An Investigation of the Design Parameters Affecting the Microtexture and Macrotexture of 4.75mm Superpave Mixtures

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ABSTRACT

The use of 4.75mm asphalt mixtures is gaining popularity in the United States as an efficient paving alternative. These mixes are placed in thin lifts, thereby reducing the quantity and cost of materials, as well as construction time. Although there are many advantages associated with 4.75mm mixtures, there are some issues that must be considered prior to the placement of these mixes. 4.75mm mixtures are comprised primarily of fine aggregates that produce tight and smooth mixes, which could pose safety concerns related to surface friction.

The primary goal of this research effort was to determine what actions could be taken during the design of a 4.75mm Superpave asphalt mixture to improve its frictional performance. Specific tasks included 1) an investigation of variations in 4.75mm mix design properties with respect to the microtexture and macrotexture of the mixes, 2) an evaluation of the characteristics of the constituent aggregate materials in order to determine fine aggregate properties that can be used during design to improve the skid resistance of the resulting mixes, and 3) a relative comparison of the skid resistance of 4.75mm mixes with that of typical 9.5mm and 12.5mm surface mixes. Three aggregate sources were used to develop the Superpave mixtures. The British Pendulum Tester was used to quantify the microtexture of the mixes, and a modified laboratory sand patch test was used to quantify the macrotexture. A number of aggregate properties, including source and consensus properties were used to describe fine aggregate characteristics.

The results indicate that, in general, both the microtexture and macrotexture of the 4.75mm mixes were relatively unaffected by the various mixture parameters. Aggregate source did produce a significant effect. Aggregate gradation affected the microtexture and macrotexture of the mixes such that a gap-graded blend could be used to increase skid resistance. Aggregate source and consensus properties can also be used to improve the frictional performance of mixes. Skid resistance can be improved by limiting the percent loss for durability and soundness of the fine aggregate, and by increasing the angularity of the fine aggregate. When compared to mixes composed of larger aggregates, the microtexture of the 4.75mm mixes was superior to that of the 9.5mm and 12.5mm mixes; although the 4.75mm mixes possessed limited macrotexture.

Overall, when fine aggregate properties are properly considered, 4.75mm Superpave mixes can be designed with adequate microtexture for use on low speed roadways, and in a manner that may partially compensate for the lesser macrotexture, thereby providing adequate skid resistance for high speed roadways.

1. INTRODUCTION

Skid resistance of hot-mix asphalt (HMA) pavements is critical to the safety of the driving public. In general, skid resistance is provided by the frictional resistance between the vehicle tire and the pavement surface. The microtexture and macrotexture of the pavement surface are key components in providing this resistance. In order to improve the frictional properties of the pavement surface, it is desirable to construct a pavement that possesses the properties that most efficiently improve the HMA texture. If skid resistance considerations could be incorporated during the design of an asphalt mixture, greater efficiency could be realized in terms of cost, construction, and long-term safety.

In this project, three aggregate sources were used to investigate the microtexture and macrotexture of 4.75mm Superpave mixes. Design parameters were varied in order to gain a more comprehensive understanding of aggregate and mixture properties that significantly affect the skid resistance of HMA mixes. This was done with the express purpose of formulating design guidelines which can assist in creating roadways with improved frictional resistance and greater driver safety.

2. BACKGROUND

Skid resistance is critical to driver safety, and is affected by roadway geometry, the environment, and roadway surface characteristics. Geometric features of the roadway such as curve radius and grade affect the ability of the driver to maneuver safely. Environmental features affect driver safety in that wet pavements provide less skid resistance than dry pavements. The surface characteristics of the roadway are certainly important in that pavement texture affects the ability of vehicles to stop. This feature of skid resistance can be affected during the asphalt mixture design process, and should be considered by mix designers.

The skid resistance of the roadway surface is a function of the microtexture and macrotexture of its surface. The microtexture of a pavement is extremely important in creating skid resistance, and is created primarily by the fine aggregate in the asphalt mixture. The macrotexture of the pavement is also important in that it provides a pavement with avenues for water, thereby removing it from the roadway and reducing the risk of hydroplaning. At high speeds, both the microtexture and macrotexture are important. At low speeds, the microtexture governs skid resistance.

Asphalt mixtures designed by the Superpave method may be designed with a nominal maximum aggregate size (NMAS) ranging from 4.75mm to 37.5mm. However, many agencies have only recently considered the implementation of 4.75mm mixes. The use of 4.75mm HMA mixtures offer many advantages and can be used in a wide variety of applications. They can be used for low volume roadways, in maintenance applications, and to seal the surfaces of high volume roadways. Due to the small nature of the aggregate components, they can be placed in thin lifts, often as thin as 19.0 mm. This results in the potential for considerable savings in terms of materials, costs, and construction time. Also, this type of mix creates a smooth and tight surface that is aesthetically pleasing to the eye. Although a smooth roadway is desirable, concern has been expressed that the tight nature of 4.75mm mixes could possess inadequate skid resistance. Thus, the consideration of frictional resistance during the mix design process is believed to be especially important for 4.75mm Superpave mixes.

Guidelines for designing 4.75mm mixes are published by the American Association of State Highway and Transportation Officials (AASHTO) in method M 323. These guidelines include parameters for both aggregate and mixture properties including gradation, design air voids, and dust proportion, among others. A summary of these requirements is given in Table 1. Notably, parameters relating to skid resistance are not included in the specification.

Aggregate Requirements			**Mixture Requirements**	
Sieve Size	% Passing		Property	Range
12.5mm	100		Air Voids (%)	4.0
9.5mm	95 – 100		VMA (%)	16.0 – 18.0
4.75mm	90 – 100		VFA (%)	75 – 78*
1.18mm	30 – 60		DP	0.9 – 2.0
0.075mm	6 - 12			

*Depending on traffic level

TABLE 1 – AASHTO M 323 Mixture Requirements for 4.75mm Mixes

3. OBJECTIVES

The primary goal of this research effort was to determine what action could be taken during the design of a 4.75mm Superpave asphalt mixture in order to maximize its skid resistance. Specifically, a number of mix designs were created which incorporated variations in design parameters. The effects of these variations on the microtexture and macrotexture of the resulting mix were then quantified. In addition, a number of properties of the constituent aggregate materials were considered, and the relationships of the aggregates to the microtexture and macrotexture of the mixes were investigated. Finally, comparisons were made between the 4.75mm mixes and traditional surface mixes.

4. RESEARCH APPROACH

To accomplish the stated objectives, a substantial series of laboratory investigations was performed for 4.75mm mixtures. Aggregates from three sources were chosen, including limestone, sandstone, and syenite. A polymer modified, performance-graded binder of PG 70-22 was used for all mixes.

4.1 MIX DESIGN

Although the AASHTO design procedure recommends designing mixes at 4 percent air voids, Arkansas specifications require that all mixes designed using PG 70-22 binder be designed at 4.5 percent air voids. However, research has shown that improved performance of 4.75mm mixes can be achieved if designed at 6 percent air voids. Thus, the design air void content was varied at two levels – 4.5 and 6.0 percent air voids. Design compaction level was also varied because 4.75mm mixes have the potential to be placed in a wide variety of applications, thus serving a wide range of traffic levels. 4.75mm mixes were designed at three levels of compaction, including 50, 75, and 100 design gyrations, and were compacted in the Superpave Gyratory Compactor (SGC). These compaction levels are consistent with low, medium, and high volumes of traffic.

Although other intentional variations in design could pose significant changes in skid resistance, the other factors are interrelated and could not be varied independently. For example, voids in the mineral aggregate (VMA) is dependent upon air voids, and was not varied separately from air void content. Also, the percent of voids filled with asphalt (VFA) is dependent upon VMA and could not be varied without affecting VMA. Thus, ranges of design values for VMA and VFA were shifted according to the intentional changes in design air voids.

In order to create the target mixture properties, blend gradations and binder contents were adjusted until the desired characteristics were achieved. The material adjustments made to create the intended mixture design parameters generated changes in other mix properties such as VMA, VFA, effective binder content (the percent of unabsorbed binder), dust proportion (the relationship of "dust" in the mix to effective binder content), aggregate gradation, and fineness modulus. For each of the three aggregate sources, mixes were designed for each of the six possible combinations of air void content and compaction level, resulting in a total of 18 mixes. Replicate samples were prepared for each mix.

4.2 AGGREGATE PROPERTIES

Aggregate properties can also affect mixture performance in terms of skid resistance. In the Superpave mixture design method, emphasis is placed on the source and consensus properties of the aggregate. Source properties are characteristics that are inherent to the aggregate source, including toughness, soundness, and deleterious materials. Consensus properties relate to the shape and texture of the aggregate, and are generally believed to affect mixture performance. These properties can often be affected by changes in crushing operations. The consensus properties are coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. Since these properties are already included in the mix design process, correlations with resulting skid resistance would be a significant step toward the inclusion of skid resistance considerations during the mixture design process. Because 4.75mm mixes are fine aggregate mixes, only the applicable source and consensus properties were considered in this study.

4.3 TEST METHODS

To complete the testing plan, a number of test methods were used. The Superpave Gyratory Compactor and AASHTO standard test methods associated with aggregate blending and HMA mixture design were performed for the purpose of determining mixture properties. The Micro-Deval and sodium sulfate soundness tests were performed to characterize durability and soundness, and the fine aggregate angularity test was used to characterize aggregate shape and texture. The British Pendulum Tester was used to assess the microtexture of the mixtures, and a modified sand patch test was used to quantify macrotexture. A summary of each test method follows.

4.3.1 Micro-Deval

The Micro-Deval test was used to assess aggregate durability. This test, outlined in AASHTO T 327, is most often a coarse aggregate test, so an adjusted procedure for fine aggregate was used in this study. In this method, a specific grading of aggregate is placed in a canister with water, and the canister is then rotated such that the aggregate particles tumble over each other in the presence of water. This test method is similar to the Los Angeles abrasion test, but the interactions of the aggregate particles during the test are not subjected to impact interactions. Upon completion, the Micro-Deval test data provides a measure of the percent loss (or degradation), which is calculated based on the change in gradation of the material after testing.

4.3.2 Sodium Sulfate Soundness

The sodium sulfate soundness test, outlined in AASHTO T 104, was used to simulate the resistance of the aggregate to degradation from environmental factors. In this test, a specific grading of aggregate is subjected to soaking in a sodium sulfate solution, then dried. The soaking period simulates freezing and the forces of expansion within the particle. The drying period simulates a thawing action, as these forces are removed. Repeated cycles represent the behavior of the aggregate during freezing and thawing. After five cycles of soaking and subsequent drying are completed, the gradation of the aggregate sample is determined. The amount of aggregate breakdown is reported as the percent loss.

4.3.3 Fine Aggregate Angularity

The fine aggregate angularity test, detailed in AASHTO T 304, is a method for quantifying the shape (and to some extent the texture) of the aggregate particles. In this method, a specifically graded sample of fine aggregate is prepared and allowed to freefall through a funnel into a calibrated cylindrical cup. Based on the volume of the cup, the weight of the material in the cup, and the bulk specific gravity of the fine aggregate, the percent of uncompacted voids is calculated. The more angular and textured the material, the less the material will consolidate in the cup, thus increasing the volume of void spaces in the sample. Higher percentages of uncompacted voids indicate greater angularity.

4.3.4 British Pendulum Test

The British Pendulum Tester, shown in Figure 1, was used to describe the microtexture of the surfaces of the laboratory-compacted HMA samples. In this method, described in ASTM E 303, an asphalt sample is placed under a pendulum arm and rubber slider foot, then aligned such that the length of contact between the rubber foot and sample is between 124 and 127 mm. The geometry of the testing configuration is such that a gyratory-compacted specimen with a 150 mm diameter is suitable for the test. After the specimen is carefully aligned, the pendulum arm is released from a fixed position and the rubber foot skids across the sample. In order to simulate a wet pavement (i.e., worst case condition), the surface of the test sample is sprayed with water prior to releasing the arm. The measurement obtained from the scale represents the skid resistance of the material due to microtexture, such that higher values indicate greater skid resistance. The British Pendulum Number (BPN) is approximately 100 times the coefficient of friction.

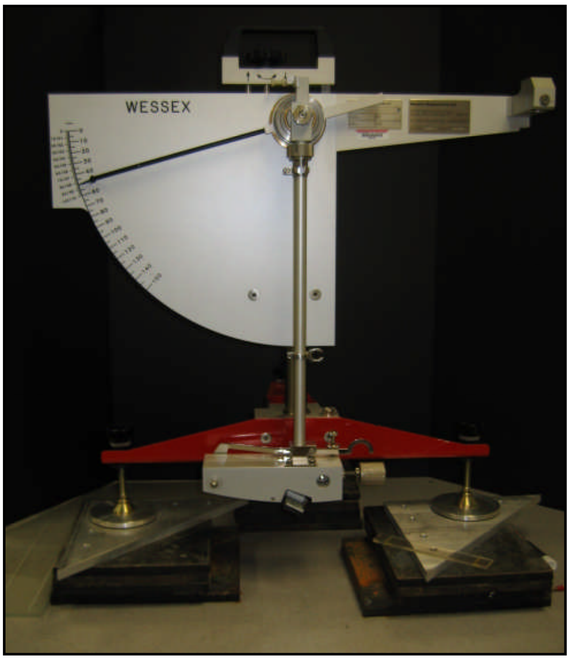

FIGURE 1 – British Pendulum Tester

4.3.5 Modified Sand Patch Test

The sand patch test is a method often used in conjunction with the BPT for field testing. In this method, a known volume of sand is spread in a circular shape on the surface of a pavement. The diameter of the circular patch is measured, and the area of the circle is calculated. Next, the volume and area of sand are used to estimate texture depth. Texture depth describes macrotexture, and represents the amount of space in the surface of the roadway that could be used to hold water.

Since all of the testing in this research was performed in the laboratory, a modified procedure was developed for estimating the texture depth of laboratory-compacted specimens. In the modified procedure, the specific gravity of finely graded sand was determined; then, the mass and average diameter of the specimen were determined (based on four diameter measurements). Next, the sand was carefully brushed onto the surface of the specimen so as to essentially fill the surface voids with sand, and a strike-off bar was used to eliminate the excess. This process is illustrated in Figure 2. Sand was then carefully brushed from the sides of the specimen, and the weight of the "sanded" specimen was determined. The net mass of the sand was calculated and the volume of sand filling the voids was estimated based on its density. Finally, the surface area of the sample and the volume of sand were used to calculate texture depth.

5. RESULTS AND DISCUSSION

In keeping with the stated objectives of the research, a number of analyses were performed on the data. These analyses were performed using statistically sound procedures at a 95 percent level of significant ($\alpha = 0.05$).

FIGURE 2 – Modified Sand Patch Test

5.1 MIX DESIGN PARAMETERS

5.1.1 Microtexture

First, the intentionally varied mix design parameters of design air voids and compaction level were evaluated with respect to their effects on microtexture. Four replicate tests were performed for each of four samples from each mix design. Analysis of Variance (ANOVA) was used to determine whether changes in these design parameters generated significant changes in skid resistance properties. The results of the BPT testing are shown in Table 2.

		Compaction Level		
	Design Air Voids (%)	N_{des} = 50	N_{des} = 75	N_{des} = 100
Limestone	4.5	63.94	62.77	63.67
	6.0	62.15	62.98	65.16
Sandstone	4.5	70.58	71.09	72.73
	6.0	73.81	71.42	70.06
Syenite	4.5	71.22	71.75	71.44
	6.0	55.75	66.02	70.48

TABLE 2 – Microtexture Testing Results by BPT (BPN)

Statistically, the only significant factor of interest was design air void content. Compaction level did not significantly affect the microtexture of the samples. It was noted that aggregate source was a significant factor. The results of the ANOVA are shown in Table 3.

Factor	**df**	**F-calc**	**P-value**
Aggregate Source	2	79.15	<0.0001
Design Air Voids	1	5.80	**0.0167**
Compaction Level	2	2.31	0.1015
Air*Compaction	2	0.36	0.7014
Error	255		

TABLE 3 – ANOVA Results – Laboratory British Pendulum Testing

Although the design air void content was statistically significant, it was arguably not practically significant. The average BPN for all samples designed at 4.5 percent air voids was 68.8, while the average BPN for those designed at 6.0 percent was 67.5. This is a difference of only 1.3 BPN. Thus, it was concluded that microtexture is largely insensitive to the design parameters of air void content and compaction level, however a slight increase in microtexture may be gained by designing 4.75mm mixtures at a lower air void content.

5.1.1 Macrotexture

The modified sand patch test, as previously described for laboratory-compacted specimens, was performed for each of the 18 mix designs. Triplicate testing was performed for each of four replicate samples of each design. Average texture depths measured for each design are presented in Table 4.

		Compaction Level		
	Design Air Voids (%)	N_{des} = 50	N_{des} = 75	N_{des} = 100
Limestone	4.5	0.179*	0.177	0.188
	6.0	0.145	0.144	0.155
Sandstone	4.5	0.168	0.190	0.187
	6.0	0.187	0.177	0.202
Syenite	4.5	0.120	0.088	0.085
	6.0	0.102*	0.115	0.077

*Sample damaged

TABLE 4 – Modified Sand Patch Test Data (Texture Depth, mm)

The 4.75mm mixes have relatively small texture depths, which is to be expected since these mixes contain fine aggregate. It was noted that the texture depth appears to be extremely dependent upon aggregate type. In fact, the texture depths of the limestone and sandstone mixes were approximately twice that of the syenite mixes. According to the ANOVA, design air void content was again the only factor of interest that had statistical significance, and aggregate source was significant as well. The results of this analysis are provided in Table 5. As with the analysis of microtexture, the effect of design air void content was statistically significant, but did not appear to be practically significant. The average texture depth was 0.152 mm for mixes designed at 4.5 percent air voids, and 0.142 mm for those designed with 6.0 percent air voids. Thus, it was concluded that the macrotexture of the mixes tested was not seriously impacted by the mix design parameters of air voids and compaction level, but that a slight increase in macrotexture may be generated by designing 4.75mm mixtures at lower air void contents.

TEXTURE DEPTH, mm			
Factor	**df**	**F-calc**	**P-value**
Aggregate Source	2	212.20	<0.0001
Design Air Voids	1	6.77	**0.0100**
Compaction Level	2	0.59	0.5538
Air*Compaction	2	0.44	0.6438
Error	178		

TABLE 5 – ANOVA Results - Modified Sand Patch Testing

In general, the skid resistance of a 4.75mm mixture is relatively unaffected by changes in compaction level and design air void content, but did appear to be significantly affected by aggregate source.

5.2 ADDITIONAL MIX DESIGN PROPERTIES

Although design air voids and compaction level were the only two factors which were intentionally varied in the experimental plan, variations existed in other mix properties as a result of the design changes. These properties were VMA, VFA, effective binder content, and dust proportion. Because these properties were not intentionally varied in a controlled experimental manner, an ANOVA could not be performed. Rather, regression analysis was utilized in order to determine whether significant trends were present with respect to microtexture and macrotexture.

5.2.1 Microtexture

Figure 3 displays the relationships of BPN to VMA, VFA, effective binder content, and dust proportion. For each relationship, the trendline was essentially flat, and the correlation coefficient (R^2) was extremely low. This indicates that the relationships were extremely weak. It was concluded that the mix properties investigated did not significantly affect HMA microtexture as tested by the BPT.

5.2.2 Macrotexture

Figure 4 displays similar relationships for macrotexture as quantified by texture depth. In general, these relationships were also extremely weak, however some trends were noted. Increasing the VMA and/or effective binder content causes a slight decrease in texture depth, while an increase in dust proportion generates an increase in texture depth. It would seem that increasing the VMA would increase the texture depth because a greater percentage of voids is created between the aggregate. However, remember that a lower design air void content generated a statistically higher texture depth. The trend for VMA is consistent with this conclusion. Note that the R^2 values associated with the linear regression line for each of these relationships are extremely low. Thus, nothing more than slight trends were demonstrated by the data.

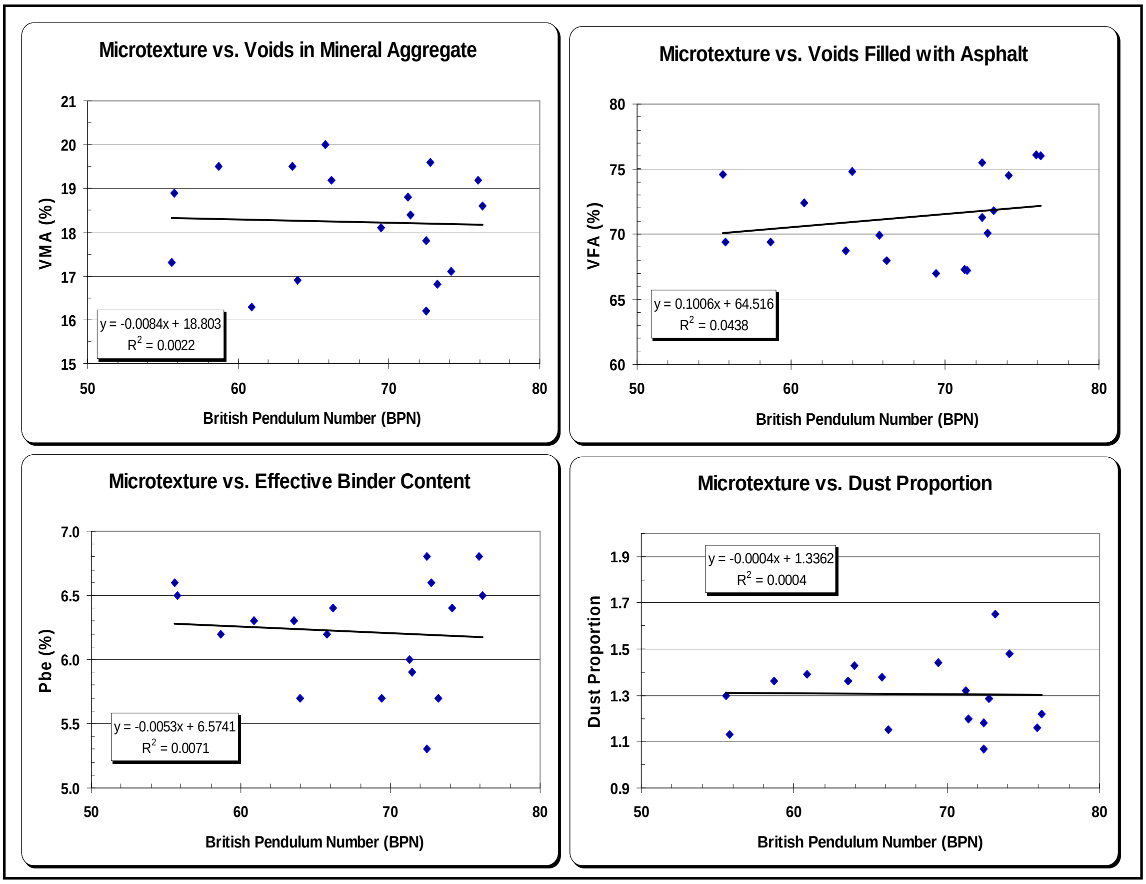

FIGURE 3 – Relationships of Other Mix Design Properties to Microtexture

5.3 AGGREGATE GRADATION

While HMA skid resistance appeared to be relatively insensitive to changes in mixture properties, the ANOVA results did indicate that both microtexture and macrotexture were significantly affected by aggregate source. Thus aggregate properties were investigated. The blend gradation for each of the mix designs was analyzed with respect to microtexture and macrotexture. For each mix, the percent of material passing the 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm, and 0.075 mm sieves was compared to average BPT and texture depth values.

5.2.1 Microtexture

In terms of BPN, some interesting trends were noted with respect to gradation. For the 2.36 mm sieve, percent passing and BPN were negatively correlated, meaning that microtexture increased as the percent passing decreased. For the 1.18 mm sieve, the trendline was essentially flat, meaning that there was no relationship. For the 0.60 mm sieve (and subsequent smaller sieves), the trend reversed such that microtexture increased with an increase in percent passing. These trends are presented in Figure 5. Decreasing the percent passing the 2.36 mm sieve while increasing the percent passing the 0.60 mm sieve serves to create a gap in the gradation, minimizing the amount of material on the 1.18 mm sieve. This phenomenon suggests that a gap-graded aggregate blend could help to provide additional microtexture.

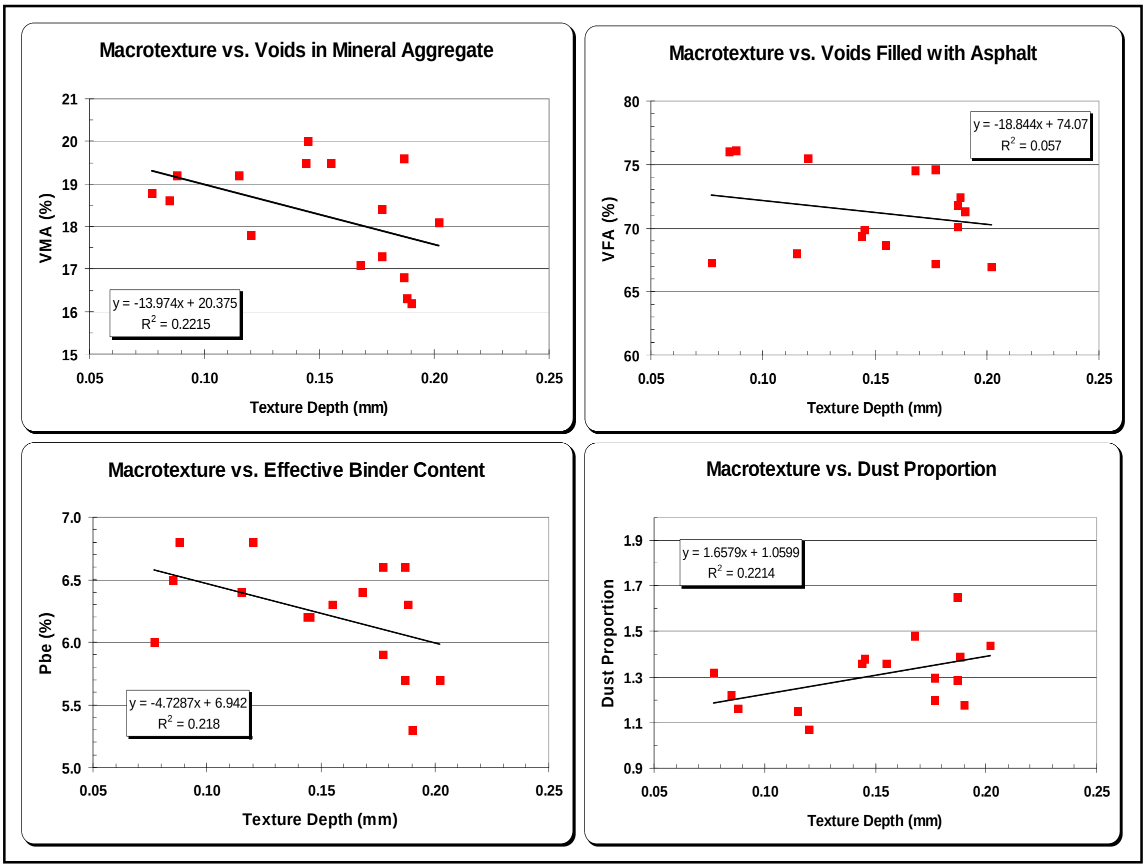

FIGURE 4 – Relationships of Other Mix Design Properties to Macrotexture

Although the statistical validity of the relationships is weak, aggregate gradation appeared to have a stronger relationship to microtexture than the mixture properties. Some of the gradation correlations are able to explain over half the variability in the data (demonstrated by the R^2 values).

5.2.2 Macrotexture

In terms of texture depth, similar trends were noted with respect to gradation, and these trends are presented in Figure 6. The 1.18 mm and 0.60 mm sieves were negatively correlated with texture depth, and the .30 mm sieve showed virtually no correlation. The correlation began to shift positively as sieve size decreased to 0.15 mm. This shifting of trendlines throughout subsequent sieves suggests that a gap-graded aggregate blend may also assist in improving the macrotexture of a 4.75mm HMA mix.

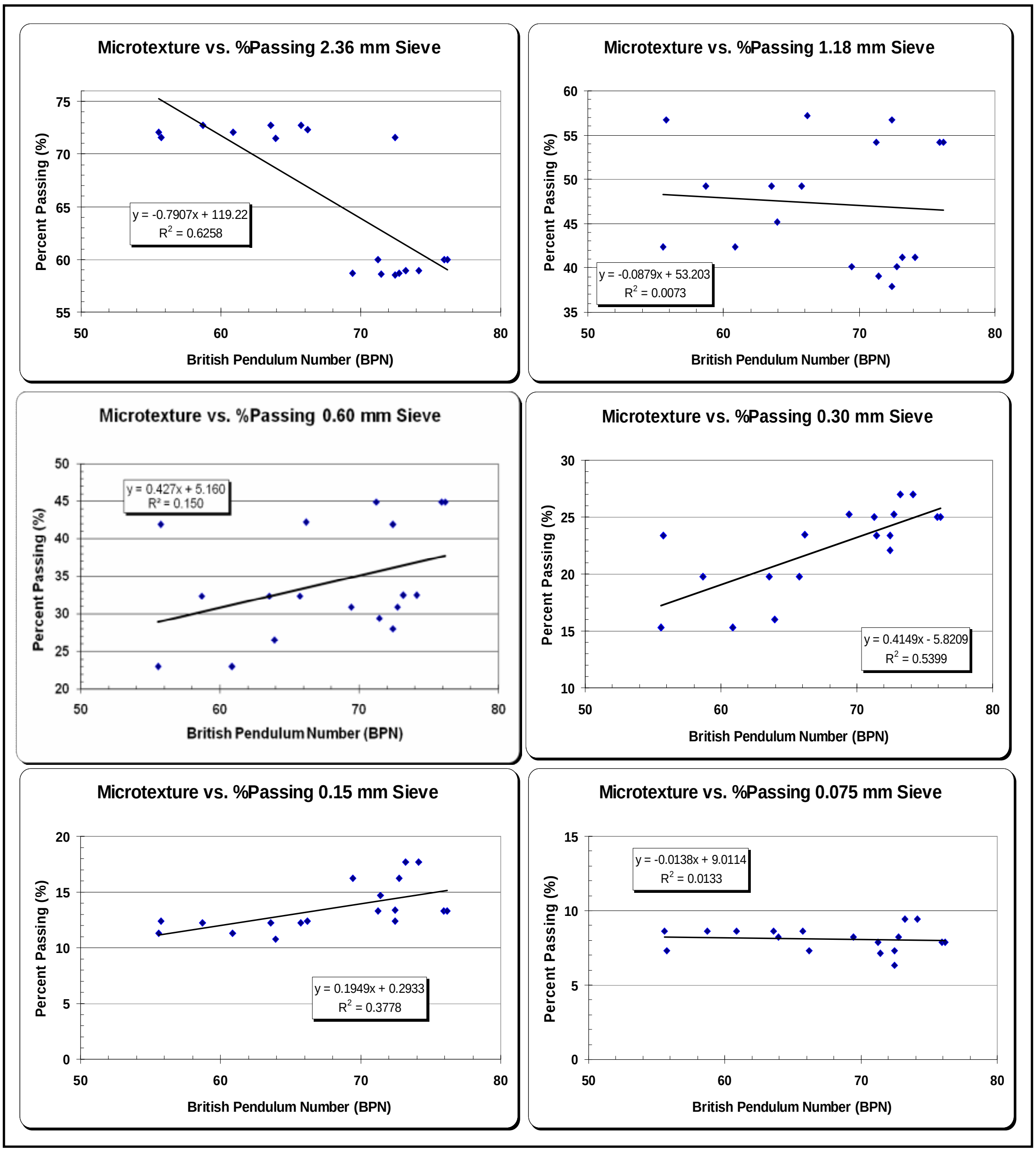

FIGURE 5 – Relationships of Blend Gradation to Microtexture

5.3 ADDITIONAL AGGREGATE PROPERTIES

Next, fine aggregate source and consensus properties were compared to the measures of microtexture and macrotexture. The properties included in this research were aggregate durability by the Micro-Deval, sodium sulfate soundness, and fine aggregate angularity. Fineness modulus, which is a function of the aggregate blend gradation, was also considered. Regression analysis was used to seek relationships between these aggregate properties and mixture skid resistance.

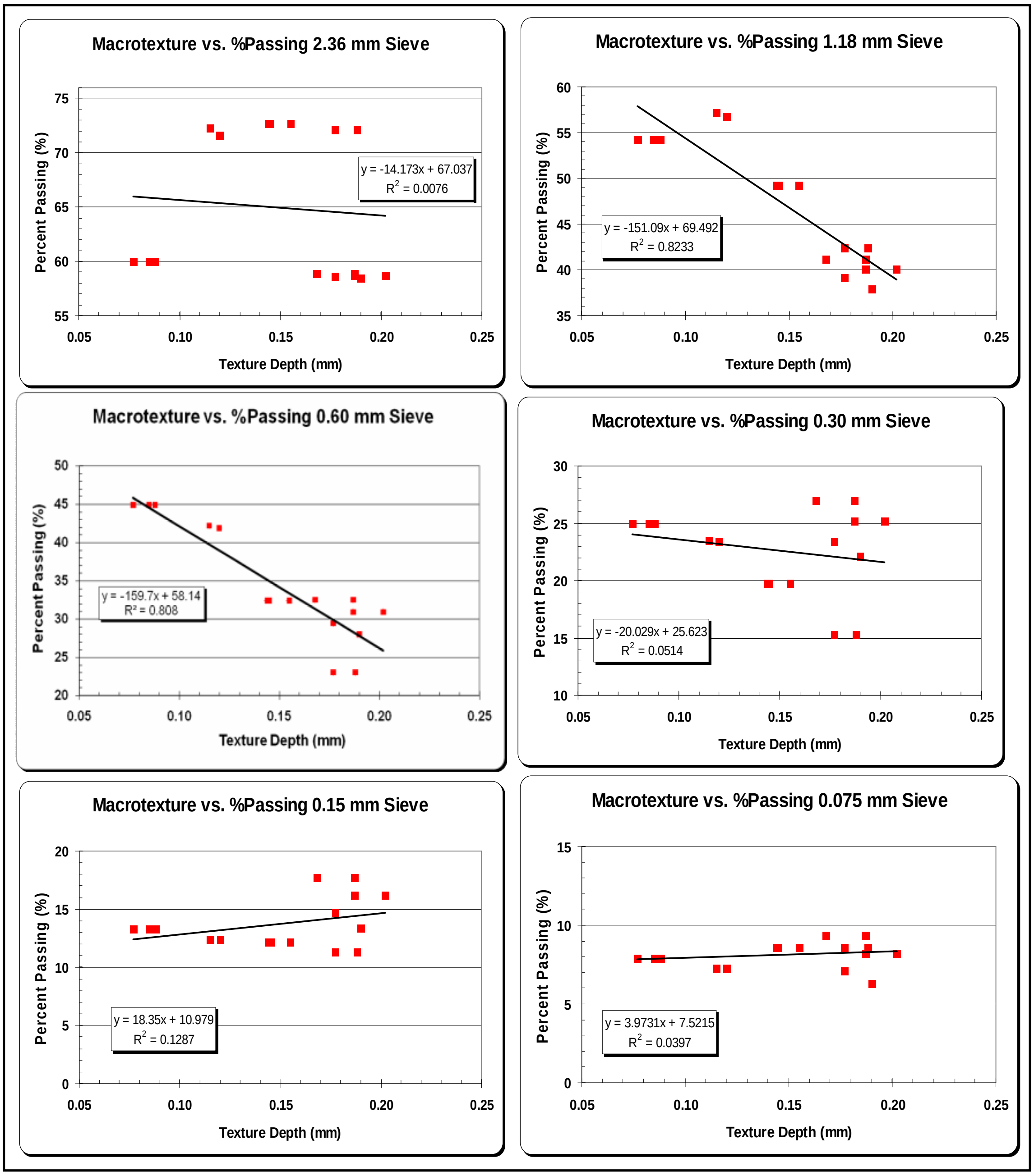

FIGURE 6 – Relationships of Blend Gradation to Macrotexture

5.3.1 Microtexture

The correlations developed between BPN and aggregate properties are shown in Figure 7. While the mathematical relationships were not especially strong, some definite trends were noted. As the percent loss by the Micro-Deval durability test decreased (i.e., the aggregate is more durable) the BPN increased. In general, for each percent increase in percent loss by the Micro-Deval, there was approximately a 0.75 unit decrease in microtexture., such that 15 percent loss corresponds with a BPN of just over 65. Thus, mix designers could improve the skid resistance of a 4.75mm mix by placing greater emphasis on aggregate durability. For a desired BPN of 65, the data suggests that a maximum of 15 percent loss by Micro-Deval may be a reasonable limitation.

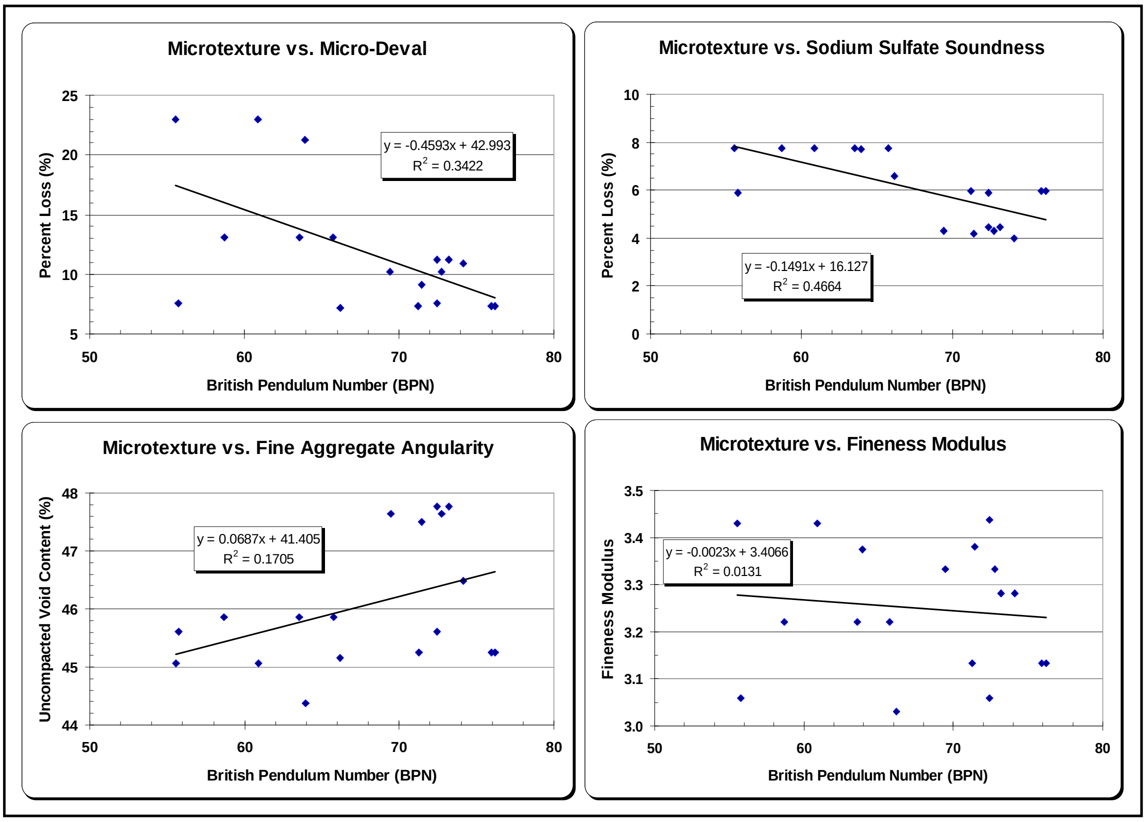

FIGURE 7 – Relationships of Aggregate Properties to Microtexture

The trend relating microtexture and percent loss by the sodium sulfate soundness test was reasonably strong, indicating an increase in BPN as percent loss decreased. In other words, a more sound aggregate generated higher BPN values. Overall, there was a loss of approximately 3 BPN units for every percent increase in percent loss in soundness. This relationship demonstrates a definite trend, but the mathematical model is certainly not adequate for predictive purposes. Based on the data generated in this project, a requiring a maximum of 6.5 percent loss by sodium sulfate soundness could be implemented in order to create a minimum desired BPN of 65.

Fine aggregate angularity showed a slight trend toward increased BPN values with increased angularity. It appears that for each percent increase in uncompacted voids, there is an increase of approximately 2.5 BPN units. According to this relationship, a BPN of 65 may be achieved by imposing a minimum fine aggregate angularity requirement of 46 percent uncompacted voids.

Microtexture was relatively unaffected by fineness modulus, indicating that this single descriptor of aggregate blend gradation would not be a beneficial factor for assistance in designing 4.75mm mixes with high skid resistance.

5.3.2 Macrotexture

The relationships of macrotexture to the other aggregate properties determined in the study are shown in Figure 8.

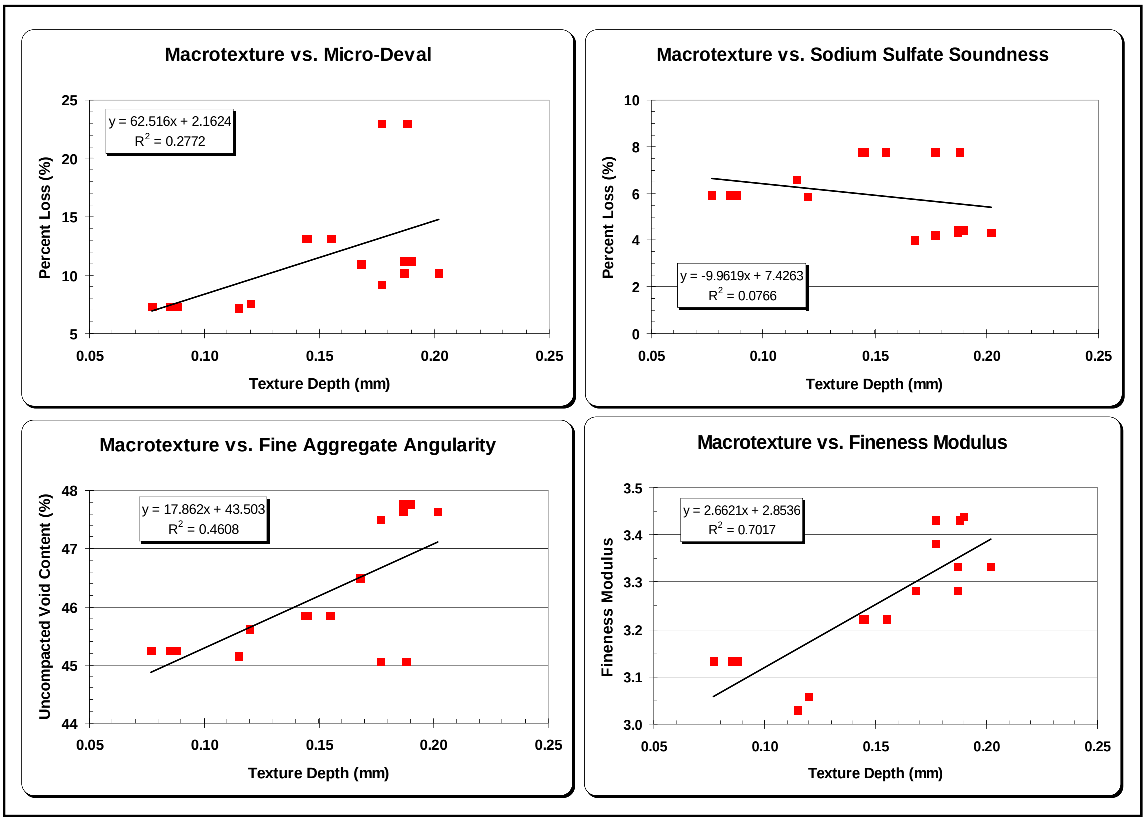

FIGURE 8 – Relationships of Aggregate Properties to Macrotexture

The relationship to percent loss in the Micro-Deval test was such that as percent loss increased, the texture depth also increased. This was an unexpected result, and no explanation was determined for this unexpected trend, however two data points appeared to significantly impact the slope of the trendline. If those points were removed, the trendline was relatively flat, meaning that the Micro-Deval durability values are not substantially related to the macrotexture of the HMA mix.

The sodium sulfate soundness test was also unsuccessful in describing variability in macrotexture measurements. Thus this test method was deemed ineffective as a design tool for macrotexture of 4.75mm mixes.

Fine aggregate angularity provided a relatively strong trend such that as angularity increased, macrotexture also increased. This is reasonable since a higher percentage of uncompacted voids indicates a greater number of void spaces, some of which should be located on the surface of the HMA. Overall, approximately 0.06 mm of texture depth was added for each percent increase in uncompacted voids. A minimum of 46 percent uncompacted voids was suggested in order to provide a BPN of 65. This level of fine aggregate angularity corresponds with a texture depth of approximately 0.14 mm.

Fineness modulus provided one of the strongest relationships to macrotexture in that as fineness modulus increased, the texture depth also increased. As the gradation of the aggregate blend became coarser, the fineness modulus increased. Thus, the texture depth increased as the gradation became coarser. In fact, each 0.1 increase in fineness modulus resulted in an increase of approximately 0.04 mm in texture depth. A texture depth of 0.15 corresponded with a fineness modulus of approximately 3.25.

5.4 COMPARISON TO TRADITIONAL SURFACE MIXES

At the time of the research project, no 4.75mm mixes had been placed in the state of Arkansas, and thus no field study could be performed in order to validate the findings of the laboratory study. Thus, a relative comparison of laboratory performance was used to imply the relative field performance of the various NMAS mixes.

In order to provide a relative comparison of skid resistance, laboratory-compacted specimens of typical surface mixes were prepared and tested. These mixes were 9.5mm and 12.5mm NMAS and had aggregate and mixture properties similar to the 4.75mm mixes tested. British Pendulum and modified sand patch testing was performed for the additional mixes and compared to the 4.75mm mixes. Figures 9 and 10 illustrate the comparison of average results for microtexture and macrotexture, respectively.

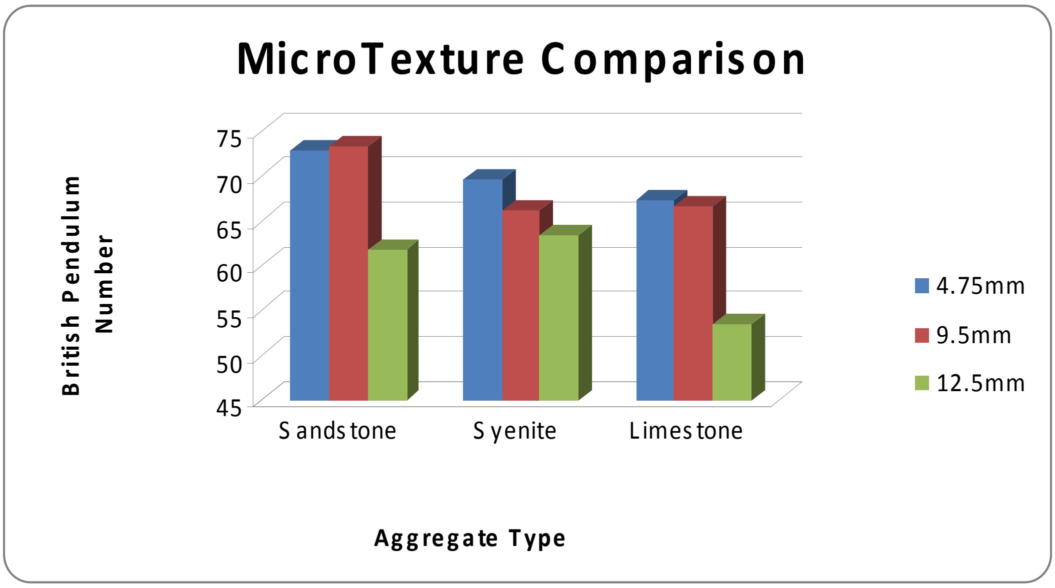

Figure 9 – Effect of NMAS on Microtexture

In terms of microtexture, the 4.75mm mixes were the best performers. The skid resistance of the 4.75mm mixes was significantly greater than that of the 12.5mm mixes for all aggregate sources, and was similar or greater than that of the 9.5mm mixes. In terms of macrotexture, as quantified by texture depth, the 12.5mm mixes were the best performers. The 12.5mm mixes possessed a texture depth that was significantly greater than that of the 4.75m mixes for all aggregate sources, and the 9.5mm mixes had a texture depth that was similar to or greater than that of the 4.75mm mixes. This conclusion was not unexpected, but is important to consider when designing a 4.75mm mixture for a relatively high speed roadway.

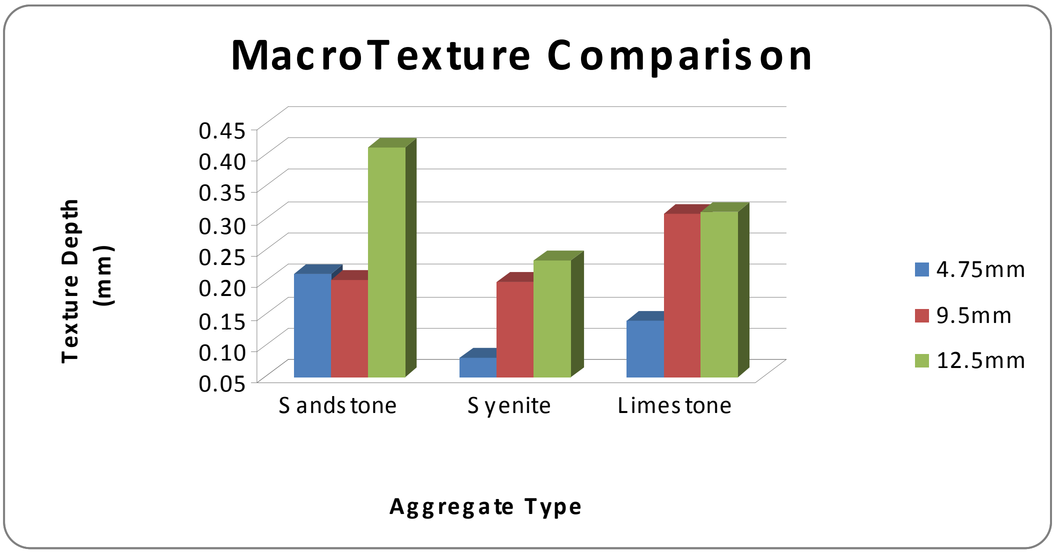

Figure 10 – Effect of NMAS on Macrotexture

6. CONCLUSIONS AND RECOMMENDATIONS

The intention of this research was to provide guidance regarding procedures for ensuring adequate skid resistance of 4.75mm mixtures during the mix design process. If a direct measure of skid resistance is not feasible for inclusion in standard mix design procedures, then perhaps some form of guidance regarding other parameters that significantly affect skid resistance could prove beneficial.

Three aggregate sources were used to generate a total of 18 mix designs with varying combinations of design air void content and compaction level. Aggregate and mixture properties were determined and related to microtexture (as measured by the British Pendulum) and macrotexture (as measured by a modified sand patch test). Based on the results of the testing program, the following conclusions were made.

- Overall, the skid resistance of 4.75mm mixes was more sensitive to aggregate properties than mixture characteristics.
- Skid resistance of 4.75mm mixtures was not significantly affected by changes in design compaction level.
- Design air void level produce a statistically significant effect on skid resistance; however the effect lacked practical significance. Skid resistance may be increased slightly by designing mixes at a lower air void content.
- Both microtexture and macrotexture were relatively insensitive to the mixture properties of VMA, VFA, effective binder content, and dust proportion.
- Microtexture and macrotexture appeared to be affected by aggregate gradation. In general, it seems that a gap-graded aggregate blend could serve to increase the skid resistance of the mix.
- Relative to aggregate source and consensus properties, microtexture increased

as percent loss by Micro-Deval and sodium sulfate soundness tests decreased, and as fine aggregate angularity increased.

- Macrotexture appeared to be most sensitive to fine aggregate angularity in that an increase in uncompacted void content led to an increase in texture depth.
- Macrotexture was significantly affected by the fineness modulus of the aggregate blend. As fineness modulus increased, texture depth increased.
- According to the data generated in this study, the following limitations on aggregate properties may serve to improve the skid resistance of 4.75mm mixes:
  - a maximum of 15 percent loss by Micro-Deval
  - a maximum of 6.5 percent loss by sodium sulfate soundness
  - a minimum of 46 percent uncompacted voids (fine aggregate angularity)
  - a minimum fineness modulus of 3.25
- The microtexture of the 4.75mm mixes tested was equal to or greater than that of typical surface mixes of similar composition.
- The microtexture of the 4.75mm mixes tested was less than that of the typical surface mixes of similar composition.

4.75mm mixes are recommended for use in a wide variety of applications. Since 4.75mm mixes are designed using fine aggregate, and microtexture is governed by the fine aggregate, the consideration of the microtexture of 4.75mm mixes is indeed necessary during the mix design process. Additionally, skid resistance for low speed roadways is dominated by the microtexture. Thus, considering factors that affect microtexture during the design of 4.75mm mixtures for low speed roadways can result in adequate skid resistance. High speed roadways depend on both microtexture and macrotexture. By considering the aggregate characteristics in order to maximize both components of skid resistance, the microtexture of 4.75mm mixes may be able to partially compensate for its lesser macrotexture, resulting in a skid resistance adequate for high speed roadways.

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