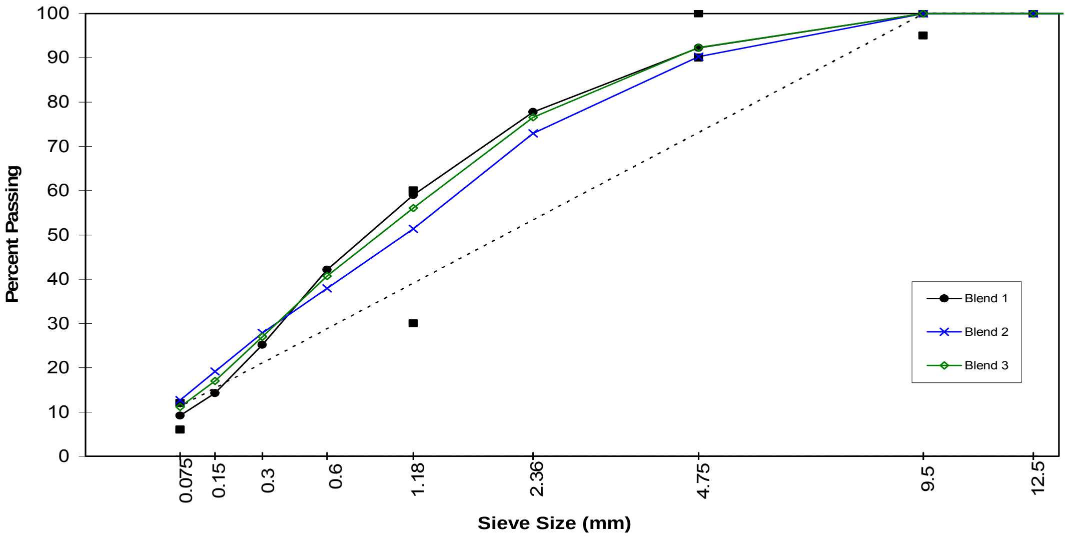
Blend	Ndes	%AC	Va	VMA	VFA
1	50	6.0	9.8	20.5	52.3
2	50	6.0	5.6	16.3	65.5
3	50	6.0	7.5	18.3	59.1

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	84.3	1.8	2.427	2.189	2.661
2	87.4	2.7	2.426	2.289	2.660
3	85.9	2.3	2.424	2.243	2.657

Blend	Est. %ac	Est. VMA	Est. VFA
1	8.3	19.4	79.4
2	6.7	16.0	75.0
3	7.4	17.6	77.3

Blend 3 was chose for mix design

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	92.3	90.2	92.3
#8	77.7	72.9	76.5
#16	59.0	51.4	56.1
#30	42.2	37.9	40.7
#50	25.2	27.9	27.0
#100	14.3	19.2	17.1
#200	9.2	12.7	11.1
Gsb	2.601	2.586	2.593
Gsa	2.661	2.656	2.658
Absorption%	0.94	1.14	1.05



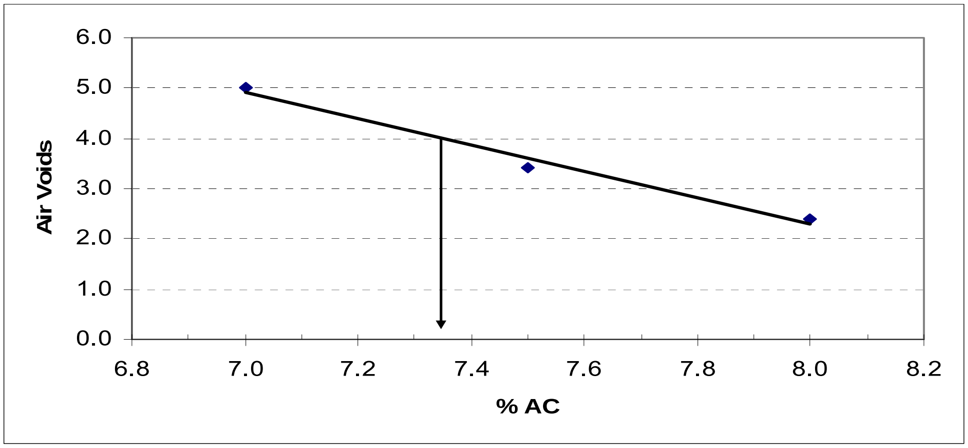
Alabama Binder

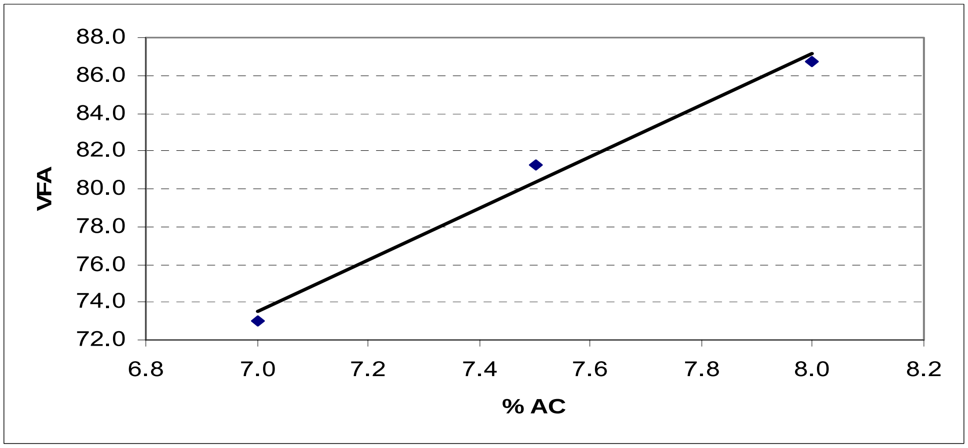
Binder Series Results

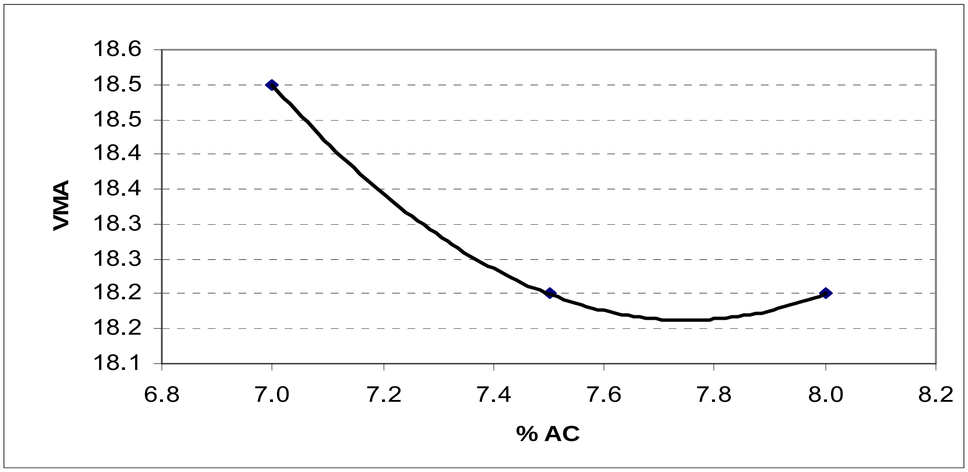
Series	Ndes	%AC	Va	VMA	VFA
1	50	7.0	5	18.5	73.0
2	50	7.5	3.4	18.2	81.3
3	50	8.0	2.4	18.2	86.7

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	88.0	1.8	2.393	2.274
2	89.5	1.7	2.374	2.293
3	90.7	1.6	2.361	2.304

Series	Est. %ac	Est. VMA	Est. VFA
1	7.4	18.3	78.1
2	7.3	18.3	78.1
3	7.4	18.4	78.3







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Verification for AL-50-4

Verification Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	7.4	4.0	18.5	78.4

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	89.0	1.7	2.378	2.28

JMF

sieve size	Blend 3	Spec
3/8"	100.0	100 - 95
#4	92.3	100 - 90
#8	76.5	
#16	56.1	30 - 60
#30	40.7	
#50	27.0	
#100	17.1	
#200	11.1	6 - 12
Gsb	2.593	
Gsa	2.658	
Absorption%	1.045	

% Binder =	7.4	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	67	>40
FAA =	46.3	>40
VMA =	18.5	>16
VFA =	78.4	70-80
%Gmm@Nini =	89	?91.5
DP =	1.7	0.9-2.0

Verification for AL-50-4

Verification Series Results

				Min 16%	
Series	Ndes	%AC	Va	VMA	VFA
1	50	6.7	6.0	18.8	68.1

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.2	1.9	2.401	2.257

JMF

sieve size	Blend 3	Spec
3/8"	100.0	100 - 95
#4	92.3	100 - 90
#8	76.5	
#16	56.1	30 - 60
#30	40.7	
#50	27.0	
#100	17.1	
#200	11.1	6 - 12
Gsb	2.593	
Gsa	2.658	
Absorption%	1.045	
Gsb	2.593	
Gsa	2.658	
Absorption%	1.045	

% Binder =	6.7	
Ndes =	50	
Design Va% =	6.0	Spec
SE =	67	>40
FAA =	46.3	>40
VMA =	18.8	>16
VFA =	68.1	70-80
%Gmm@Nini =	87.2	?91.5
DP =	1.9	0.9-2.0

A1.2 Tennessee Limestone Mix Design

Tennessee Trial Blends

Aggregate

	Stockpile		
sieve size	# 10 Hard	Natural	#10 soft
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	100
#4	93.3	98.8	93.3
#8	62.9	92.3	64.8
#16	40.7	80.1	41.3
#30	28.1	56.5	28.4
#50	21.0	10.4	21.8
#100	16.8	0.8	17.8
#200	14.4	0.2	14.9
Gsb	2.544	2.591	2.579
Gsa	2.721	2.642	2.727
Absorption%	4.00	0.70	2.10

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	94.4	95.0	93.9
#8	69.1	71.9	66.4
#16	48.7	52.6	44.8
#30	33.8	36.6	31.0
#50	19.0	17.9	20.2
#100	13.8	12.1	15.5
#200	11.6	10.2	13.1
Gsb	2.559	2.560	2.558
Gsa	2.706	2.698	2.714
Absorption%	3.02	2.88	3.16

Trial Blend Proportions

Blend	# 10 Hard	Natural	#10 soft
1	63%	20%	17%
2	63%	30%	7%
3	63%	10%	27%

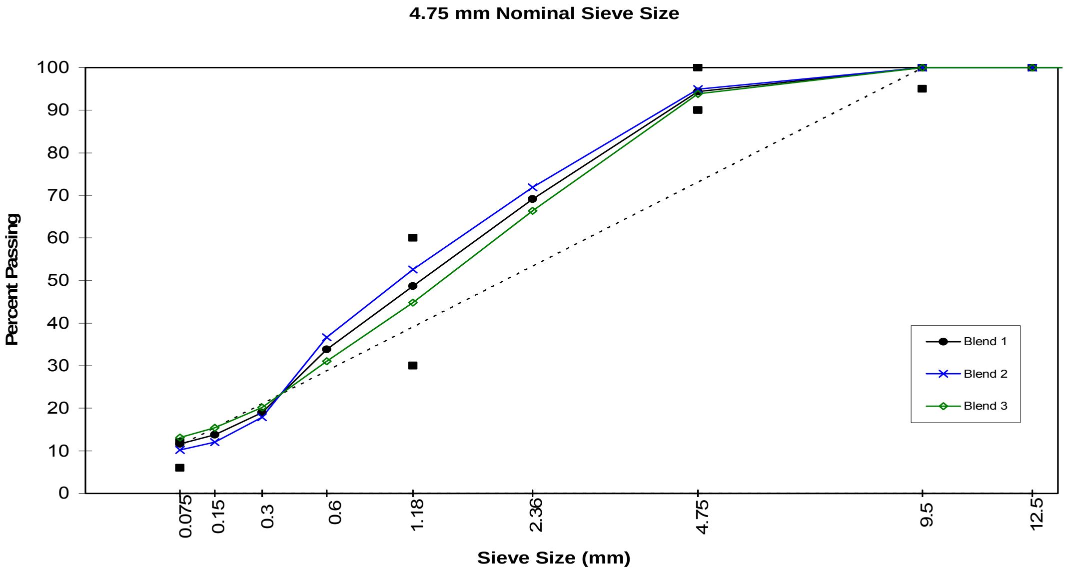
Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	6.2	6.8	17.4	60.9
2	50	6.2	8.6	19.0	55.0
3	50	6.2	7.0	17.2	59.4

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	85.4	2.4	2.418	2.254	2.659
2	84.4	2.1	2.417	2.21	2.658
3	83.8	2.8	2.428	2.258	2.672

Blend	Est. %ac	Est. VMA	Est. VFA
1	7.3	16.8	76.2
2	8.0	18.1	77.9
3	7.4	16.6	75.9

Blend 1 was chose for mix design



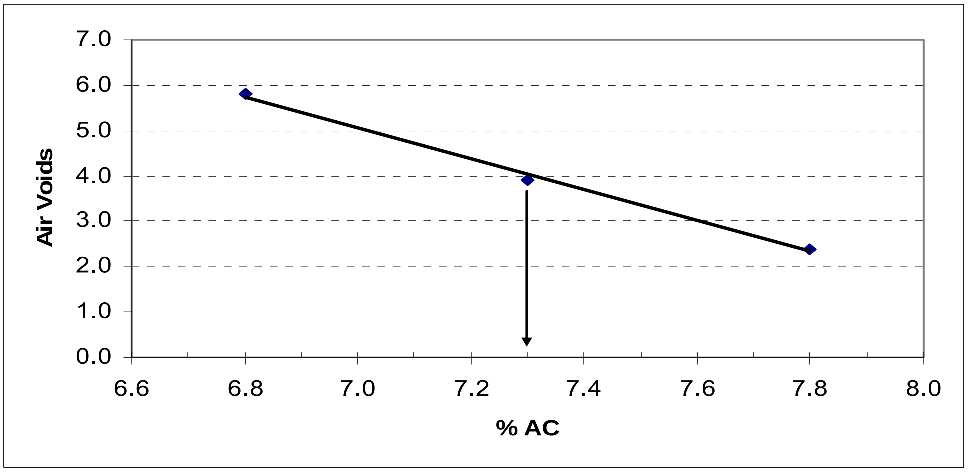
Tennessee Binder Series for TN-50-4

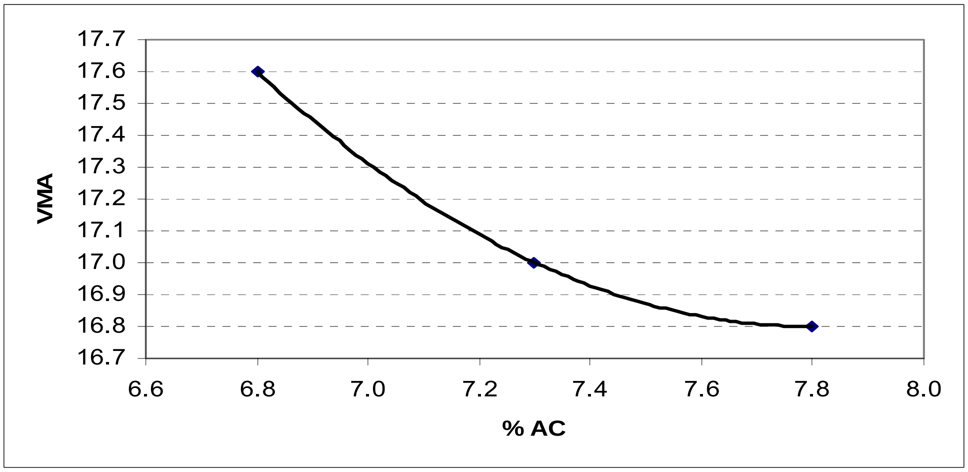
Binder Series Results

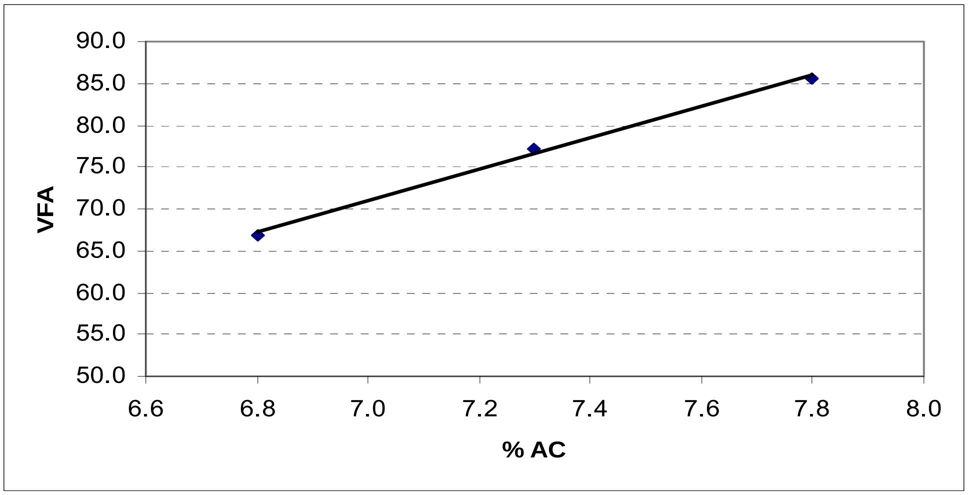
Series	Ndes	%AC	Va	VMA	VFA
1	50	6.8	5.8	17.6	66.9
2	50	7.3	3.9	17	77.2
3	50	7.8	2.4	16.8	85.6

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	85.9	2.2	2.402	2.262
2	87.8	2	2.384	2.292
3	89.3	1.8	2.367	2.31

Series	Est. %ac	Est. VMA	Est. VFA
1	7.5	17.2	76.8
2	7.2	17.0	76.5
3	7.2	16.9	76.4







Verification for TN-50-4

Verification Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	7.3	4.0	16.9	76.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.8	2.0	2.387	2.293

JMF

sieve size	Blend 1	Spec		
1"	100		% Binder =	7.3
3/4"	100		Ndes =	50
1/2"	100		Design Va% =	4.0
3/8"	100.0	100 - 95	SE =	69
#4	94.4	100 - 90	FAA =	44.8
#8	69.1			
#16	48.7	30 - 60		
#30	33.8			
#50	19.0			
#100	13.8			
#200	11.6	6 - 12		
Gsb	2.559			
Gsa	2.706			
Absorption%	3.020			

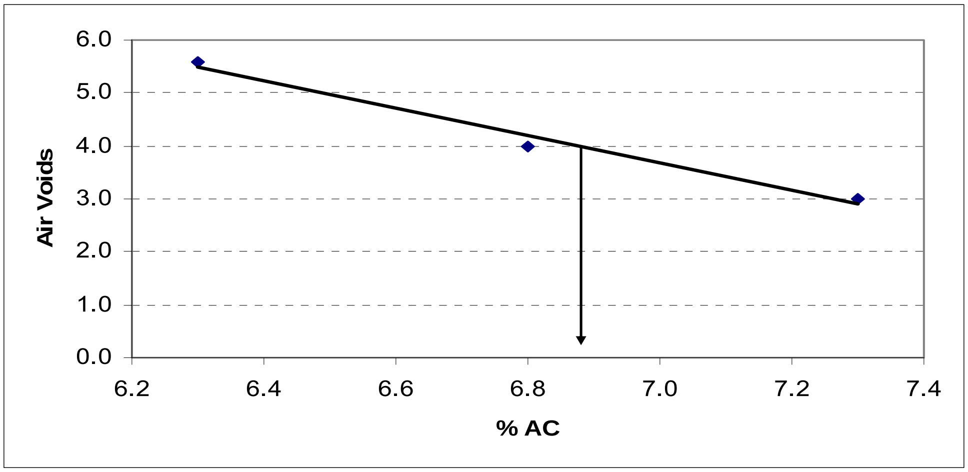
Tennessee Binder Series for TN-75-4

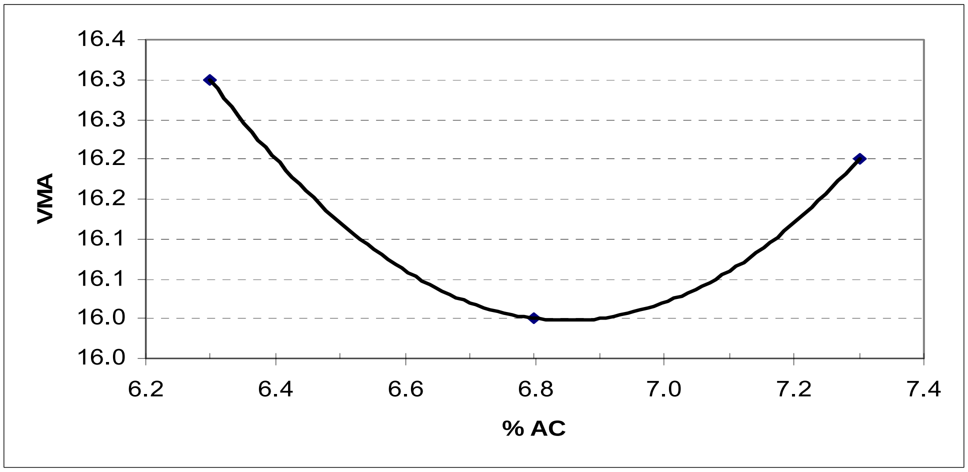
Binder Series Results

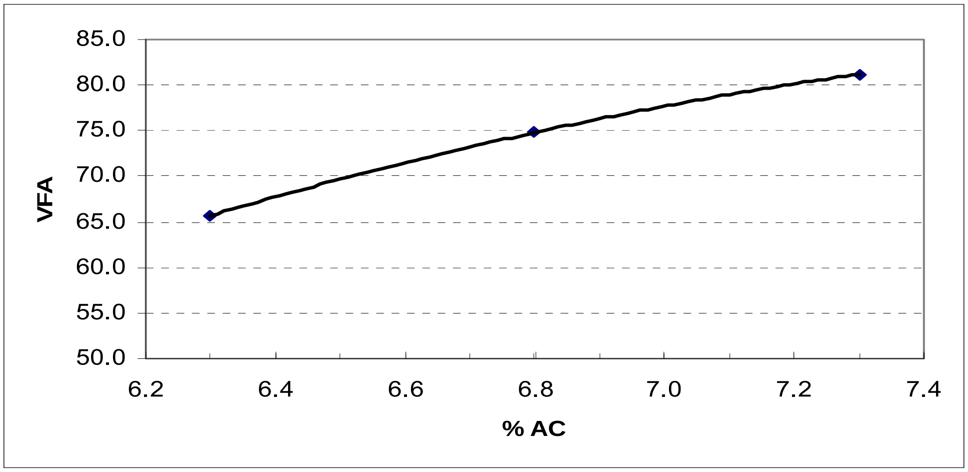
Series	Ndes	%AC	Va	VMA	VFA
1	75	6.3	5.6	16.3	65.7
2	75	6.8	4.0	16.0	74.8
3	75	7.3	3.0	16.2	81.2

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	85.7	2.4	2.421	2.286
2	87.2	2.2	2.403	2.306
3	88.0	2.0	2.387	2.315

Series	Est. %ac	Est. VMA	Est. VFA
1	6.9	16.0	75.0
2	6.8	16.0	75.0
3	6.9	16.3	75.4







Verification for TN-75-4

Verification Series Results

				Min 16%	
Series	Ndes	%AC	Va	VMA	VFA
1	75	6.8	4.0	16	74.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.2	2.2	2.403	2.306

JMF

sieve size	Blend 3	Spec
1"	100	
3/4"	100	
1/2"	100	
3/8"	100.0	100 - 95
#4	94.4	100 - 90
#8	69.1	
#16	48.7	30 - 60
#30	33.8	
#50	19.0	
#100	13.8	
#200	11.6	6 - 12
Gsb	2.559	
Gsa	2.706	
Absorption%	3.020	

% Binder = 6.8
Ndes = 75
Design Va% = 4.0

SE = 69
FAA = 44.8

A1.3 Missouri Mix Design

Missouri Trial Blends

Aggregate

	Stockpile			
sieve size	Mo13	Mo15	Mo14	D008
3/4"	100	100	100	100
1/2"	100	100	100	100
3/8"	98.7	100	100	100
#4	36.7	100.0	99.6	98.7
#8	4.8	90.6	83.0	94.5
#16	2.4	70.1	61.2	84.5
#30	2.2	55.9	47.7	61.2
#50	2.0	32.6	36.0	24.5
#100	1.8	7.6	24.0	2.5
#200	1.6	1.6	15.5	1.9
Gsb	2.709	2.707	2.745	2.620
Gsa	2.801	2.792	2.813	2.640
Absorption%	1.30	1.10	1.10	0.30

	Trial Blends			
sieve size	Blend 1	Blend 2	Blend 3	Blend 4
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	100	100	100	100
3/8"	99.9	99.8	99.9	99.9
#4	93.4	90.2	95.3	93.2
#8	76.3	72.8	79.4	76.9
#16	56.7	54.2	59.2	58.8
#30	44.4	42.5	46.5	45.2
#50	32.1	30.2	32.8	30.9
#100	19.3	17.4	18.5	18.6
#200	12.0	10.6	11.2	12.1
Gsb	2.736	2.732	2.733	2.723
Gsa	2.809	2.807	2.807	2.786
Absorption%	1.12	1.13	1.11	1.0

Trial Blend Proportions

Blend	Mo13	Mo15	Mo14	D008
1	10%	15%	75%	
2	15%	20%	65%	
3	7%	24%	69%	.
4	10%		75%	15%

Trial Blend Results

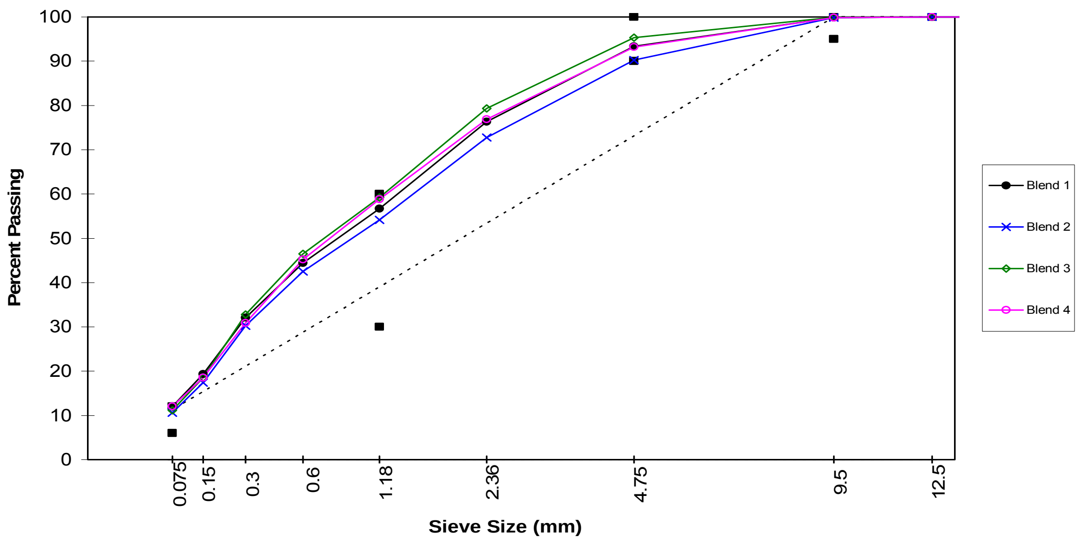
Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	3.3	17.9	81.7
2	50	7.0	2.8	17.3	83.7
3	50	7.0	4.4	18.9	76.6
4	50	7.0	2.6	17.2	85.0

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	89.3	1.9	2.497	2.415	2.797
2	89.6	1.7	2.500	2.430	2.801
3	88.2	1.8	2.494	2.384	2.793
4	91.0	1.9	2.487	2.423	2.783

Blend	Est. %ac	Est. VMA	Est. VFA
1	6.7	18	77.8
2	6.5	17.4	77.0
3	7.2	18.8	78.7
4	6.4	17.4	77.0

Blend 2 was chose for mix design

4.75 mm Nominal Sieve Size



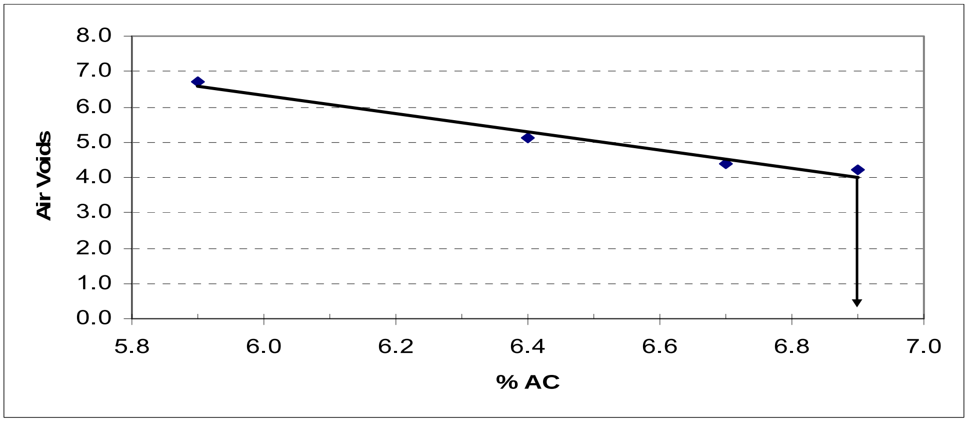
Missouri Binder Series

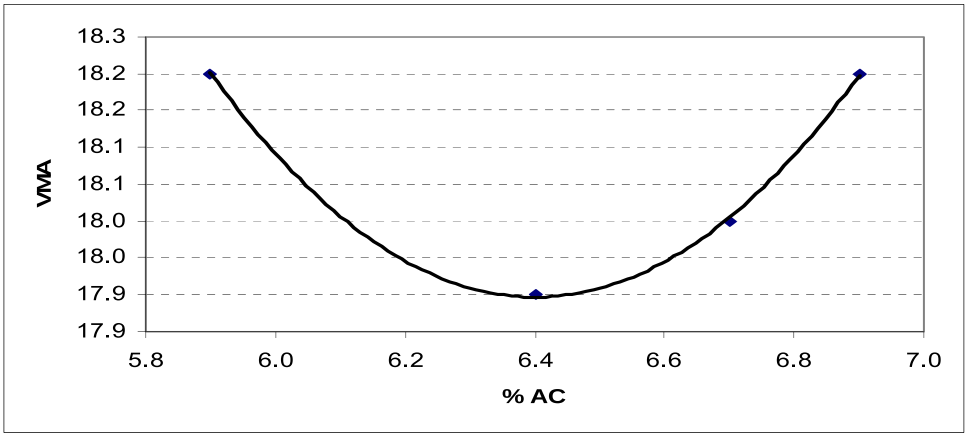
Binder Series Results

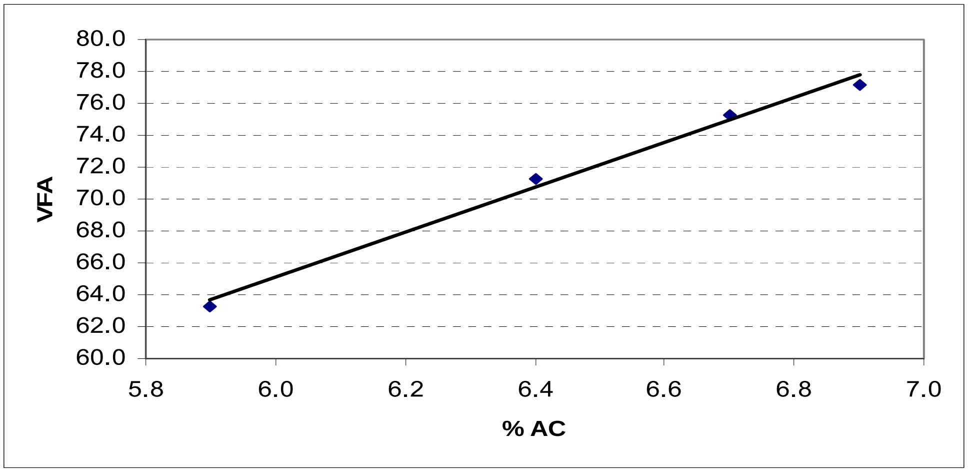
Series	Ndes	%AC	Va	VMA	VFA
1	50	5.9	6.7	18.2	63.3
2	50	6.4	5.1	17.9	71.3
3	50	6.9	4.2	18.2	77.2
4	50	6.7	4.4	18.0	75.3

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.6	2.1	2.545	2.375
2	87.7	1.9	2.525	2.395
3	88.6	1.8	2.505	2.401
4	88.3	1.8	2.513	2.402

Series	Est. %ac	Est. VMA	Est. VFA
1	7.0	17.7	77.3
2	6.9	17.7	77.4
3	7.0	18.2	78.0
4	6.9	17.9	77.7







Missouri Verification for MO-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	6.9	4.0	18.2	78.2

Series	%Gmm@Nini	$Dust_{ratio}$	Gmm	Gmb
1	88.8	1.7	2.500	2.401

JMF

sieve size	Blend 2	Spec	% Binder =	6.9	
3/8"	99.8	100 - 95	Ndes =	50	
#4	90.2	100 - 90	Design Va% =	4.0	Spec
#8	72.8		SE =	74	>40
#16	54.2	30 - 60	FAA =	49	>40
#30	42.5		VMA =	18.2	>16
#50	30.2		VFA =	78.2	70-80
#100	17.4		%Gmm@Nini =	88.8	?91.5
#200	10.6	6 - 12	DP =	1.7	0.9-2.0
Gsb	2.732				
Gsa	2.807				
Absorption%	1.130				

Verification for Missouri MO-50-6

Verification Series Results

				Min 16%	
Series	Ndes	%AC	Va	VMA	VFA
1	50	6.2	6.1	18.4	66.7

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.9	2.0	2.531	2.376

JMF

sieve size	Blend 2	Spec	% Binder =	6.2	
3/8"	99.8	100 - 95	Ndes =	50	
#4	90.2	100 - 90	Design Va% =	6.0	Spec
#8	72.8		SE =	74	>40
#16	54.2	30 - 60	FAA =	49	>40
#30	42.5		VMA =	18.4	>16
#50	30.2		VFA =	66.7	70-80
#100	17.4		%Gmm@Nini =	86.9	?91.5
#200	10.6	6 - 12	DP =	2.0	0.9-2.0
Gsb	2.732				
Gsa	2.807				
Absorption%	1.130				

A1.4 Virginia Mix Design

Virginia Trial Blends

Aggregate

	Stockpile	
sieve size	#10	Natural Sand
3/4"	100	100
1/2"	100	100
3/8"	100	100
#4	97.7	98.7
#8	74.3	88.8
#16	52.2	68.0
#30	37.4	39.4
#50	26.9	12.2
#100	18.7	3.4
#200	12.7	2.1
Gsb	2.408	2.583
Gsa	2.692	2.655
Absorption%	4.40	1.10

Trial Blend Proportions

Blend	#10	Natural Sand
1	75%	25%
2	68%	32%
3	55%	45%

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.2	9.1	17.9	49.4
2	50	7.0	10.3	19.1	45.9
3	50	6.7	12.4	21.1	41.3

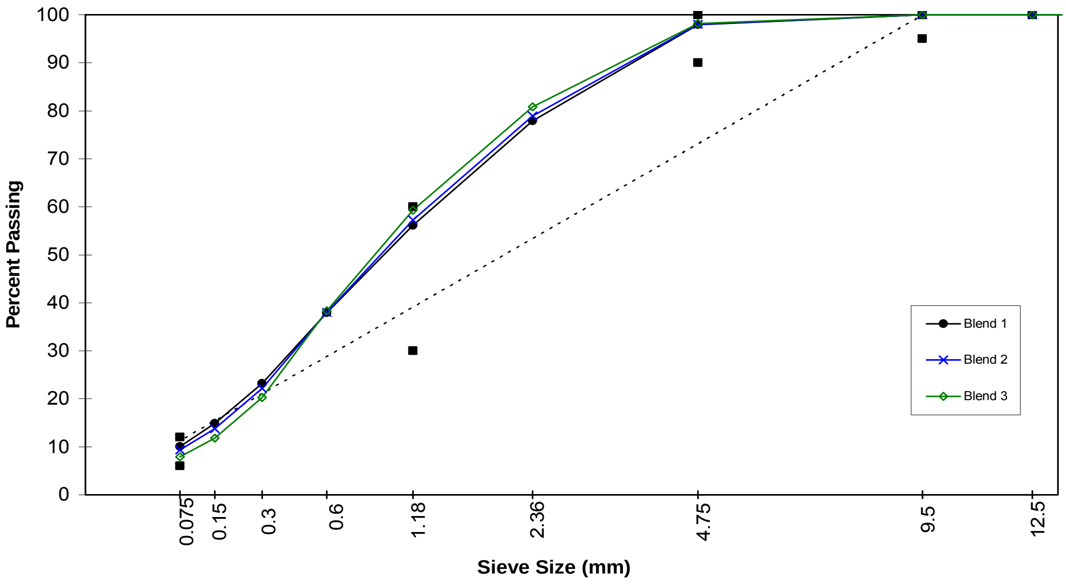
Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	84.1	2.4	2.382	2.166	2.652
2	83.0	2.2	2.388	2.142	2.651
3	81.4	1.9	2.398	2.101	2.651

Blend	Est. %ac	Est. VMA	Est. VFA	%Gmm@Nini
1	9.2	16.9	76.3	96.0
2	9.5	17.8	77.5	96.0
3	10.1	19.4	79.4	96.0

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	98.0	98.0	98.2
#8	77.9	78.9	80.8
#16	56.2	57.3	59.3
#30	37.9	38.0	38.3
#50	23.2	22.2	20.3
#100	14.9	13.8	11.8
#200	10.1	9.3	7.9
Gsb	2.449	2.614	2.484
Gsa	2.683	2.680	2.675
Absorption%	3.58	3.34	2.92

Blend 1 was chose for mix design

4.75 mm Nominal Sieve Size

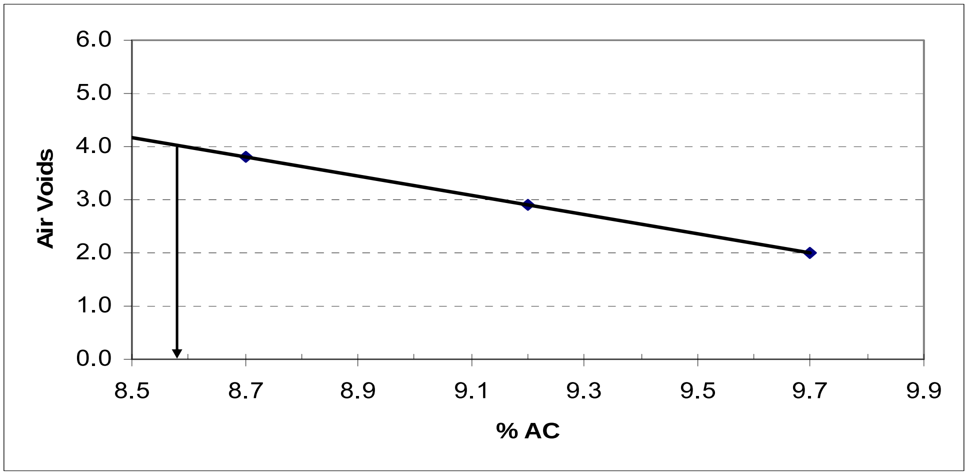


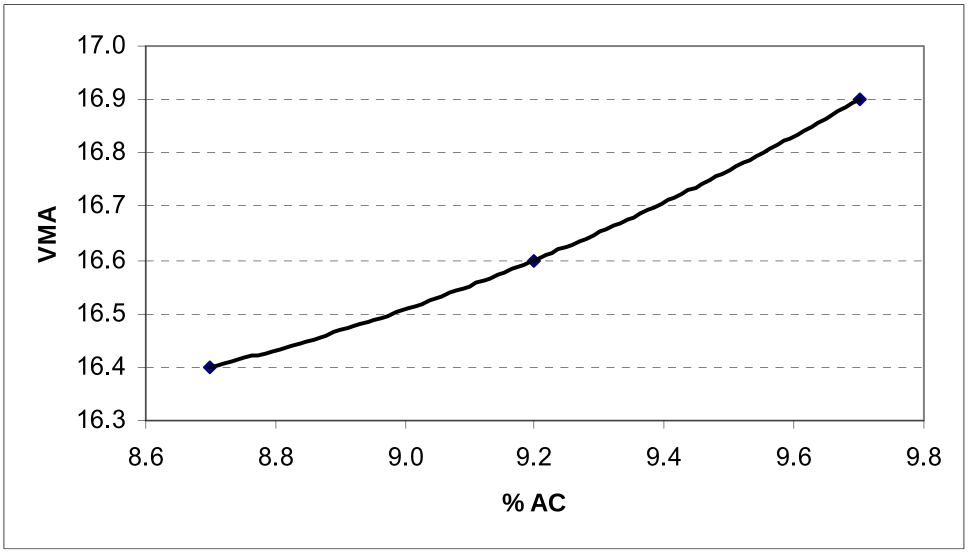
Binder Series for VA-50-4

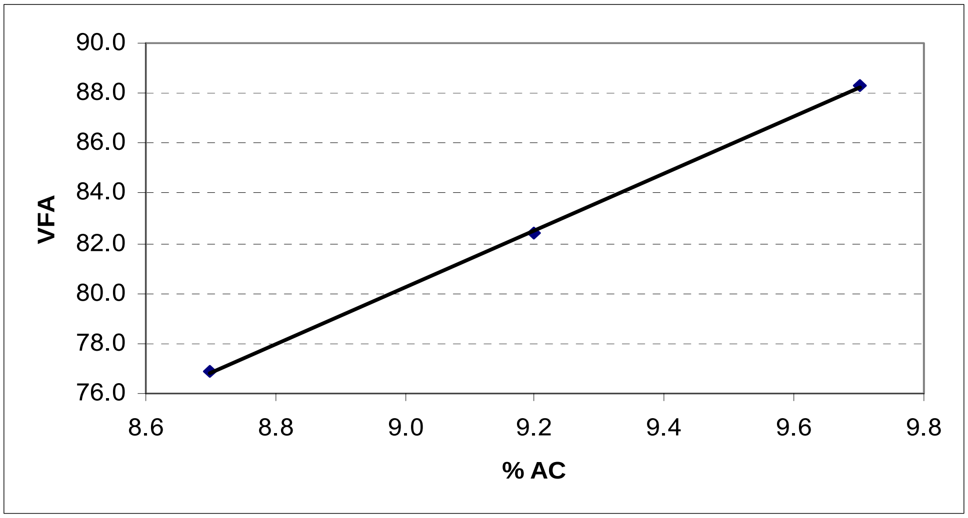
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.7	3.8	16.4	76.9
2	50	9.2	2.9	16.6	82.4
3	50	9.7	2.0	16.9	88.3

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	89.2	1.7	2.331	2.243
2	90.2	1.6	2.316	2.248
3	91.8	1.5	2.300	2.254







Verification for Virginia VA-50-4

Verification Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.8	4.1	16.8	75.8

Series	%Gmm@Nini	DP	Gmm	Gmb
1	88.4	1.7	2.329	2.234

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	77.9	
#16	56.2	30 - 60
#30	37.9	
#50	23.2	
#100	14.9	
#200	10.1	6 - 12
Gsb	2.449	
Gsa	2.683	
Absorption%	3.575	

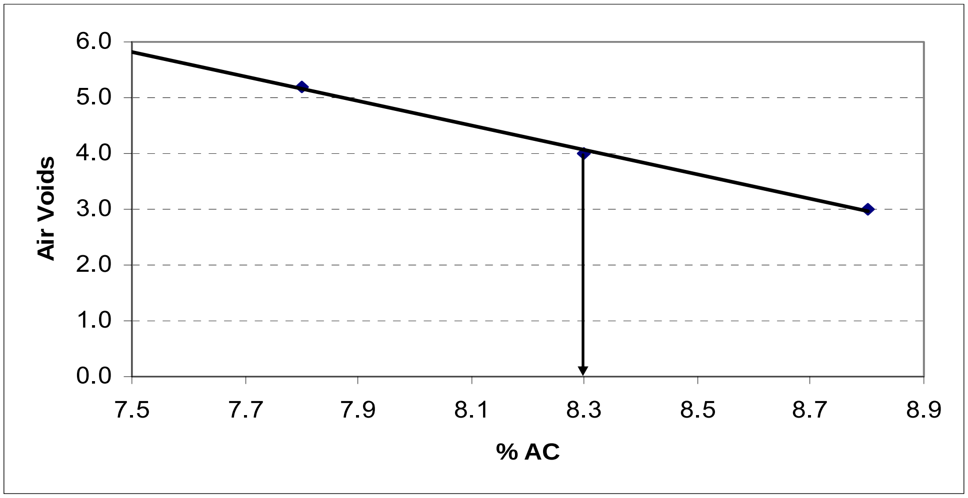
% Binder =	8.8	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	76	>40
FAA =	45	>40
VMA =	16.8	>16
VFA =	75.8	70-80
%Gmm@Nini =	88.4	?91.5
DP =	1.7	0.9-2.0

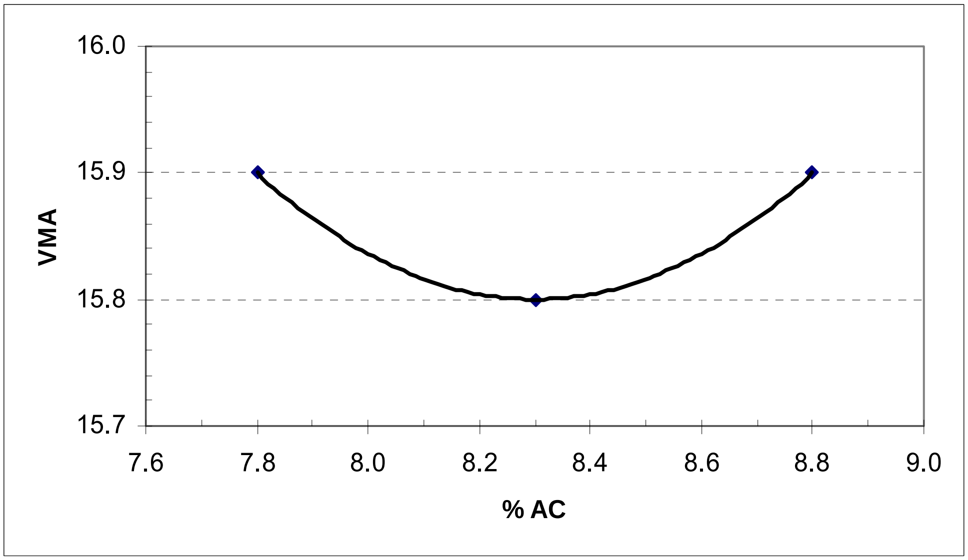
Binder Series for Virginia VA-75-4

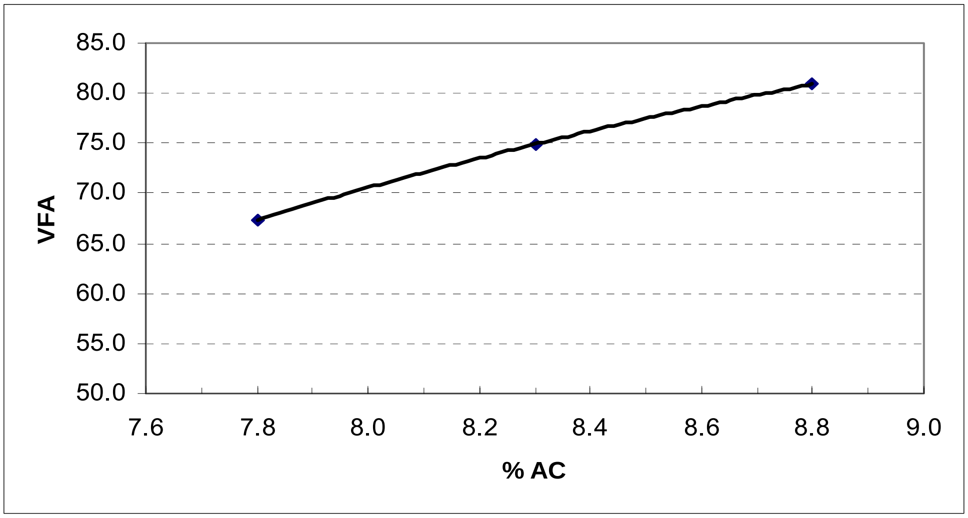
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	75	7.8	5.2	15.9	67.4
2	75	8.3	4.0	15.8	74.9
3	75	8.8	3.0	15.9	80.9

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	87.6	2.1	2.357	2.235
	88.5	1.9	2.341	2.248
	89.2	1.7	2.329	2.258







Verification for Virginia VA-75-4

Series	Ndes	%AC	Va	VMA	VFA
	75	8.3	4.0	15.8	74.9

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	88.5	1.9	2.341	2.248

JMF

sieve size	Blend 3	Spec			
3/8"	100.0	100 - 95			
#4	98.0	100 - 90	% Binder =	8.3	
#8	77.9		Ndes =	75	
#16	56.2	30 - 60	Design Va% =	4.0	Spec
#30	37.9		SE =	76	>40
#50	23.2		FAA =	45	>40
#100	14.9		VMA =	15.8	>16
#200	10.1	6 - 12	VFA =	4.9	70-80
Gsb	2.449		%Gmm@Nini =	88.5	?91.5
Gsa	2.683		DP =	1.9	0.9-2.0
Absorption%	3.575				

A1.5 Florida Mix Design

Trial Blends

Aggregate

	Stockpile	
sieve size	Screen	Sand
3/4"	100	100
1/2"	100	100
3/8"	100	100
#4	95.2	100.0
#8	77.0	99.9
#16	54.0	99.7
#30	36.3	95.4
#50	23.4	56.4
#100	11.8	10.5
#200	8.1	2.6
Gsb	2.458	2.623
Gsa	2.664	2.65
Absorption%	3.10	0.40

Trial Blend Proportions

Blend	Screen	Sand
1	85%	15%
2	100%	
3	92%	8%

Trial Blend Results

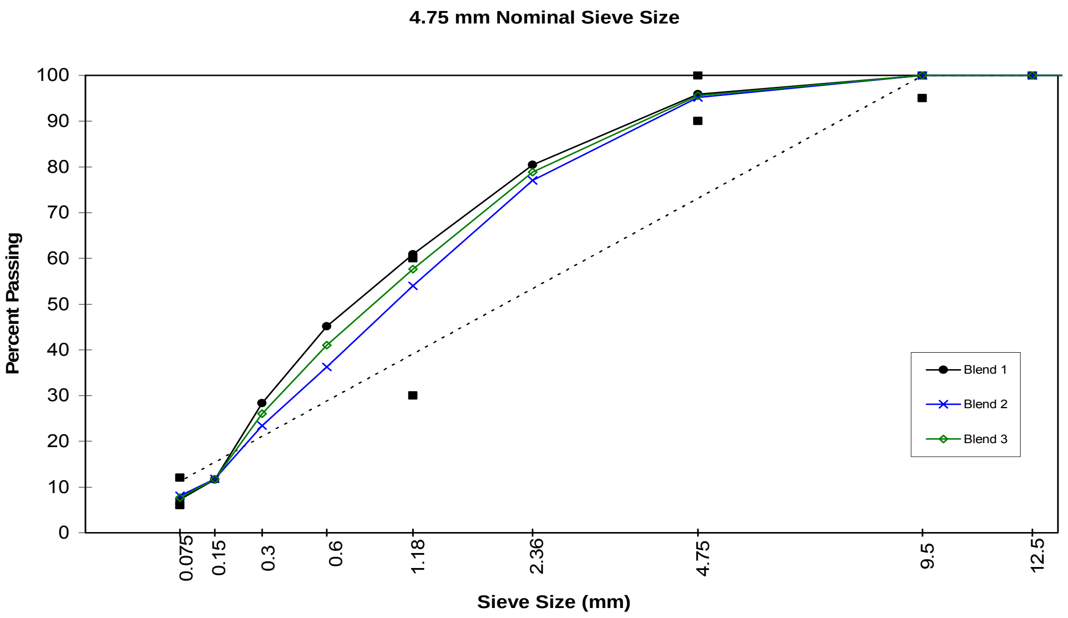
Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	13.6	24.1	43.6
2	50	7.0	15.8	24.9	36.4
3	50	7.0	13.6	23.5	42.3

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	80.9	1.4	2.343	2.025	2.592
2	77.7	1.7	2.359	1.986	2.613
3	80.3	1.5	2.350	2.031	2.601

Blend	Est. %ac	Est. VMA	Est. VFA
1	10.8	22.2	82
2	11.7	22.5	82.2
3	10.8	21.6	81.5

Blend 3 was chose for mix design

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	95.9	95.2	95.6
#8	80.4	77.0	78.8
#16	60.9	54.0	57.7
#30	45.2	36.3	41.0
#50	28.4	23.4	26.0
#100	11.6	11.8	11.7
#200	7.3	8.1	7.7
Gsb	2.481	2.458	2.470
Gsa	2.662	2.664	2.663
Absorption%	2.70	3.10	2.88



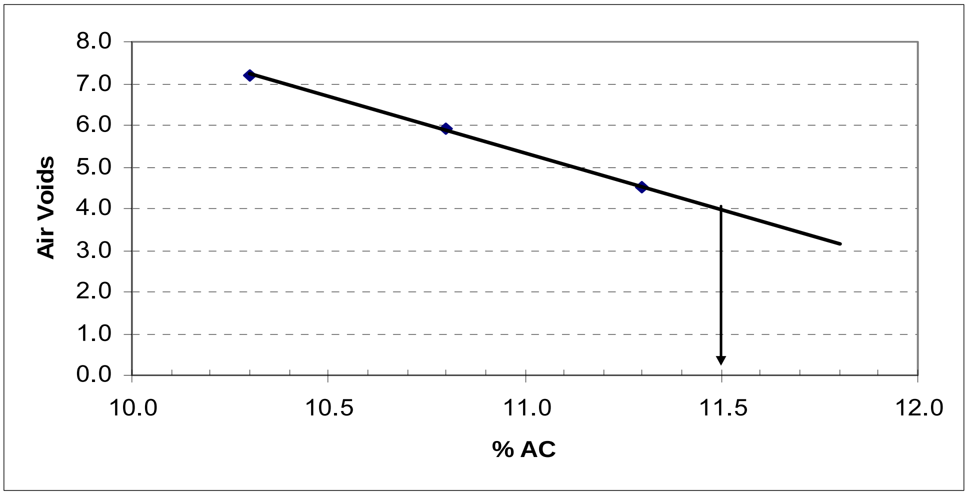
Binder Series for Florida FL-50-4

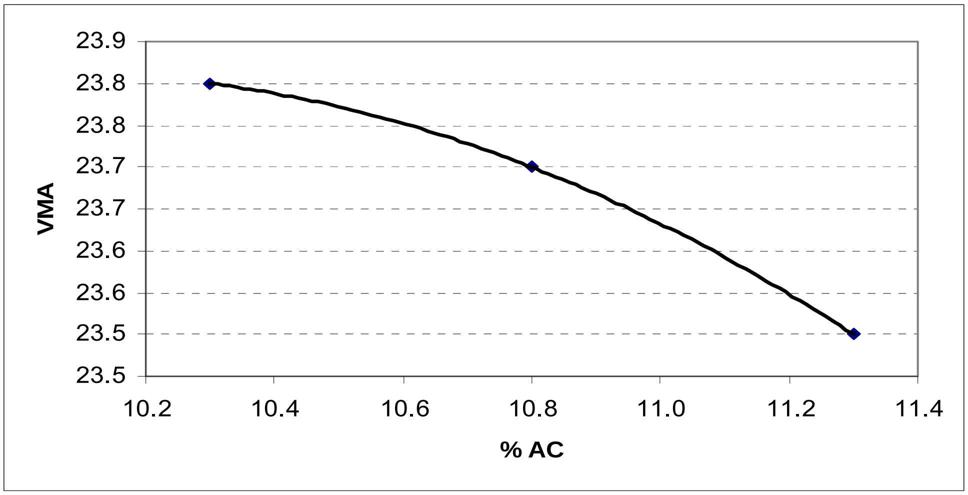
Binder Series Results

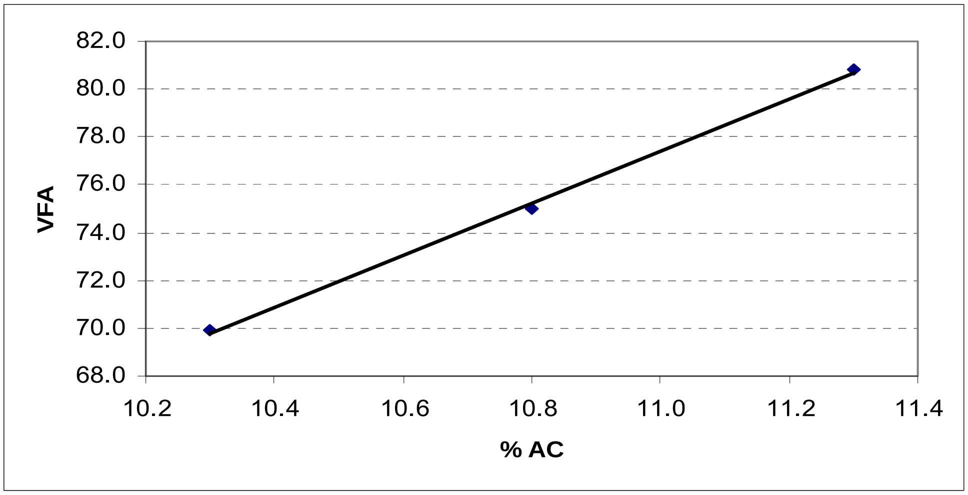
Series	Ndes	%AC	Va	VMA	VFA
1	50	10.3	7.2	23.8	69.9
2	50	10.8	5.9	23.7	75.0
3	50	11.3	4.5	23.5	80.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	85.7	0.9	2.26	2.098
2	86.6	0.9	2.245	2.112
3	87.7	0.8	2.231	2.13

Series	Est. %ac	Est. VMA	Est. VFA
1	11.6	23.2	82.7
2	11.6	23.3	82.9
3	11.5	23.4	82.9




23.9
23.8
23.8
23.7
23.7
23.6
23.6
23.5
23.5
VMA
10.2
10.4
10.6
10.8
11.0
11.2
11.4
% AC


82.0
80.0
78.0
76.0
74.0
72.0
70.0
68.0
VFA
10.2
10.4
10.6
10.8
11.0
11.2
11.4
% AC

Verification for Florida FL-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	11.8	4.1	24.2	82.8

Series	%Gmm@Nini	Dust$_{ratio}$	Gmm	Gmb
1	88.9	0.8	2.216	2.124

JMF

sieve size	Blend 3	Spec
1"	100.0	
3/4"	100.0	
1/2"	100.0	
3/8"	100.0	100 - 95
#4	95.6	100 - 90
#8	78.8	
#16	57.7	30 - 60
#30	41.0	
#50	26.0	
#100	11.7	
#200	7.7	6 - 12
Gsb	2.470	
Gsa	2.663	
Absorption%	2.884	

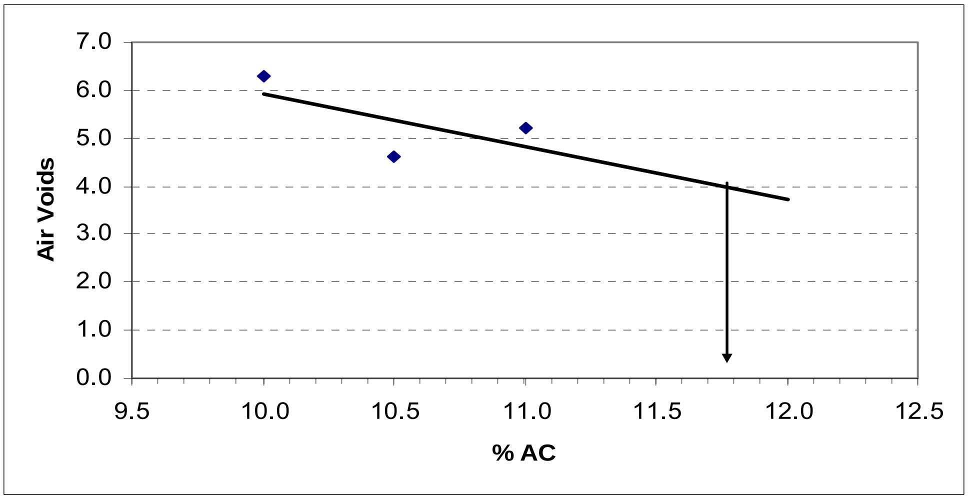
		Spec
% Binder =	11.8	
Ndes =	50	
Design Va% =	4.0	
SE =	67	>40
FAA =	46.3	>40
VMA =	24.2	>16
VFA =	82.8	70-80
%Gmm@Nini =	87.7	?91.5
DP =	0.8	0.9-2.0

Binder Series for Florida at 75 Gyrations

Series	Ndes	%AC	Va	VMA	VFA
1	75	10.0	6.3	22.5	71.9
2	75	10.5	4.6	22.0	79.2
3	75	11.0	5.2	23.5	77.9

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.0	1.0	2.270	2.126
2	87.3	0.9	2.255	2.152
3	87.5	0.9	2.240	2.124

Series	Est. %ac	Est. VMA	Est. VFA
1	10.9	22.1	81.9
2	10.7	21.9	81.7
3	11.5	23.2	82.8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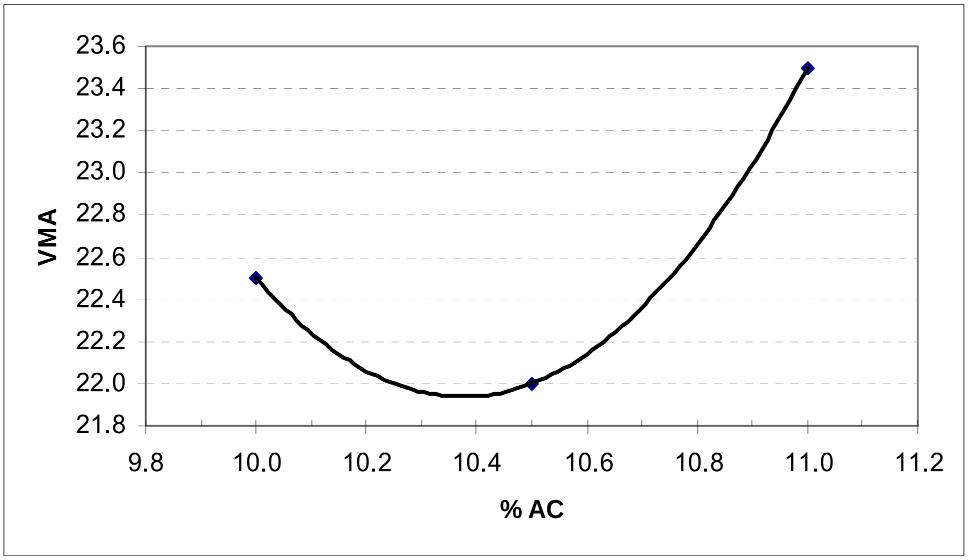
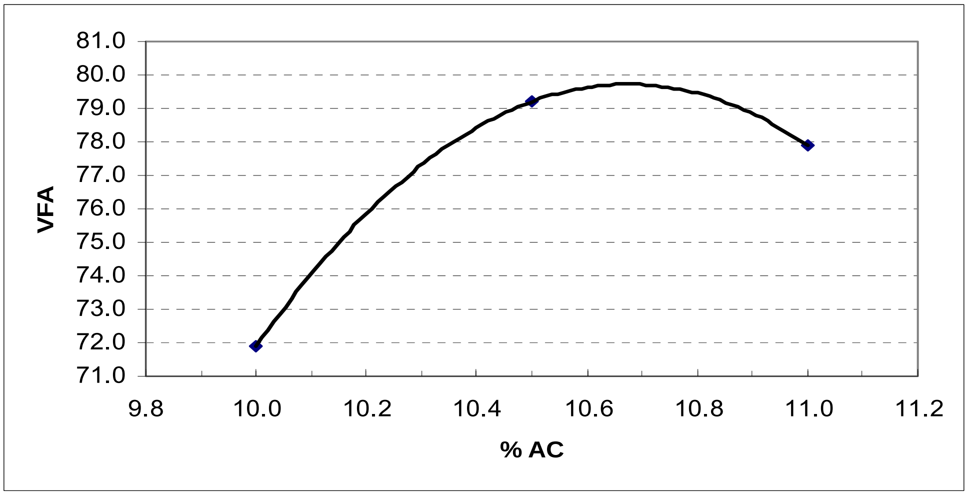
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Air Voids
9.5
10.0
10.5
11.0
11.5
12.0
12.5
% AC


23.6
23.4
23.2
23.0
22.8
22.6
22.4
22.2
22.0
21.8
VMA
9.8
10.0
10.2
10.4
10.6
10.8
11.0
11.2
% AC


81.0
80.0
79.0
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
VFA
9.8
10.0
10.2
10.4
10.6
10.8
11.0
11.2
% AC

Verification Series for Florida FL-75-4

Series	Ndes	%AC	Va	VMA	VFA
1	75	11.0	4.1	22.6	81.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.3	0.9	2.243	2.099

JMF

sieve size	Blend 3	Spec
1"	100.0	
3/4"	100.0	
1/2"	100.0	
3/8"	100.0	100 - 95
#4	95.6	100 - 90
#8	78.8	
#16	57.7	30 - 60
#30	41.0	
#50	26.0	
#100	11.7	
#200	7.7	6 - 12
Gsb	2.470	
Gsa	2.663	
Absorption%	2.884	

% Binder =	11	
Ndes =	75	
Design Va% =	4.0	Spec
SE =	67	>40
FAA =	46.3	>40
VMA =	22.6	>16
VFA =	81.8	70-80
%Gmm@Nini =	86.3	?91.5
DP =	0.9	0.9-2.0

Verification for Florida FL-75-6

Series	Ndes	%AC	Va	VMA	VFA
1	75	10.1	5.9	22.5	73.7

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.4	1.0	2.262	2.128

JMF

sieve size	Blend 3	Spec			
1"	100.0				
3/4"	100.0				
1/2"	100.0				
3/8"	100.0	100 - 95	% Binder =	10.1	
#4	95.6	100 - 90	Ndes =	75	
#8	78.8		Design Va% =	6.0	Spec
#16	57.7	30 - 60	SE =	67	>40
#30	41.0		FAA =	46.3	>40
#50	26.0		VMA =	22.5	>16
#100	11.7		VFA =	73.7	70-80
#200	7.7	6 - 12	%Gmm@Nini =	86.4	?91.5
Gsb	2.470		DP =	1	0.9-2.0
Gsa	2.663				
Absorption%	2.884				

A1.6 Connecticut Mix Design

Connecticut Trial Blends

Aggregate

sieve size	Stockpile WSD	W1/4"	NB	SS	SS sr
3/4"	100	100	100	100	100
1/2"	100	100	100	100	100
3/8"	100	100	100	99.9	100
#4	98.9	71.6	98.7	99.6	98.8
#8	53.4	10.1	47.3	72.1	46.0
#16	31.7	3.5	24.2	43.4	23.2
#30	22.7	1.8	19.6	28.9	19.0
#50	17.7	1.3	17.4	20.3	17.0
#100	13.6	1.1	15.2	12.7	15.1
#200	10.2	0.9	11.7	6.9	11.8
Gsb	2.832	2.861	2.789	2.787	2.720
Gsa	2.989	2.992	3.059	3.044	2.720
Absorption%	1.8	1.60	2.20	1.60	1.9

Trial Blend Proportions

Blend	WSD	W1/4"	NB	SS	SS sr
1	60%	20%	20%	0%	0%
2	0%	0%	0%	80%	20%
3	100%	0%	0%	0%	0%
4	0%	0%	0%	100%	0%

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	13.6	26.4	48.4
2	50	7.0	9	20.5	56.2
3	50	7.0	11.8	25.6	53.9
4	50	7.0	10.2	21.8	53.4

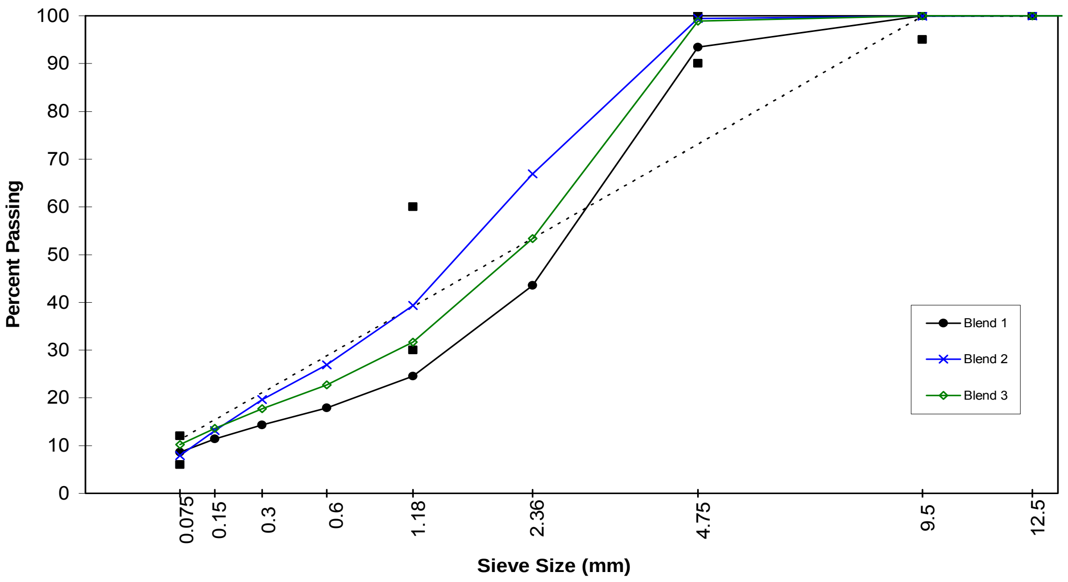
	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	77.6	1.5	2.591	2.238	2.925
2	82.5	1.6	2.605	2.371	2.944
3	78.9	1.6	2.568	2.265	2.893
4	81.5	1.3	2.608	2.342	2.948

Blend	Est. %ac	Est. VMA	Est. VFA	%Gmm@Nini
1	10.9	24.5	83.7	87.2
2	9	19.5	79.5	87.4
3	10.1	24.1	83.4	86.8
4	9.5	20.6	80.6	87.7

Blend 2 was chose for mix design

sieve size	Trial Blends Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	99.9	100.0
#4	93.4	99.4	98.9
#8	43.5	66.9	53.4
#16	24.6	39.4	31.7
#30	17.9	26.9	22.7
#50	14.4	19.6	17.7
#100	11.4	13.2	13.6
#200	8.6	7.9	10.2
Gsb	2.829	2.773	2.832
Gsa	3.004	2.973	2.989
Absorption%	1.84	1.66	1.80

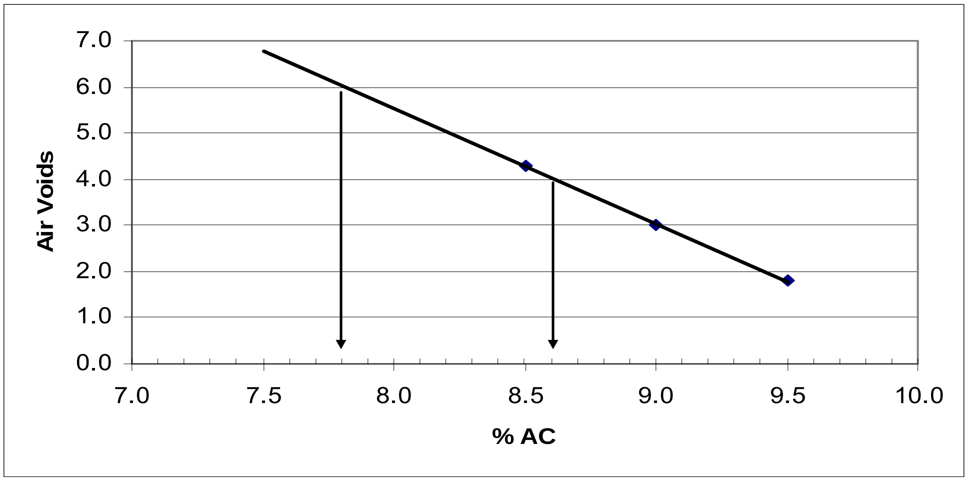
4.75 mm Nominal Sieve Size

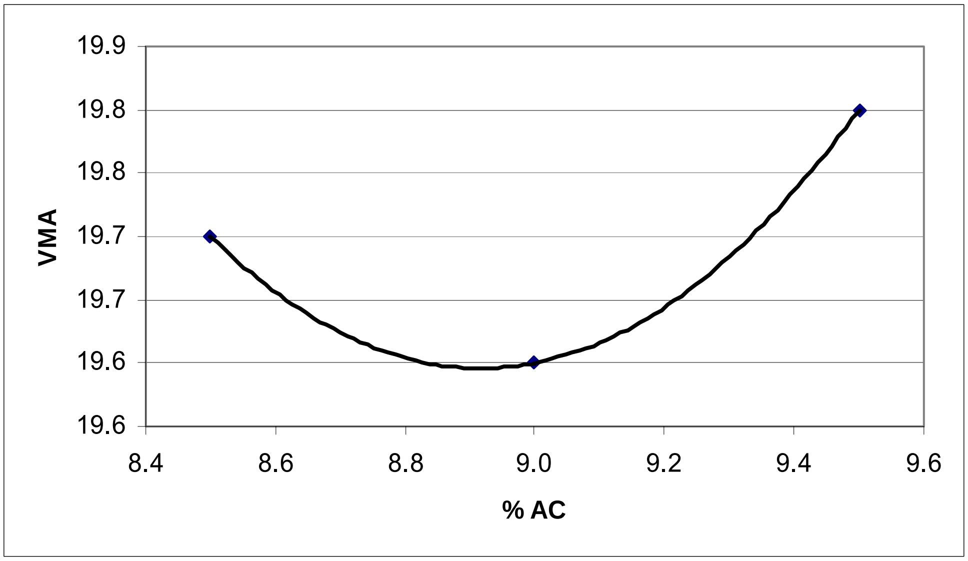


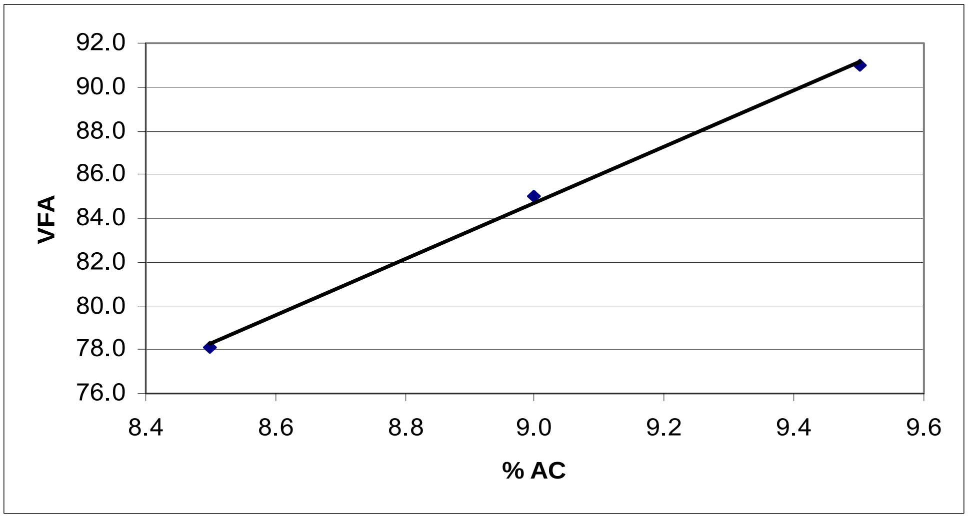
Connecticut Binder Series

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.5	4.3	19.7	78.1
2	50	9.0	3.0	19.6	85.0
3	50	9.5	1.8	19.8	91.0

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.1	1.2	2.543	2.433
2	87.4	1.1	2.523	2.448
3	88.5	1.0	2.503	2.459







Verification for Connecticut CT-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.8	3.8	19.9	80.9

Series	%Gmm@Nini	DP	Gmm	Gmb
1	86.8	1.2	2.531	2.435

JMF

sieve size	Blend 2	Spec
3/8"	100.0	100 - 95
#4	99.4	100 - 90
#8	66.9	
#16	39.4	30 - 60
#30	26.9	
#50	19.6	
#100	13.2	
#200	7.9	6 - 12
Gsb	2.773	
Gsa	2.973	
Absorption%	1.660	

% Binder =	8.8	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	79	>40
FAA =	40.7	>40
VMA =	19.9	>16
VFA =	80.9	70-80
%Gmm@Nini =	86.8	≤91.5
DP =	1.2	0.9-2.0

Verification for Connecticut CT-50-6

Series	Ndes	%AC	Va	VMA	VFA
1	50	7.2	6.0	19.0	68.5

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	85.1	1.4	2.574	2.42

JMF

sieve size	Blend 3	Spec
3/8"	100.0	100 - 95
#4	99.4	100 - 90
#8	66.9	
#16	39.4	30 - 60
#30	26.9	
#50	19.6	
#100	13.2	
#200	7.9	6 - 12
Gsb	2.773	
Gsa	2.973	
Absorption%	1.660	

% Binder =	7.2	
Ndes =	50	
Design Va% =	6.0	Spec
SE =	79	>40
FAA =	40.7	>40
VMA =	19.0	>16
VFA =	68.5	70-80
%Gmm@Nini =	85.1	?91.5
DP =	1.4	0.9-2.0

A1.7 Minnesota Mix Design

Minnesota Trial Blends

Aggregate

	Stockpile	
sieve size	Evtac	Evtac fine
3/4"	100	100
1/2"	100	100
3/8"	100	100
#4	97.7	100.0
#8	84.4	100.0
#16	55.3	100.0
#30	29.6	99.0
#50	12.3	95.0
#100	4.2	86.0
#200	2.2	71.6
Gsb	2.837	2.649
Gsa	2.991	2.803
Absorption%	1.80	1.80

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	98.0	97.8	97.9
#8	86.4	85.3	86.0
#16	61.1	58.0	59.8
#30	38.6	33.8	36.5
#50	23.1	17.3	20.6
#100	14.8	9.1	12.4
#200	11.2	6.4	9.1
Gsb	2.811	2.825	2.817
Gsa	2.965	2.979	2.971
Absorption%	1.80	1.80	1.80

Trial Blend Proportions

Blend	Evtac	Evtac fine
1	87%	13%
2	94%	6%
3	90%	10%

Trial Blend Results

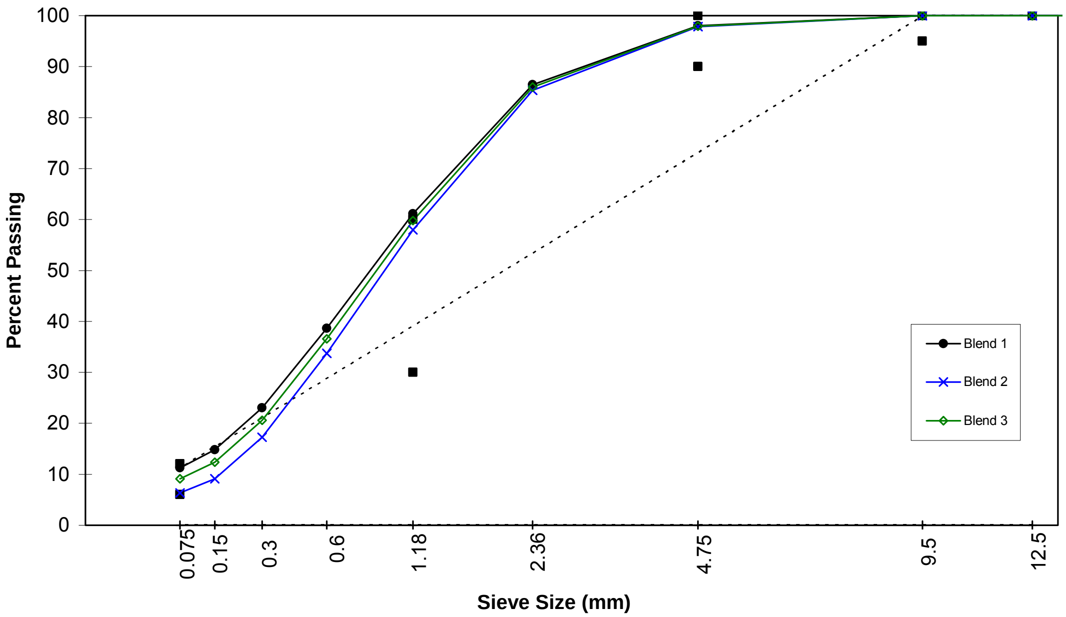
Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.5	8.2	21.6	62.1
2	50	7.5	13.7	26.7	48.8
3	50	7.5	9.6	23.1	58.2

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	84.2	1.9	2.596	2.384	2.961
2	79.4	1.1	2.593	2.239	2.957
3	82.5	1.5	2.593	2.343	2.957

Blend	Est. %ac	Est. VMA	Est. VFA	%Gmm@Nini
1	9.2	20.7	80.7	88.4
2	11.4	24.8	83.8	89.0
3	9.8	21.9	81.8	88.1

Blend 1 was chose for mix design

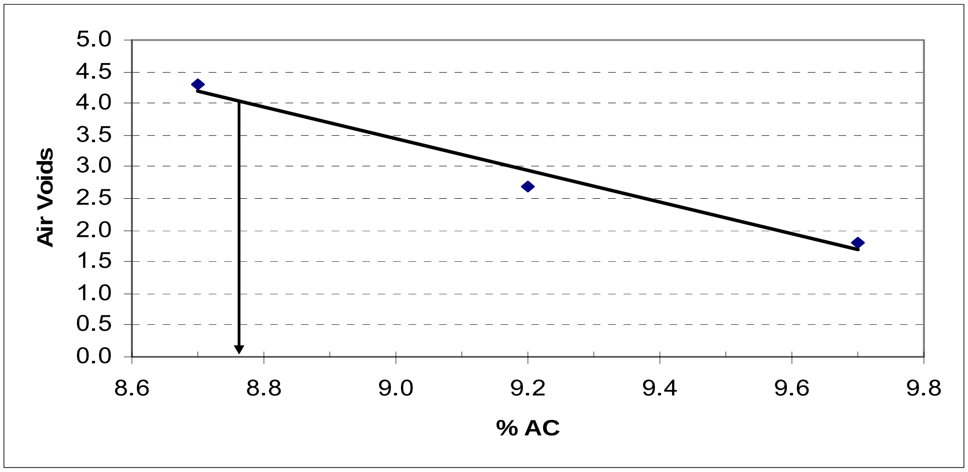
4.75 mm Nominal Sieve Size



Binder Series for Minnesota MN-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.7	4.3	21.0	79.7
2	50	9.2	2.7	20.8	86.9
3	50	9.7	1.8	21.2	91.3

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.2	1.6	2.540	2.432
2	88.7	1.5	2.520	2.451
3	90.4	1.4	2.500	2.545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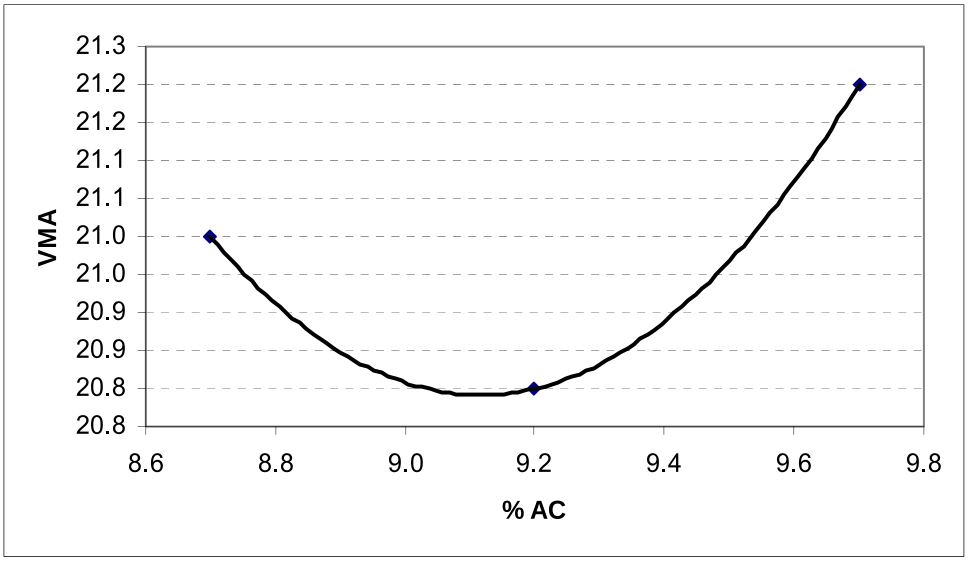
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Air Voids
8.6
8.8
9.0
9.2
9.4
9.6
9.8
% AC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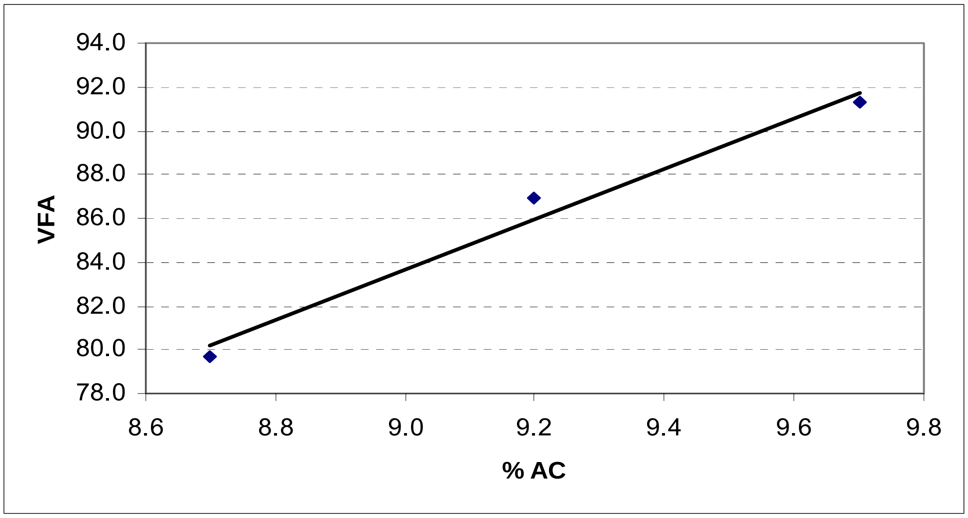
21.2
21.2
21.1
21.1
21.0
21.0
20.9
20.9
20.8
20.8
VMA
8.6
8.8
9.0
9.2
9.4
9.6
9.8
% AC



Verification for Minnesota MN-50-4

Series	Ndes	%AC	Va	VMA	VFA
	50	8.8	4.1	21.1	80.4

Series	%Gmm@Nini	DP	Gmm	Gmb
	87.5	1.6	2.536	2.431

JMF

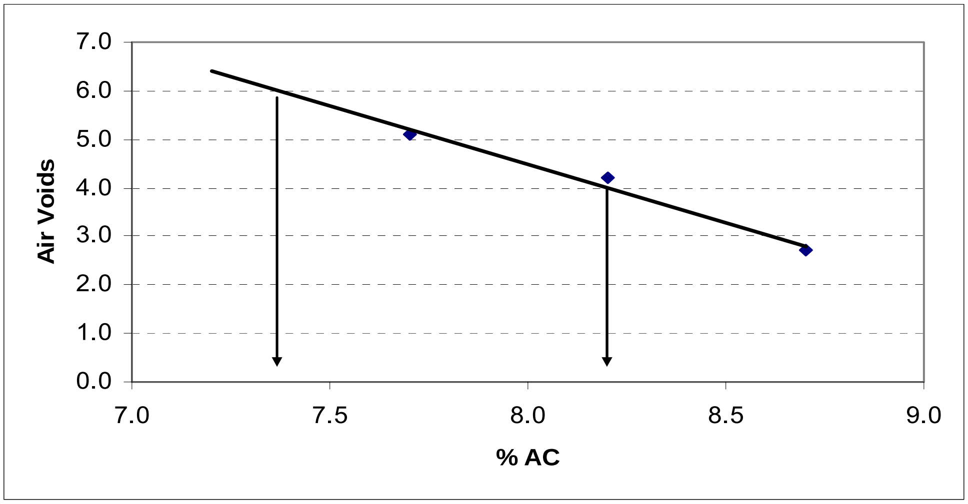
sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	86.4	
#16	61.1	30 - 60
#30	38.6	
#50	23.1	
#100	14.8	
#200	11.2	6 - 12
Gsb	2.811	
Gsa	2.965	
Absorption%	1.800	

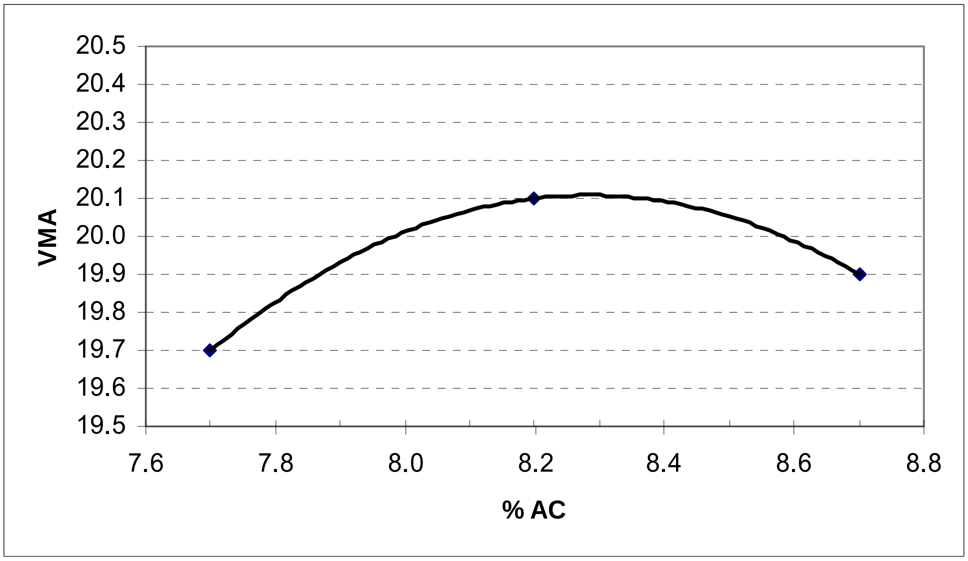
% Binder =	8.8	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	67	<40
FAA =	46.2	<40
VMA =	21.1	>16
VFA =	80.4	70-80
%Gmm@Nini =	87.5	?91.5
DP =	1.6	0.9-2.0

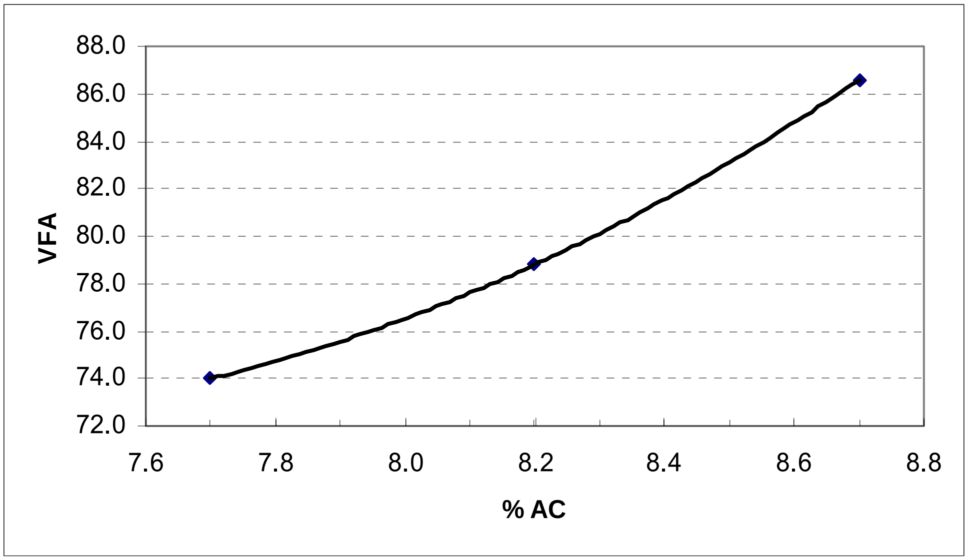
Binder Series for Minnesota at 75 Gyrations

Series	Ndes	%AC	Va	VMA	VFA
1	75	7.7	5.1	19.7	74.0
2	75	8.2	4.2	20.1	78.8
3	75	8.7	2.7	19.9	86.6

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.1	1.8	2.577	2.445
2	86.8	1.7	2.556	2.447
3	88.4	1.6	2.535	2.468







Verification for Minnesota MN-75-4

Series	Ndes	%AC	Va	VMA	VFA
	75	8.3	4.1	20.1	79.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	86.9	1.7	2.552	2.448

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	86.4	
#16	61.1	30 - 60
#30	38.6	
#50	23.1	
#100	14.8	
#200	11.2	6 - 12
Gsb	2.811	
Gsa	2.965	
Absorption%	1.800	

		Spec
% Binder =	8.3	
Ndes =	75	
Design Va% =	4.0	
SE =	67	>40
FAA =	46.2	>40
VMA =	20.1	>16
VFA =	79.8	70-80
%Gmm@Nini =	86.9	?91.5
DP =	1.7	0.9-2.0

Verification for Minnesota MN-75-6

Series	Ndes	%AC	Va	VMA	VFA
	75	7.4	5.9	19.7	70.1

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	85.3	1.9	2.590	2.437

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	86.4	
#16	61.1	30 - 60
#30	38.6	
#50	23.1	
#100	14.8	
#200	11.2	6 - 12
Gsb	2.811	
Gsa	2.965	
Absorption%	1.800	

% Binder =	7.4	
Ndes =	75	
Design Va% =	6.0	Spec
SE =	67	>40
FAA =	46.2	>40
VMA =	19.7	>16
VFA =	70.1	70-80
%Gmm@Nini =	85.3	?91.5
DP =	1.9	0.9-2.0

A1.8 New Hampshire Mix Design

Trial Blends

Aggregate

	Stockpile		
sieve size	WMS	D dust	Rap
3/4"	100	100	10
1/2"	100	100	100
3/8"	100	100	97.8
#4	99.4	99.4	67.4
#8	74.6	79.0	48.7
#16	48.6	57.6	37.1
#30	31.7	43.3	28.0
#50	18.7	31.8	19.8
#100	8.4	21.2	13.5
#200	3.7	13.0	9.0
Gsb	2.672	2.696	2.695
Gsa	2.746	2.762	2.762
Absorption%	1.00	0.90	0.95

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	99.7	99.8	99.7
#4	94.6	96.2	94.6
#8	71.2	72.8	71.4
#16	47.8	49.2	48.3
#30	32.3	33.5	33.0
#50	20.2	21.3	21.0
#100	10.4	11.3	11.2
#200	5.4	6.0	6.0
Gsb	2.678	2.679	2.679
Gsa	2.750	2.751	2.751
Absorption%	0.98	0.98	0.98

Trial Blend Proportions

Blend	WMS	D dust	Rap
1	75%	10%	15%
2	71%	19%	10%
3	69%	16%	15%

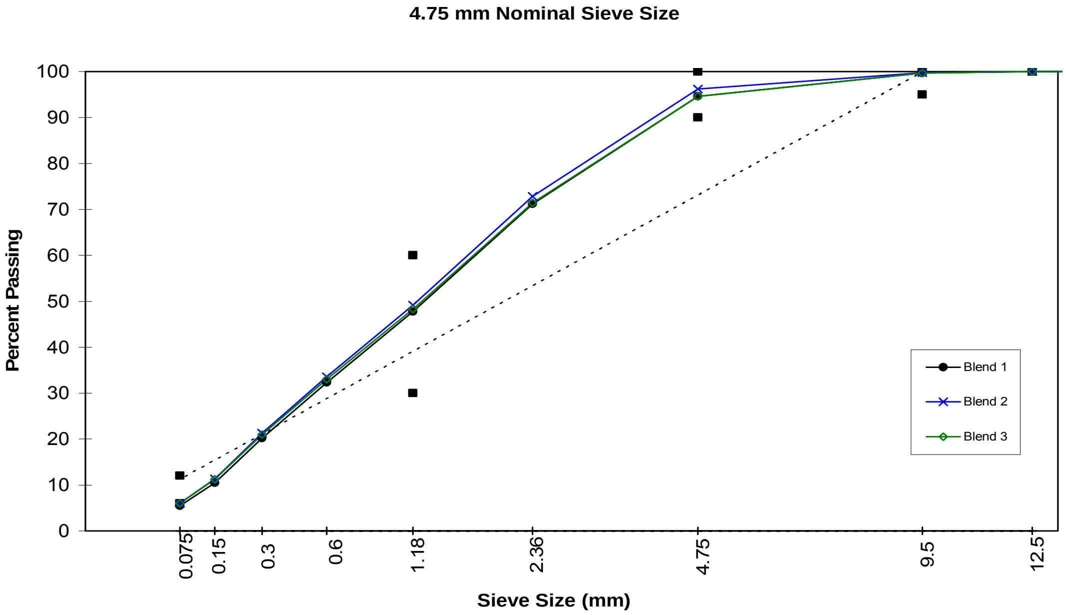
Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	11.5	24.7	53.6
2	50	7.0	11.9	24.9	52.2
3	50	8.8	4.0	22.2	81.8

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	82.7	0.9	2.450	2.169	2.734
2	82.4	1.0	2.455	2.163	2.740
3	90.2	1.5	2.397	2.300	2.749

Blend	Est. %ac	Est. VMA	Est. VFA
1	10.0	23.2	82.7
2	10.2	23.3	82.9
3	8.8	22.1	81.9

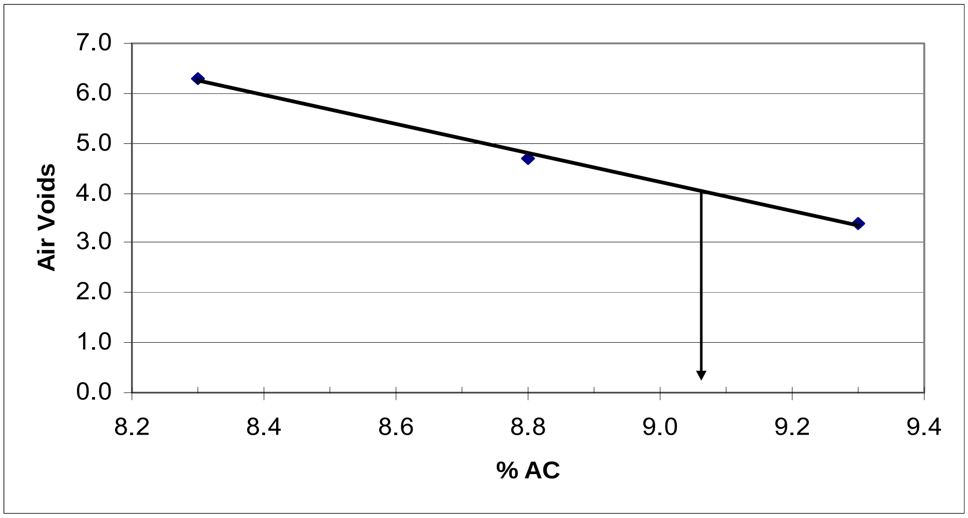
Blend 3 was chose for mix design

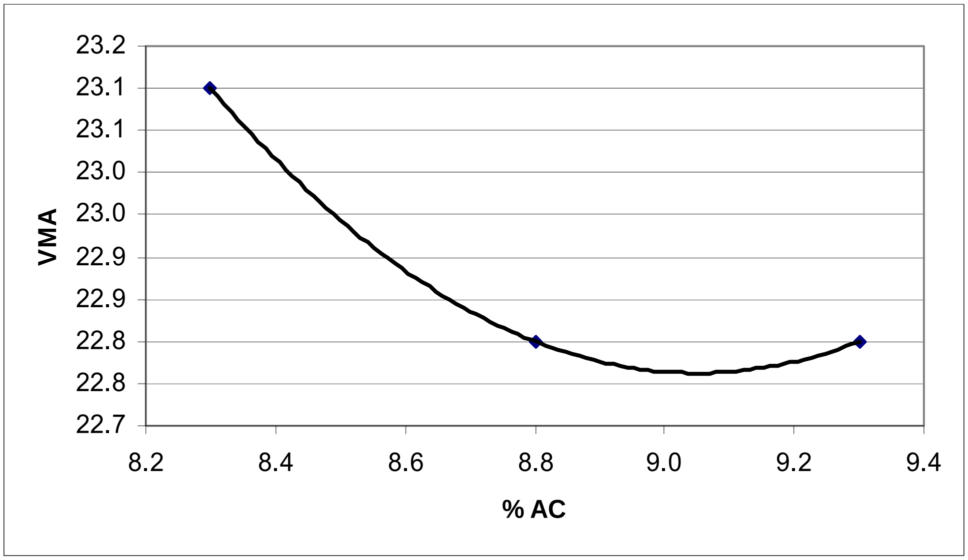


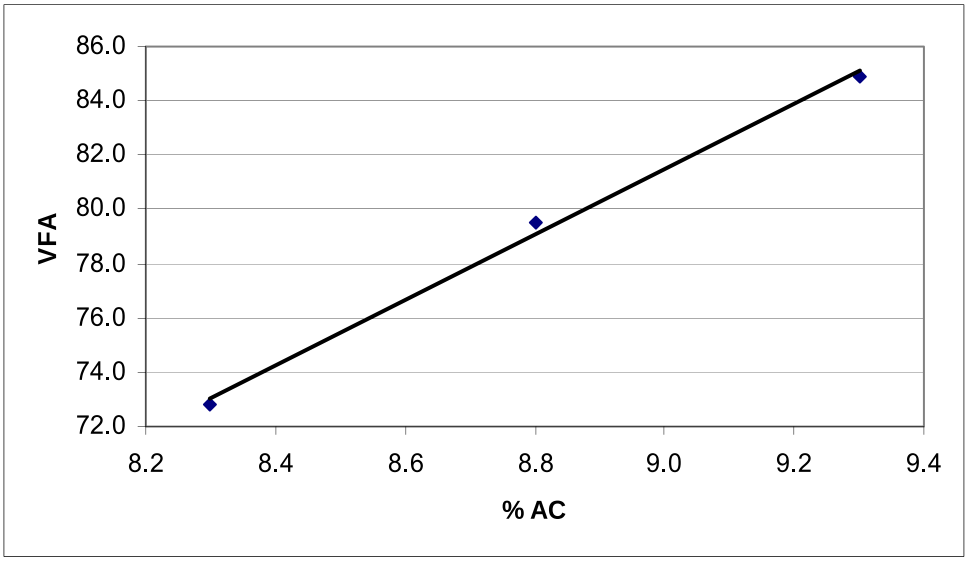
Binder Series for New Hampshire NH-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.3	6.3	23.1	72.8
2	50	8.8	4.7	22.8	79.5
3	50	9.3	3.4	22.8	84.9

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.7	1.2	2.405	2.254
2	89.1	1.1	2.387	2.275
3	90.6	1.0	2.369	2.287




23.2
23.1
23.1
23.0
23.0
22.9
22.9
22.8
22.8
22.7
VMA
8.2
8.4
8.6
8.8
9.0
9.2
9.4
% AC


86.0
84.0
82.0
80.0
78.0
76.0
74.0
72.0
VFA
8.2
8.4
8.6
8.8
9.0
9.2
9.4
% AC

Verification for New Hampshire NH-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	9.7	3.9	23.8	83.6

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	2.4	0.7	2.352	2.260

JMF

sieve size	Blend 3	Spec			
1"	100.0				
3/4"	100.0				
1/2"	100.0				
3/8"	99.7	100 - 95	% Binder =	9.7	
#4	94.6	100 - 90	Ndes =	50	
#8	71.4		Design Va% =	4.0	Spec
#16	48.3	30 - 60	SE =	85	>40
#30	33.0		FAA =	51	>40
#50	21.0		VMA =	23.8	>16
#100	11.2		VFA =	83.6	70-80
#200	6.0	6 - 12	%Gmm@Nini =	2.4	?91.5
Gsb	2.679		DP =	0.7	0.9-2.0
Gsa	2.751				
Absorption%	0.977				

Verification for New Hampshire NH-75-4

Series	Ndes	%AC	Va	VMA	VFA
1	75	9.3	3.7	22.9	84.0

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	89.4	0.7	2.365	2.279

JMF

sieve size	Blend 3	Spec			
1"	100.0				
3/4"	100.0				
1/2"	100.0				
3/8"	99.7	100 - 95	% Binder =	9.3	
#4	94.6	100 - 90	Ndes =	75	
#8	71.4		Design Va% =	4.0	Spec
#16	48.3	30 - 60	SE =	85	>40
#30	33.0		FAA =	51	>40
#50	21.0		VMA =	22.9	>16
#100	11.2		VFA =	84	70-80
#200	6.0	6 - 12	%Gmm@Nini =	89.4	?91.5
Gsb	2.679		DP =	0.7	0.9-2.0
Gsa	2.751				
Absorption%	0.977				

Verification for New Hampshire NH-75-6

Series	Ndes	%AC	Va	VMA	VFA
1	75	8.6	5.8	23.1	75.0

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.4	0.8	2.392	2.254

JMF

sieve size	Blend 3	Spec
1"	100.0	
3/4"	100.0	
1/2"	100.0	
3/8"	99.7	100 - 95
#4	94.6	100 - 90
#8	71.4	
#16	48.3	30 - 60
#30	33.0	
#50	21.0	
#100	11.2	
#200	6.0	6 - 12
Gsb	2.679	
Gsa	2.751	
Absorption%	0.977	

% Binder =	8.6	
Ndes =	75	
Design Va% =	6.0	Spec
SE =	85	>40
FAA =	51	>40
VMA =	23.1	>16
VFA =	75	70-80
%Gmm@Nini =	87.4	?91.5
DP =	0.8	0.9-2.0

A1.9 Wisconsin Mix Design

Wisconsin Trial Blends

Aggregate

	Stockpile		
sieve size	1/4"	Manf.	Nat.Sand
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	99.8
#4	84.6	93.5	87.2
#8	49.0	65.3	72.6
#16	33.9	40.0	57.8
#30	25.9	23.7	41.0
#50	21.3	13.0	14.9
#100	18.1	7.7	5.1
#200	14.7	5.5	3.8
Gsb	2.694	2.703	2.614
Gsa	2.852	2.828	2.744
Absorption%	2.10	1.60	1.80

Trial Blend Proportions

Blend	1/4"	Manf.	Nat.Sand
1	20%	65%	15%
2	30%	50%	20%
3	44%	56%	

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	3.5	16.2	78.7
2	50	7.0	3.3	16.0	79.6
3	50	7.0	3.6	16.3	78.0

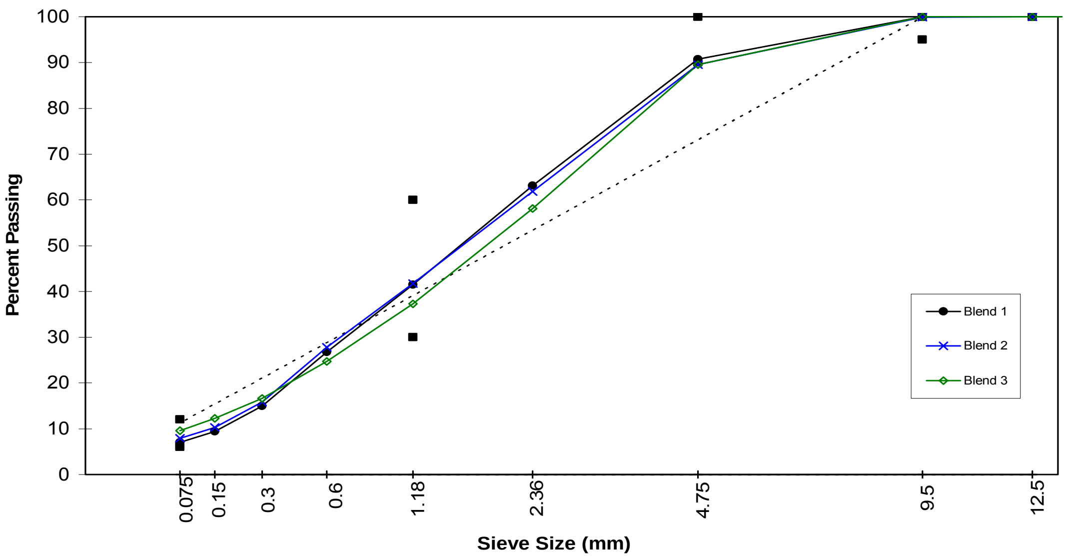
Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	88.4	1.3	2.507	2.42	2.81
2	88.9	1.5	2.504	2.422	2.806
3	87.5	1.8	2.519	2.429	2.827

Blend	Est. %ac	Est. VMA	Est. VFA	%Gmm@Nini
1	6.8	16.3	75.4	87.9
2	6.7	16.1	75.1	88.2
3	6.8	16.4	75.5	87.1

Blend 1 was chose for mix design

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	90.8	89.6	89.6
#8	63.1	61.9	58.1
#16	41.5	41.7	37.3
#30	26.7	27.8	24.7
#50	14.9	15.9	16.7
#100	9.4	10.3	12.3
#200	7.1	7.9	9.5
Gsb	2.687	2.683	2.699
Gsa	2.820	2.818	2.839
Absorption%	1.73	1.79	1.82

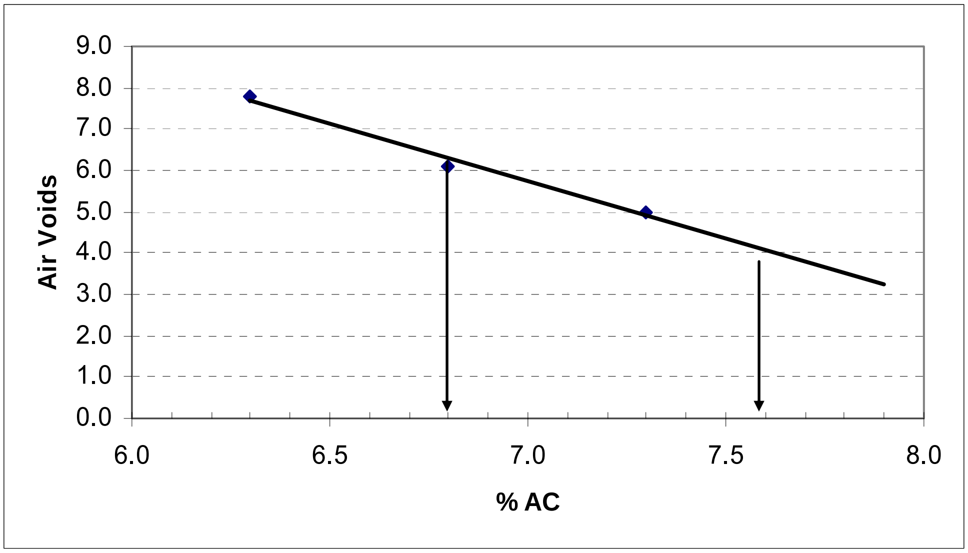
4.75 mm Nominal Sieve Size

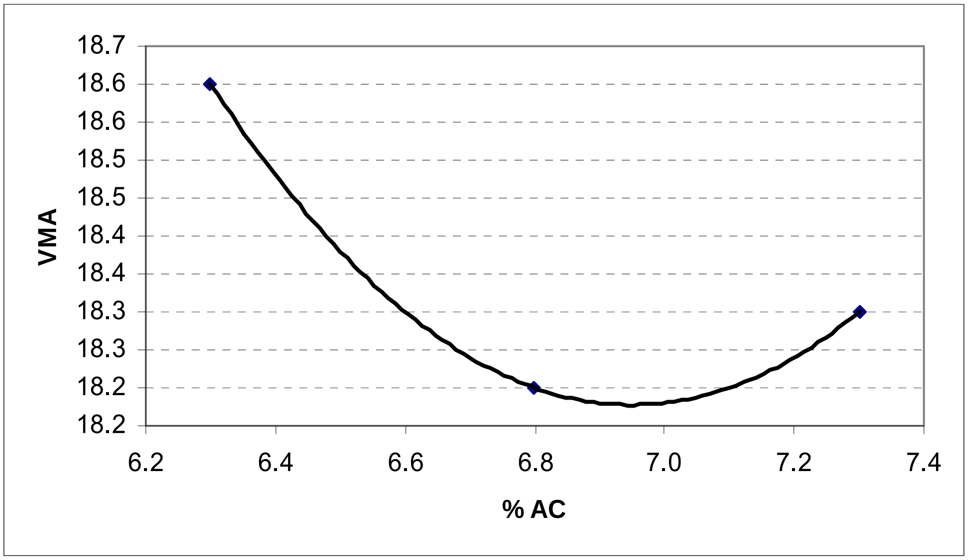


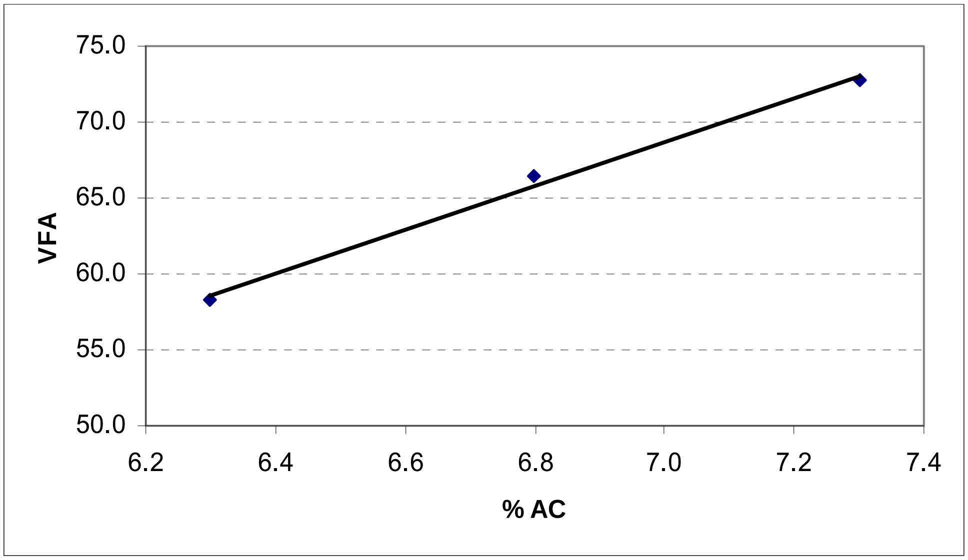
Binder Series for Wisconsin

Series	Ndes	%AC	Va	VMA	VFA
1	50	6.3	7.8	18.6	58.3
2	50	6.8	6.1	18.2	66.4
3	50	7.3	5	18.3	72.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	84.3	1.5	2.530	2.333
2	85.6	1.3	2.511	2.357
3	86.5	1.2	2.491	2.367







Verification for Wisconsin WI-50-4

Series	Ndes	%AC	Va	VMA	VFA
	50	7.5	4.1	18	77.4

Series	%Gmm@Nini	DP	Gmm	Gmb
	87.7	1.2	2.484	2.383

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	90.8	100 - 90
#8	63.1	
#16	41.5	30 - 60
#30	26.7	
#50	14.9	
#100	9.4	
#200	7.1	6 - 12
Gsb	2.687	
Gsa	2.820	
Absorption%	1.730	

		Spec
% Binder =	7.5	
Ndes =	50	
Design Va% =	4.0	
SE =	81	>40
FAA =	43.7	>40
VMA =	18	>16
VFA =	77.5	70-80
%Gmm@Nini =	87.7	?91.5
DP =	1.2	0.9-2.0

Verification for Wisconsin WI-50-6

Series	Ndes	%AC	Va	VMA	VFA
	50	6.7	5.9	17.8	66.9

Series	%Gmm@Nini	DP	Gmm	Gmb
	86.7	1.4	2.515	2.367

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	90.8	100 - 90
#8	63.1	
#16	41.5	30 - 60
#30	26.7	
#50	14.9	
#100	9.4	
#200	7.1	6 - 12
Gsb	2.687	
Gsa	2.820	
Absorption%	1.730	

% Binder =	6.7	
Ndes =	50	
Design Va% =	6.0	Spec
SE =	81	<40
FAA =	43.7	<40
VMA =	17.8	>16
VFA =	66.9	70-80
%Gmm@Nini =	86.7	?91.5
DP =	1.4	0.9-2.0

A1.10 Wisconsin Blend Adjustment

Trial Blends for Wisconsin Blend Adjustment

Aggregate

sieve size	Stockpile 1/4"	Manf.	Nat.Sand
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	99.8
#4	84.6	93.5	87.2
#8	49.0	65.3	72.6
#16	33.9	40.0	57.8
#30	25.9	23.7	41.0
#50	21.3	13.0	14.9
#100	18.1	7.7	5.1
#200	14.7	5.5	3.8
Gsb	2.694	2.703	2.614
Gsa	2.852	2.828	2.744
Absorption%	2.10	1.60	1.80

Trial Blend Proportions

Blend	1/4"	Manf.	Nat.Sand
1	44%	56%	
2	70%	30%	
3			

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.0	2.7	15.6	82.5
2	50	7.0	1.8	14.4	87.7

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	88.1	1.8	2.519	2.450	2.827
2	90.3	2.3	2.526	2.481	2.836

sieve size	Trial Blends Blend 1	Blend 2
1"	100	100
3/4"	100	100
1/2"	100	100
3/8"	100.0	100.0
#4	89.6	87.3
#8	58.1	53.9
#16	37.3	35.7
#30	24.7	25.2
#50	16.7	18.8
#100	12.3	15.0
#200	9.5	11.9
Gsb	2.699	2.697
Gsa	2.839	2.845
Absorption%	1.82	1.95

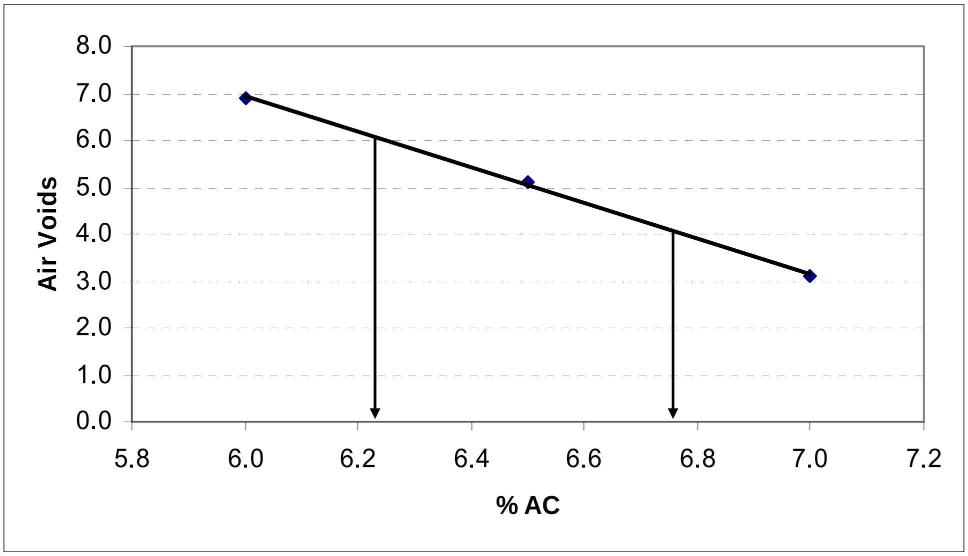
Blend 1 was chose for mix design

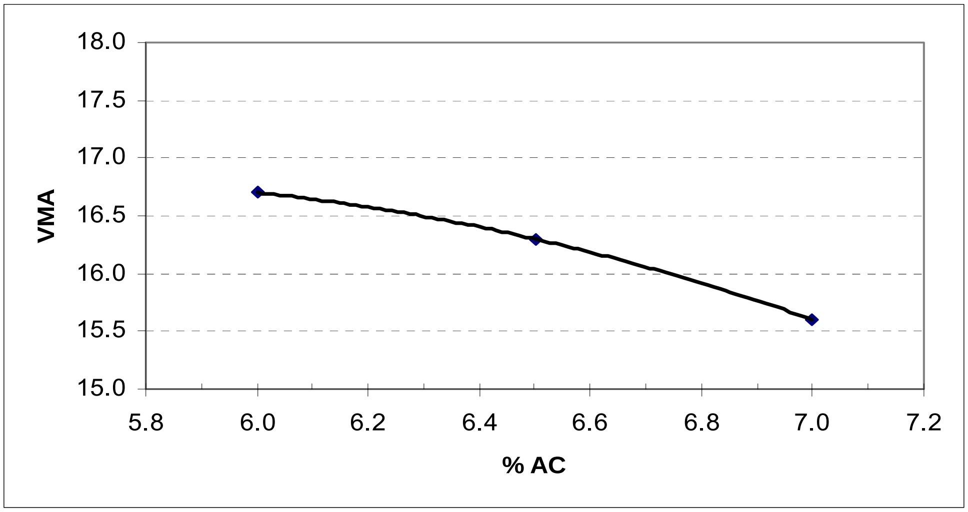
Binder Series for Wisconsin Blend Adjustment

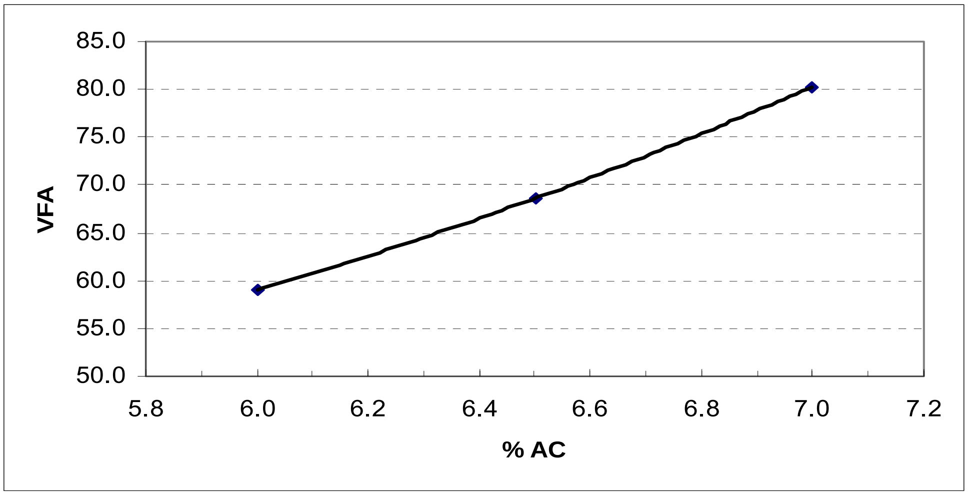
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	6.0	6.9	16.7	59.0
2	50	6.5	5.1	16.3	68.6
3	50	7.0	3.1	15.6	80.3

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	84.5	2.2	2.567	2.391
2	85.9	2	2.547	2.417
3	88.1	1.8	2.527	2.449


Air Voids
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
% AC


VMA
18.0
17.5
17.0
16.5
16.0
15.5
15.0
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
% AC



Verification for Wisconsin Blend Adjustment WI adj-50-4

Series	Ndes	%AC	Va	VMA	VFA
	50	6.8	4.1	16.1	74.4

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	87.1	1.9	2.535	2.431

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	89.6	100 - 90
#8	58.1	
#16	37.3	30 - 60
#30	24.7	
#50	16.7	
#100	12.3	
#200	9.5	6 - 12
Gsb	2.699	
Gsa	2.839	
Absorption%	1.820	

% Binder =	6.8	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	81	>40
FAA =	45.8	>40
VMA =	16.1	>16
VFA =	74.4	70-80
%Gmm@Nini =	87.1	?91.5
DP =	1.9	0.9-2.0

Verification for Wisconsin Blend Adjustment WI adj-50-6

Series	Ndes	%AC	Va	VMA	VFA
	50	6.3	5.9	16.5	64.4

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
	85.3	2.1	2.555	2.405

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	89.6	100 - 90
#8	58.1	
#16	37.3	30 - 60
#30	24.7	
#50	16.7	
#100	12.3	
#200	9.5	6 - 12
Gsb	2.699	
Gsa	2.839	
Absorption%	1.820	

% Binder =	6.3	
Ndes =	50	
Design Va% =	6.0	Spec
SE =	81	>40
FAA =	45.8	>40
VMA =	16.5	>16
VFA =	64.4	70-80
%Gmm@Nini =	85.3	≤91.5
DP =	2.1	0.9-2.0

A1.11 Florida Blend Adjustment Mix Design

Florida Blend Adjustment Aggregate Trials

Aggregate

	Stockpile		
sieve size	Screen	Sand	Bag house
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	100
#4	95.2	100.0	100.0
#8	77.0	99.9	100.0
#16	54.0	99.7	100.0
#30	36.3	95.4	100.0
#50	23.4	56.4	100.0
#100	11.8	10.5	100.0
#200	8.1	2.6	100.0
Gsb	2.458	2.623	2.532
Gsa	2.664	2.65	2.532
Absorption%	3.10	0.40	0.00

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	100.0
#4	95.7	95.6	95.6
#8	79.3	78.8	79.1
#16	58.6	57.7	58.1
#30	42.3	41.2	41.9
#50	27.6	27.8	29.0
#100	13.5	15.3	17.1
#200	9.5	11.6	13.4
Gsb	2.470	2.467	2.467
Gsa	2.663	2.658	2.655
Absorption%	2.88	2.87	2.83

Trial Blend Proportions

Blend	Screen	Sand	B.House
1	90%	8%	2%
2	92%	4%	4%
3	91%	3%	6%

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	10.5	3.8	21.9	82.6
2	50	10.5	3.7	21.4	82.8
3	50	10.5	2.1	20.3	89.5

Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	89.4	1.1	2.241	2.155	2.6
2	88.9	1.4	2.247	2.164	2.609
3	90.7	1.6	2.240	2.192	2.598

Blend	Est. %ac	Est. VMA	Est. VFA
1	10.4	21.9	81.7
2	10.4	21.4	81.3
3	9.8	20.5	80.5

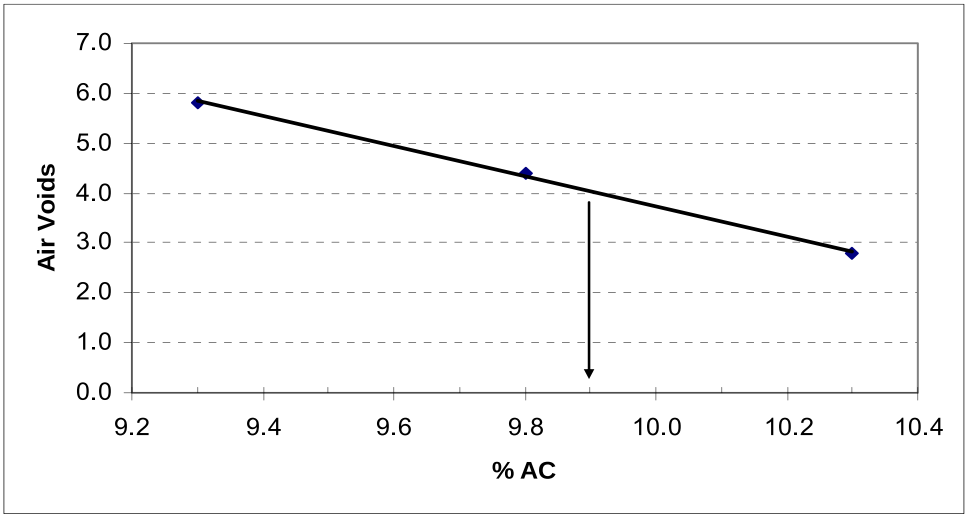
Blend 3 was chose for mix design

Binder Series for Florida Blend Adjustment FL adj-50-4

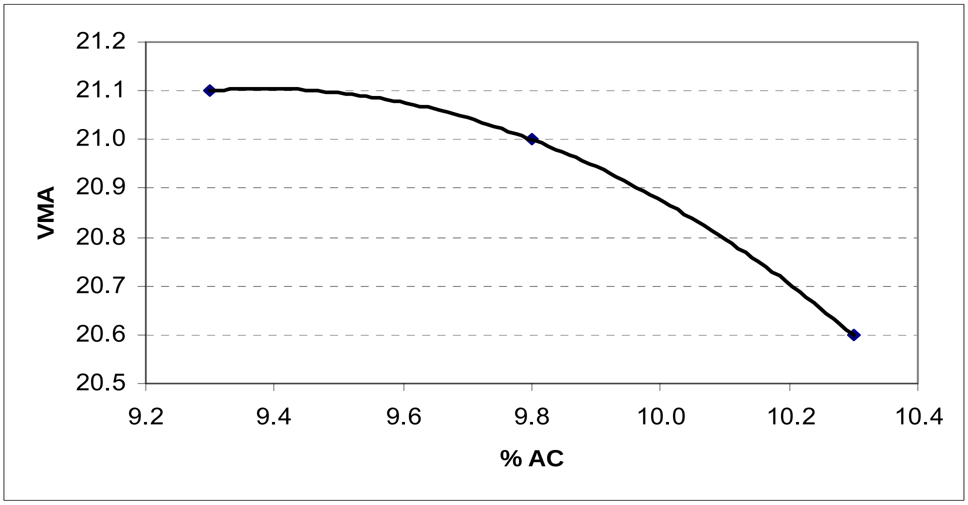
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	9.3	5.8	21.1	72.8
2	50	9.8	4.4	21.0	78.9
3	50	10.3	2.8	20.6	86.6

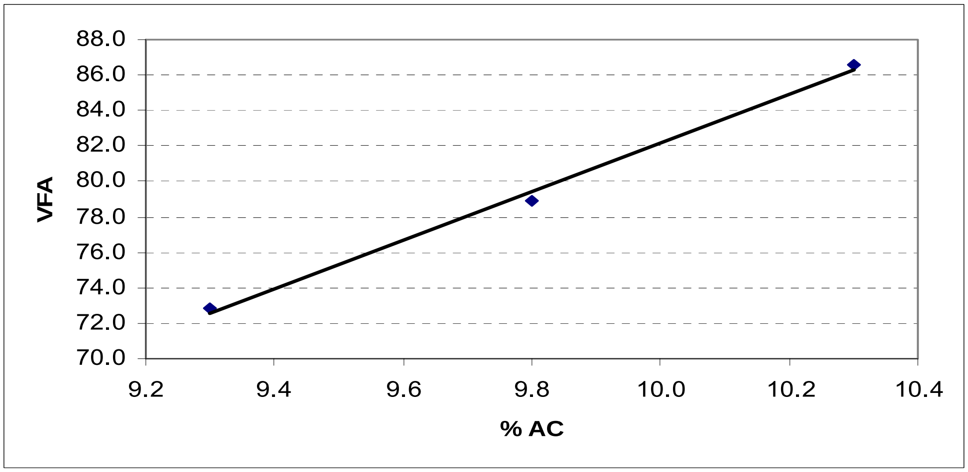
Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.7	1.8	2.276	2.145
2	88.1	1.7	2.261	2.161
3	90.4	1.6	2.246	2.184



7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Air Voids
9.2
9.4
9.6
9.8
10.0
10.2
10.4
% AC



21.2
21.1
21.0
20.9
20.8
20.7
20.6
20.5
VMA
9.2
9.4
9.6
9.8
10.0
10.2
10.4
% AC



88.0
86.0
84.0
82.0
80.0
78.0
76.0
74.0
72.0
70.0
VFA
9.2
9.4
9.6
9.8
10.0
10.2
10.4
% AC

Verification for Florida Blend Adjustment FLadj-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	10.0	4.0	21.1	80.8

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	88.9	1.7	2.255	2.164

JMF

sieve size	Blend 3	Spec
1"	100.0	
3/4"	100.0	
1/2"	100.0	
3/8"	100.0	100 - 95
#4	95.6	100 - 90
#8	79.1	
#16	58.1	30 - 60
#30	41.9	
#50	29.0	
#100	17.1	
#200	13.4	6 - 12
Gsb	2.467	
Gsa	2.655	
Absorption%	2.830	

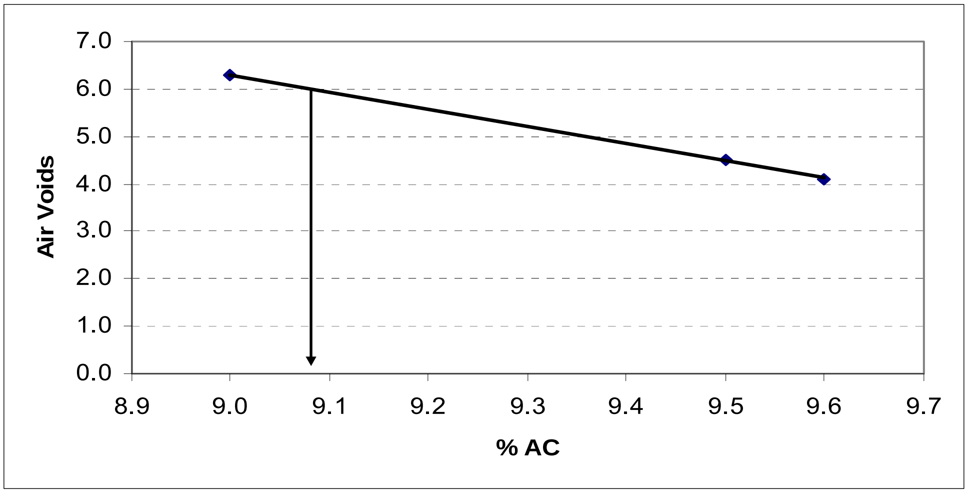
% Binder =	10.0	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	79	>40
FAA =	44.5	>40
VMA =	21.1	>16
VFA =	80.8	70-80
%Gmm@Nini =	88.9	?91.5
DP =	1.7	0.9-2.0

Binder Series for Florida Blend Adjustments FLadj-75-6

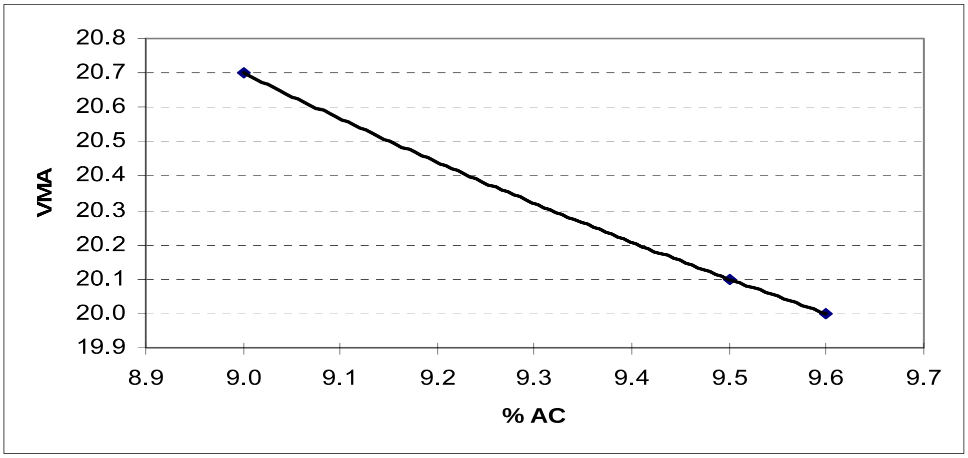
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	75	9.0	6.3	20.7	69.5
2	75	9.5	4.5	20.1	77.6
3	75	9.6	4.1	20.0	79.6

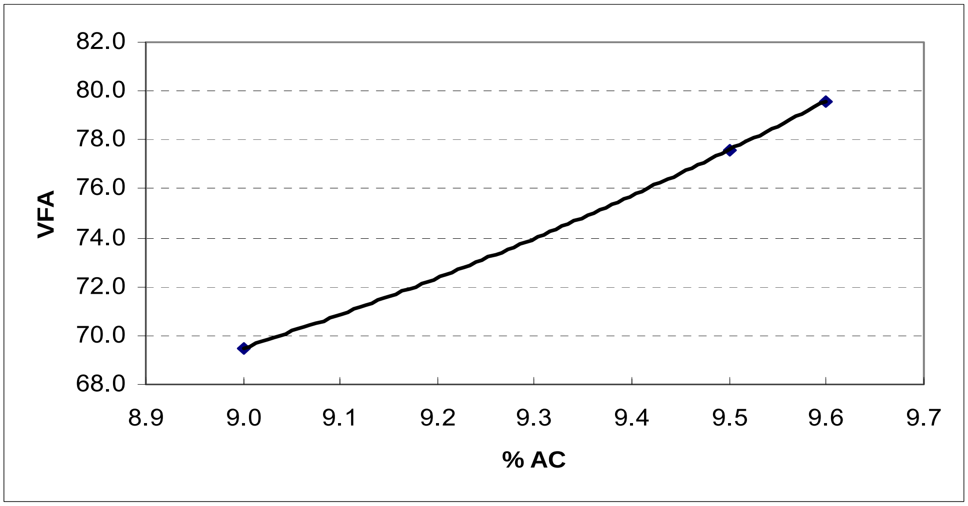
Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.4	1.9	2.295	2.15
2	87.8	1.8	2.28	2.177
3	88.4	1.8	2.277	2.184



7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Air Voids
8.9
9.0
9.1
9.2
9.3
9.4
9.5
9.6
9.7
% AC



20.8
20.7
20.6
20.5
20.4
20.3
20.2
20.1
20.0
19.9
VMA
8.9
9.0
9.1
9.2
9.3
9.4
9.5
9.6
9.7
% AC



82.0
80.0
78.0
76.0
74.0
72.0
70.0
68.0
VFA
8.9
9.0
9.1
9.2
9.3
9.4
9.5
9.6
9.7
% AC

Verification for Florida Blend Adjustment FLadj-75-6

Series	Ndes	%AC	Va	VMA	VFA
1	75	9.1	6.0	20.6	71.0

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.7	1.9	2.292	2.155

JMF

sieve size	Blend 3	Spec
1"	100.0	
3/4"	100.0	
1/2"	100.0	
3/8"	100.0	100 - 95
#4	95.6	100 - 90
#8	79.1	
#16	58.1	30 - 60
#30	41.9	
#50	29.0	
#100	17.1	
#200	13.4	6 - 12
Gsb	2.467	
Gsa	2.655	
Absorption%	2.830	

% Binder =	9.1	
Ndes =	75	
Design Va% =	6.0	Spec
SE =	79	>40
FAA =	44.5	>40
VMA =	20.6	>16
VFA =	71.0	70-80
%Gmm@Nini =	86.7	≤91.5
DP =	1.9	0.9-2.0

A1.12 Virginia Blend Adjustment Mix Design

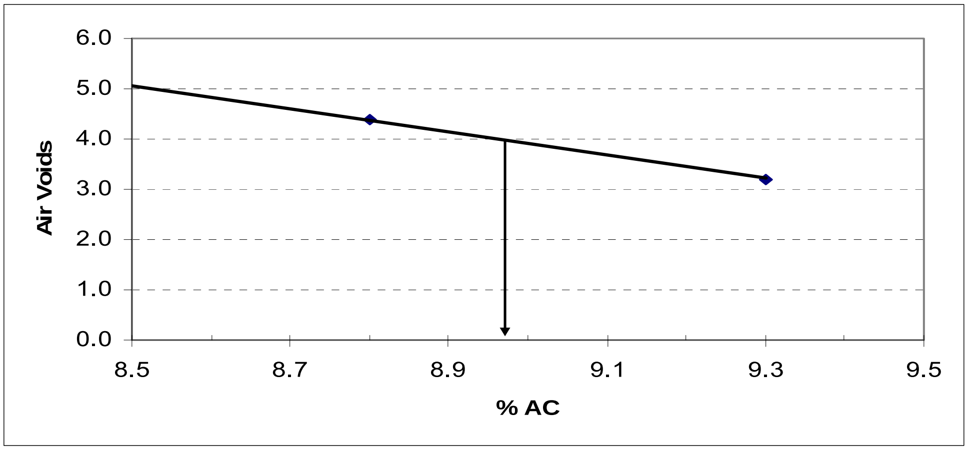
Bend Adjustment was performed with Citco PG 70-22 Binder

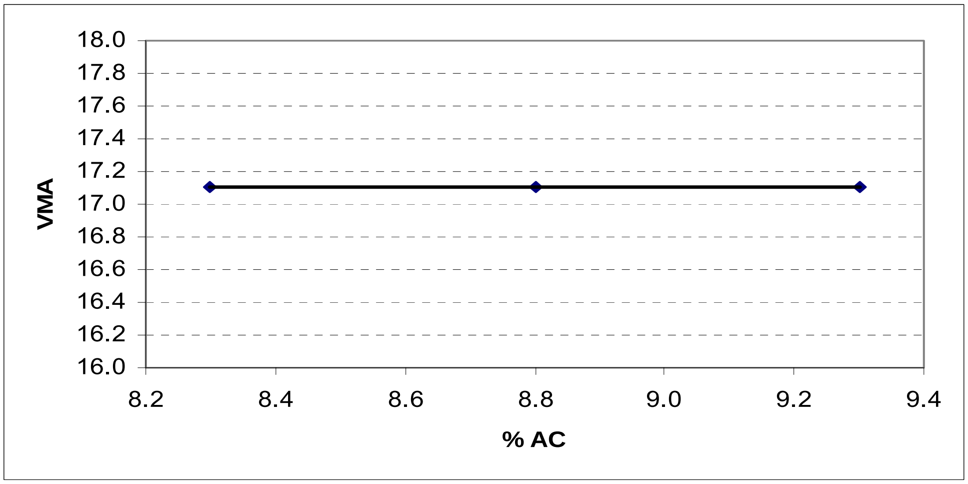
Binder Series for Virginia Blend Adjustment VAadj-50-4

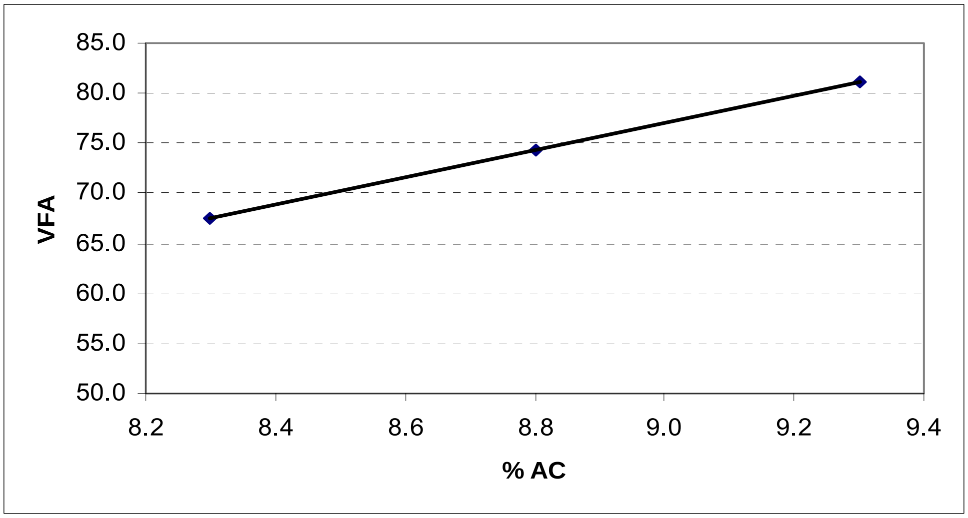
Binder Series Results

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.3	5.5	17.1	67.5
2	50	8.8	4.4	17.1	74.3
3	50	9.3	3.2	17.1	81.1

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	87.3	1.9	2.345	2.215
2	88.3	1.7	2.329	2.227
3	89.4	1.6	2.313	2.238







Verification for Virginia Blend Adjustment VAadj-50-4

Series	Ndes	%AC	Va	VMA	VFA
1	50	9.0	4.0	16.8	76.4

Series	%Gmm@Nini	DP	Gmm	Gmb
1	88.5	1.7	2.331	2.238

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	77.9	
#16	56.2	30 - 60
#30	37.9	
#50	23.2	
#100	14.9	
#200	10.1	6 - 12
Gsb	2.449	
Gsa	2.683	
Absorption%	3.575	

% Binder =	9.0	
Ndes =	50	
Design Va% =	4.0	Spec
SE =	76	<40
FAA =	45	<40
VMA =	16.8	>16
VFA =	76.4	70-80
%Gmm@Nini =	88.5	≤91.5
DP =	1.7	0.9-2.0

Verification for Virginia Blend Adjustment VAadj-75-4

Series	Ndes	%AC	Va	VMA	VFA
	75	8.7	4.0	16.5	75.6

Series	%Gmm@Nini	DP	Gmm	Gmb
	88.0	1.7	2.333	2.239

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	98.0	100 - 90
#8	77.9	
#16	56.2	30 - 60
#30	37.9	
#50	23.2	
#100	14.9	
#200	10.1	6 - 12
Gsb	2.449	
Gsa	2.683	
Absorption%	3.575	

% Binder =	8.7	
Ndes =	75	
Design Va% =	4.0	Spec
SE =	76	>40
FAA =	45	>40
VMA =	16.5	>16
VFA =	75.6	70-80
%Gmm@Nini =	88	?91.5
DP =	1.7	0.9-2.0

\

A1.13 Tennessee Gravel Mix Design

Trial Blends

Aggregate

	Stockpile			
sieve size	#10 soft	Nat sand	agg lime	T10
3/4"	100	100	100	100
1/2"	100	100	99.7	100
3/8"	100	100	99.7	100
#4	96.9	99.3	99.4	94.1
#8	61.1	92.7	97.6	57.7
#16	36.0	83.5	81.3	33.3
#30	26.9	62.6	62.1	20.4
#50	21.1	13.4	44.6	13.4
#100	17.2	0.6	31.2	9.3
#200	14.6	0.4	24.0	7.1
Gsb	2.527	2.618	2.460	2.388
Gsa	2.723	2.667	2.790	2.675
Absorption%	2.90	0.70	3.70	6.30

Trial Blend Proportions

Blend	#10 soft	Nat sand	agg lime	T10
1	18%	19%	6%	57%
2				100%
3		25%	25%	50%

Trial Blend Results

Blend	Ndes	%AC	Va	VMA	VFA
1	50	7.5	8.9	20.9	57.7
2	50	7.5	18.3	28.6	36.1
3	50	7.5	9.6	26.4	63.5

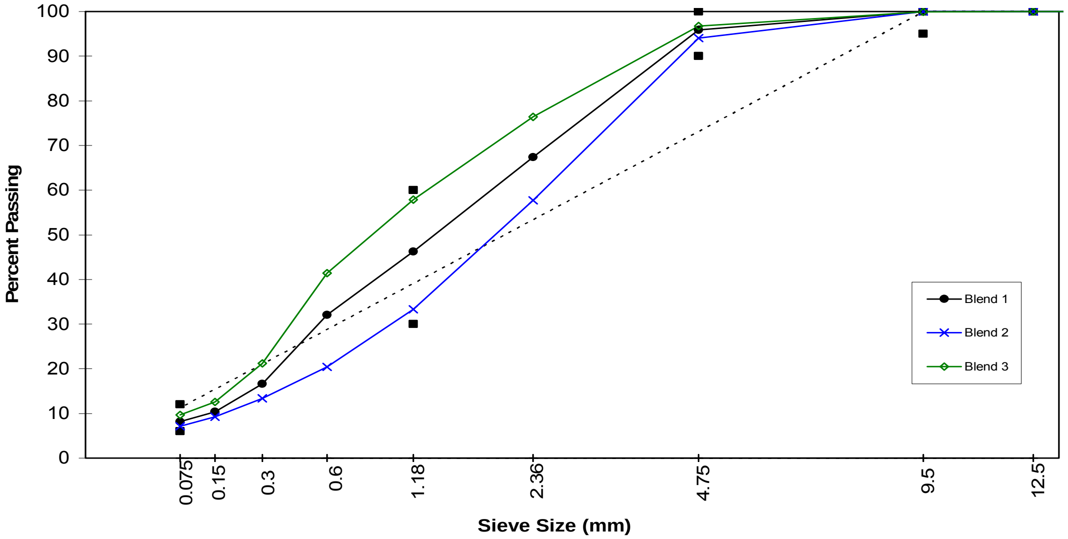
Blend	%Gmm@Nini	Dustratio	Gmm	Gmb	Gse
1	84.0	1.4	2.305	2.101	2.563
2	74.6	1.2	2.256	1.844	2.497
3	83.6	1.2	2.316	2.093	2.577

Blend	Est. %ac	Est. VMA	Est. VFA	%Gmm@Nini
1	9.4	20	80	88.9
2	13.2	25.7	84.4	88.8
3	9.8	25.2	84.1	89.2

Blend 1 was chose for mix design

	Trial Blends		
sieve size	Blend 1	Blend 2	Blend 3
1"	100	100	100
3/4"	100	100	100
1/2"	100	100	100
3/8"	100.0	100.0	99.9
#4	95.9	94.1	96.7
#8	67.4	57.7	76.4
#16	46.2	33.3	57.9
#30	32.1	20.4	41.4
#50	16.7	13.4	21.2
#100	10.4	9.3	12.6
#200	8.2	7.1	9.7
Gsb	2.458	2.388	2.460
Gsa	2.689	2.675	2.701
Absorption%	3.44	6.30	3.35

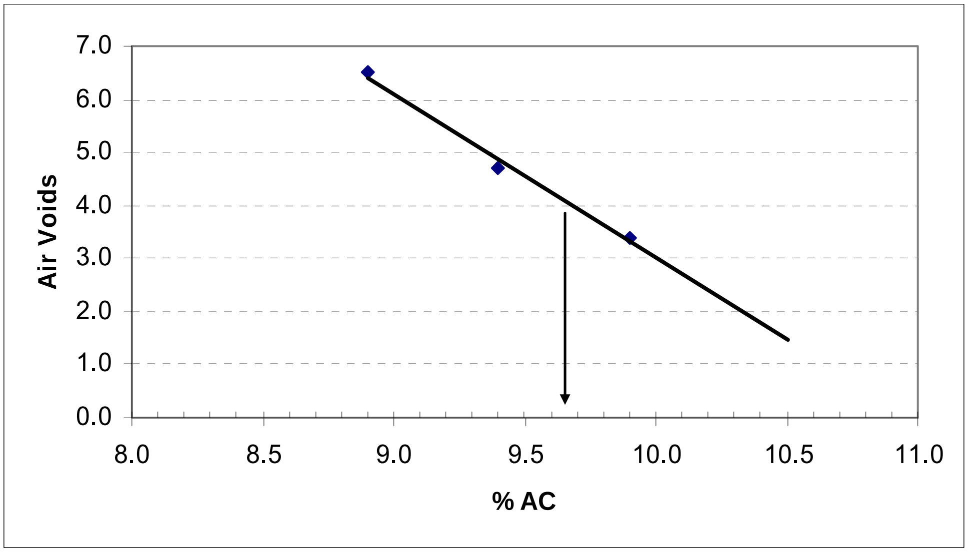
4.75 mm Nominal Sieve Size

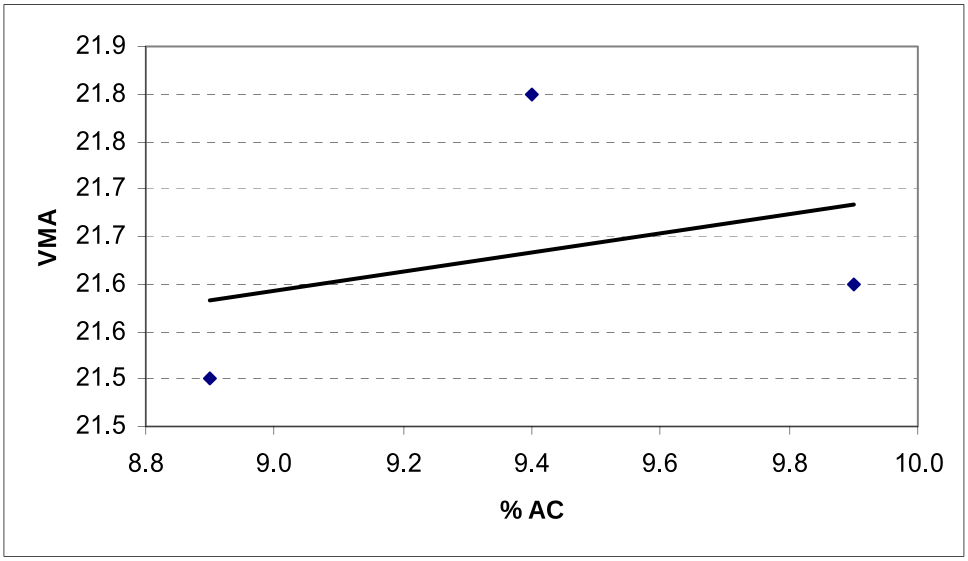


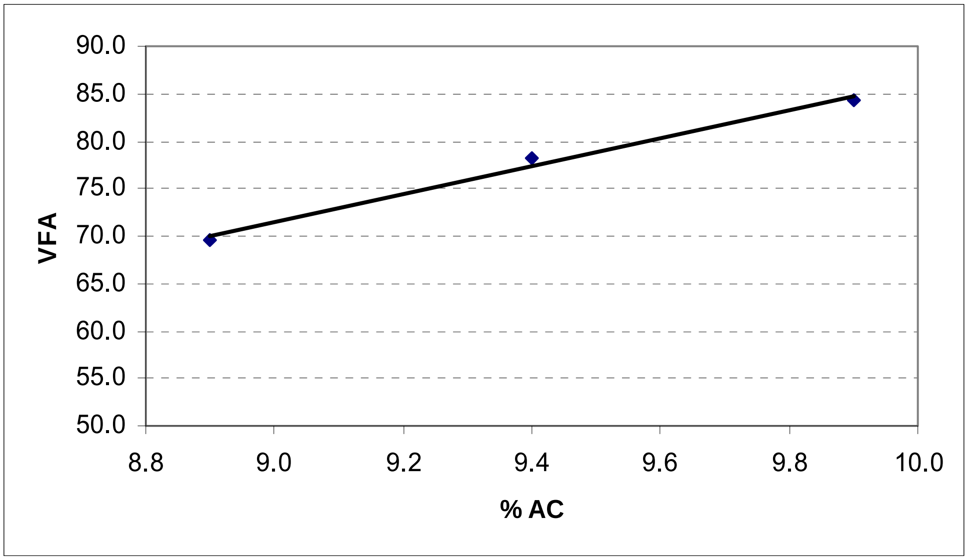
Binder Series for Tennessee Gravel Mix

Series	Ndes	%AC	Va	VMA	VFA
1	50	8.9	6.5	21.5	69.6
2	50	9.4	4.7	21.8	78.3
3	50	9.9	3.4	21.6	84.3

Series	%Gmm@Nini	Dustratio	Gmm	Gmb
1	86.1	1.1	2.266	2.118
2	87.5	1.0	2.252	2.145
3	88.7	0.9	2.237	2.161







Verification for Tennessee Gravel Mix TNGM-50-4

Series	Ndes	%AC	Va	VMA	VFA
	50	9.7	4.0	20.9	80.7

Series	%Gmm@Nini	DP	Gmm	Gmb
	88.1	1	2.243	2.153

JMF

sieve size	Blend 1	Spec			
3/8"	100.0	100 - 95			
#4	95.9	100 - 90	% Binder =	9.7	
#8	67.4		Ndes =	50	
#16	46.2	30 - 60	Design Va% =	4.0	Spec
#30	32.1		SE =	70	>40
#50	16.7		FAA =	42.2	>40
#100	10.4		VMA =	20.9	>16
#200	8.2	6 - 12	VFA =	80.7	70-80
Gsb	2.458		%Gmm@Nini =	88.1	≤91.5
Gsa	2.689		DP =	1.2	0.9-2.0
Absorption%	3.44				

Verification For Tennessee Gravel Mix TNGM-75-4

Series	Ndes	%AC	Va	VMA	VFA
	75	9.3	4.1	17.5	76.5

Series	%Gmm@Nini	DP	Gmm	Gmb
	87.5	1.3	2.255	2.163

JMF

sieve size	Blend 1	Spec
3/8"	100.0	100 - 95
#4	95.9	100 - 90
#8	67.4	
#16	46.2	30 - 60
#30	32.1	
#50	16.7	
#100	10.4	
#200	8.2	6 - 12
Gsb	2.458	
Gsa	2.689	
Absorption%	3.44	

% Binder =	9.3	
Ndes =	75	
Design Va% =	4.0	Spec
SE =	70	>40
FAA =	42.2	>40
VMA =	17.5	>16
VFA =	76.5	70-80
%Gmm@Nini =	87.5	?91.5
DP =	1.3	0.9-2.0

Appendix B

Tensile Strength Ratio Data

Project: 4.75mm Project-Alabama

Date: Apl. 29 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: AL-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.2	No.3	No.8	No.4	No.5	No.6
(A) Diameter, in	5.916	5.917	5.916	5.921	5.911	5.919
(B) Height, in	3.715	3.707	3.718	3.711	3.713	3.715
(C) Weight in Air, gm	3598.4	3598.3	3605.5	3598.6	3603.9	3605.5
(D) SSD Weight, gm	3609.8	3602.9	3611.7	3604.6	3608.6	3611.9
(E) Submerged Weight, gm	1950.9	1948.1	1948.4	1944.0	1953.2	1949.0
(F) Bulk Specific Gravity [C/(D - E)]	2.169	2.174	2.168	2.167	2.177	2.168
(G) Theoretical Maximum Gravity	2.378	2.378	2.378	2.378	2.378	2.378
(H) % Air Voids [100*(1-F/G)]	8.8	8.6	8.8	8.9	8.5	8.8
(I) Volume of Air Voids [H*(D - E)/100]	145.696	141.638	147.110	147.312	139.883	146.710
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3682.8			N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	84.40					
(L) % Saturation [100*(K/I)]	57.9					
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	3703.4	3700.3	3717.1	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	105.0	102.0	111.6			
(O) % Saturation [100*(N/I)]	72.1	72.0	75.9			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	3500	2900	4100	5900	6200	6400
(Q) Dry S_T, psi [2P/(A*B*π)]	N/A	N/A	N/A	170.9	179.8	185.3
(R) Conditioned S_T, psi [2P/(A*B*π)]	101.4	84.2	118.7	N/A	N/A	N/A
(S) Average S_T, psi	101.4			178.7		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.57		

Project: 4.75mm Project-Alabama

Date: May 04 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: AL-50-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.3	No.5	No.6	No.2	No.4	No.7
(A) Diameter, in	5.923	5.924	5.931	5.923	5.926	5.918
(B) Height, in	3.727	3.728	3.728	3.739	3.752	3.722
(C) Weight in Air, gm	3642.2	3646.5	3641.2	3637.3	3646.9	3644.9
(D) SSD Weight, gm	3644.8	3649.8	3645.7	3640.3	3650.6	3650.1
(E) Submerged Weight, gm	1973.8	1979.5	1970.9	1967.3	1974.2	1982.4
(F) Bulk Specific Gravity [C/(D - E)]	2.180	2.183	2.174	2.174	2.175	2.186
(G) Theoretical Maximum Gravity	2.401	2.401	2.401	2.401	2.401	2.401
(H) % Air Voids [100*(1-F/G)]	9.2	9.1	9.4	9.4	9.4	9.0
(I) Volume of Air Voids [H*(D - E)/100]	154.0	151.6	158.3	158.1	157.5	149.6
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3764.3	3763.8	3761.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	122.1	117.3	120.5			
(L) % Saturation [100*(K/I)]	79.3	77.4	76.1			
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	1650	1600	1500	4400	4500	5000
(Q) Dry S_T, psi [2P/(A*B*ξ)]	N/A	N/A	N/A	126.5	128.8	144.5
(R) Conditioned S_T, psi [2P/(A*B*ξ)]	47.6	46.1	43.2	N/A	N/A	N/A
(S) Average S_T, psi	45.6			133.3		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.34		

Project: 4.75mm Project - Tennessee, Limestone

Date: Aug. 23-26 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: TN-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.9	No.10	No.11	No.5	No.7	No.8
(A) Diameter, in	5.917	5.935	5.918	5.919	5.921	5.939
(B) Height, in	3.659	3.673	3.660	3.667	3.659	3.671
(C) Weight in Air, gm	3530.3	3531.8	3527.6	3527.3	3532.4	3528.0
(D) SSD Weight, gm	3555.1	3568.8	3553.2	3554.7	3553.9	3562.7
(E) Submerged Weight, gm	1933.3	1934.2	1931.7	1930.2	1932.7	1929.2
(F) Bulk Specific Gravity [C/(D - E)]	2.177	2.161	2.176	2.171	2.179	2.160
(G) Theoretical Maximum Gravity	2.387	2.387	2.387	2.387	2.387	2.387
(H) % Air Voids [100*(1-F/G)]	8.8	9.5	8.9	9.0	8.7	9.5
(I) Volume of Air Voids [H*(D - E)/100]	142.83	155.00	143.66	146.79	141.35	155.49
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm		3626.6		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]		94.80				
(L) % Saturation [100*(K/I)]		61.2				
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	3631.1	3643.6	3629.8	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	100.8	111.8	102.2			
(O) % Saturation [100*(N/I)]	70.6	72.1	71.1			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	2050	1850	1950	5050	4600	4200
(Q) Dry S_T, psi [2P/(A*B*π)]	N/A	N/A	N/A	148.1	135.2	122.6
(R) Conditioned S_T, psi [2P/(A*B*π)]	60.3	54.0	57.3	N/A	N/A	N/A
(S) Average S_T, psi	57.2			135.3		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.42		

Project: 4.75mm Project - Tennessee, Limestone

Date: Sep. 13-15 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: TN-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.2	No.5	No.8	No.3	No.4	No.7
(A) Diameter, in	5.929	5.934	5.937	5.940	5.936	5.936
(B) Height, in	3.722	3.717	3.725	3.719	3.725	3.723
(C) Weight in Air, gm	3593.2	3619.5	3624.7	3613.7	3616.9	3626.1
(D) SSD Weight, gm	3630.2	3642.6	3643.9	3632.0	3638.6	3646.2
(E) Submerged Weight, gm	1979.3	1988.1	1986.9	1972.5	1982.2	1989.1
(F) Bulk Specific Gravity [C/(D - E)]	2.177	2.188	2.188	2.178	2.184	2.188
(G) Theoretical Maximum Gravity	2.403	2.403	2.403	2.403	2.403	2.403
(H) % Air Voids [100*(1-F/G)]	9.4	9.0	9.0	9.4	9.1	8.9
(I) Volume of Air Voids [H*(D - E)/100]	155.60	148.26	148.59	155.67	151.24	148.11
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3715.1	3732.5	3737.4	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	121.90	113.00	112.70			
(L) % Saturation [100*(K/I)]	78.3	76.2	75.8			
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	3250	3300	3650	5550	5850	5700
(Q) Dry S_T, psi [2P/(A*B*÷)]	N/A	N/A	N/A	159.9	168.4	164.2
(R) Conditioned S_T, psi [2P/(A*B*÷)]	93.8	95.2	105.1	N/A	N/A	N/A
(S) Average S_T, psi	98.0			164.2		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.60		

Project: 4.75mm Project - Missouri

Date: Sep. 13-15 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: MO-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	F	G	H	C	D	E
(A) Diameter, in	5.926	5.916	5.930	5.932	5.915	5.933
(B) Height, in	3.705	3.691	3.700	3.705	3.692	3.709
(C) Weight in Air, gm	3748.6	3744.3	3750.2	3748.5	3752.9	3749.6
(D) SSD Weight, gm	3757.9	3750.8	3762.4	3757.3	3759.3	3761.3
(E) Submerged Weight, gm	2105.2	2110.7	2112.1	2105.5	2115.7	2106.5
(F) Bulk Specific Gravity [C/(D - E)]	2.268	2.283	2.272	2.269	2.283	2.266
(G) Theoretical Maximum Gravity	2.500	2.500	2.500	2.500	2.500	2.500
(H) % Air Voids [100*(1-F/G)]	9.3	8.7	9.1	9.2	8.7	9.4
(I) Volume of Air Voids [H*(D - E)/100]	153.26	142.38	150.22	152.40	142.44	154.96
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3870.9	3858.0	3863.4	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	122.30	113.70	113.20			
(L) % Saturation [100*(K/I)]	79.8	79.9	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	3150	3000	3100	5500	5900	5200
(Q) Dry S_T, psi [2P/(A*B*÷)]	N/A	N/A	N/A	159.3	172.0	150.4
(R) Conditioned S_T, psi [2P/(A*B*÷)]	91.3	87.5	89.9	N/A	N/A	N/A
(S) Average S_T, psi	89.6			160.6		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.56		

Project: 4.75mm

Date: 9/21/2005

Tested By: MR

Calculated By:

Sample Identification: MO-50-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	2	3	7	4	6	8
(A) Diameter, in	5.910	5.910	5.910	5.910	5.910	5.910
(B) Height, in	3.696	3.690	3.685	3.686	3.684	3.695
(C) Weight in Air, gm	3798.8	3796.7	3798.6	3804.8	3804.3	3802.4
(D) SSD Weight, gm	3802.6	3800.6	3803.0	3810.5	3808.6	3805.6
(E) Submerged Weight, gm	2157.7	2156.1	2161.5	2164.3	2161.9	2157.8
(F) Bulk Specific Gravity [C/(D - E)]	2.309	2.309	2.314	2.311	2.310	2.308
(G) Theoretical Maximum Gravity	2.531	2.531	2.531	2.531	2.531	2.531
(H) % Air Voids [100*(1-F/G)]	8.8	8.8	8.6	8.7	8.7	8.8
(I) Volume of Air Voids [H*(D - E)/100]	143.991	144.421	140.670	142.921	143.618	145.469
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3902.1	3903.3	3902.0	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	103.30	106.60	103.40			
(L) % Saturation [100*(K/I)]	71.7	73.8	73.5			
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	3600	3850	3350	7340	6800	6700
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	214.5	198.8	195.3
(R) Conditioned S_T, psi [2P/(A*B*□)]	104.9	112.4	97.9	N/A	N/A	N/A
(S) Average S_T, psi	105.1			202.9		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.52		

Project: 4.75mm Project - Virginia

Date: Sep. 21-23 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: VA-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.1	No.3	No.4	No.5	No.6	No.8
(A) Diameter, in	5.919	5.925	5.924	5.931	5.925	5.921
(B) Height, in	3.701	3.700	3.696	3.697	3.698	3.687
(C) Weight in Air, gm	3497.9	3499.1	3499.9	3497.8	3500.4	3487.7
(D) SSD Weight, gm	3514.4	3503.3	3504.0	3503.0	3504.5	3492.3
(E) Submerged Weight, gm	1864.2	1851.0	1854.8	1850.0	1854.1	1848.0
(F) Bulk Specific Gravity [C/(D - E)]	2.120	2.118	2.122	2.116	2.121	2.121
(G) Theoretical Maximum Gravity	2.329	2.329	2.329	2.329	2.329	2.329
(H) % Air Voids [100*(1-F/G)]	9.0	9.1	8.9	9.1	8.9	8.9
(I) Volume of Air Voids [H*(D - E)/100]	148.31	149.90	146.45	151.15	147.44	146.79
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3603.4	3602.0		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	105.50	102.90				
(L) % Saturation [100*(K/I)]	71.1	68.6				
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm		3606.0	3607.4	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]		106.9	107.5			
(O) % Saturation [100*(N/I)]		71.3	73.4			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	900	1250	1000	4300	4600	4600
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	124.8	133.7	134.1
(R) Conditioned S_T, psi [2P/(A*B*□)]	26.2	36.3	29.1	N/A	N/A	N/A
(S) Average S_T, psi	30.5			130.9		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.23		

Project: 4.75mm Project - Virginia

Date: Sep. 28-30 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: VA-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.4	No.5	No.7	No.2	No.3	No.6
(A) Diameter, in	5.939	5.936	5.936	5.939	5.935	5.936
(B) Height, in	3.683	3.682	3.682	3.681	3.685	3.684
(C) Weight in Air, gm	3520.1	3519.4	3516.5	3518.9	3518.7	3522.4
(D) SSD Weight, gm	3525.4	3526.9	3523.9	3528.5	3526.2	3527.2
(E) Submerged Weight, gm	1876.5	1879.0	1877.2	1881.1	1877.5	1878.6
(F) Bulk Specific Gravity [C/(D - E)]	2.135	2.136	2.135	2.136	2.134	2.137
(G) Theoretical Maximum Gravity	2.341	2.341	2.341	2.341	2.341	2.341
(H) % Air Voids [100*(1-F/G)]	8.8	8.8	8.8	8.8	8.8	8.7
(I) Volume of Air Voids [H*(D - E)/100]	145.23	144.53	144.56	144.24	145.62	143.94
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3624.2			N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	104.10					
(L) % Saturation [100*(K/I)]	71.7					
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	3627.4	3630.4	3627.9	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	107.3	111.0	111.4			
(O) % Saturation [100*(N/I)]	73.9	76.8	77.1			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	2125	1850	1875	4650	4100	4600
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	135.4	119.3	133.9
(R) Conditioned S_T, psi [2P/(A*B*□)]	61.8	53.9	54.6	N/A	N/A	N/A
(S) Average S_T, psi	56.8			129.6		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.44		

Project: 4.75mm
Date: 10/19/2005

Tested By: GJ
Calculated By:

Sample Identification: FL-74-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	6	8	3	5	7
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	5.906
(B) Height, in	3.637	3.634	3.636	3.655	3.631	3.631
(C) Weight in Air, gm	3295.6	3301.8	3295.7	3297.2	3296.5	3299.0
(D) SSD Weight, gm	3304.4	3307.6	3302.5	3311.6	3302.1	3303.4
(E) Submerged Weight, gm	1686.1	1685.5	1685.6	1684.5	1685.2	1686.6
(F) Bulk Specific Gravity [C/(D - E)]	2.036	2.036	2.038	2.026	2.039	2.040
(G) Theoretical Maximum Gravity	2.240	2.240	2.240	2.240	2.240	2.240
(H) % Air Voids [100*(1-F/G)]	9.1	9.1	9.0	9.5	9.0	8.9
(I) Volume of Air Voids [H*(D - E)/100]	147.050	148.082	145.605	155.136	145.248	144.032
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3407.2	3411.6	3408.9	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	111.60	109.80	113.20			
(L) % Saturation [100*(K/I)]	75.9	74.1	77.7			
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	3200	3500	2700	4000	4300	3800
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	118.0	127.7	112.8
(R) Conditioned S_T, psi [2P/(A*B*□)]	94.8	103.8	80.0	N/A	N/A	N/A
(S) Average S_T, psi	92.9			119.5		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.78		

Project: 4.75mm

Date: 10/26/2005

Tested By:

Calculated By:

Sample Identification: FL-75-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	5	6	3	7	8
(A) Diameter, in	3.630	3.630	3.630	3.630	3.630	3.630
(B) Height, in	5.906	5.906	5.906	5.906	5.906	5.906
(C) Weight in Air, gm	3346.0	3348.3	3345.0	3343.1	3344.0	3345.1
(D) SSD Weight, gm	3350.1	3353.7	3349.5	3349.4	3350.5	3350.8
(E) Submerged Weight, gm	1725.2	1728.3	1725.3	1726.1	1725.3	1728.3
(F) Bulk Specific Gravity [C/(D - E)]	2.059	2.060	2.059	2.059	2.058	2.062
(G) Theoretical Maximum Gravity	2.262	2.262	2.262	2.262	2.262	2.262
(H) % Air Voids [100*(1-F/G)]	9.0	8.9	9.0	9.0	9.0	8.9
(I) Volume of Air Voids [H*(D - E)/100]	145.678	145.161	145.420	145.360	146.862	143.676
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3450.4	3454.7	3456.9	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	104.40	106.40	111.90			
(L) % Saturation [100*(K/I)]	71.7	73.3	76.9			
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	3450	3800	3850	5200	5750	5300
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	154.4	170.7	157.4
(R) Conditioned S_T, psi [2P/(A*B*□)]	102.4	112.8	114.3	N/A	N/A	N/A
(S) Average S_T, psi	109.9			160.8		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.68		

Project: 4.75mm

Date: 10/19/2005

Tested By: GJ

Calculated By:

Sample Identification: CT-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	3	4	5	6	7	8
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	5.906
(B) Height, in	3.634	3.629	3.632	3.631	3.633	3.623
(C) Weight in Air, gm	3712.0	3709.7	3709.1	3709.8	3710.1	3705.1
(D) SSD Weight, gm	3719.0	3715.2	3715.7	3715.6	3716.0	3710.5
(E) Submerged Weight, gm	2110.9	2112.1	2106.3	2111.5	2108.3	2105.9
(F) Bulk Specific Gravity [C/(D - E)]	2.308	2.314	2.305	2.313	2.308	2.309
(G) Theoretical Maximum Gravity	2.531	2.531	2.531	2.531	2.531	2.531
(H) % Air Voids [100*(1-F/G)]	8.8	8.6	8.9	8.6	8.8	8.8
(I) Volume of Air Voids [H*(D - E)/100]	141.486	137.395	143.932	138.355	141.837	140.712
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3823.0	3819.0	3824.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	111.00	109.30	115.60			
(L) % Saturation [100*(K/I)]	78.5	79.6	80.3			
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	3700	3400	3350	3900	4000	4000
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	115.8	118.7	119.0
(R) Conditioned S_T, psi [2P/(A*B*□)]	109.7	101.0	99.4	N/A	N/A	N/A
(S) Average S_T, psi	103.4			117.8		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.88		

Project: 4.75mm

Date: 10/26/2005

Tested By:

Calculated By:

Sample Identification: CT 7.2%AC for 50gyr 6%Va

	Conditioned Samples			Unconditioned Samples		
Sample Number	2	5	6	3	4	
(A) Diameter, in	3.640	3.630	3.630	3.630	3.630	
(B) Height, in	5.906	5.906	5.906	5.906	5.906	
(C) Weight in Air, gm	3775.4	3800.1	3797.5	3796.1	3796.6	
(D) SSD Weight, gm	3792.1	3810.3	3809.7	3811.0	3810.8	
(E) Submerged Weight, gm	2171.6	2193.6	2193.2	2190.9	2194.4	
(F) Bulk Specific Gravity [C/(D - E)]	2.330	2.351	2.349	2.343	2.349	
(G) Theoretical Maximum Gravity	2.574	2.574	2.574	2.574	2.574	2.574
(H) % Air Voids [100*(1-F/G)]	9.5	8.7	8.7	9.0	8.7	
(I) Volume of Air Voids [H*(D - E)/100]	153.756	140.360	141.170	145.314	141.419	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3885.5	3905.1	3909.6	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	110.10	105.00	112.10			
(L) % Saturation [100*(K/I)]	71.6	74.8	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	4500	5200	4800	6500	6300	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	193.0	187.1	
(R) Conditioned S_T, psi [2P/(A*B*□)]	133.3	154.4	142.5	N/A	N/A	N/A
(S) Average S_T, psi	143.4			190.0		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.75		

Project: 4.75mm

Date: 11/2/2005

Tested By: GJ

Calculated By:

Sample Identification: MN-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	5	6	7	3	4	8
(A) Diameter, in	5.901	5.901	5.901	5.901	5.901	5.901
(B) Height, in	3.606	3.606	3.610	3.610	3.610	3.601
(C) Weight in Air, gm	3732.3	3733.5	3731.5	3733.0	3733.8	3730.1
(D) SSD Weight, gm	3736.2	3737.2	3735.3	3736.7	3737.0	3735.2
(E) Submerged Weight, gm	2120.0	2122.7	2119.0	2118.1	2120.9	2119.3
(F) Bulk Specific Gravity [C/(D - E)]	2.309	2.312	2.309	2.306	2.310	2.308
(G) Theoretical Maximum Gravity	2.536	2.536	2.536	2.536	2.536	2.536
(H) % Air Voids [100*(1-F/G)]	8.9	8.8	9.0	9.1	8.9	9.0
(I) Volume of Air Voids [H*(D - E)/100]	144.473	142.300	144.888	146.597	143.781	145.040
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3834.1	3835.8	3839.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	101.80	102.30	108.20			
(L) % Saturation [100*(K/I)]	70.5	71.9	74.7			
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	4400	3850	3900	5000	4800	4400
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	149.4	143.4	131.8
(R) Conditioned S_T, psi [2P/(A*B*□)]	131.6	115.2	116.5	N/A	N/A	N/A
(S) Average S_T, psi	121.1			141.6		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.86		

Project: 4.75mm

Date: 11/2/2005

Tested By: GJ

Calculated By:

Sample Identification: MN-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	6	8	2	3	5
(A) Diameter, in	5.901	5.901	5.901	5.901	5.901	5.901
(B) Height, in	3.611	3.611	3.600	3.616	3.607	3.609
(C) Weight in Air, gm	3761.7	3764.0	3768.2	3755.4	3761.2	3763.5
(D) SSD Weight, gm	3767.8	3767.2	3771.7	3764.1	3766.1	3768.7
(E) Submerged Weight, gm	2145.0	2148.5	2150.5	2146.4	2144.2	2149.7
(F) Bulk Specific Gravity [C/(D - E)]	2.318	2.325	2.324	2.321	2.319	2.325
(G) Theoretical Maximum Gravity	2.556	2.556	2.556	2.556	2.556	2.556
(H) % Air Voids [100*(1-F/G)]	9.3	9.0	9.1	9.2	9.3	9.1
(I) Volume of Air Voids [H*(D - E)/100]	151.086	146.087	146.943	148.451	150.382	146.582
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3878.5	3871.4	3874.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	116.80	107.40	106.50			
(L) % Saturation [100*(K/I)]	77.3	73.5	72.5			
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	4750	4000	3900	5300	5300	5250
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	158.1	158.5	156.9
(R) Conditioned S_T, psi [2P/(A*B*□)]	141.9	119.5	116.9	N/A	N/A	N/A
(S) Average S_T, psi	126.1			157.9		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.80		

Project: 4.75mm

Date: 11/16/2005

Tested By: MR

Calculated By:

Sample Identification: MN-75-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	6		2	8	
(A) Diameter, in	5.910	5.910		5.910	5.910	
(B) Height, in	3.585	3.585		3.585	3.591	
(C) Weight in Air, gm	3764.5	3766.2		3758.0	3769.1	
(D) SSD Weight, gm	3768.7	3769.4		3765.9	3776.1	
(E) Submerged Weight, gm	2172.1	2171.8		2173.7	2167.2	
(F) Bulk Specific Gravity [C/(D - E)]	2.358	2.357		2.360	2.343	
(G) Theoretical Maximum Gravity	2.590	2.590		2.590	2.590	
(H) % Air Voids [100*(1-F/G)]	9.0	9.0		8.9	9.5	
(I) Volume of Air Voids [H*(D - E)/100]	143.125	143.469		141.235	153.649	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3865.0	3867.1		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	100.50	100.90				
(L) % Saturation [100*(K/I)]	70.2	70.3				
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	4000	4100		6300	5500	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	189.3	165.0	
(R) Conditioned S_T, psi [2P/(A*B*□)]	120.2	123.2		N/A	N/A	N/A
(S) Average S_T, psi	121.7			177.1		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.69		

Project: 4.75mm Project - New Hampshire
Date: Nov. 15-18 2005

Tested By: Osamu Takahashi
Calculated By:

Sample Identification: NH-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.3	No.7	No.10	No.4	No.5	No.9
(A) Diameter, in	5.939	5.945	5.947	5.953	5.940	5.947
(B) Height, in	3.597	3.598	3.582	3.604	3.591	3.583
(C) Weight in Air, gm	3445.6	3446.3	3458.1	3446.9	3444.8	3468.5
(D) SSD Weight, gm	3458.0	3454.4	3463.3	3456.8	3451.0	3479.4
(E) Submerged Weight, gm	1849.4	1843.3	1852.1	1837.8	1844.4	1868.5
(F) Bulk Specific Gravity [C/(D - E)]	2.142	2.139	2.146	2.129	2.144	2.153
(G) Theoretical Maximum Gravity	2.352	2.352	2.352	2.352	2.352	2.352
(H) % Air Voids [100*(1-F/G)]	8.9	9.1	8.7	9.5	8.8	8.5
(I) Volume of Air Voids [H*(D - E)/100]	143.63	145.84	140.92	153.48	141.97	136.20
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3549.8	3553.2	3559.9	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	104.20	106.90	101.80			
(L) % Saturation [100*(K/I)]	72.5	73.3	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	1750	1925	1750	3800	4050	3100
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	112.8	120.9	92.6
(R) Conditioned S_T, psi [2P/(A*B*□)]	52.2	57.3	52.3	N/A	N/A	N/A
(S) Average S_T, psi	53.9			108.7		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.50		

Project: 4.75mm Project - New Hampshire
Date: Nov. 30-Dec. 1 2005

Tested By: Osamu Takahashi
Calculated By:

Sample Identification: NH-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.4	No.5	No.10	No.3	No.6	No.9
(A) Diameter, in	5.947	5.959	5.940	5.933	5.961	5.934
(B) Height, in	3.625	3.633	3.554	3.633	3.636	3.555
(C) Weight in Air, gm	3497.2	3496.4	3426.0	3507.2	3500.5	3443.6
(D) SSD Weight, gm	3509.3	3509.3	3430.4	3519.6	3511.2	3452.9
(E) Submerged Weight, gm	1886.0	1876.3	1840.2	1892.5	1875.6	1861.7
(F) Bulk Specific Gravity [C/(D - E)]	2.154	2.141	2.154	2.155	2.140	2.164
(G) Theoretical Maximum Gravity	2.365	2.365	2.365	2.365	2.365	2.365
(H) % Air Voids [100*(1-F/G)]	8.9	9.5	8.9	8.9	9.5	8.5
(I) Volume of Air Voids [H*(D - E)/100]	144.57	154.61	141.57	144.14	155.47	135.13
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3598.5	3607.3	3524.5	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	101.30	110.90	98.50			
(L) % Saturation [100*(K/I)]	70.1	71.7	69.6			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	3602.9		3531.3	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	105.7		105.3			
(O) % Saturation [100*(N/I)]	73.1		74.4			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	2900	3050	2700	3250	4500	3200
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	96.0	132.2	96.6
(R) Conditioned S_T, psi [2P/(A*B*□)]	85.6	89.7	81.4	N/A	N/A	N/A
(S) Average S_T, psi	85.6			108.2		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.79		

Project: 4.75mm Project - New Hampshire

Date: Dec. 14-16 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: NH-75-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.5	No.6	No.7	No.2	No.3	No.4
(A) Diameter, in	5.946	5.942	5.941	5.938	5.944	5.948
(B) Height, in	3.594	3.591	3.591	3.594	3.591	3.593
(C) Weight in Air, gm	3516.2	3516.9	3516.9	3519.6	3515.5	3513.4
(D) SSD Weight, gm	3521.7	3521.7	3523.0	3527.5	3520.7	3520.1
(E) Submerged Weight, gm	1907.6	1908.4	1910.6	1915.5	1907.3	1905.5
(F) Bulk Specific Gravity [C/(D - E)]	2.178	2.180	2.181	2.183	2.179	2.176
(G) Theoretical Maximum Gravity	2.392	2.392	2.392	2.392	2.392	2.392
(H) % Air Voids [100*(1-F/G)]	8.9	8.9	8.8	8.7	8.9	9.0
(I) Volume of Air Voids [H*(D - E)/100]	144.12	143.02	142.12	140.60	143.71	145.79
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3620.1	3620.5	3622.3	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	103.90	103.60	105.40			
(L) % Saturation [100*(K/I)]	72.1	72.4	74.2			
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	1850	1650	2100	3500	3600	3500
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	104.4	107.4	104.3
(R) Conditioned S_T, psi [2P/(A*B*□)]	55.1	49.2	62.7	N/A	N/A	N/A
(S) Average S_T, psi	55.7			105.3		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.53		

Project: 4.75mm

Date: 2/9/2006

Tested By: JM

Calculated By:

WI-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	2	5	6	7	3
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	5.906
(B) Height, in	3.511	3.531	3.517	3.522	3.523	3.516
(C) Weight in Air, gm	3539.5	3555.9	3538.8	3540.1	3545.3	3539.6
(D) SSD Weight, gm	3558.0	3567.6	3558.8	3556.5	3555.0	3553.7
(E) Submerged Weight, gm	1983.0	2002.9	1993.4	1981.9	1992.9	1992.5
(F) Bulk Specific Gravity [C/(D - E)]	2.247	2.273	2.261	2.248	2.270	2.267
(G) Theoretical Maximum Gravity	2.484	2.484	2.484	2.484	2.484	2.484
(H) % Air Voids [100*(1-F/G)]	9.5	8.5	9.0	9.5	8.6	8.7
(I) Volume of Air Voids [H*(D - E)/100]	150.081	133.178	140.762	149.439	134.846	136.240
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3660.0	3649.9	3647.1	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	120.50	94.00	108.30			
(L) % Saturation [100*(K/I)]	80.3	70.6	76.9			
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	2700	2600	3000	4300	4300	4800
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	131.6	131.6	147.2
(R) Conditioned S_T, psi [2P/(A*B*□)]	82.9	79.4	91.9	N/A	N/A	N/A
(S) Average S_T, psi	84.7			136.8		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.62		

Project: 4.75mm

Date: 2/9/2006

Tested By: JM

Calculated By:

WI-50-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	5	8	3	6	
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	
(B) Height, in	3.531	3.525	3.526	3.535	3.528	
(C) Weight in Air, gm	3624.2	3617.8	3619.4	3616.1	3617.3	
(D) SSD Weight, gm	3638.5	3638.6	3636.0	3632.1	3635.6	
(E) Submerged Weight, gm	2057.1	2063.0	2063.4	2048.7	2063.2	
(F) Bulk Specific Gravity [C/(D - E)]	2.292	2.296	2.302	2.284	2.300	
(G) Theoretical Maximum Gravity	2.515	2.515	2.515	2.515	2.515	
(H) % Air Voids [100*(1-F/G)]	8.9	8.7	8.5	9.2	8.5	
(I) Volume of Air Voids [H*(D - E)/100]	140.366	137.111	133.475	145.587	134.110	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3725.8	3720.1	3720.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	101.60	102.30	101.40			
(L) % Saturation [100*(K/I)]	72.4	74.6	76.0			
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	3500	3700	3700	4600	5000	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	140.3	152.8	
(R) Conditioned S_T, psi [2P/(A*B*□)]	106.8	113.1	113.1	N/A	N/A	N/A
(S) Average S_T, psi	111.0			146.5		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.76		

Project: 4.75mm
Date: 11/29/2005

Tested By: GJ
Calculated By:

Sample Identification: TNGM-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	5	8		2	3	
(A) Diameter, in	5.906	5.906		5.906	5.906	
(B) Height, in	3.609	3.609		3.609	3.609	
(C) Weight in Air, gm	3263.5	3274.7		3267.0	3264.9	
(D) SSD Weight, gm	3279.5	3292.3		3283.9	3277.9	
(E) Submerged Weight, gm	1676.1	1680.7		1679.0	1669.7	
(F) Bulk Specific Gravity [C/(D - E)]	2.035	2.032		2.036	2.030	
(G) Theoretical Maximum Gravity	2.243	2.243		2.243	2.243	
(H) % Air Voids [100*(1-F/G)]	9.3	9.4		9.2	9.5	
(I) Volume of Air Voids [H*(D - E)/100]	148.429	151.636		148.369	152.605	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3366.9	3382.6		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	103.40	107.90				
(L) % Saturation [100*(K/I)]	69.7	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	3200	4200		5500	5200	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	164.3	155.3	
(R) Conditioned S_T, psi [2P/(A*B*□)]	95.6	125.4		N/A	N/A	N/A
(S) Average S_T, psi	110.5			159.8		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.69		

Project: 4.75mm
Date: 4/12/2006

Tested By: JM
Calculated By:

TNGM-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	3	4	5	6	7	8
(A) Diameter, in	5.910	5.910	5.910	5.910	5.910	5.910
(B) Height, in	3.543	3.543	3.543	3.543	3.543	3.543
(C) Weight in Air, gm	3146.1	3146.9	3153.5	3153.3	3150.6	3153.5
(D) SSD Weight, gm	3171.9	3173.5	3171.3	3170.3	3175.8	3177.3
(E) Submerged Weight, gm	1620.0	1622.5	1620.5	1622.0	1622.0	1624.8
(F) Bulk Specific Gravity [C/(D - E)]	2.027	2.029	2.033	2.037	2.028	2.031
(G) Theoretical Maximum Gravity	2.255	2.255	2.255	2.255	2.255	2.255
(H) % Air Voids [100*(1-F/G)]	10.1	10.0	9.8	9.7	10.1	9.9
(I) Volume of Air Voids [H*(D - E)/100]	156.734	155.479	152.352	149.941	156.638	154.052
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3267.2	3263.6	3271.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	121.10	116.70	118.20			
(L) % Saturation [100*(K/I)]	77.3	75.1	77.6			
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	1600	1650	1600	3350	3250	3425
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	101.9	98.8	104.1
(R) Conditioned S_T, psi [2P/(A*B*□)]	48.6	50.2	48.6	N/A	N/A	N/A
(S) Average S_T, psi	49.2			101.6		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.48		

Project: 4.75mm

Date: 4/19/2006

Tested By: Mr

Calculated By:

VA adj-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2		3	4	
(A) Diameter, in	5.910	5.910		5.910	5.910	
(B) Height, in	3.449	3.416		3.501	3.501	
(C) Weight in Air, gm	3251.3	3280.3		3272.7	3290.7	
(D) SSD Weight, gm	3256.8	3285.6		3279.6	3294.3	
(E) Submerged Weight, gm	1724.0	1729.8		1730.9	1735.6	
(F) Bulk Specific Gravity [C/(D - E)]	2.121	2.108		2.113	2.111	
(G) Theoretical Maximum Gravity	2.331	2.331		2.331	2.331	
(H) % Air Voids [100*(1-F/G)]	9.0	9.5		9.3	9.4	
(I) Volume of Air Voids [H*(D - E)/100]	137.991	148.550		144.710	146.988	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3355.9	3395.8		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	104.60	115.50				
(L) % Saturation [100*(K/I)]	75.8	77.8				
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	1400	1700		4000	3700	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	123.1	113.8	
(R) Conditioned S_T, psi [2P/(A*B*□)]	43.7	53.6		N/A	N/A	N/A
(S) Average S_T, psi	48.7			118.5		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.41		

Project: 4.75 mm

Date: 4/20/2006

Tested By: JM

Calculated By:

VA adj-75-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	1	3	4	2	5	6
(A) Diameter, in	5.910	5.910	5.910	5.910	5.910	5.910
(B) Height, in	3.454	3.447	3.444	3.447	3.450	3.448
(C) Weight in Air, gm	3253.4	3292.4	3240.1	3278.2	3256.6	3259.7
(D) SSD Weight, gm	3259.0	3294.9	3243.6	3281.0	3260.0	3262.0
(E) Submerged Weight, gm	1712.8	1748.1	1707.2	1730.0	1712.9	1717.6
(F) Bulk Specific Gravity [C/(D - E)]	2.104	2.129	2.109	2.114	2.105	2.111
(G) Theoretical Maximum Gravity	2.333	2.333	2.333	2.333	2.333	2.333
(H) % Air Voids [100*(1-F/G)]	9.8	8.8	9.6	9.4	9.8	9.5
(I) Volume of Air Voids [H*(D - E)/100]	151.686	135.570	147.587	145.856	151.215	147.186
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3364.4	3389.6	3345.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	111.00	97.20	105.70			
(L) % Saturation [100*(K/I)]	73.2	71.7	71.6			
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	2200	2700	1800	4700	5100	4700
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	146.9	159.2	146.8
(R) Conditioned S_T, psi [2P/(A*B*□)]	68.6	84.4	56.3	N/A	N/A	N/A
(S) Average S_T, psi	69.8			151.0		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.46		

Project: 4.75mm Date:

Tested By: jm Calculated By:

FL adj-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	7	8	2	1	3	6
(A) Diameter, in	3.544	3.544	3.533	3.571	3.538	3.539
(B) Height, in	5.906	5.906	5.906	5.906	5.906	5.906
(C) Weight in Air, gm	3258.5	3257.7	3257.5	3264.0	3259.2	3257.8
(D) SSD Weight, gm	3267.1	3265.2	3268.7	3285.0	3267.7	3271.5
(E) Submerged Weight, gm	1681.0	1675.5	1683.0	1694.9	1682.8	1681.3
(F) Bulk Specific Gravity [C/(D - E)]	2.054	2.049	2.054	2.053	2.056	2.049
(G) Theoretical Maximum Gravity	2.255	2.255	2.255	2.255	2.255	2.255
(H) % Air Voids [100*(1-F/G)]	8.9	9.1	8.9	9.0	8.8	9.1
(I) Volume of Air Voids [H*(D - E)/100]	141.089	145.044	141.132	142.650	139.578	145.499
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3364.9	3368.9	3365.5	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	106.40	111.20	108.00			
(L) % Saturation [100*(K/I)]	75.4	76.7	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	3700	3800	3700	3600	4000	4000
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	108.7	121.9	121.8
(R) Conditioned S_T, psi [2P/(A*B*□)]	112.5	115.6	112.9	N/A	N/A	N/A
(S) Average S_T, psi	113.7			117.5		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.97		

Project: 4.75 mm Date: 4/23/2006

Tested By: JM Calculated By:

FL adj-75-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	5	3	4	6
(A) Diameter, in	5.910	5.910	5.910	5.910	5.910	5.910
(B) Height, in	3.529	3.522	3.526	3.523	3.514	3.523
(C) Weight in Air, gm	3272.4	3271.6	3277.9	3276.4	3274.0	3273.4
(D) SSD Weight, gm	3278.3	3274.7	3283.2	3279.0	3277.7	3278.6
(E) Submerged Weight, gm	1711.0	1706.7	1716.5	1707.7	1709.3	1714.3
(F) Bulk Specific Gravity [C/(D - E)]	2.088	2.086	2.092	2.085	2.087	2.093
(G) Theoretical Maximum Gravity	2.292	2.292	2.292	2.292	2.292	2.292
(H) % Air Voids [100*(1-F/G)]	8.9	9.0	8.7	9.0	8.9	8.7
(I) Volume of Air Voids [H*(D - E)/100]	139.551	140.600	136.552	141.806	139.953	136.115
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3372.3	3371.7	3373.2	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	99.90	100.10	95.30			
(L) % Saturation [100*(K/I)]	71.6	71.2	69.8			
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	3300	3400	3300	3200	3400	3500
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	97.8	104.2	107.0
(R) Conditioned S_T, psi [2P/(A*B*□)]	100.7	104.0	100.8	N/A	N/A	N/A
(S) Average S_T, psi	101.8			103.0		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.99		

Project: 4.75 mm

Date: 4/19/2006

Tested By: MR

Calculated By:

WI adj-50-4

	Conditioned Samples			Unconditioned Samples		
Sample Number	2B	3A		4B	4A	
(A) Diameter, in	5.910	5.910		5.910	5.910	
(B) Height, in	3.531	3.483		3.530	3.481	
(C) Weight in Air, gm	3597.0	3558.6		3600.1	3555.2	
(D) SSD Weight, gm	3613.0	3567.0		3615.0	3566.5	
(E) Submerged Weight, gm	2045.6	2032.2		2050.3	2025.0	
(F) Bulk Specific Gravity [C/(D - E)]	2.295	2.319		2.301	2.306	
(G) Theoretical Maximum Gravity	2.535	2.535		2.535	2.535	
(H) % Air Voids [100*(1-F/G)]	9.5	8.5		9.2	9.0	
(I) Volume of Air Voids [H*(D - E)/100]	148.465	131.013		144.542	139.054	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3710.2	3659.8		N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	113.20	101.20				
(L) % Saturation [100*(K/I)]	76.2	77.2				
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	2800	2600		3800	3300	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	116.0	102.1	
(R) Conditioned S_T, psi [2P/(A*B*□)]	85.4	80.4		N/A	N/A	N/A
(S) Average S_T, psi	82.9			109.0		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.76		

Project: 4.75 mm

Date: 4/13/2006

Tested By: JM

Calculated By:

WI adj-50-6

	Conditioned Samples			Unconditioned Samples		
Sample Number	4	5	6	2	3	
(A) Diameter, in	5.910	5.910	5.910	5.910	5.910	
(B) Height, in	3.493	3.492	3.502	3.498	3.495	
(C) Weight in Air, gm	3568.9	3567.2	3567.7	3553.6	3567.2	
(D) SSD Weight, gm	3579.6	3580.6	3578.1	3563.4	3574.1	
(E) Submerged Weight, gm	2040.7	2040.6	2039.1	2026.5	2032.6	
(F) Bulk Specific Gravity [C/(D - E)]	2.319	2.316	2.318	2.312	2.314	
(G) Theoretical Maximum Gravity	2.555	2.555	2.555	2.555	2.555	
(H) % Air Voids [100*(1-F/G)]	9.2	9.3	9.3	9.5	9.4	
(I) Volume of Air Voids [H*(D - E)/100]	142.070	143.836	142.640	146.059	145.336	
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3666.5	3668.1	3667.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	97.60	100.90	100.10			
(L) % Saturation [100*(K/I)]	68.7	70.1	70.2			
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	2400	2500	2400	3400	3200	
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	104.7	98.6	
(R) Conditioned S_T, psi [2P/(A*B*□)]	74.0	77.1	73.8	N/A	N/A	N/A
(S) Average S_T, psi	75.0			101.7		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.74		

Project: Georgia 4.75mm

Date:

Tested By: mr

Calculated By:

Sample Identification: Georgia

	Conditioned Samples			Unconditioned Samples		
Sample Number	T-10	T-11	T-12	T-3	T-4	T-5
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	5.906
(B) Height, in	3.740	3.740	3.740	3.740	3.740	3.740
(C) Weight in Air, gm	3701.4	3701.1	3705.1	3701.5	3701.9	3702.5
(D) SSD Weight, gm	3708.6	3710.5	3710.5	3717.0	3715.0	3717.0
(E) Submerged Weight, gm	2053.6	2054.4	2054.4	2062.0	2060.7	2062.2
(F) Bulk Specific Gravity [C/(D - E)]	2.236	2.235	2.237	2.237	2.238	2.237
(G) Theoretical Maximum Gravity	2.457	2.457	2.457	2.457	2.457	2.457
(H) % Air Voids [100*(1-F/G)]	9.0	9.0	8.9	9.0	8.9	8.9
(I) Volume of Air Voids [H*(D - E)/100]	148.5	149.8	148.1	148.5	147.6	147.9
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3806.5	3813.6	3809.5	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	105.1	112.5	104.4			
(L) % Saturation [100*(K/I)]	70.8	75.1	70.5			
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	4250	4350	4550	4700	4875	4700
(Q) Dry S_T, psi [2P/(A*B*≅)]	N/A	N/A	N/A	135.5	140.5	135.5
(R) Conditioned S_T, psi [2P/(A*B*≅)]	122.5	125.4	131.1	N/A	N/A	N/A
(S) Average S_T, psi	126.3			137.1		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.92		

Project: 4.75mm

Date: 11/8/2005

Tested By: GJ

Calculated By:

Sample Identification: Michigan Baseline

	Conditioned Samples			Unconditioned Samples		
Sample Number	5	7	8	3	4	6
(A) Diameter, in	5.906	5.906	5.906	5.906	5.906	5.906
(B) Height, in	3.614	3.613	3.612	3.626	3.626	3.608
(C) Weight in Air, gm	3745.4	3744.4	3742.8	3741.6	3744.2	3743.9
(D) SSD Weight, gm	3749.2	3749.1	3747.3	3752.9	3748.6	3748.5
(E) Submerged Weight, gm	2130.3	2131.4	2132.2	2132.7	2132.2	2133.3
(F) Bulk Specific Gravity [C/(D - E)]	2.314	2.315	2.317	2.309	2.316	2.318
(G) Theoretical Maximum Gravity	2.545	2.545	2.545	2.545	2.545	2.545
(H) % Air Voids [100*(1-F/G)]	9.1	9.1	8.9	9.3	9.0	8.9
(I) Volume of Air Voids [H*(D - E)/100]	147.230	146.423	144.452	150.023	145.202	144.119
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3851.0	3852.7	3849.7	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	105.60	108.30	106.90			
(L) % Saturation [100*(K/I)]	71.7	74.0	74.0			
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	5500	5300	5700	7000	7000	7100
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	208.1	208.1	212.1
(R) Conditioned S_T, psi [2P/(A*B*□)]	164.0	158.1	170.1	N/A	N/A	N/A
(S) Average S_T, psi	164.1			209.4		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.78		

Project: 4.75mm Project Mississippi

Date: May 11 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: Mississippi

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.3	No.5	No.6	No.8	No.10	No.11
(A) Diameter, in	5.918	5.915	5.919	5.920	5.924	5.912
(B) Height, in	3.721	3.716	3.727	3.719	3.715	3.710
(C) Weight in Air, gm	3617.5	3620.4	3619.6	3617.0	3614.9	3620.0
(D) SSD Weight, gm	3649.7	3640.8	3649.6	3649.1	3646.0	3647.4
(E) Submerged Weight, gm	1991.9	1992.4	1991.8	1992.9	1990.2	2000.7
(F) Bulk Specific Gravity [C/(D - E)]	2.182	2.196	2.183	2.184	2.183	2.198
(G) Theoretical Maximum Gravity	2.404	2.404	2.404	2.404	2.404	2.404
(H) % Air Voids [100*(1-F/G)]	9.2	8.6	9.2	9.2	9.2	8.6
(I) Volume of Air Voids [H*(D - E)/100]	153.0	142.4	152.1	151.6	152.1	140.9
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3704.6	3719.9	3729.8	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	87.1	99.5	110.2			
(L) % Saturation [100*(K/I)]	56.9	69.9	72.4			
Second Vacuum Saturation Conditioning (If required)						
(M) SSD Weight, gm	3729.0	3723.5	3729.8	N / A		
(N) Vol. Of Absorbed Water, cc [M - C]	111.5	103.1	110.2			
(O) % Saturation [100*(N/I)]	72.9	72.4	72.4			
Tensile Strength (S_T) Calculations						
(P) Failure Load, lbs	6000	6700	6800	7500	7300	8000
(Q) Dry S_T, psi [2P/(A*B*□)]	N/A	N/A	N/A	216.9	211.2	232.2
(R) Conditioned S_T, psi [2P/(A*B*□)]	173.5	194.1	196.2	N/A	N/A	N/A
(S) Average S_T, psi	187.9			220.1		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.85		

Project: 4.75mm Project - Maryland Mix

Date: May 19-22 2005

Tested By: Osamu Takahashi

Calculated By:

Sample Identification: Maryland

	Conditioned Samples			Unconditioned Samples		
Sample Number	No.C	No.D	No.E	No.F	No.G	No.J
(A) Diameter, in	5.916	5.925	5.912	5.922	5.915	5.919
(B) Height, in	3.709	3.714	3.708	3.709	3.700	3.714
(C) Weight in Air, gm	3648.8	3656.9	3656.0	3655.0	3655.7	3656.1
(D) SSD Weight, gm	3666.7	3673.5	3669.0	3668.6	3666.3	3672.8
(E) Submerged Weight, gm	2014.0	2015.9	2022.7	2014.9	2019.5	2014.7
(F) Bulk Specific Gravity [C/(D - E)]	2.208	2.206	2.221	2.210	2.220	2.205
(G) Theoretical Maximum Gravity	2.433	2.433	2.433	2.433	2.433	2.433
(H) % Air Voids [100*(1-F/G)]	9.3	9.3	8.7	9.2	8.8	9.4
(I) Volume of Air Voids [H*(D - E)/100]	153.0	154.6	143.6	151.4	144.3	155.4
Initial Vacuum Saturation Conditioning						
(J) SSD Weight, gm	3762.1	3773.3	3761.1	N / A		
(K) Vol. Of Absorbed Water, cc [J - C]	113.3	116.4	105.1			
(L) % Saturation [100*(K/I)]	74.1	75.3	73.2			
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	4250	4650	4450	5600	5500	5900
(Q) Dry S_T, psi [2P/(A*B*π)]	N/A	N/A	N/A	162.3	160.0	170.9
(R) Conditioned S_T, psi [2P/(A*B*π)]	123.3	134.5	129.2	N/A	N/A	N/A
(S) Average S_T, psi	129.0			164.4		
Tensile Strength Ratio [Avg Conditioned S_T / Avg Dry S_T]:				0.78		

Appendix C

Material Verification Tester Rut Depths

Pill #1

Sample ID	AL-50-4-A		
Location	1	2	average
Initial Reading	4.94	5.00	4.97
Final Reading	20.12	19.04	19.58
Rut Depth	15.18	14.04	14.61
Cycles	8000		
Pill #2			
Sample ID	AL-50-6-B		
Location	1	2	average
Initial Reading	3.87	3.57	3.72
Final Reading	19.4	20.26	19.83
Rut Depth	15.53	16.69	16.11
Cycles	8000		
Average	**15.4**		

Pill #1

Sample ID	AL-50-6-B		
Location	1	2	average
Initial Reading	2.35	2.69	2.52
Final Reading	18.36	19.6	18.98
Rut Depth	16.01	16.91	16.46
Cycles	8000		
Pill #2			
Sample ID	AL50-6-D		
Location	1	2	average
Initial Reading	3.34	3.22	3.28
Final Reading	20.73	19.07	19.9
Rut Depth	17.39	15.85	16.62
Cycles	8000		
Average	**16.5**		

Pill #1

Sample ID	TN-50-4-C		
Location	1	2	average
Initial Reading	5.94	5.89	5.915
Final Reading	25.69	27.66	26.675
Rut Depth	19.75	21.77	20.76
Cycles	8000		
Pill #2			
Sample ID	TN-50-4-A		
Location	1	2	average
Initial Reading	7.04	6.78	6.91
Final Reading	21.14	22.09	21.615
Rut Depth	14.1	15.31	14.705
Cycles	8000		
Average	**17.7**		

Pill #1

Sample ID	TN-75-4-A		
Location	1	2	average
Initial Reading	9.21	9.30	9.255
Final Reading	22.73	22.85	22.79
Rut Depth	13.52	13.55	13.535
Cycles	8000		
Pill #2			
Sample ID	TN-75-4-B		
Location	1	2	average
Initial Reading	8.88	8.69	8.785
Final Reading	21.67	22.94	22.305
Rut Depth	12.79	14.25	13.52
Cycles	8000		
Average	**13.5**		

Pill #1

Sample ID	MO-50-4-A		
Location	1	2	average
Initial Reading	6.74	6.53	6.635
Final Reading	19.88	19.5	19.69
Rut Depth	13.14	12.97	13.055
Cycles	8000		
Pill #2			
Sample ID	MO-50-4-B		
Location	1	2	average
Initial Reading	7.96	7.53	7.745
Final Reading	18.26	19.68	18.97
Rut Depth	10.3	12.15	11.225
Cycles	8000		
Average	**12.1**		

Pill #1

Sample ID	MO-50-6-A		
Location	1	2	average
Initial Reading	6.6	6.69	6.645
Final Reading	18.87	18.72	18.795
Rut Depth	12.27	12.03	12.15
Cycles	8000		
Pill #2			
Sample ID	MO-50-6-B		
Location	1	2	average
Initial Reading	8.57	8.38	8.475
Final Reading	18.36	19.49	18.925
Rut Depth	9.79	11.11	10.45
Cycles	8000		
Average	**11.3**		

Pill #1

Sample ID	VA-50-4-A		
Location	1	2	average
Initial Reading	6.75	6.86	6.805
Final Reading	28.2	27.95	28.075
Rut Depth	21.45	21.09	21.27
Cycles	6228		
Pill #2			
Sample ID	VA-50-4-B		
Location	1	2	average
Initial Reading	7.66	7.13	7.395
Final Reading	25.75	24.85	25.3
Rut Depth	18.09	17.72	17.905
Cycles	6228		
Average	**19.6**		

Pill #1

Sample ID	VA-75-4-A		
Location	1	2	average
Initial Reading	6.19	6.44	6.315
Final Reading	21.07	19.81	20.44
Rut Depth	14.88	13.37	14.125
Cycles	8000		
Pill #2	VA-75-4-B		
Sample ID			
Location	1	2	average
Initial Reading	7.88	7.76	7.82
Final Reading	20.78	21.43	21.105
Rut Depth	12.9	13.67	13.285
Cycles	8000		
Average	**13.7**		

Pill #1

Sample ID	FL-50-4-A		
Location	1	2	average
Initial Reading	4.71	4.86	4.785
Final Reading	23.65	24.05	23.85
Rut Depth	18.94	19.19	19.065
Cycles	1205		
Pill #2			
Sample ID	FL-50-4-B		
Location	1	2	average
Initial Reading	6.08	5.6	5.84
Final Reading	25.09	26.27	25.68
Rut Depth	19.01	20.67	19.84
Cycles	1205		
Average	**19.5**		

Pill #1

Sample ID	FL-75-4-A		
Location	1	2	average
Initial Reading	6.5	6.91	6.705
Final Reading	22.76	21.87	22.315
Rut Depth	16.26	14.96	15.61
Cycles	2047		
Pill #2			
Sample ID	FL-75-4-B		
Location	1	2	average
Initial Reading	6.36	6.08	6.22
Final Reading	21.18	21.59	21.385
Rut Depth	14.82	15.51	15.165
Cycles	2047		
Average	**15.4**		

Pill #1

Sample ID	FL-75-6-A		
Location	1	2	average
Initial Reading	5.09	5.73	5.41
Final Reading	23.36	20.68	22.02
Rut Depth	18.27	14.95	16.61
Cycles	2425		
Pill #2			
Sample ID	FL-75-6-B		
Location	1	2	average
Initial Reading	5.7	7.26	6.48
Final Reading	18.93	19.21	19.07
Rut Depth	13.23	11.95	12.59
Cycles	2425		
Average	**14.6**		

Pill #1

Sample ID			
Location	1	2	average
Initial Reading			#DIV/0!
Final Reading			#DIV/0!
Rut Depth	0	0	#DIV/0!
Cycles	8000		
Pill #2			
Sample ID			
Location	1	2	average
Initial Reading			#DIV/0!
Final Reading			#DIV/0!
Rut Depth	0	0	#DIV/0!
Cycles	8000		
Average	**#DIV/0!**		

Pill #1

Sample ID	CT-50-4-A		
Location	1	2	average
Initial Reading	8.83	9.73	9.28
Final Reading	27.81	27.36	27.585
Rut Depth	18.98	17.63	18.305
Cycles	8000		
Pill #2			
Sample ID	CT-50-4B		
Location	1	2	average
Initial Reading	12.42	11.98	12.2
Final Reading	28.79	27.66	28.225
Rut Depth	16.37	15.68	16.025
Cycles	8000		
Average	**17.2**		

Pill #1

Sample ID	CT-50-6-A		
Location	1	2	average
Initial Reading	7.49	7.88	7.685
Final Reading	21.87	22.04	21.955
Rut Depth	14.38	14.16	14.27
Cycles	8000		
Pill #2	CT-50-6-B		
Sample ID			
Location	1	2	average
Initial Reading	10.56	10.36	10.46
Final Reading	21.27	21.9	21.585
Rut Depth	10.71	11.54	11.125
Cycles	8000		
Average	**12.7**		

Pill #1

Sample ID	MN-50-4-A		
Location	1	2	average
Initial Reading	9.6	10.04	9.82
Final Reading	29.52	29.85	29.685
Rut Depth	19.92	19.81	19.865
Cycles	5724		
Pill #2			
Sample ID	MN-50-4-B		
Location	1	2	average
Initial Reading	12.35	12.18	12.265
Final Reading	29.93	31.3	30.615
Rut Depth	17.58	19.12	18.35
Cycles	5724		
Average	**19.1**		

Pill #1

Sample ID	MN-75-4		
Location	1	2	average
Initial Reading	12.03	12.22	12.125
Final Reading	26.73	28.38	27.555
Rut Depth	14.7	16.16	15.43
Cycles	5256		
Pill #2			
Sample ID	MN-75-4-B		
Location	1	2	average
Initial Reading	12.72	11.95	12.335
Final Reading	28.91	28.15	28.53
Rut Depth	16.19	16.2	16.195
Cycles	5256		
Average	**15.8**		

Pill #1

Sample ID	MN-75-6-A		
Location	1	2	average
Initial Reading	13.3	13.76	13.53
Final Reading	26.36	24.87	25.615
Rut Depth	13.06	11.11	12.085
Cycles	5074		
Pill #2			
Sample ID	MN-75-6-B		
Location	1	2	average
Initial Reading	13.69	13.68	13.685
Final Reading	29.09	29.49	29.29
Rut Depth	15.4	15.81	15.605
Cycles	5074		
Average	**13.8**		

Pill #1

Sample ID	NH-50-4		
Location	1	2	average
Initial Reading	8.52	8.64	8.58
Final Reading	23.48	24.35	23.915
Rut Depth	14.96	15.71	15.335
Cycles	3595		
Pill #2			
Sample ID	NH-50-4b		
Location	1	2	average
Initial Reading	9.35	9.22	9.285
Final Reading	22.85	23	22.925
Rut Depth	13.5	13.78	13.64
Cycles	3595		
Average	**14.5**		

Pill #1

Sample ID	NH-75-4-A		
Location	1	2	average
Initial Reading	10.35	10.75	10.55
Final Reading	28.43	28.94	28.685
Rut Depth	18.08	18.19	18.135
Cycles	4220		
Pill #2			
Sample ID	NH-75-4-B		
Location	1	2	average
Initial Reading	10.23	9.97	10.1
Final Reading	25.55	26.85	26.2
Rut Depth	15.32	16.88	16.1
Cycles	4220		
Average	**17.1**		

Pill #1

Sample ID	NH-75-6-A		
Location	1	2	average
Initial Reading	8.15	8.44	8.295
Final Reading	22.03	20.99	21.51
Rut Depth	13.88	12.55	13.215
Cycles	8000		
Pill #2			
Sample ID	NH-75-6-B		
Location	1	2	average
Initial Reading	7.51	7.39	7.45
Final Reading	20.74	20.06	20.4
Rut Depth	13.23	12.67	12.95
Cycles	8000		
Average	**13.1**		

Pill #1

Sample ID	WI-50-4-A		
Location	1	2	average
Initial Reading	8.66	9.43	9.045
Final Reading	23.43	23.39	23.41
Rut Depth	14.77	13.96	14.365
Cycles	8000		
Pill #2			
Sample ID	WI-50-4-B		
Location	1	2	average
Initial Reading	10.88	10.82	10.85
Final Reading	25.36	23.6	24.48
Rut Depth	14.48	12.78	13.63
Cycles	8000		
Average	**14.0**		

Pill #1

Sample ID	WI-50-6-A		
Location	1	2	average
Initial Reading	2.9	3.35	3.125
Final Reading	18.19	17.57	17.88
Rut Depth	15.29	14.22	14.755
Cycles	8000		
Pill #2			
Sample ID	WI-50-6-B		
Location	1	2	average
Initial Reading	2.71	2.53	2.62
Final Reading	15.74	15.84	15.79
Rut Depth	13.03	13.31	13.17
Cycles	8000		
Average	**14.0**		

Pill #1

Sample ID	TNGM-50-4-A		
Location	1	2	average
Initial Reading	5.59	5.90	5.745
Final Reading	26.6	26.65	26.625
Rut Depth	21.01	20.75	20.88
Cycles	2795		
Pill #2			
Sample ID	TNGM-50-4-B		
Location	1	2	average
Initial Reading	4.87	4.64	4.755
Final Reading	26.01	26.87	26.44
Rut Depth	21.14	22.23	21.685
Cycles	2795		
Average	**21.3**		

Pill #1

Sample ID	TNGM-75-4		
Location	1	2	average
Initial Reading	10.35	10.75	10.55
Final Reading	28.43	28.94	28.685
Rut Depth	18.08	18.19	18.135
Cycles	8000		
Pill #2			
Sample ID	TNGM-75-4		
Location	1	2	average
Initial Reading	10.23	9.97	10.1
Final Reading	25.55	26.85	26.2
Rut Depth	15.32	16.88	16.1
Cycles	8000		
Average	**17.1**		

Pill #1

Sample ID	FL adj-50-4-A		
Location	1	2	average
Initial Reading	9.8	9.92	9.86
Final Reading	24.29	23.51	23.9
Rut Depth	14.49	13.59	14.04
Cycles	8000		
Pill #2			
Sample ID	FL adj-50-4-B		
Location	1	2	average
Initial Reading	10.75	10.63	10.69
Final Reading	25.43	24.9	25.165
Rut Depth	14.68	14.27	14.475
Cycles	8000		
Average	**14.3**		

Pill #1

Sample ID	FL adj-75-6		
Location	1	2	average
Initial Reading	8.71	8.99	8.85
Final Reading	18.77	18.02	18.395
Rut Depth	10.06	9.03	9.545
Cycles	8000		
Pill #2			
Sample ID	FL adj-75-6-B		
Location	1	2	average
Initial Reading	9.2	8.64	8.92
Final Reading	23.1	22.97	23.035
Rut Depth	13.9	14.33	14.115
Cycles	8000		
Average	**11.8**		

Pill #1

Sample ID	WI adj-50-4-A		
Location	1	2	average
Initial Reading	14.02	14.41	14.215
Final Reading	19.37	18.99	19.18
Rut Depth	5.35	4.58	4.965
Cycles	8000		
Pill #2			
Sample ID	WI adj-50-4-B		
Location	1	2	average
Initial Reading	14.4	13.94	14.17
Final Reading	19.93	19.51	19.72
Rut Depth	5.53	5.57	5.55
Cycles	8000		
Average	**5.3**		

Pill #1

Sample ID	WI adj-50-6-A		
Location	1	2	average
Initial Reading	12.79	13.25	13.02
Final Reading	20.11	21.14	20.625
Rut Depth	7.32	7.89	7.605
Cycles	8000		
Pill #2			
Sample ID	WI adj-50-6-B		
Location	1	2	average
Initial Reading	13.84	13.88	13.86
Final Reading	20.96	21.43	21.195
Rut Depth	7.12	7.55	7.335
Cycles	8000		
Average	**7.5**		

Pill #1

Sample ID	VA adj-50-4-A		
Location	1	2	average
Initial Reading	10.28	10.16	10.22
Final Reading	19.41	20.18	19.795
Rut Depth	9.13	10.02	9.575
Cycles	8000		
Pill #2			
Sample ID	VA adj-50-4-B		
Location	1	2	average
Initial Reading	10.92	10.56	10.74
Final Reading	20.62	20.9	20.76
Rut Depth	9.7	10.34	10.02
Cycles	8000		
Average	**9.8**		

Pill #1

Sample ID	VA adj-75-4-A		
Location	1	2	average
Initial Reading	8.62	8.92	8.77
Final Reading	19.8	20.08	19.94
Rut Depth	11.18	11.16	11.17
Cycles	8000		
Pill #2			
Sample ID	VA adj-75-4-B		
Location	1	2	average
Initial Reading	7.51	7.39	7.45
Final Reading	17.77	19.16	18.465
Rut Depth	10.26	11.77	11.015
Cycles	8000		
Average	**11.1**		

Pill #1

Sample ID	GA-A		
Location	1	2	average
Initial Reading	11.2	11.28	11.24
Final Reading	20.6	19.03	19.815
Rut Depth	9.4	7.75	8.575
Cycles	8000		
Pill #2			
Sample ID	GA-B		
Location	1	2	average
Initial Reading	10.45	10.05	10.25
Final Reading	18.4	19.3	18.85
Rut Depth	7.95	9.25	8.6
Cycles	8000		
Average	**8.6**		

Pill #1

Sample ID	MS-A		
Location	1	2	average
Initial Reading	7.42	7.30	7.36
Final Reading	10.76	10.4	10.58
Rut Depth	3.34	3.1	3.22
Cycles	8000		
Pill #2			
Sample ID	MS-B		
Location	1	2	average
Initial Reading	6.49	6.35	6.42
Final Reading	10.62	10.86	10.74
Rut Depth	4.13	4.51	4.32
Cycles	8000		
Average	**3.8**		

Pill #1

Sample ID	MD-A		
Location	1	2	average
Initial Reading	6.7	6.96	6.83
Final Reading	15.43	14.84	15.135
Rut Depth	8.73	7.88	8.305
Cycles	8000		
Pill #2			
Sample ID	MD-B		
Location	1	2	average
Initial Reading	5.77	5.62	5.695
Final Reading	16.85	15.77	16.31
Rut Depth	11.08	10.15	10.615
Cycles	8000		
Average	**9.5**		

Pill #1

Sample ID	MI-A		
Location	1	2	average
Initial Reading	5.62	6.06	5.84
Final Reading	21.98	21.06	21.52
Rut Depth	16.36	15	15.68
Cycles	8000		
Pill #2			
Sample ID	MI-B		
Location	1	2	average
Initial Reading	6.23	6.03	6.13
Final Reading	21.04	22.64	21.84
Rut Depth	14.81	16.61	15.71
Cycles	8000		
Average	**15.7**		

Appendix D

Permeability Data

Distance to zero mark on tube: 2.54
Inside Diameter of Pipe (mm): 31.75
Pedistal Plate to Outlet (mm): 135

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
AL-50-4	26.03	150.80	178.68	65.00	50.00	128	0.0003	0.0003	22.0	0.953	33.31
	26.03	150.80	178.68	65.00	50.00	130	0.0003	0.0003	22.0	0.953	32.80
	26.03	150.80	178.68	65.00	50.00	132	0.0003	0.0003	22.0	0.953	32.30
	26.03	150.80	178.68	65.00	50.00	135	0.0003	0.0003	22.0	0.953	31.58
AL-50-4	25.35	150.36	177.64	65.00	50.00	65	0.0007	0.0006	22.0	0.953	64.34
	25.35	150.36	177.64	65.00	50.00	65	0.0007	0.0006	22.0	0.953	64.34
	25.35	150.36	177.64	65.00	50.00	65	0.0007	0.0006	22.0	0.953	64.34
	25.35	150.36	177.64	65.00	50.00	66	0.0007	0.0006	22.0	0.953	63.36
AL-50-4	27.16	150.50	177.97	65.00	50.00	87	0.0005	0.0005	22.0	0.953	51.22
	27.16	150.50	177.97	65.00	50.00	86	0.0005	0.0005	22.0	0.953	51.82
	27.16	150.50	177.97	65.00	50.00	87	0.0005	0.0005	22.0	0.953	51.22
	27.16	150.50	177.97	65.00	50.00	87	0.0005	0.0005	22.0	0.953	51.22
										Average=	**49.32**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
AL-50-6	25.51	150.13	177.09	65.00	50.00	71	0.0006	0.0006	22.0	0.953	59.44
	25.51	150.13	177.09	65.00	50.00	71	0.0006	0.0006	22.0	0.953	59.44
	25.51	150.13	177.09	65.00	50.00	72	0.0006	0.0006	22.0	0.953	58.61
	25.51	150.13	177.09	65.00	50.00	72	0.0006	0.0006	22.0	0.953	58.61
AL-50-6	26.63	150.22	177.30	65.00	50.00	103	0.0004	0.0004	22.0	0.953	42.62
	26.63	150.22	177.30	65.00	50.00	104	0.0004	0.0004	22.0	0.953	42.21
	26.63	150.22	177.30	65.00	50.00	106	0.0004	0.0004	22.0	0.953	41.42
	26.63	150.22	177.30	65.00	50.00	112	0.0004	0.0004	22.0	0.953	39.20
										Average=	**50.19**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
TN-50-4	25.50	150.16	177.16	65.00	50.00	44	0.0010	0.0009	24.0	0.910	91.51
	25.50	150.16	177.16	65.00	50.00	44	0.0010	0.0009	24.0	0.910	91.51
	25.50	150.16	177.16	65.00	50.00	43	0.0010	0.0009	24.0	0.910	93.64
	25.50	150.16	177.16	65.00	50.00	43	0.0010	0.0009	24.0	0.910	93.64
TN-50-4	26.16	150.41	177.75	65.00	50.00	75	0.0006	0.0005	24.0	0.910	54.82
	26.16	150.41	177.75	65.00	50.00	78	0.0006	0.0005	24.0	0.910	52.71
	26.16	150.41	177.75	65.00	50.00	83	0.0005	0.0005	24.0	0.910	49.54
	26.16	150.41	177.75	65.00	50.00	86	0.0005	0.0005	24.0	0.910	47.81
TN-50-5	26.08	150.23	177.33	65.00	50.00	64	0.0007	0.0006	24.0	0.910	64.21
	26.08	150.23	177.33	65.00	50.00	63	0.0007	0.0007	24.0	0.910	65.23
	26.08	150.23	177.33	65.00	50.00	64	0.0007	0.0006	24.0	0.910	64.21
	26.08	150.23	177.33	65.00	50.00	64	0.0007	0.0006	24.0	0.910	64.21
TN-50-5	24.19	150.28	177.45	65.00	50.00	61	0.0007	0.0006	24.0	0.910	62.68
	24.19	150.28	177.45	65.00	50.00	62	0.0007	0.0006	24.0	0.910	61.67
	24.19	150.28	177.45	65.00	50.00	63	0.0007	0.0006	24.0	0.910	60.69
	24.19	150.28	177.45	65.00	50.00	64	0.0007	0.0006	24.0	0.910	59.74
										Average=	**67.36**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
TN-75-4	26.64	150.35	177.61	65.00	50.00	39	0.0012	0.0010	26.0	0.869	102.51
	26.64	150.35	177.61	65.00	50.00	39	0.0012	0.0010	26.0	0.869	102.51
	26.64	150.35	177.61	65.00	50.00	39	0.0012	0.0010	26.0	0.869	102.51
	26.64	150.35	177.61	65.00	50.00	39	0.0012	0.0010	26.0	0.869	102.51
TN-75-4	24.50	150.29	177.47	65.00	50.00	76	0.0006	0.0005	26.0	0.869	48.62
	24.50	150.29	177.47	65.00	50.00	77	0.0006	0.0005	26.0	0.869	47.99
	24.50	150.29	177.47	65.00	50.00	77	0.0006	0.0005	26.0	0.869	47.99
	24.50	150.29	177.47	65.00	50.00	78	0.0005	0.0005	26.0	0.869	47.37
										Average=	**75.25**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MO-50-4	25.14	150.07	176.95	65.00	50.00	200	0.0002	0.0002	22.5	0.942	20.59
	25.14	150.07	176.95	65.00	50.00	197	0.0002	0.0002	22.5	0.942	20.90
	25.14	150.07	176.95	65.00	50.00	195	0.0002	0.0002	22.5	0.942	21.11
	25.14	150.07	176.95	65.00	50.00	192	0.0002	0.0002	22.5	0.942	21.44
MO-50-4	26.86	150.20	177.26	65.00	50.00	198	0.0002	0.0002	22.5	0.942	22.10
	26.86	150.20	177.26	65.00	50.00	201	0.0002	0.0002	22.5	0.942	21.77
	26.86	150.20	177.26	65.00	50.00	200	0.0002	0.0002	22.5	0.942	21.88
	26.86	150.20	177.26	65.00	50.00	199	0.0002	0.0002	22.5	0.942	21.99
										Average=	**21.47**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MO-50-6	24.23	150.05	176.90	65.00	50.00	85	0.0005	0.0005	23.0	0.931	46.23
	24.23	150.05	176.90	65.00	50.00	84	0.0005	0.0005	23.0	0.931	46.78
	24.23	150.05	176.90	65.00	50.00	85	0.0005	0.0005	23.0	0.931	46.23
	24.23	150.05	176.90	65.00	50.00	86	0.0005	0.0005	23.0	0.931	45.70
MO-50-6	25.49	150.18	177.21	65.00	50.00	136	0.0003	0.0003	23.0	0.931	30.27
	25.49	150.18	177.21	65.00	50.00	137	0.0003	0.0003	23.0	0.931	30.05
	25.49	150.18	177.21	65.00	50.00	138	0.0003	0.0003	23.0	0.931	29.83
	25.49	150.18	177.21	65.00	50.00	137	0.0003	0.0003	23.0	0.931	30.05
										Average=	**38.14**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
VA-50-4	25.05	150.26	177.40	65.00	50.00	90	0.0005	0.0005	22.5	0.942	45.47
	25.05	150.26	177.40	65.00	50.00	90	0.0005	0.0005	22.5	0.942	45.47
	25.05	150.26	177.40	65.00	50.00	90	0.0005	0.0005	22.5	0.942	45.47
	25.05	150.26	177.40	65.00	50.00	89	0.0005	0.0005	22.5	0.942	45.99
VA-50-4	26.70	150.51	177.99	65.00	50.00	99	0.0005	0.0004	22.5	0.942	43.77
	26.70	150.51	177.99	65.00	50.00	99	0.0005	0.0004	22.5	0.942	43.77
	26.70	150.51	177.99	65.00	50.00	98	0.0005	0.0004	22.5	0.942	44.22
	26.70	150.51	177.99	65.00	50.00	98	0.0005	0.0004	22.5	0.942	44.22
										Average=	**44.80**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
VA75-8	25.12	150.76	178.58	65.00	50.00	187	0.0002	0.0002	23.0	0.931	21.54
2nd Vacuum	25.12	150.76	178.58	65.00	50.00	193	0.0002	0.0002	23.0	0.931	20.87
	25.12	150.26	177.40	65.00	50.00	195	0.0002	0.0002	23.0	0.931	20.80
	25.12	150.26	177.40	65.00	50.00	196	0.0002	0.0002	23.0	0.931	20.69
VA75-9	25.76	150.05	176.90	65.00	50.00	105	0.0004	0.0004	23.0	0.931	39.67
	25.76	150.05	176.90	65.00	50.00	104	0.0004	0.0004	23.0	0.931	40.05
	25.76	150.05	176.90	65.00	50.00	105	0.0004	0.0004	23.0	0.931	39.67
	25.76	150.05	176.90	65.00	50.00	105	0.0004	0.0004	23.0	0.931	39.67
										Average=	**30.37**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
FL-50-4	26.69	151.30	179.86	65.00	50.00	28	0.0016	0.0016	20.0	1.000	162.54
	26.69	151.30	179.86	65.00	50.00	29	0.0016	0.0016	20.0	1.000	156.93
	26.69	151.30	179.86	65.00	50.00	29	0.0016	0.0016	20.0	1.000	156.93
	26.69	151.30	179.86	65.00	50.00	31	0.0015	0.0015	20.0	1.000	146.81
FL-50-4	26.29	150.90	178.91	65.00	50.00	29	0.0016	0.0016	20.0	1.000	155.52
	26.29	150.90	178.91	65.00	50.00	29	0.0016	0.0016	20.0	1.000	155.52
	26.29	150.90	178.91	65.00	50.00	30	0.0015	0.0015	20.0	1.000	150.34
	26.29	150.90	178.91	65.00	50.00	30	0.0015	0.0015	20.0	1.000	150.34
										Average=	**154.37**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
FL-75-4	26.27	151.11	179.41	65.00	50.00	41	0.0011	0.0010	23.0	0.931	102.05
	26.27	151.11	179.41	65.00	50.00	41	0.0011	0.0010	23.0	0.931	102.05
	26.27	151.11	179.41	65.00	50.00	42	0.0011	0.0010	23.0	0.931	99.62
	26.27	151.11	179.41	65.00	50.00	41	0.0011	0.0010	23.0	0.931	102.05
FL-75-4	25.35	150.27	177.42	65.00	50.00	27	0.0016	0.0015	23.0	0.931	151.49
	25.35	150.27	177.42	65.00	50.00	27	0.0016	0.0015	23.0	0.931	151.49
	25.35	150.27	177.42	65.00	50.00	27	0.0016	0.0015	23.0	0.931	151.49
	25.35	150.27	177.42	65.00	50.00	27	0.0016	0.0015	23.0	0.931	151.49
										Average=	**126.47**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
FL-75-6	26.39	150.87	178.84	65.00	50.00	36	0.0013	0.0012	23.0	0.931	117.10
	26.39	150.87	178.84	65.00	50.00	36	0.0013	0.0012	23.0	0.931	117.10
	26.39	150.87	178.84	65.00	50.00	36	0.0013	0.0012	23.0	0.931	117.10
	26.39	150.87	178.84	65.00	50.00	37	0.0012	0.0011	23.0	0.931	113.94
FL-75-6	26.95	150.31	177.52	65.00	50.00	101	0.0005	0.0004	23.0	0.931	42.90
	26.95	150.31	177.52	65.00	50.00	102	0.0005	0.0004	23.0	0.931	42.48
	26.95	150.31	177.52	65.00	50.00	103	0.0005	0.0004	23.0	0.931	42.06
	26.95	150.31	177.52	65.00	50.00	103	0.0005	0.0004	23.0	0.931	42.06
										Average=	**79.34**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MN 75-6	23.80	150.00	176.79	65.00	50.00	369	0.0001	0.0001	20.5	0.988	11.12
	23.80	150.00	176.79	65.00	50.00	526	0.0001	0.0001	20.5	0.988	7.80
	23.80	150.00	176.79	65.00	50.00	667	0.0001	0.0001	20.5	0.988	6.15
	23.80	150.00	176.79	65.00	50.00	801	0.0001	0.0001	20.5	0.988	5.12
										Average=	**7.55**
MN 75-4	22.89	150.00	176.79	65.00	50.00	176	0.0002	0.0002	20.5	0.988	22.46
	22.89	150.00	176.79	65.00	50.00	215	0.0002	0.0002	20.5	0.988	18.39
	22.89	150.00	176.79	65.00	50.00	255	0.0002	0.0002	20.5	0.988	15.50
	22.89	150.00	176.79	65.00	50.00	306	0.0001	0.0001	20.5	0.988	12.92
										Average=	**17.32**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MN-50-4	22.23	150.00	176.79	65.00	50.00	276	0.0001	0.0001	20.0	1.0	14.10
	22.23	150.00	176.79	65.00	50.00	383	0.0001	0.0001	20.0	1.0	10.16
	22.23	150.00	176.79	65.00	50.00	506	0.0001	0.0001	20.0	1.0	7.69
	22.23	150.00	176.79	65.00	50.00	613	0.0001	0.0001	20.0	1.0	6.35
MN-50-4	25.10	150.00	176.79	65.00	50.00	334	0.0001	0.0001	20.0	1.0	13.08
	25.10	150.00	176.79	65.00	50.00	554	0.0001	0.0001	20.0	1.0	7.88
	25.10	150.00	176.79	65.00	50.00	905	0.0000	0.0000	20.0	1.0	4.83
	25.10	150.00	176.79	65.00	50.00	1421	0.0000	0.0000	20.0	1.0	3.07
										Average=	**8.39**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
NH-50-4	24.67	150.66	178.34	65.00	50.00	88	0.0005	0.0005	20.0	1.000	48.40
	24.67	150.66	178.34	65.00	50.00	93	0.0005	0.0005	20.0	1.000	45.80
	24.67	150.66	178.34	65.00	50.00	96	0.0004	0.0004	20.0	1.000	44.37
	24.67	150.66	178.34	65.00	50.00	100	0.0004	0.0004	20.0	1.000	42.59
NH-50-4	25.24	150.52	178.01	65.00	50.00	172	0.0003	0.0003	20.0	1.000	25.35
	25.39	150.83	178.75	65.00	50.00	184	0.0002	0.0002	20.0	1.000	23.74
	25.39	150.83	178.75	65.00	50.00	194	0.0002	0.0002	20.0	1.000	22.51
	25.39	150.83	178.75	65.00	50.00	207	0.0002	0.0002	20.0	1.000	21.10
										Average=	**34.23**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
NH-75-4	26.30	150.38	177.68	65.00	50.00	85	0.0005	0.0005	21.0	0.976	52.16
	26.30	150.38	177.68	65.00	50.00	85	0.0005	0.0005	21.0	0.976	52.16
	26.30	150.38	177.68	65.00	50.00	87	0.0005	0.0005	21.0	0.976	50.97
	26.30	150.38	177.68	65.00	50.00	88	0.0005	0.0005	21.0	0.976	50.39
NH-75-4	25.39	150.83	178.75	65.00	50.00	78	0.0006	0.0005	21.0	0.976	54.65
	25.39	150.83	178.75	65.00	50.00	78	0.0006	0.0005	21.0	0.976	54.65
	25.39	150.83	178.75	65.00	50.00	80	0.0005	0.0005	21.0	0.976	53.28
	25.39	150.83	178.75	65.00	50.00	84	0.0005	0.0005	21.0	0.976	50.75
										Average=	**52.38**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
NH-75-6	26.20	150.88	178.87	65.00	50.00	311	0.0001	0.0001	23.0	0.931	13.46
	26.20	150.88	178.87	65.00	50.00	355	0.0001	0.0001	23.0	0.931	11.79
	26.20	150.88	178.87	65.00	50.00	397	0.0001	0.0001	23.0	0.931	10.55
	26.20	150.88	178.87	65.00	50.00	429	0.0001	0.0001	23.0	0.931	9.76
NH-75-6	24.95	151.25	179.74	65.00	50.00	174	0.0002	0.0002	23.0	0.931	22.86
	24.95	151.25	179.74	65.00	50.00	217	0.0002	0.0002	23.0	0.931	18.33
	24.95	151.25	179.74	65.00	50.00	233	0.0002	0.0002	23.0	0.931	17.07
	24.95	151.25	179.74	65.00	50.00	256	0.0002	0.0002	23.0	0.931	15.53
										Average=	**14.92**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
WI-50-4	26.15	150.26	177.40	65.00	50.00	17	0.0027	0.0025	22.5	0.942	250.77
	26.15	150.26	177.40	65.00	50.00	17	0.0027	0.0025	22.5	0.942	250.77
	26.15	150.26	177.40	65.00	50.00	17	0.0027	0.0025	22.5	0.942	250.77
	26.15	150.26	177.40	65.00	50.00	17	0.0027	0.0025	22.5	0.942	250.77
WI-50-4	25.99	150.51	177.99	65.00	50.00	24	0.0019	0.0018	22.5	0.942	176.01
	25.99	150.51	177.99	65.00	50.00	25	0.0018	0.0017	22.5	0.942	168.97
	25.99	150.51	177.99	65.00	50.00	25	0.0018	0.0017	22.5	0.942	168.97
	25.99	150.51	177.99	65.00	50.00	25	0.0018	0.0017	22.5	0.942	168.97
										Average=	**210.75**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
WI-50-6	25.97	150.26	177.40	65.00	50.00	20	0.0022	0.0020	26.0	0.869	195.36
	25.97	150.26	177.40	65.00	50.00	20	0.0022	0.0020	26.0	0.869	195.36
	25.97	150.26	177.40	65.00	50.00	20	0.0022	0.0020	26.0	0.869	195.38
	25.97	150.26	177.40	65.00	50.00	20	0.0022	0.0020	26.0	0.869	195.36
WI-50-6	25.96	150.51	177.99	65.00	50.00	24	0.0019	0.0016	26.0	0.869	162.20
	25.96	150.51	177.99	65.00	50.00	24	0.0019	0.0016	26.0	0.869	162.20
	25.96	150.51	177.99	65.00	50.00	24	0.0019	0.0016	26.0	0.869	162.20
	25.96	150.51	177.99	65.00	50.00	24	0.0019	0.0016	26.0	0.869	162.20
										Average=	**178.78**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
TNGM-75-4	24.51	150.00	176.79	65.00	55.00	14	0.00	0.00	22.0	0.953	203.06
	24.51	150.00	176.79	65.00	50.00	23	0.00	0.00	22.0	0.953	183.99
TNGM-75-4	25.06	150.00	176.79	65.00	55.00	20	0.00	0.00	22.0	0.953	152.38
	25.06	150.00	176.79	65.00	55.00	20	0.00	0.00	22.0	0.953	152.38
	25.06	150.00	176.79	65.00	55.00	20	0.00	0.00	22.0	0.953	152.38
	25.06	150.00	176.79	65.00	55.00	20	0.00	0.00	22.0	0.953	152.38
TNGM-75-4	25.06	150.00	176.79	65.00	50.00	32	0.00	0.00	22.0	0.953	135.05
	25.06	150.00	176.79	65.00	50.00	32	0.00	0.00	22.0	0.953	135.05
	25.06	150.00	176.79	65.00	50.00	31	0.00	0.00	22.0	0.953	139.41
	25.06	150.00	176.79	65.00	50.00	32	0.00	0.00	22.0	0.953	135.05
										Average=	**160.7**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
FL adj-50-4	26.69	151.30	179.86	65.00	50.00	30	0.0015	0.0015	20.0	1.000	151.70
	26.69	151.30	179.86	65.00	50.00	31	0.0015	0.0015	20.0	1.000	146.81
	26.69	151.30	179.86	65.00	50.00	32	0.0014	0.0014	20.0	1.000	142.22
	26.69	151.30	179.86	65.00	50.00	33	0.0014	0.0014	20.0	1.000	137.91
FL adj-50-4	26.29	150.90	178.91	65.00	50.00	24	0.0019	0.0019	20.0	1.000	187.92
	26.29	150.90	178.91	65.00	50.00	25	0.0018	0.0018	20.0	1.000	180.41
	26.29	150.90	178.91	65.00	50.00	26	0.0017	0.0017	20.0	1.000	173.47
	26.29	150.90	178.91	65.00	50.00	27	0.0017	0.0017	20.0	1.000	167.04
										Average=	**177.21**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
FL adj-75-6	26.30	151.30	179.86	65.00	50.00	36	0.0012	0.0012	20.0	1	124.66
	26.30	151.30	179.86	65.00	50.00	36	0.0012	0.0012	20.0	1	124.66
	26.30	151.30	179.86	65.00	50.00	36	0.0012	0.0012	20.0	1	124.66
	26.30	151.30	179.86	65.00	50.00	37	0.0012	0.0012	20.0	1	121.30
										Average=	**123.82**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
WI adj-50-4	26.24	150.26	177.40	65.00	55.00	119	0.0003	0.0002	26.0	0.869	23.58
	26.24	150.26	177.40	65.00	55.00	123	0.0003	0.0002	26.0	0.869	22.82
	26.24	150.26	177.40	65.00	55.00	123	0.0003	0.0002	26.0	0.869	22.82
	26.24	150.26	177.40	65.00	55.00	122	0.0003	0.0002	26.0	0.869	23.00
WI adj-50-4	27.65	150.51	177.99	65.00	55.00	72	0.0005	0.0004	26.0	0.869	40.83
	27.65	150.51	177.99	65.00	55.00	77	0.0004	0.0004	26.0	0.869	38.18
	27.65	150.51	177.99	65.00	55.00	76	0.0004	0.0004	26.0	0.869	38.68
	27.65	150.51	177.99	65.00	55.00	78	0.0004	0.0004	26.0	0.869	37.69
										Average=	**31.0**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
WI adj-50-6	25.18	150.26	177.40	65.00	55.00	34	0.0009	0.0008	26.0	0.869	79.37
	25.18	150.26	177.40	65.00	55.00	34	0.0009	0.0008	26.0	0.869	79.37
	25.18	150.26	177.40	65.00	55.00	34	0.0009	0.0008	26.0	0.869	79.37
	25.18	150.26	177.40	65.00	55.00	34	0.0009	0.0008	26.0	0.869	79.37
WI adj-50-6	24.06	150.51	177.99	65.00	55.00	33	0.0009	0.0008	26.0	0.869	78.04
	24.06	150.51	177.99	65.00	55.00	33	0.0009	0.0008	26.0	0.869	78.04
	24.06	150.51	177.99	65.00	55.00	34	0.0009	0.0008	26.0	0.869	75.74
	24.06	150.51	177.99	65.00	55.00	34	0.0009	0.0008	26.0	0.869	75.74
										Average=	**78.1**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
GA-1	25.50	150.14	177.12	65.00	50.00	37	0.0012	0.0011	22.0	0.953	114.00
	25.50	150.14	177.12	65.00	50.00	36	0.0012	0.0012	22.0	0.953	117.16
	25.50	150.14	177.12	65.00	50.00	37	0.0012	0.0011	22.0	0.953	114.00
	25.50	150.14	177.12	65.00	50.00	38	0.0012	0.0011	22.0	0.953	111.00
GA-2	27.70	150.45	177.85	65.00	50.00	44	0.0011	0.0010	22.0	0.953	103.26
	27.70	150.45	177.85	65.00	50.00	45	0.0011	0.0010	22.0	0.953	100.96
	27.70	150.45	177.85	65.00	50.00	45	0.0011	0.0010	22.0	0.953	100.96
	27.70	150.45	177.85	65.00	50.00	46	0.0010	0.0010	22.0	0.953	98.77
										Average=	**107.5**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MD-2	26.33	150.83	178.75	65.00	50.00	55	0.0008	0.0008	23.0	0.931	76.53
	26.33	150.83	178.75	65.00	50.00	60	0.0008	0.0007	23.0	0.931	70.15
	26.33	150.83	178.75	65.00	50.00	66	0.0007	0.0006	23.0	0.931	63.77
	26.33	150.83	178.75	65.00	50.00	71	0.0006	0.0006	23.0	0.931	59.28
MD-4	26.35	150.74	178.53	65.00	50.00	67	0.0007	0.0006	23.0	0.931	62.94
	26.35	150.74	178.53	65.00	50.00	75	0.0006	0.0006	23.0	0.931	56.23
	26.35	150.74	178.53	65.00	50.00	80	0.0006	0.0005	23.0	0.931	52.71
	26.35	150.74	178.53	65.00	50.00	85	0.0005	0.0005	23.0	0.931	49.61
										Average=	**61.4**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MI	26.60	150.26	177.40	65.00	50.00	44	0.0010	0.0010	20.0	1	104.53
	26.60	150.26	177.40	65.00	50.00	44	0.0010	0.0010	20.0	1	104.53
	26.60	150.26	177.40	65.00	50.00	43	0.0011	0.0011	20.0	1	106.96
	26.60	150.26	177.40	65.00	50.00	43	0.0011	0.0011	20.0	1	106.96
MI	25.90	150.51	177.99	65.00	50.00	52	0.0009	0.0009	20.0	1	85.96
	25.90	150.51	177.99	65.00	50.00	52	0.0009	0.0009	20.0	1	85.96
	25.90	150.51	177.99	65.00	50.00	52	0.0009	0.0009	20.0	1	85.96
	25.90	150.51	177.99	65.00	50.00	52	0.0009	0.0009	20.0	1	85.96
										Average=	**95.9**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
MS-3	26.61	150.33	177.56	65.00	50.00	116	0.0004	0.0004	22.0	0.953	37.77
	26.61	150.33	177.56	65.00	50.00	118	0.0004	0.0004	22.0	0.953	37.13
	26.61	150.33	177.56	65.00	50.00	122	0.0004	0.0004	22.0	0.953	35.91
	26.61	150.33	177.56	65.00	50.00	124	0.0004	0.0004	22.0	0.953	35.33
MS-4	26.74	150.51	177.99	65.00	50.00	73	0.0006	0.0006	22.0	0.953	60.14
	26.74	150.51	177.99	65.00	50.00	73	0.0006	0.0006	22.0	0.953	60.14
	26.74	150.51	177.99	65.00	50.00	74	0.0006	0.0006	22.0	0.953	59.33
	26.74	150.51	177.99	65.00	50.00	74	0.0006	0.0006	22.0	0.953	59.33
										Average=	**48.1**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
CT-50-4	25.18	150.26	177.40	65.00	50.00	37	0.0012	0.0012	20.0	1	118.00
	25.18	150.26	177.40	65.00	50.00	36	0.0012	0.0012	20.0	1	121.28
	25.18	150.26	177.40	65.00	50.00	37	0.0012	0.0012	20.0	1	118.00
	25.18	150.26	177.40	65.00	50.00	37	0.0012	0.0012	20.0	1	118.00
CT-50-4	24.06	150.51	177.99	65.00	50.00	64	0.0007	0.0007	20.0	1	65.11
	24.06	150.51	177.99	65.00	50.00	65	0.0006	0.0006	20.0	1	64.11
	24.06	150.51	177.99	65.00	50.00	66	0.0006	0.0006	20.0	1	63.14
	24.06	150.51	177.99	65.00	50.00	66	0.0006	0.0006	20.0	1	63.14
										Average=	**91.3**

Sample ID	Ht. (mm)	Ave.Dia. (mm)	Sample A (cm^2)	Start ht. (cm)	end ht. (cm)	Time (s)	k (cm/s)	k@20 C	Water Temp (°C)	Rt	Permeabiliby cm/s*10^-5
CT-50-6	25.05	150.26	177.40	65.00	50.00	48	0.0009	0.0009	20.0	1.000	90.51
	25.05	150.26	177.40	65.00	50.00	50	0.0009	0.0009	20.0	1.000	86.89
	25.05	150.26	177.40	65.00	50.00	52	0.0008	0.0008	20.0	1.000	83.55
	25.05	150.26	177.40	65.00	50.00	54	0.0008	0.0008	20.0	1.000	80.46
CT-50-6	26.70	150.51	177.99	65.00	50.00	32	0.0014	0.0014	20.0	1.000	143.77
	26.70	150.51	177.99	65.00	50.00	33	0.0014	0.0014	20.0	1.000	139.41
	26.70	150.51	177.99	65.00	50.00	34	0.0014	0.0014	20.0	1.000	135.31
	26.70	150.51	177.99	65.00	50.00	35	0.0013	0.0013	20.0	1.000	131.44
										Average=	**111.4**

Appendix E

Fracture Energy Data

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
al1bd1	Al	50	4.0	7.4	0	2.391	9.2
al2ad1	Al	50	4.0	7.4	0	3.519	8.7
alad1	Al	50	4.0	7.4	0	4.787	8.7
					average	3.566	8.9
					stdev	1.199	0.3
al2bd6	Al	50	4.0	7.4	6	4.497	8.8
al3bd6	Al	50	4.0	7.4	6	2.587	9.1
al4ad6	Al	50	4.0	7.4	6	3.865	8.7
					average	3.650	8.9
					stdev	0.973	0.2
	Difference =	(0.08)	Kpa	p-value=	0.929		
	Ratio =	102%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
al7ad1	Al	50	6.0	6.9	0	7.660	8.8
al8ad1	Al	50	6.0	6.9	0	3.915	9.4
al6ad1	Al	50	6.0	6.9	0	5.036	8.9
al3bd1	Al	50	6.0	6.9	0	7.774	8.5
					average	6.096	8.9
					stdev	1.927	0.4
al3ad6	AL	50	6.0	6.9	6	5.130	9.3
al2ad6	AL	50	6.0	6.9	6	3.087	8.8
al4ad6	AL	50	6.0	6.9	6	5.155	8.9
al5ad6	AL	50	6.0	6.9	6	5.996	8.7
					average	4.842	8.9
					stdev	1.237	0.3
	Difference =	1.25	Kpa	p-value=	0.315		
	Ratio =	79%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
mo698ad1	Mo	50	4.0	6.9	0	6.750	9.0
mo695ad1	Mo	50	4.0	6.9	0	4.216	9.5
mo696ad1	Mo	50	4.0	6.9	0	7.705	9.3
mo698bd1	Mo	50	4.0	6.9	0	4.706	8.7
					average	5.844	9.1
					stdev	1.656	0.4
mo692bd6	Mo	50	4.0	6.9	6	3.415	8.9
mo693ad6	Mo	50	4.0	6.9	6	3.558	9.3
mo694ad6	Mo	50	4.0	6.9	6	3.441	9.3
mo697ad6	Mo	50	4.0	6.9	6	3.400	9.2
					average	3.454	9.2
					stdev	0.072	0.2
	Difference =	2.39	Kpa	p-value=	0.028		
	Ratio =	59%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
tn736ad1	Tn	50	4.0	7.3	0	3.273	8.7
tn732ad1	Tn	50	4.0	7.3	0	2.436	8.8
tn733ad1	Tn	50	4.0	7.3	0	3.873	9.0
tn738ad1	Tn	50	4.0	7.3	0	5.230	8.7
					average	3.703	8.8
					stdev	1.176	0.1
tn731ad6	Tn	50	4.0	7.3	6	1.396	8.8
tn734ad6	Tn	50	4.0	7.3	6	2.042	8.7
tn735ad6	Tn	50	4.0	7.3	6	2.815	8.8
tn737ad6	Tn	50	4.0	7.3	6	2.563	8.9
					average	2.204	8.8
					stdev	0.628	0.1
	Difference =	1.50	Kpa	p-value=	0.066		
	Ratio =	60%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
tn689a1	Tn	75	4.0	6.8	0	2.04	8.5
tn6810a1	Tn	75	4.0	6.8	0	2.79	8.6
tn6811a1	Tn	75	4.0	6.8	0	3.09	8.5
tn6812a1	Tn	75	4.0	6.8	0	3.54	8.5
					average	2.86	8.5
					stdev	0.63	0.0
tn681ad6	Tn	75	4.0	6.8	6	2.33	8.7
tn682ad6	Tn	75	4.0	6.8	6	2.07	8.6
tn683ad6	Tn	75	4.0	6.8	6	2.46	8.5
					average	2.29	8.6
					stdev	0.20	0.1
	Difference =	0.58	Kpa	p-value=	0.193		
	Ratio =	80%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
NH972D1	NH	50	4.0	9.7	0	5.201	9.5
NH973D1	NH	50	4.0	9.7	0	5.476	9.4
NH977D1	NH	50	4.0	9.7	0	4.278	9.2
NH979D1	NH	50	4.0	9.7	0	6.846	9.5
					average	5.450	9.4
					stdev	1.062	0.1
NH976D6	NH	50	4.0	9.7	6	7.560	9.4
NH975D6	NH	50	4.0	9.7	6	6.792	9.4
NH974D6	NH	50	4.0	9.7	6	8.540	9.4
NH978D6	NH	50	4.0	9.7	6	6.912	9.4
					average	7.451	9.4
					stdev	0.801	0.0
	Difference =	(2.00)	Kpa	p-value=	0.024		
	Ratio =	137%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
VA8822D1	VA	50	4.0	8.8	0	4.584	9.5
VA8832D1	VA	50	4.0	8.8	0	3.810	9.2
VA8852D1	VA	50	4.0	8.8	0	5.890	9.5
VA8881D1	VA	50	4.0	8.8	0	3.872	9.5
					average	4.539	9.4
					stdev	0.967	0.1
VA884D6	VA	50	4.0	8.8	6	1.686	9.5
VA887D6	VA	50	4.0	8.8	6	1.752	9.4
VA8812D6	VA	50	4.0	8.8	6	4.520	9.2
VA8842D6	VA	50	4.0	8.8	6	4.326	9.4
					average	3.071	9.4
					stdev	1.563	0.1
	Difference =	1.47	Kpa	p-value=	0.161		
	Ratio =	67.7%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MI4D1	MI	60	4.0	6.0	0	7.216	9.1
MI6D1	MI	60	4.0	6.0	0	8.567	9.1
MI7D1	MI	60	4.0	6.0	0	6.033	9.1
MI8D1	MI	60	4.0	6.0	0	7.151	9.3
					average	7.242	9.2
					stdev	1.037	0.1
MI1D6	MI	60	4.0	6.0	6	4.286	9.1
MI2D6	MI	60	4.0	6.0	6	5.607	9.3
MI3D1	MI	60	4.0	6.0	6	3.659	9.1
MI5D1	MI	60	4.0	6.0	6	6.183	9.0
					average	4.934	9.1
					stdev	1.163	0.1
	Difference =	2.31	Kpa	p-value=	0.025		
	Ratio =	68.1%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MN888D1	MN	50	4.0	8.8	0	9.142	8.6
MN884D1	MN	50	4.0	8.8	0	6.592	8.6
MN886D1	MN	50	4.0	8.8	0	7.741	8.7
MN889D1	MN	50	4.0	8.8	0	7.736	8.8
					average	7.803	8.7
					stdev	1.044	0.1
MN881D6	MN	50	4.0	8.8	6	9.711	8.7
MN882D6	MN	50	4.0	8.8	6	10.623	8.9
MN883D6	MN	50	4.0	8.8	6	7.753	8.6
MN885D6	MN	50	4.0	8.8	6	7.656	8.7
					average	8.936	8.7
					stdev	1.470	0.1
	Difference =	(1.13)	Kpa	p-value=	0.256		
	Ratio =	114.5%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MN836D1	MN	75	4.0	8.3	0	7.016	8.8
MN837D1	MN	75	4.0	8.3	0	8.709	8.7
MN838D1	MN	75	4.0	8.3	0	6.309	8.7
MN839D1	MN	75	4.0	8.3	0	7.474	8.6
					average	7.377	8.7
					stdev	1.009	0.1
MN832D6	MN	75	4.0	8.3	6	7.924	8.5
MN833D6	MN	75	4.0	8.3	6	8.862	8.8
MN834D6	MN	75	4.0	8.3	6	7.872	8.8
MN835D6	MN	75	4.0	8.3	6	7.678	8.6
					average	8.084	8.7
					stdev	0.529	0.1
	Difference =	(0.71)	Kpa	p-value=	0.261		
	Ratio =	109.6%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MO622AD1	Mo	50	6.0	6.9	0	3.958	8.5
MO623AD1	Mo	50	6.0	6.9	0	5.060	8.6
MO6223D1	Mo	50	6.0	6.9	0	5.115	9.1
MO6273D1	Mo	50	6.0	6.9	0	4.910	9.3
					average	4.761	8.9
					stdev	0.542	0.4
MO6233D6	Mo	50	6.0	6.9	6	3.295	8.9
MO6243D6	Mo	50	6.0	6.9	6	4.352	9.3
MO6253D6	Mo	50	6.0	6.9	6	3.148	9.1
MO6263D6	Mo	50	6.0	6.9	6	3.226	9.1
					average	3.505	9.1
					stdev	0.568	0.2
	Difference =	1.26	Kpa	p-value=	0.024		
	Ratio =	74%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
VA831D1	VA	75	4.0	8.3	0	6.295	9.3
VA832D1	VA	75	4.0	8.3	0	6.224	9.4
VA833D1	VA	75	4.0	8.3	0	4.878	9.4
VA836D1	VA	75	4.0	8.3	0	8.066	9.2
				8.3	average	6.366	9.3
					stdev	1.308	0.1
VA834D6	VA	75	4.0	8.3	6	5.865	9.4
VA835D6	VA	75	4.0	8.3	6	6.553	9.4
VA837D6	VA	75	4.0	8.3	6	6.392	9.2
VA838D6	VA	75	4.0	8.3	6	4.338	9.3
					average	5.787	9.3
					stdev	1.010	0.1
	Difference =	0.58	Kpa	p-value=	0.51		
	Ratio =	91%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
WI672D1	WI	50	6.0	6.7	0	5.982	9.4
WI675D1	WI	50	6.0	6.7	0	7.389	9.0
WI676D1	WI	50	6.0	6.7	0	6.154	9.1
WI679D1	WI	50	6.0	6.7	0	4.683	8.6
					average	6.052	9.0
					stdev	1.107	0.3
WI673D6	WI	50	6.0	6.7	6	5.067	9.2
WI674D6	WI	50	6.0	6.7	6	5.034	9.1
WI677D6	WI	50	6.0	6.7	6	5.242	8.9
WI678D6	WI	50	6.0	6.7	6	5.322	9.0
					average	5.166	9.1
					stdev	0.138	0.1
	Difference =	0.89	Kpa	p-value=	0.163		
	Ratio =	85%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
WI752D1	WI	50	4.0	7.5	0	6.225	8.7
WI755D1	WI	50	4.0	7.5	0	5.787	9.2
WI757D1	WI	50	4.0	7.5	0	5.318	9.0
WI758D1	WI	50	4.0	7.5	0	4.700	8.9
					average	5.508	9.0
					stdev	0.653	0.2
WI753D6	WI	50	4.0	7.5	6	4.020	9.2
W1754D6	WI	50	4.0	7.5	6	2.836	9.2
WI756D6	WI	50	4.0	7.5	6	7.339	8.9
WI759D6	WI	50	4.0	7.5	6	5.959	9.1
					average	5.039	9.1
					stdev	2.002	0.1
	Difference =	0.47	Kpa	p-value=	0.686		
	Ratio =	91%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
NH865D1	NH	75	6.0	8.6	0	5.946	9.3
NH866D1	NH	75	6.0	8.6	0	8.140	9.5
NH867D1	NH	75	6.0	8.6	0	7.574	9.3
NH868D1	NH	75	6.0	8.6	0	6.584	9.2
					average	7.061	9.3
					stdev	0.983	0.1
NH861D6	NH	75	6.0	8.6	6	7.857	9.3
NH862D6	NH	75	6.0	8.6	6	6.550	9.2
NH863D6	NH	75	6.0	8.6	6	7.758	9.5
NH864D6	NH	75	6.0	8.6	6	7.736	9.4
					average	7.475	9.4
					stdev	0.619	0.1
	Difference =	(0.41)	Kpa	p-value=	0.502		
	Ratio =	106%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
NH931D1	NH	75	4.0		0	4.018	9.1
NH934D1	NH	75	4.0		0	6.086	9.3
NH937D1	NH	75	4.0		0	5.682	9.0
NH939D1	NH	75	4.0		0	7.831	9.2
					average	5.904	9.2
					stdev	1.566	0.1
NH933D6	NH	75	4.0		6	5.354	9.3
NH935D6	NH	75	4.0		6	4.687	9.5
NH936D6	NH	75	4.0		6	6.308	9.0
NH938D6	NH	75	4.0		6	6.513	9.1
					average	5.716	9.2
					stdev	0.852	0.2
	Difference =	0.19	Kpa	p-value=	0.839		
	Ratio =	97%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MN745D1	MN	75	6.0	7.4	0	5.692	8.6
MN753D1	MN	75	6.0	7.4	0	6.116	8.5
MN748D1	MN	75	6.0	7.4	0	8.113	8.7
MN749D1	MN	75	6.0	7.4	0	6.000	8.7
					average	6.480	8.6
					stdev	1.103	0.1
MN746D6	MN	75	6.0	7.4	6	4.628	8.5
MN744D6	MN	75	6.0	7.4	6	6.653	8.5
MN747D6	MN	75	6.0	7.4	6	7.096	8.9
MN742D6	MN	75	6.0	7.4	6	5.911	8.6
					average	6.072	8.6
					stdev	1.080	0.2
	Difference =	0.41	Kpa	p-value=	0.616		
	Ratio =	94%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
TNGM976D1	TNGM	50	4.0	9.7	0	5.832	9.2
TNGM979D1	TNGM	50	4.0	9.7	0	5.795	9.7
TNGM978D1	TNGM	50	4.0	9.7	0	4.740	9.2
					0		
					average	5.456	9.4
					stdev	0.620	0.3
TNGM973D6	TNGM	50	4.0	9.7	6	6.685	9.7
TNGM975D6	TNGM	50	4.0	9.7	6	6.775	9.5
TNGM974D6	TNGM	50	4.0	9.7	6	6.040	8.9
TNGM972D6	TNGM	50	4.0	9.7	6	6.983	9.2
					average	6.621	9.3
					stdev	0.407	0.4
	Difference =	(1.17)	Kpa	p-value=	0.029		
	Ratio =	121%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
CT881D1	CT	50	4.0	8.8	0	5.906	8.5
CT882D1	CT	50	4.0	8.8	0	5.302	8.8
					0		
					0		
					average	5.604	8.7
					stdev	0.427	0.2
CT883D6	CT	50	4.0	8.8	6	8.797	8.6
CT884D6	CT	50	4.0	8.8	6	8.169	8.5
					6		
					6		
					average	8.483	8.6
					stdev	0.444	0.1
	Difference =	(2.88)	Kpa	p-value=	0.022		
	Ratio =	151%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
CT721D1	CT	50	6.0	7.2	0	7.857	8.5
CT722D1	CT	50	6.0	7.2	0	5.935	8.5
					0		
					0		
					average	6.896	8.5
					stdev	1.359	0.0
CT723D6	CT	50	6.0	7.2	6	8.423	8.5
CT724D6	CT	50	6.0	7.2	6	5.874	8.8
					6		
					6		
					average	7.149	8.7
					stdev	1.802	0.2
	Difference =	(0.25)	Kpa	p-value=	0.889		
	Ratio =	104%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
FL115D1	FL	75	4.0	11.0	0	4.938	8.7
FL111D1	FL	75	4.0	11.0	0	5.152	8.5
FL112D1	FL	75	4.0	11.0	0	5.120	8.9
					0		
					average	5.070	8.7
					stdev	0.115	0.2
FL114D6	FL	75	4.0	11.0	6	5.323	8.5
FL116D6	FL	75	4.0	11.0	6	3.529	8.8
FL113D6	FL	75	4.0	11.0	6	4.571	8.7
					6		
					average	4.474	8.7
					stdev	0.901	0.2
	Difference =	0.60	Kpa	p-value=	0.319		
	Ratio =	88%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
FL1185D1	FL	50	4.0	11.8	0	3.380	8.6
FL1183D1	FL	50	4.0	11.8	0	4.878	8.5
FL1184D1	FL	50	4.0	11.8	0	5.229	8.5
					0		
					average	4.496	8.5
					stdev	0.982	0.1
FL1186D6	FL	50	4.0	11.8	6	6.046	9.2
FL1181D6	FL	50	4.0	11.8	6	6.738	8.7
FL1182D6	FL	50	4.0	11.8	6	4.385	8.7
					6		
					average	5.723	8.9
					stdev	1.209	0.3
	Difference =	(1.23)	Kpa	p-value=	0.244		
	Ratio =	127%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
FL1012D1	FL	75	6.0	10.1	0	5.095	9.5
FL1013D1	FL	75	6.0	10.1	0	6.666	9.5
FL1011D1	FL	75	6.0	10.1	0	5.251	9.1
					0		
					average	5.671	9.4
					stdev	0.866	0.2
FL1016D6	FL	75	6.0	10.1	6	5.687	9.5
FL1014D6	FL	75	6.0	10.1	6	5.637	9.0
FL1015D6	FL	75	6.0	10.1	6	4.723	9.5
					6		
					average	5.349	9.3
					stdev	0.543	0.3
	Difference =	0.32	Kpa	p-value=	0.614		
	Ratio =	94%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
VA873BD1	VAadj	75	4.0	8.7	0	6.679	9.1
VA871AD1	VAadj	75	4.0	8.7	0	6.011	9.3
VA871BD1	VAadj	75	4.0	8.7	0	5.733	9.3
VA872AD1	VAadj	75	4.0	8.7	0	4.329	8.6
					average	5.688	9.1
					stdev	0.989	0.3
VA875AD6	VAadj	75	4.0	8.7	6	5.683	9.0
VA874AD6	VAadj	75	4.0	8.7	6	4.948	9.2
					6		
					6		
					average	5.316	9.1
					stdev	0.520	0.1
	Difference =	0.37	Kpa	p-value=	0.656		
	Ratio =	93%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
VA93AD1	VAadj	50	4.0	9.1	0	6.375	9.1
VA91AD1	VAadj	50	4.0	9.1	0	5.938	9.1
VA92BD1	VAadj	50	4.0	9.1	0	4.943	8.9
			4.0		0		
					average	5.752	9.0
					stdev	0.734	0.1
VA95BD6	VAadj	50	4.0	9.1	6	7.768	9.2
VA94BD6	VAadj	50	4.0	9.1	6	7.692	8.8
VA95AD6	VAadj	50	4.0	9.1	6	7.278	9.4
					6		
					average	7.579	9.1
					stdev	0.264	0.3
	Difference =	(1.83)	Kpa	p-value=	0.056		
	Ratio =	132%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
MD4BD1	MD	75	3.5	6.5	0	4.273	9.3
MD5BD1	MD	75	3.5	6.5	0	5.673	9.1
MD5D1	MD	75	3.5	6.5	0	6.092	8.5
MD2BD1	MD	75	3.5	6.5	0	6.290	9.5
					average	5.582	9.1
					stdev	0.910	0.4
MD3BD6	MD	75	3.5	6.5	6	4.660	9.1
MD1BD6	MD	75	3.5	6.5	6	5.118	9.5
MD3D6	MD	75	3.5	6.5	6	4.362	8.5
MD4D6	MD	75	3.5	6.5	6	3.628	8.6
					average	4.442	8.9
					stdev	0.625	0.5
	Difference =	1.14	Kpa	p-value=	0.084		
	Ratio =	80%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
FL108D1	Fladj	50	4.0	10.0	0	4.880	8.9
FL109D1	Fladj	50	4.0	10.0	0	4.888	9.5
FL106D1	Fladj	50	4.0	10.0	0	5.020	9.2
FL107D1	Fladj	50	4.0	10.0	0	5.600	9.5
					average	5.097	9.3
					stdev	0.341	0.3
FL103D6	Fladj	50	4.0	10.0	6	4.460	9.4
FL104D6	Fladj	50	4.0	10.0	6	6.331	9.1
FL105D6	Fladj	50	4.0	10.0	6	4.368	9.4
FL102D6	Fladj	50	4.0	10.0	6	5.943	9.2
					average	5.276	9.3
					stdev	1.008	0.2
	Difference =	(0.18)	Kpa	p-value=	0.749		
	Ratio =	104%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
WI634D1	WI	50	6.0	6.3	0	4.052	8.8
WI633D1	WI	50	6.0	6.3	0	5.652	8.5
WI635D1	WI	50	6.0	6.3	0	4.658	8.6
					0		
					average	4.787	8.6
					stdev	0.808	0.2
WI636D6	WI	50	6.0	6.3	6	2.951	8.6
WI638D6	WI	50	6.0	6.3	6	4.156	8.8
WI637D6	WI	50	6.0	6.3	6	3.788	8.7
WI639D6	WI	50	6.0	6.3	6	4.538	8.5
					average	3.858	8.7
					stdev	0.678	0.1
	Difference =	0.93	Kpa	p-value=	0.158		
	Ratio =	81%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
WI687D1	WI	50	4.0	6.8	0	6.756	9.9
WI683D1	WI	50	4.0	6.8	0	5.553	9.5
WI686D1	WI	50	4.0	6.8	0	8.104	9.0
					0		
					average	6.804	9.5
					stdev	1.276	0.5
WI689D6	WI	50	4.0	6.8	6	4.669	9.9
WI684D6	WI	50	4.0	6.8	6	6.012	9.3
WI685D6	WI	50	4.0	6.8	6	6.317	9.0
WI688D6	WI	50	4.0	6.8	6	5.288	9.2
					average	5.572	9.4
					stdev	0.740	0.4
	Difference =	1.23	Kpa	p-value=	0.164		
	Ratio =	82%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
FL915D1	FL adj	75	6.0	9.1	0	6.000	
FL916D1	FL adj	75	6.0	9.1	0	6.146	
FL917D1	FL adj	75	6.0	9.1	0	5.537	
					0		
					average	5.894	#DIV/0!
					stdev	0.318	#DIV/0!
FL913D1	FL adj	75	6.0	9.1	6	5.442	
FL914D1	FL adj	75	6.0	9.1	6	3.188	
FL911D6	FL adj	75	6.0	9.1	6	3.421	
FL912D6	FL adj	75	6.0	9.1	6	2.127	
					average	3.545	#DIV/0!
					stdev	1.385	#DIV/0!
	Difference =	2.35	Kpa	p-value=	0.037		
	Ratio =	60%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
TNGM933D1	TNGM	75	4.0	9.3	0	5.640	8.5
TNGM932D1	TNGM	75	4.0	9.3	0	4.487	8.5
					0		
					0		
					average	5.064	8.5
					stdev	0.815	0.0
TNGM934D6	TNGM	75	4.0	9.3	6	5.761	8.7
TNGM931D6	TNGM	75	4.0	9.3	6	4.015	9.0
					6		
					6		
					average	4.888	8.9
					stdev	1.235	0.2
	Difference =	0.18	Kpa	p-value=	0.882		
	Ratio =	97%					

Sample ID	Mix Id	Ndes	design Va%	AC%	Cure time	FE (Kpa)	Air voids
GA6D1	GA	50	6.0	6.0	0	4.835	
GA4D1	GA	50	6.0	6.0	0	4.346	
GA5D1	GA	50	6.0	6.0	0	5.481	
					0		
					average	4.887	#DIV/0!
					stdev	0.569	#DIV/0!
GA1D6	GA	50	6.0	6.0	6	3.911	
GA3D6	GA	50	6.0	6.0	6	3.331	
GA2D6	GA	50	6.0	6.0	6	4.606	
					6		
					average	3.949	#DIV/0!
					stdev	0.638	#DIV/0!
	Difference =	0.94	Kpa	p-value=			
	Ratio =	81%					