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Evaluation of the Effect of Aggregate Structure on Rutting Performance of Asphalt Pavement

아스팔트 포장의 소성변형에 대한 골재 구조의 영향 평가

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요 지

아스팔트 포장에서의 골재분리(segregation)는 혼합물 내의 굵은골재와 잔골재가 고르게 분포하지 않은 결과이며, 균열, 레블링(raveling), 박리(stripping)와 같은 조기 파손을 야기한다. 그러나 소성변형에 대한 골재분리의 효과는 아직까지 제대로 규명되지 못하고 있다. 본 연구에서 수행된 실험 및 분석 결과, 아스팔트 포장의 소성변형은 혼합물의 골재분리보다는 혼합물 내의 골재 구조에 더 큰 영향을 받음을 알 수 있었다. 또한 굵은골재의 체적이 증가함에 따라 혼합물의 소성변형 저항성은 증가하였다. 그러나 이러한 현상은 낮은 공극율을 갖는 혼합물에서는 잘 일치하였지만, 높은 공극율을 갖는 혼합물에서는 골재의 체적 증가 보다는 공극율 자체가 소성변형에 더 큰 영향을 줌을 알 수 있었다. 즉, 공극율10%를 기준으로, 이를 초과하는 혼합물은 굵은 골재의 체적이 큼에도 불구하고 소성변형 저항성은 크게 감소함을 알 수 있었다.

핵심용어 : 골재분리, 소성변형, 골재 구조, 공극율, 슈퍼페이브 혼합물

Abstract

Segregation in asphalt pavements occurs as a result of the non-uniform distribution of coarse and fine aggregates and causes premature distresses, such as cracking, raveling, and stripping. The effect of segregation on rutting, however, has not been clearly identified. Experimental and analytical work performed in this study indicates that rutting performance is affected by segregation of mixtures. However, the aggregate structure of mixtures appears to be a more critical factor that determines the rutting performance, rather than the level of segregation. Based on the field mixtures evaluated, an increase of coarse aggregate volume in an asphalt mixture is an important factor that results in good rutting performance. This effect holds true for mixtures with lower levels of air voids, but for mixtures with higher levels of air voids, the air voids effect becomes dominant, resulting in a reduction in rutting performance. An air void content of 10% appears to be a threshold that determines the rutting performance of Superpave mixtures. Once the air void content exceeds 10%, the rutting performance of Superpave mixtures decreases significantly, despite the coarse aggregate volume.

Keywords: segregation, rutting, aggregate structures, air voids, superpave mixtures

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INTRODUCTION

Background

Segregation in flexible pavements occurs as a result of the non-uniform distribution of coarse and fine aggregates. Segregation can typically be visually identified from the areas where coarse-aggregate-rich surface texture exists along the pavement surface. In general, coarse-aggregate-rich mixtures have high air voids and low asphalt contents. From the literature (Brown et al. 1989, and Cross and Brown 1993, Williams et al. 1996, and Stroup-Gardiner 2000), these mixtures lead to premature distresses, such as cracking, raveling, and stripping. Consequently, these distresses will reduce the performance and serviceability of the in-situ pavement.

Instability rutting, which is shear related and occurs when the compacted mixture cannot resist critical stress conditions occurred at the pavement surface, is a major distress mode in flexible pavements. Nevertheless, the effect of segregation on the performance of rutting has not been clearly identified. The pavement condition survey conducted on the pavements with various levels of segregation in six states in U.S. reported that rutting performance was not strongly influenced by gradation segregation, except some areas with higher air voids (STROUP-GARDINER and Brown 2000). A similar conclusion was also reported by Cross (2000). In his study, laboratory tests performed using Asphalt Pavement Analyzer (APA) on two different mixtures with different levels of segregation did not show clear correlation between rut depths and the levels of segregation. This indicates that segregation may have positive and negative effects on the performance of rutting, but the field performance data or the laboratory testing alone appears to be limited to identify these effects. Therefore, a suitable approach that can identify the positive and negative effects on the rutting performance needs to be developed.

The aggregate structure of asphalt mixtures has been well studied on the basis of experience and identified as an important factor that determines the performance of mixtures. For example, the rutting performance of mixtures appears to be significantly affected by aggregate gradation variation and air void content (Elliott et al. 1991). Also, Vavrik et al. (2001 and 2002) and Kim et al. (2005) indicate that the effect of coarse aggregate will provide great potential for evaluating the rutting performance of hot-mix asphalt. For the same reason, the performance of segregated mixtures may not be only a function of the level of segregation, but also related to the aggregate structure. Furthermore, considering that segregation changes the aggregate structure of a mixture, it is of particular interest to know what relationship can be made between segregation and its original gradation, and how the change can be related to the rutting performance of the mixture. An analytical approach based on the finite element method was considered and developed. To this purpose, a finite element program (ADINA) was used to evaluate these effects on the rutting potential of asphalt mixtures.

Objective

The primary objectives of this research study are listed below:

- Evaluate the effect of segregation on the rutting performance of dense-graded Superpave mixtures.
- Identify and evaluate the effect of aggregate structure on the rutting performance of asphalt mixtures with different gradations, asphalt contents, air void levels, and different levels of segregation.
- Develop and identify a criterion to effectively assess

the rutting performance of segregated mixtures related to their gradation and volumetric properties.

Scope

This research focuses on identifying the effect of segregation on the rutting performance of hot-mix asphalts. This study involves segregated and non-segregated mixtures obtained from three in-service pavements in the state of Florida. The mixtures were composed of a variety of aggregates, including limestones and granites typically used in the state of Florida.

The experimental portion of this study can be classified into two parts: determining volumetric properties and evaluating rutting performance. A complete set of laboratory tests that are commonly used to determine the volumetric properties of mixtures were performed on each cored sample, and rutting tests using the Asphalt Pavement Analyzer (APA), which is widely used as a rutting performance test of asphalt mixtures, were performed on part of the cored samples.

The analytical work involved in this study is to predict rutting performance of the mixtures that have different gradations and different levels of segregation based on the aggregate structure. An analytical approach was developed using the finite element method (FEM). A finite element program (ADINA) was used to evaluate the effect of coarse aggregates and air voids on the rutting performance of asphalt mixtures.

DESCRIPTION OF TEST SECTIONS

Three pavements having different degrees of visual segregation were selected for sampling and evaluation. The age of all pavements was less than one year when cores were obtained, and all mixtures used were designed by the Superpave mix design method. For each pavement, segregated and non-segregated areas were visually identified, and ten cores from each area were obtained. A brief description of each site follows:

Site 1

The mixtures cored at Site 1 were fine graded, 12.5 mm nominal size aggregate, with PG 67-22 binder. From a picture taken of the core samples, Figure 1(a), segregation was apparent, but less significant than Site 2 or Site 3. Therefore, visual observations concluded that this site could be ranked as a low segregated site.

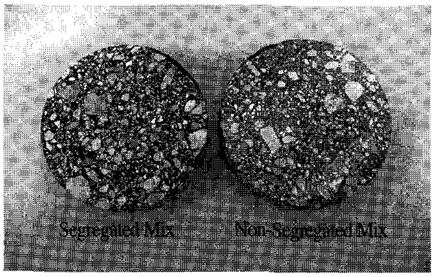
Site 2

The mixtures cored at Site 2 were fine graded, 12.5 mm nominal size aggregate, with PG 76-22 binder. From a picture taken of the core samples, Figure 1(b), segregation was less significant than Site 3, but more significant than Site 1. Thus, this site could be ranked as a medium segregated site.

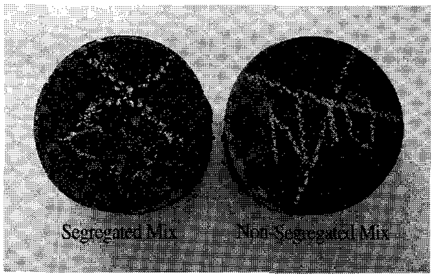
Site 3

The mixtures cored at Site 3 were fine graded, 12.5 mm nominal size aggregate, with PG 76-22 binder. From a picture taken of the core samples, Figure 1(c), segregation was heavy. Thus, this site could be ranked as a heavily segregated site.

In summary, six sections from three pavements were evaluated to investigate the effect of segregation among mixtures having different gradations. Sites 1-N, 2-N, and 3-N represent non-segregated areas as well as mixtures with different gradations, while Sites 1-S, 2-S, and 3-S represent areas segregated from the different gradations. In addition, it should be noted that the overwhelming mixture type used for Florida Department of Transportation (FDOT) work is a 12.5 mm nominal size aggregate mixture. Hence, the three mixtures chosen for this study are that type.



(a) Site 1



(b) Site 2

(c) Site 3

Figure 1. Cored Samples

Specimen Preparation

This study intended to directly measure volumetric properties and laboratory rut depths from the segregated and non-segregated specimens. Thus, the commonly used laboratory segregation technique (Khedaywi and White 1995) was not considered.

A total of twenty cores were obtained from the segregated and non-segregated areas of each pavement site. The coring location was carefully selected through field inspection as being representative of segregated and non-segregated pavement conditions. All cores were carefully marked and delivered to the laboratory. Upon inspection in the laboratory, six (approximately 40 mm thick by 150 mm in diameter) specimens of the surface mixture were taken and prepared for the volumetric tests that determine volumetric properties, and four 75 mm thick specimens, which were obtained by removing the bottom of cored mixtures, were taken and prepared for the rutting performance tests using Asphalt Pavement Analyzer (APA).

EVALUATION OF VOLUMETRIC PROPERTIES

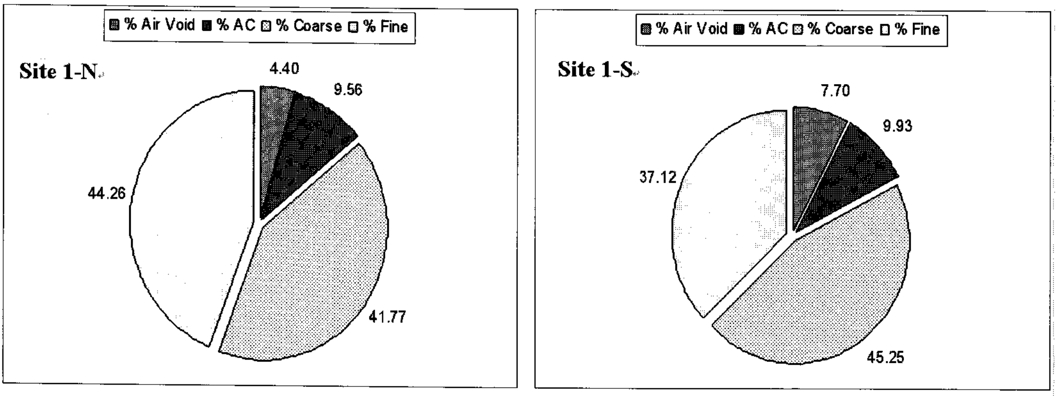
Laboratory Testing

The bulk specific gravity of six specimens was measured (AASHTO T-166) and then the specimens were dried. Two specimens, representing each mixture, were used for determination of maximum theoretical density (AASHTO T-209). The remaining cores were assigned for determination of asphalt contents using the ignition oven (AASHTO T-308) and sieve analyses (AASHTO T-30).

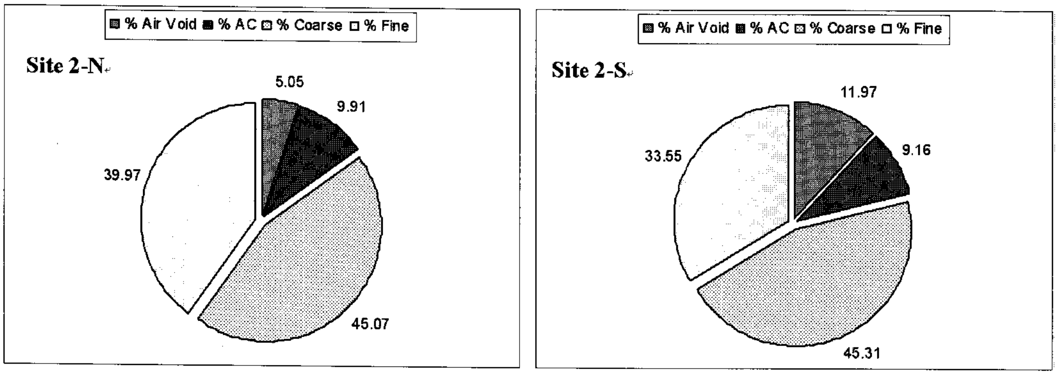
Summary of Laboratory Test Results

Segregation in flexible pavements occurs as a result of the non-uniform distribution of coarse and fine aggregates. The areas where coarse-aggregate-rich surface texture exists can be visually identified as segregated areas. Since segregated mixtures have a higher amount of coarse aggregate than the non-segregated mixtures, these mixtures generally have lower asphalt contents and higher air voids.

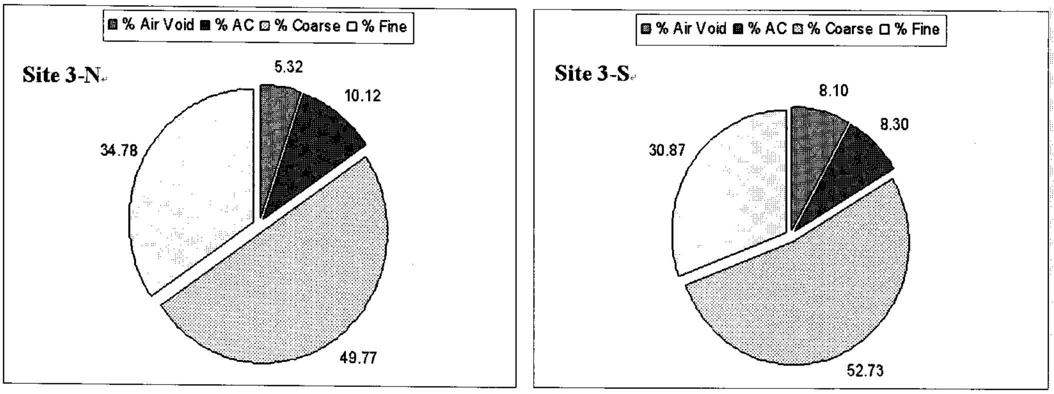
The laboratory tests performed on the segregated and non-segregated mixtures correlated with the fact illustrated above. Based on volume, results of each site are shown in a simple phase diagram (Figure 2) illustrating four phases: coarse aggregate and fine aggregate, where the 2.36 mm sieve was selected as the size separating coarse and fine aggregates, asphalt content, and air voids.



(a) Site 1



(b) Site 2



(c) Site 3

Figure 2. Phase Diagram of Six Mixtures

Determination of Degree of Segregation

Although visual assessment is commonly used to detect potentially segregated mixtures, it appears subjective and may not be reliable. From literature review, it was found that the degree of segregation couldn't be accurately determined from field observations alone (Wu and Romero 2003). Likewise, a poor correlation was found from the comparison between the visual observations and the degree of segregation determined in this study.

A large segregation study performed on four pavements from the Kansas state (Cross et al. 1998) showed that a No. 4 sieve could be used for the determination of the level of segregation. Four severity levels of segregation, 0%, 5%, 10%, and 20%, were defined by the authors based on the gradations of field cores. The amount of segregation was quantified by subtracting the percent retained on the No. 4 sieve of each segregated core from the average percent retained on the No. 4 sieve of non-segregated cores. Another segregation study (Brown et al. 1989) performed on 19 sections suggested to use a No. 8 sieve for detecting segregation. The authors reported that segregated areas were generally 8 to 15 percent coarser than non-segregated areas based on the No. 8 sieve, and these mixtures also exhibited a significant loss of desirable mixture properties, such as tensile strength. National Cooperative Highway Research Program (NCHRP) project 9-11 on segregation examined 14 projects and provided more detailed definitions of segregation. This research defined no, low, medium, and high levels of segregation based on statistical changes in key volumetric properties: gradation, asphalt content, and air voids (Stroup-Gardiner and Brown 2000).

Although many researchers provided the various definitions that determine the level of segregation, the average percent retained on the No. 4 sieve of the segregated mixtures evaluated in this study were clearly discriminated from that of the non-segregated mixtures. Four levels of segregation, no, low, medium, and high levels, were defined. Considering construction variability, 5, 10, and 20 % changes retained on the No. 4 sieve were used as threshold values that separate each level. According to these criteria, the Site 1-S, which was ranked visually as a low segregated site, corresponded with the criterion of the medium level of segregation, and Site 2-S and Site 3-S, which were ranked visually as medium and heavy segregated sites, respectively, corresponded with the criterion of the low level of segregation. Consequently, Sites 1-N, 2-N, and 3-N were ranked as non-segregated sites; Sites 1-S, 2-S, and 3-S were ranked as medium, low, and low segregated sites, respectively. The average percent retained on the No. 4 sieve from the sites are shown Table 1.

Table 1. Level of Segregation

Size (mm)	Sieve	Sections (Average Percent Retained)					
		Site 1-N	Site 1-S	Site 2-N	Site 2-S	Site 3-N	Site 3-S
19	3/4"	0.0	0.0	0.0	0.0	0.0	0.0
12.5	1/2"	5.2	9.5	0.9	2.6	7.4	9.0
9.5	3/8"	8.9	15.9	8.9	13.4	12.6	16.2
4.75	# 4	**27.7**	**38.1**	**36.2**	**41.8**	**39.1**	**44.7**
2.36	# 8	48.2	56.6	52.6	56.6	58.9	62.4
1.18	# 16	61.6	67.0	61.5	65.0	68.4	70.5
0.6	# 30	69.8	73.8	67.2	70.6	74.2	75.5
0.3	# 50	81.7	83.9	78.1	80.8	81.4	81.8
0.15	# 100	91.7	92.6	89.6	90.9	90.7	90.7
0.075	# 200	94.9	95.2	92.3	93.6	95.0	95.0
Segregation Level		Medium(>= 10%)		Low(>= 5%)		Low(>= 5%)	

EVALUATION OF RUTTING PERFORMANCE USING ASPHALT PAVEMENT ANALYZER (APA)

Overview

More mechanistic-based rutting prediction tests, such as triaxial or simple shear tests, may provide more meaningful results for the prediction of rutting performance. However, they are relatively more complicated and costly than commonly used torture tests, such as the Hamburg Wheel-Track Test, French Pavement Rutting Tester, Asphalt Pavement Analyzer, etc. Also, the cored specimens obtained from the field sections may not meet the size requirements required by the mechanistic tests.

The Georgia Loaded Wheel Tester (GLWT) developed by the Georgia Institute of Technology has been subsequently modified and improved since 1985 to evaluate the rutting susceptibility of asphalt mixtures (Lai 1986b, Collins et al. 1995, and Collins et al. 1996). The Asphalt Pavement Analyzer (APA), which is the second generation of the GLWT, was first manufactured in 1996 by Pavement Technology, Inc. The APA has been widely used in an attempt to evaluate the rutting, fatigue, and moisture resistance of asphalt mixtures. Although the APA is not a mechanistic test, it does tend to simulate the realistic situation in the field. A load is applied through an aluminum wheel onto a linear hose with internal pressure that simulates the effect of a pneumatic tire. The wheel tracks back and force to simulate traffic loads in the field. Lai (1986a) reported that results of the GLWT were more compatible with the rutting characteristics normally experienced in flexible pavements under vehicular loading than those achieved by the triaxial and creep tests. Also, Williams and Prowell (1999) reported that rut depths obtained from the APA tests correlated well with the permanent deformation of the WesTrack sections with 89.9% accuracy. Therefore, the APA was favorably selected as a tool for the prediction of rutting performance.

Laboratory Tests

The twenty-four specimens obtained from the segregated and non-segregated areas in each of the three pavement sites were tested at 64 ℃. The internal horse pressure was set to 700 kPa and the vertical load was set for 445 N. Specimens were heated for 14 hours to reach test temperature prior to testing. A 25 cycle seating load was applied and initial rut depths were manually recorded. Final rut depths were also manually recorded after an additional 8000 loading cycles. All procedures for determining the rutting performance using the APA followed the standard method as described in AASHTO TP 63-03.

Summary of APA Test Results

The APA tests were performed for the six sections from three pavement sites. Figure 3 shows the rut depths of six sections, Site 1-N, Site 1-S, Site 2-N, Site 2-S, Site 3-N, and Site 3-S. Site 1-S, which was determined as the medium level of segregation, shows better rutting performance than that of the non-segregated section, Site 1-N. However, Site 2-S, which was determined as the low level of segregation, shows worse rutting performance than Site 2-N, as well as the worst rutting performance among the segregated sections. Meanwhile, Site 3-S, which was determined as the low level of segregation, shows about the same rutting performance as Site 3-N. No consistent trend from the results of test data related to the level of segregation was identified in this analysis. It may indicate that the rutting performance of segregated mixtures is not a primary function of their levels of segregation. It appears to be affected by something else. Therefore, a more analytical approach was examined.

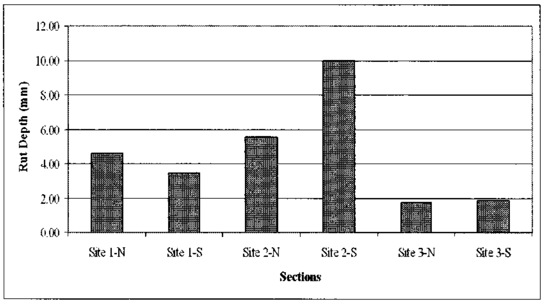


Figure 3. APA Results

PREDICTION OF RUTTING PERFORMANCE USING A FINITE ELEMENT METHOD (FEM)

Overview

Instability rutting in an asphalt layer usually occurs in the top 100 mm of the pavement surface and develops gradually with increasing numbers of load applications, typically appearing as a longitudinal depression channel with a small upheaval to each side of the wheel path. In many cases, instability rutting is caused by a combination of extra compaction due to air voids and dislocation of the aggregate or asphalt binder in an asphalt mixture.

The aggregate structure of asphalt mixtures plays an important role in determining the performance of flexible pavements. From the literature, the effect of coarse aggregate appears important for resistance to rutting (Vavrik et al. 2001 and 2002, and Kim et al. 2005). Also, Elliott et al. (1991) emphasized the importance of air void content for the performance of cracking and rutting in hot-mix asphalts. In this study, the development of a theoretical and conceptual approach to evaluate the effect of coarse aggregates and air voids on rutting performance was a primary focus. Considering that segregation increases the amount of coarse aggregate and air void content in an asphalt mixture, this approach may be also applicable to identifying the effect of segregation on rutting performance.

Development of Theoretical Approach

Several studies have shown that the shear properties of asphalt mixtures are fundamental in resisting instability rutting. Harvey et al. (2001) indicated that rutting was mainly caused by shear distortion. Shear moduli measured from simple shear tests in the laboratory correlated best with rutting performance in the field. Bekheet (2004) also reported that shear stiffness directly measured from in-situ shear testing had a good agreement with the rutting of the test sections. Even though these approaches have a limitation where viscosity or visco-elasticity is not considered, it appears that shear is a key factor that determines the amount of permanent deformation in asphalt mixtures.

To evaluate rutting performance using a finite element method, a proper model that can represent the effect of different aggregate structures as well as the effect of shear response needs to be identified. To this purpose, the pure shear stress condition (Figure 4) was favorably selected due to its simplicity and capability to examine pure shear response. The concept used in this approach was if the square element with a particular aggregate structure, used in the stress condition, yields higher shear deformation under the given stress level, then the effect of the aggregate structure becomes dominant, while if the element yields lower shear deformation under the same stress level, then the effect of the aggregate structure becomes less. By generating several elements with different aggregate characteristics, the effect of a target component can be identified in terms of the shear deformation. Finally, by comparing these results to the equivalent rut depths measured from the APA tests, the effect of the target component can be identified.

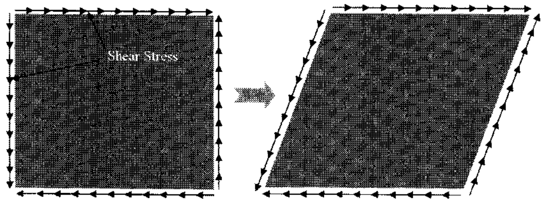
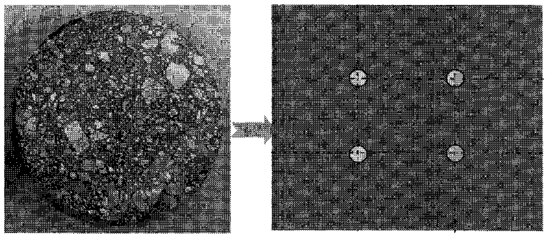


Figure 4. Pure Shear Stress Condition

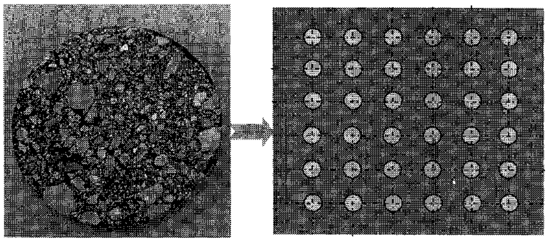
Development of Conceptual Approach

A primary concept employed in this conceptual development is to simulate the interaction between coarse aggregates and air voids. First, to simulate the effect of coarse aggregate, it was hypothesized that the total volume of an asphalt mixture can be divided into two volumes: primary and circumferential volumes. The primary volume (PV) represents the volume of coarse aggregate, while the circumferential volume (CV) refers to the total volume (TV) excluding the primary volume. Thus, the CV includes fine aggregates, asphalt binder, and air voids. A second assumption is the PV can be divided into several circles in two-dimensional space where each circle represents the dominant effect of coarse aggregates. Therefore, to simulate the volume increase of coarse aggregates, more circles (PV) can be added into the CV. Second, to simulate the effect of air voids, the same hypothesis was used above, but for this case, the PV represents the volume of air voids, while the CV includes coarse aggregates, fine aggregates, and asphalt binder.

Figure 5 shows a schematic illustration of the concept described above. The condition of an asphalt mixture was limited to the two-dimensional plane stress state. First, for the predetermined two-dimensional plate, four dashed lines passing equal distance from both the horizontal and vertical edges of the plate were assigned. Then, four circles, representing the PV, were assigned to the nodal points of the regular net with equal mesh sides. In this way, three cases, 4, 16, and 36 circles, representing the volume increase of coarse aggregates and air voids, were considered in further finite element modeling.



(a) Low Primary Volume (PV)



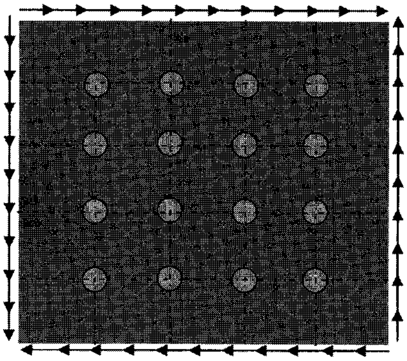
(b) High Primary Volume (PV)

Figure 5. Schematic Illustration of Conceptual Approach

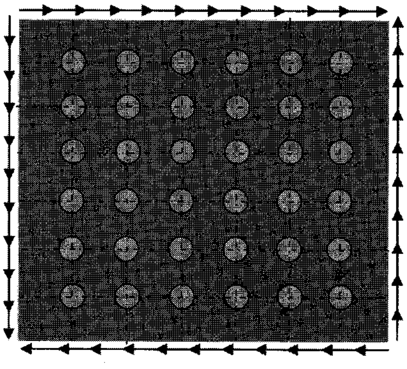
Modeling Using a Finite Element Method

Based on the theoretical and conceptual approach illustrated above, three models (Figure 6) with three levels of PV, corresponding to three levels of CV, were generated using the commercial finite element program ADINA. Since this modeling did not intend to obtain exact material responses from this modeling, but instead, intended to investigate a general rutting behavior of asphalt mixtures, the linear elastic analysis

(a) Low PV



(b) Medium PV



(c) High PV

Figure 6. Finite Element Model of Primary Volume

Table 2. Material Properties used of FEM Modeling

Case	Name of Volume	Modulus (GPa)	Poisson's ratio
Effect of Coarse Aggregate	Primary Volume(PV)	68.95	0.25
	CircumferentialVolume(CV)	2.07	0.35
Effect of Air Voids	Primary Volume(PV)	No Elements	No Elements
	CircumferentialVolume(CV)	3.45	0.35

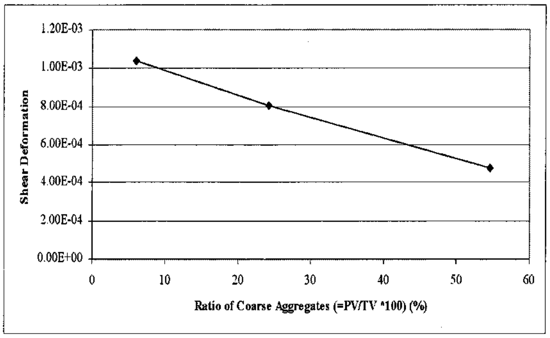


Figure 7. Effect of Coarse Aggregate Volume from FEM Analysis

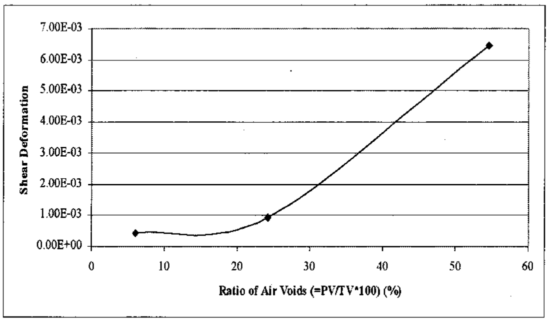


Figure 8. Effect of Air Void Content from FEM Analysis

was used to reduce modeling time and computational effort. Material properties used in the FEM models are shown in Table 2. From this modeling, maximum shear deformations occurred at the corner of each model were recorded and plotted in Figures 7 and 8.

Figure 7 represents the effect of coarse aggregates. Increase of the PV, which represented the volume of coarse aggregates, decreased shear deformations continuously. It is believed that the increase of coarse aggregate volume enhances the interlocking between coarse aggregates and results in reduction of the shear deformations. Such a result indicates that the effect of coarse aggregates plays an important role in determining rutting performance. It is also interesting to note that the relation between coarse aggregate volume and shear deformation shows a complete linear trend. Meanwhile, as shown in Figure 8, increase of the PV, which now represented air void content, increased shear deformations somewhat at the lower level of PV, but increased shear deformations rapidly at the higher level of PV. This indicates that the effect of air voids is dominant when the air void content is higher, but its effect is less or negligible when it is lower. Therefore, the effect of air voids on rutting appears to have a threshold, since the relation between air void content and shear deformation was exponential.

Verification Using Experimental Results

According to the FEM analysis, it was found that shear deformation decreased linearly as the coarse aggregate volumes increased, and as air void contents increased, shear deformation increased somewhat at the lower level, but increased rapidly at the higher level. Considering that coarse aggregate volumes of the Site 1-N, 1-S, 2-N, 2-S, 3-N, and 3-S were 41.77, 45.25, 45.07, 45.31%, 49.77, and 52.73%, respectively (Figure 2), the former observation corresponds with the plot shown in Figure 9. As the coarse aggregate volumes increased, the rut depths measured from all sites proportionally decreased, except that of Site 2-S. Meanwhile, considering the air void content of Site 2-S was relatively higher than the others (Figure 2), the later observation corresponds with the plot shown in Figure 10. In this plot, the rut depths measured from all sites did not show an apparent trend regarding the air void contents, except that of Site 2-S. From this observation, it is interesting to note that at the lower levels of air voids, the rutting performance was dominated by the effect of coarse aggregates, but once the air void content reached a certain critical point, the effect of coarse aggregates became less and were overwhelmed by the air void effect.

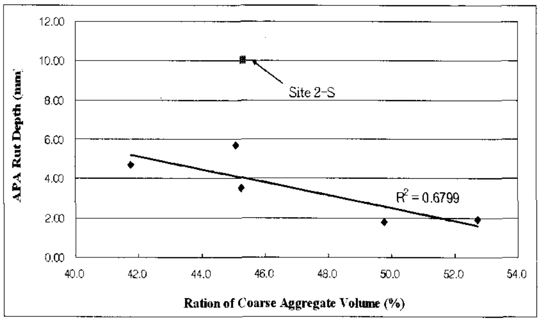


Figure 9. Coarse Aggregate Volume versus APA Rut Depth

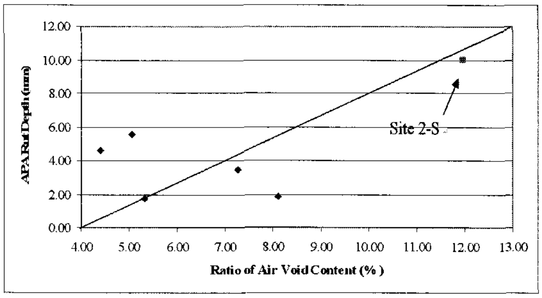


Figure 10. Air Void Content versus APA Rut Depth

This implies that not all the segregated mixtures reduce rutting performance, but instead, their gradations and air void contents appear more critical. Although some variations exist in this analysis due to different material characteristics, such as aggregate, asphalt binder, aging, or testing variability, it appears that the gradation and air void content of mixtures are the key factors that determine rutting performance. From the mixtures evaluated, the increase of coarse aggregate volume appears to show good rutting performance at the lower level of air voids. However, rutting performance decreased significantly as the air void content increased to more than 10%. Therefore, 10% air voids appears to be an important threshold that is related to the rutting performance of asphalt mixtures.

SUMMARY AND CONCLUSIONS

A primary focus of this research was to identify the effect of segregation on rutting performance. Three types of fine graded Superpave mixtures, representative of mixtures commonly used for the construction of state roads in the state of Florida, and two levels of segregation, occurring from construction variability in the state, were cored and evaluated.

To evaluate the rutting performance of mixtures, a total of 60 specimens were prepared, and a portion of the specimens were tested using the APA. From the experimental results combined with the analytical study performed using FEM analysis, it was found that the gradation and air void content of mixtures appear to be critical factors that determine the rutting performance, rather than the degree of segregation. Based on the findings of this investigation, the following conclusions can be made:

- Rutting performance is affected by segregation of mixtures. However, the percentage of coarse aggregate and air void content of mixtures appear to be more critical factors that determine the rutting performance, rather than the level of segregation.
- From the FEM analysis performed, the effect of coarse aggregate plays an important role in determining the rutting performance of mixtures at the lower level of air voids. Based on the limited mixtures evaluated, the increase of coarse aggregate volume appears to promise good rutting performance at the lower level of air voids.
- An air void content of 10% appears to be a threshold that determines the rutting performance of Superpave mixtures. Once the air void content exceeds 10%, the rutting performance of Superpave mixtures decreases significantly.

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