NDOT Research Report

Report No: RDT03-041

EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES VOLUME III – IMPACT OF GYRATORY COMPACTION

July 2000

Prepared by Research Division
Nevada Department of Transportation
1263 South Stewart Street
Carson City, Nevada 89712

This work was sponsored by the Nevada Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Nevada at the time of publication. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. **RDT03-041**	2. Government Accession No.	3. Recipient=s Catalog No.
4. Title and Subtitle **Evaluation of Rutting Resistance of Superpave and HVEEM Mixtures, Volume III – Impact of Gyratory Compaction**	5. Report Date **July 2000** 6. Performing Organization Code	
7. Author(s) **Peter Sebaaly, W. Marty McNamara, Jon A. Epps**	8. Performing Organization Report No. **1393-4**	
9. Performing Organization Name and Address **Pavements/Materials Program** **Department of Civil Engineering** **University of Nevada** **Reno, Nevada 89557**	10. Work Unit No. 11. Contract or Grant No. **138-96-803**	
12. Sponsoring Agency Name and Address **Nevada Department of Transportation** **Research Division** **1263 South Stewart** **Carson City, NV 89712**	13. Type or Report and Period Covered 14. Sponsoring Agency Code **NDOT**	
15. Supplementary Notes		

16. Abstract

This report represents the third in a series of four reports documenting the overall evaluation of rutting resistance of Superpave and Hveem mixtures. Specifically this report documents the evaluation of the impact of the gyratory compaction on the permanent deformation performance of HMA mixtures using the RSCH test.

This experiment was developed to validate the $N_{initial}$, N_{design}, and $N_{maximum}$ gyration levels associated with the Superpave volumetric mixture design system for three NDOT projects; 2751, 2827, and 2880. The primary objective of this experiment was to examine if the Superpave gyratory compactor accurately simulates the compaction a HMA mixture is subjected to in the field under traffic loading. A secondary but equally important goal was to compare air-void levels and resistance to permanent deformation of lab mixed-lab compacted (LMLC), field mixed-lab compacted (FMLC), and field mixed-field compacted (FMFC) (cores) mixes associated with the Superpave and Hveem test sections at $N_{initial}$, N_{design}, $N_{maximum}$ compactive efforts.

17. Key Words **Superpave, Hveem, gradation levels, gyratory compactor, air-void levels, rutting resistance, permanent deformation performance, HMA mixtures, RSCH test.**		18. Distribution Statement **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161**	
19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. Of Pages **75**	22. Price

EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES VOLUME III - IMPACT OF GYRATORY COMPACTION

NEVADA DEPARTMENT OF TRANSPORTATION
Materials Division
1263 South Stewart Street
Carson City, Nevada 89712

Research Report No. 1393-4
July 2000

UNIVERSITY
OF NEVADA
RENO

Pavements/Materials Program

Department of Civil Engineering
College of Engineering
University of Nevada
Reno, Nevada 89557

EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES

VOLUME III

IMPACT OF GYRATORY COMPACTION

Authors:

Peter E. Sebaaly
W. Marty McNamara
Jon A. Epps

Pavements/Materials Program
Department of Civil Engineering
University of Nevada
Reno, Nevada 89557

July 2000

TABLE OF CONTENT

INTRODUCTION

This report represents the third in a series of four reports documenting the overall evaluation of rutting resistance of Superpave and Hveem mixtures. Specifically this report documents the evaluation of the impact of the gyratory compaction on the permanent deformation performance of HMA mixtures using the RSCH test.

This experiment was developed to validate the $N_{initial}$, N_{design}, and $N_{maximum}$ gyration levels associated with the Superpave volumetric mixture design system for three NDOT projects; 2751, 2827, and 2880. The primary objective of this experiment was to examine if the Superpave gyratory compactor accurately simulates the compaction a HMA mixture is subjected to in the field under traffic loading. A secondary but equally important goal was to compare air-void levels and resistance to permanent deformation of lab mixed-lab compacted (LMLC), field mixed-lab compacted (FMLC), and field mixed-field compacted (FMFC) (cores) mixes associated with the Superpave and Hveem test sections at $N_{initial}$, N_{design}, $N_{maximum}$ compactive efforts.

After comparing both strain levels and air-void contents, statements could be made regarding relationships which may or may not exist between properties observed for samples compacted at the various gyration levels and cores sampled on a yearly basis.

The study was carried out on mixtures from NDOT contracts 2751, 2827, and 2880, which had been placed originally in the fall of 1996, 1997, and 1998, respectively. For all three contracts, Superpave and Hveem mix designs had been performed prior to the construction of the test sections. Contract 2751 was constructed in 1996 on SR 278 in Eureka County, Nevada. Contract 2827 was constructed in 1997 on US 93 in White Pine County, Nevada. Contract 2880 was constructed in 1998 on IR 80 in Churchill County, Nevada. The reader is referred to Volume I report for full description of the various projects.

For this study, LMLC materials represent the pre-construction mix designs for each contract. Using LMLC and FMLC material, samples were compacted to the individual projects $N_{initial}$, N_{design}, and $N_{maximum}$ levels using the Superpave gyratory compactor. On an annual basis, cores were sampled from both the Hveem and Superpave test sections in all three contracts. An overview of the test matrix for contracts 2751, 2827, and 2880 are shown in Tables 1, 2, and 3, respectively.

For contracts 2751 and 2827, a single asphalt binder was employed, while contract 2880 utilized two asphalt binders as shown in the test matrix. Three sources of mixtures were evaluated (LMLC, FMLC, and FMFC), with LMLC and FMLC mixtures being compacted to the three levels. This resulted in a total of 54 RSCH test specimens for contract 2751. For contract 2827 the number of RSCH samples was slightly less because only two years of cores had been sampled. Contract 2880 had two levels of binder type and two levels of gradation and thus required a total of 72 RSCH specimens. It should be noted that due to time limitations, cores (FMFC) from contract 2880 were not tested and thus reduces the ability to make conclusions regarding the overall performance differences associated with this part of the research.

MATERIALS AND MIXTURES

This gyration study incorporated material taken from the laboratory and field in the course of the analysis. As mentioned earlier, each contract has Hveem and Superpave mixtures. The materials properties and complete mix designs information for each section have been fully presented in Volume I report (1). To avoid repetitions of these properties, the reader is referred to Volume I report.

DATA ANALYSIS

As outlined in the objectives of this experiment, the data analysis will examine the following relationships on a contract-by-contract basis:

1. Air-voids among LMLC, FMLC, and cores within and between mixtures, and
2. Plastic strain after 5000 cycles among LMLC, FMLC, and cores within and between mixtures.

Utilizing the designated gyration levels in each contract (Volume I report), specimens were compacted and prepared for RSCH testing as per AASHTO TP7-94 specifications (2). Where possible, specific comparisons of the various factors in this study will be discussed in detail. However, one must keep in mind that the goal of the statistical comparisons is to help add credibility to the overall "common sense" trends observed in the data.

During this study, it became strikingly evident that different mixtures compact differently at the gyration levels used in the experiment. This difference in compaction characteristics among the various mixtures directly resulted in unequal air-void levels. It has been well documented that air-void levels play a significant role in the amount of plastic strain a sample will incur during shear testing (3,4). Moreover, a strong trend between higher air-voids and higher plastic shear strains existed in the data.

Due to the differences observed in air-void levels, the following assumptions must be kept in mind when reviewing the performance of mixtures in the RSCH and associated statistical comparisons:

1. The mixtures were compacted to the same number of gyrations. The differences observed in air-void levels in the lab are probably similar to what would be seen during the compaction process in the field. Differences in air-voids observed at an equal number of gyrations between mixtures are a function of their specific compaction characteristics.

2. The performance of mixtures in the RSCH test will be compared on a "as is" basis with no adjustment taken into account for unequal air-void contents between mixtures.

During the initial analysis of the RSCH test data, it became evident that an unequal variance problem existed between the gyration levels. The Welch's ANOVA which compares means of two factors in a similar manner to a simple t-test was utilized. Although this method was extremely time consuming because it required comparisons be performed on a factor by factor basis, it would adjust for unequal variance between the two factors when appropriate.

Contract 2751

Tables 4 and 5 summarize the volumetric and RSCH results obtained for Superpave and

Hveem mixtures for contract 2751 tested in the gyration study. Figures 1 and 2 graphically plot percent plastic strain vs. air-voids for LMLC, FMLC and cores for Superpave and Hveem mixtures respectively.

These figures and tables summarize the entire 2751 contract with regards to each mixtures resistance to permanent deformation as evaluated by the RSCH test. The following sections discuss the data in Tables 4 and 5 in details using statistical comparisons to illustrate the major findings.

Air-voids Comparison

To greatly simplify the comparison process, this section will be divided into two subsections based on mixture design method.

Superpave Mixtures

Tables 6, 7, and 8 present all statistical comparisons of air-void contents for the Superpave LMLC, FMLC, and cores tested in this study.

LMLC Mixtures: Table 6 indicates that for LMLC material, air-void levels at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ are statistically different from each other which is visually verified when observing Figure 1. Furthermore, this table indicates that none of the three gyration levels of the LMLC material has statistically the same air-void level as any cores sampled from years 0, 1 and 2. A significance level of 0.05 was used to differentiate between the specific specimens being statistically compared. The mean comparison table presents the significant level along with the letter "s" or "d" in brackets which indicate weather the comparison was statistically the same ("s"), or different ("d").

FMLC Mixtures: Upon review of the mean comparisons in Table 7 for the FMLC mixture, it was evident that air-void contents at the $N_{initial}$ gyration level is statistically different than those observed at N_{design} and $N_{maximum}$, which are not statistically different from each other. Referring to Figure 1, at the $N_{design,}$ and $N_{maximum}$ gyration levels, the field mix has less than 0.5% air-voids. This low air-void level typically occurs in mixtures with either excessive amount of asphalt binder or minus No. 200 material. Reflux extractions were performed on this field mixture and a comparison of LMLC and FMLC asphalt contents and gradations are shown in Table 8. The reflux extraction results did not confirm the belief that the field mixture contained excessive amount of asphalt or minus No.200 material, in fact the FMLC mixture had an asphalt content approximately 0.9% lower than the laboratory mixture and had less fines. No logical explanation exists to account for the over densification problem associated with the field mix. The only conclusion that can be made is that the field mixing procedure has changed the overall compaction characteristics of the aggregate in some way. Furthermore, Table 7 indicates that at the $N_{initial}$, $N_{design,}$ and $N_{maximum}$ gyration levels, the FMLC mixture has statistically different air-voids than all cores sampled from years 0, 1, and 2.

Cores (FMFC*)*: Table 6 indicates that cores sampled in years 0, 1, and 2 from the Superpave test section have the same air-void levels. This conclusion suggests that very little densification or compaction has taken place in the section since its initial laydown in the fall of 1996. This is to be expected due to the limited traffic volume associated with this section of roadway.

LMLC vs. FMLC Mixtures: Table 9 presents statistical comparisons between LMLC and FMLC Superpave mixtures. This table indicates that air-void contents at all gyration levels are statistically different between the LMLC and FMLC mixtures. This conclusion implies that compaction characteristics under identical load conditions are completely different between the LMLC and FMLC mixtures. This is alarming when one considers that the purpose of performing a laboratory mixture design is to enable the performance characteristics of the mix to be reviewed before it is placed in the field. By both mixtures having different compaction characteristics it appears in this case, performing the mix design before construction may not serve its intended purpose.

Hveem Mixture

In a similar manner to the previous section, Tables 10, 11, and 13 present all statistical comparisons of air-void contents for the Hveem LMLC, FMLC, and cores tested in the gyration study.

LMLC Mixtures: Table 10 presents mean comparison results for the LMLC mix, it is evident that air-void contents at the $N_{initial}$ gyration are statistically different than those observed at N_{design} and $N_{maximum}$, which are statistically the same as one other. This similarity in air-void levels at the higher gyration levels indicates that the mixture had reached its optimum compaction at or prior to N_{design}. The lack of densification at gyrations levels around N_{design} reaffirmed the observation that the Hveem mixture appeared over compacted in the gyratory compactor. Furthermore, Table 10 indicates at all three gyration levels, that the LMLC mixtures statistically do not have the same air-void content as any cores sampled from years 0, 1, and 2.

FMLC Mixtures: Referring to Table 11 which presents mean comparison results for the FMLC mix, it is evident that air-void contents at that the $N_{initial}$ gyration are statistically different than those observed at both N_{design} and $N_{maximum}$ which are not statistically different from each other. This trend which was present in both field and lab mixtures indicates that the compaction of the Hveem mixtures appears to level out somewhere between the $N_{initial}$ and N_{design} gyration levels at which point the mixture begins to exhibit signs of bleeding.

A similar trend of over densification as noted in the field Superpve mix was also present in the Hveem field mixture. Reflux extractions were performed on this field mixture and a comparison of LMLC and FMLC asphalt contents and gradations are shown in Table 12. As before, the reflux results did not confirm the belief that the field mixture contained excessive amounts of asphalt binder or minus No.200 material. Interestingly, the FMLC mixture had an asphalt binder and fine content approximately the same as the laboratory mixture. This difference in compaction properties between the lab and field mixtures with approximately the same aggregate gradation and asphalt binder content again had no logical explanation. However, the reoccurrence of this phenomenon in both the Superpave and Hveem field mixtures strongly points to the likelihood that the field mixing procedures have changed the overall compaction characteristics of the aggregate in some way. Furthermore, because both mixtures were fabricated using the same aggregate source, one can conclude that the change in mixture densification characteristics probably occurred during the mixing procedure at the plant.

Table 11 indicates that at N_{design} and $N_{maximum}$ gyration levels, the FMLC mixtures statistically do not have the same air-void level as any cores sampled from years 0, 1 , and 2. On the other hand cores sampled in year 2 have the same air-voids as the FMLC mixtures compacted at $N_{initial}$.

Cores (FMFC): Reviewing data presented in Table 10, it can be concluded that the cores from years 0 and 1 had statistically the same air-void contents. However, cores sampled at year 2 had statistically significant different air-void levels to those sampled in years 0 and 1. Upon review of NDOT core sampling records, it became evident that year 2 cores were sampled at different locations within the Hveem test section than those taken in years 0 and 1. This change in sampling location may help explain why year 2 cores experienced a rise in air-void content of approximately 2% to those observed in samples from the previous two years as visually shown in Figure 2. One must question the variability observed in these cores and its implications to the overall variability that may be present in the test section as a whole. For the Hveem portion of the test section, this variability in air-void contents appears to be excessively large, thus a field evaluation must be performed to see if actual field performance varies within the boundaries of the test section.

LMLC vs. FMLC Mixtures: Table 13 presents statistical comparisons between LMLC and FMLC Hveem mixtures. This table indicates that air-void contents at each of the gyration levels are statistically different between the two mixes. As with the Superpave mixture, this conclusion indicates that compaction characteristics under identical loading conditions are completely different between LMLC and FMLC mixtures.

Comparison of Superpave and Hveem Cores (FMFC)

Cores at various sampling times from both the Superpave and Hveem mixtures are statistically compared in Table 14. The overall trend indicates that the Hveem samples had statistically significant higher air-voids than those of the Superpave mixtures up to this point in the life of the project. This observation would indicate either: a) the Hveem mixture is more resistant to densification under traffic loading than the Superpave mixture, or b) during the construction of the project, the Superpave mixture was compacted to a lower air-void level then the Hveem.

Plastic Strains Comparison

The second goal of the gyration study was to compare the plastic stain values of the mixtures at the various gyration levels of $N_{initial}$, N_{design} ,and $N_{maximum}$. A test temperature of 47.0 °C was selected for all RSCH testing in this contract.

Table 15 presents a summary of average plastic strains for each mixture tested in the RSCH test in Contract 2751 along with standard deviations and coefficient of variation associated with each test average.

Comparison of RSCH performance was performed in a similar manner to that of air-voids comparison which used matrices to illustrate differences in performance between the various mixes.

Superpave Mixture

Tables 16, 17, and 18 present all statistical comparisons of plastic strain values obtained from the RSCH test for the Superpave LMLC, FMLC, and cores tested in the gyration study.

<u>LMLC Mixtures:</u> Table 16 indicates that for the LMLC mixtures, plastic strains at the $N_{initial}$ gyration level were statistically different and larger than those obtained at N_{design} and $N_{maximum}$ gyrations. Also, there were no statistically significant differences in plastic strains at the N_{design} and $N_{maximum}$ gyration levels. If one considers that the air-void levels presented in the previous section for these gyration levels were statistically different, it could be concluded that once the air-void levels fell below 3 percent, the shear resistance of the LMLC material remained somewhat constant.

Due to technical problems encountered while testing the Superpave cores sampled immediately after construction (yr. = 0), the plastic strain levels could not be used in the statistical comparison. For the LMLC mixture, plastic strains at the $N_{initial}$ gyration level was statistically different than year 1 cores, but statistically the same as year 2 cores. At N_{design} and

$N_{maximum}$ gyration levels, the plastic strains were similar to year 1 cores and different than year 2 cores. Examining Table 15, there appeared to be a significant decrease in the shear resistance of cores sampled in year 1 as compared to those sampled in year 2.

FMLC Mixtures: The same statistical performance observed in the LMLC mixtures also occurred in the FMLC mixtures as shown in Table 17 i.e. the mixtures compacted at $N_{initial}$ show different performance than the mixtures compacted at N_{design} and N_{max}. Due to over densification at the N_{design} and $N_{maximum}$ gyration levels detailed in the air-void comparison section, one would assume that the plastic strain levels between these two levels of compaction would be statistically similar. This presumption was made assuming the relationship between increased stability with reduction in air-void content typically observed in HMA mixtures held true.

For the FMLC mixtures, plastic strains at the $N_{initial}$ gyration level were statistically different than cores sampled in both years 1 and 2. At the N_{design} and $N_{maximum}$ gyration level, performance in the RSCH were statistically the same as cores tested in both years 1 and 2. This conclusion can be verified when observing Figure 1. One should recall that due to extremely low air-voids observed in the FMLC mix, conclusions regarding shear performance of the mixture should be carefully formulated. When reviewing Figure 1, it is evident that at an equal air-void content, the field mix is more resistant to permanent deformation than cores sampled in years 0, 1, and 2.

Cores (FMFC): As previously mentioned, it was observed that plastic strains and air-void levels of cores increased from year 1 to year 2. This phenomenon realistically cannot take place due to densification and subsequent anticipated reduction in air-void contents that occurs in HMA mixtures under traffic loading. Upon investigation of NDOT core sampling records, it was discovered that year 2 cores were sampled approximately 1 mile away from the sampling area used in years 0 and 1. The change in strain level of approximately 1.5% observed between the two locations may be attributed to differences in mixture properties or may be a function of variability in the RSCH test which is more pronounced at higher air-void levels. When comparing cores sampled at years 1 and 2, a statistical difference in shear resistance was observed in the RSCH test as shown in Table 16.

LMLC vs. FMLC Mixtures: Table 18 presents a comparison of plastic strain measurements between LMLC and FMLC mixtures obtained using the RSCH test at the various gyration levels. At all three gyration levels, there appears to be no difference in shear resistance between the LMLC and FMLC mixtures. This is somewhat confusing when Figure 1 is reviewed, which indicates that there is a large difference in strain levels between LMLC and FMLC mixtures at the various gyration levels. As shown in Table 15, there appears to be a large amount of variability among the test specimens associated with both LMLC and FMLC mixtures. With this large amount of variability present in the data, the Welsh comparison method was used to correct the data to account for unequal variance. With little confidence in the data, to be conservative, the mean comparison concluded that there was no difference between the two factors.

Results presented in this section for the Superpave "coarse" mixture illustrates one of the major problems associated with the RSCH test, that being the large amount of variability observed in mixtures with relatively high air-voids.

Hveem Mixture

Tables 19, 20, and 21 present all statistical comparisons of plastic strain values obtained from the RSCH test for the Hveem LMLC, FMLC, and cores tested in the gyration study.

LMLC Mixtures: Table 19 indicates that for the LMLC mixtures, plastic strains at $N_{initial}$ were statistically larger than those obtained at N_{design} and $N_{maximum}$ gyration levels. In addition, this table indicates that there was no statistical difference in shear resistance in the RSCH test between N_{design} and $N_{maximum}$ gyration levels. If one considers that the air-void levels presented in the previous section for these gyration levels were statistically different, it could be concluded that once the air-void levels fell below approximately 2 percent, the shear resistance of the LMLC mixtures remained somewhat constant. The cores sampled in years 0, 1, and 2 performed statistically better than the LMLC mixtures at the $N_{initial}$, N_{design} and $N_{maximum}$ gyration levels.

FMLC Mixtures: As shown in Table 5, air-void levels at the N_{design} and $N_{maximum}$ for the FMLC mixture were 0.280 and 0.03, respectively. Somewhere between these two air-void contents, the mixture appeared to loose stability which was confirmed when considering percent plastic stains were 0.304 and 0.729 percent at N_{design} and $N_{maximum}$ gyrations, respectively. Table 20 indicates that these two strain values are statistically different. The cores sampled in years 0, 1, and 2 performed statistically better than the FMLC mixture at the $N_{initial}$, N_{design} and $N_{maximum}$ gyration levels.

Cores (FMFC): As with the Superpve mixture, the air-void contents in the Hveem mixture increased by approximately 2.4% between years 1 and 2, which realistically could not take place. Upon investigation of NDOT core sampling records, it was discovered that cores at year 2 were taken approximately 2.5 miles away from those sampled in the previous two years. When comparing shear performance, one must keep this difference in sampling locations in mind. Table 20 indicates that plastic strain levels in the cores for all 3 sampling periods were statistically the same, which indicates that even with a 2.4% difference in air-void content, no change in RSCH performance was noted. Based on this observation one could conclude that the Hveem mixtures shear resistance was somewhat insensitive to the change in air-void content.

LMLC vs. FMLC Mixtures: Table 6.21 presents a comparison of plastic strains as measured by the RSCH test between LMLC and FMLC mixtures at the three compaction levels. At the $N_{initial}$ gyration level, it appears to be no difference in shear resistance in the RSCH test. Conversely, the performance at N_{design} and $N_{maximum}$ appears to be significantly different between laboratory and field prepared mixtures. Again, due to the over compaction of the FMLC mixture, differences at the N_{design} and $N_{maximum}$ gyration levels between LMLC mix was expected.

Comparison of Superpave and Hveem Cores (FMFC)

RSCH test results for Hveem and Superpave cores sampled in years 0, 1 and 2 are compared in Table 22. The overall trend indicates that the Hveem samples had statistically significant lower plastic strain values to those of the Superpave mixtures up to this point in the life of the project. This conclusion is surprising when one considers that the Hveem cores on average had 1% to 4% higher air-void contents than the Superpave cores as outlined in Tables 4 and 5.

General Overview of Results

Realizing that the previous sections contain a number of comparisons that can become easily confusing to the reader, this section will attempt to sum up the general trend of the data presented.

1. For both Superpave and Hveem FMLC mixtures, there is an over densification problem in the gyratory compactor.

2. For both Superpave and Hveem mixtures, differences exist between LMLC and FMLC air-void contents when compacted under the same number of gyrations.

3. Care must be taken when reviewing core data due to sampling location differences between years 0 and 1 to year 2 for both Superpave and Hveem mixes.

4. For both Superpave and Hveem mixtures, in most cases the FMLC mixtures have more shear resistance in the RSCH test then the LMLC mixtures.

5. The Superpave mixture has a greater variability among replicates than does the Hveem mixture for LMLC and FMLC materials.

6. In the RSCH test, at equal gyration levels, the Hveem LMLC and FMLC mixtures outperform Superpave LMLC and FMLC mixtures.

7. Up to the present time, Hveem cores are more resistant to the development of plastic strains than those from the Superpave section.

8. Hveem cores and FMLC specimens tested in the RSCH test have completely different permanent deformation characteristics.

At the $N_{initial}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem FMLC - (Plastic Strain = 0.948%)
2. Hveem LMLC - (Plastic Strain = 1.170%)
3. Superpave FMLC - (Plastic Strain = 2.965%)
4. Superpave LMLC - (Plastic Strain = 4.617%)

At the N_{design} compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem FMLC - (Plastic Strain = 0.304%)
2. Hveem LMLC - (Plastic Strain = 0.445%)
3. Superpave FMLC - (Plastic Strain = 0.866%)

4. Superpave LMLC - (Plastic Strain = 2.184%)

At the $N_{maximum}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem LMLC – (Plastic Strain = 0.484%)
2. Hveem FMLC – (Plastic Strain = 0.729%)
3. Superpave FMLC – (Plastic Strain = 0.842%)
4. Superpave LMLC – (Plastic Strain = 1.623%)

The reader must keep in mind that rankings shown above do not account for air-void differences between the various mixtures.

Contract 2827

Tables 23 and 24 summarize volumetric and RSCH results obtained for Superpave and Hveem mixtures tested in the gyration study for contract 2827. Figures 3 and 4 graphically plot percent plastic strain vs. air-voids for LMLC, FMLC and cores for Superpave and Hveem mixtures, respectively. These figures and tables summarize the entire 2827 contract with regards to each mixtures resistance to permanent deformation as evaluated by the RSCH test. The following sections explore Tables 23 and 24 in detail using statistical comparisons to illustrate the major findings.

Air-voids Comparison

As was done for contract 2751, to greatly simplify the comparison process, this section will be divided into a number of subsections.

Superpave Mixture

Tables 25, 26, and 27 present all the statistical comparisons for the Superpave LMLC, FMLC, and cores tested in the gyration study.

LMLC Mixtures: Table 25 indicates that the air-void levels of the LMLC mixture at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ are statistically different which is visually verified when observing Figure 3.

At the $N_{initial}$ gyration level, the air-void contents for the LMLC mix was statistically the same as cores at year 0, but different than cores from year 1. This difference in year 1 core air-void levels is directly related to densification of the mixture during the first year of traffic loading. As expected, this densification resulted in a drop in air-void content of approximately 3.3%.

At the N_{design} and $N_{maximum}$ gyration levels, the LMLC mixture air-void contents were statistically different than cores at year 0 and 1. These results agreed with Superpave methodology that assumes that the air-void content of specimens compacted at N_{design} should be achieved by the cores about 2 to 3 years after initial construction of the project.

<u>FMLC Mixtures:</u> Tables 26 indicates that the air-voids of the FMLC mixtures at $N_{initial}$, N_{design}, and $N_{maximum}$ are statistically different which is visually verified when observing Figure3. At the $N_{initial}$ gyration level, the FMLC mix had statistically the same air-void contents as cores at year 0 but different than cores sampled at year 1. As with the LMLC mixtures, this difference in year 1 cores air-void levels was directly related to densification of the mixture during the first year of traffic loading

At the N_{design} and $N_{maximum}$ gyration levels, the FMLC mixtures air-void contents were statistically different than cores at year 0 and 1.

<u>Cores (FMFC):</u> As shown in Table 23, due to the densification observed in the cores between years 0 and 1, air-void contents were found to be statistically different. This conclusion suggests that a large amount of densification or compaction has taken place under field traffic loading during the first year.

<u>LMLC vs. FMLC Mixtures:</u> Table 27 presents the statistical comparisons between laboratory and field Superpave mixtures. This table indicates that air-void contents at each of the gyration levels are statistically the same between the LMLC and FMLC mixes. By mixtures having no statistical difference, this indicates that both LMLC and FMLC materials have very similar compaction characteristics in the gyratory compactor.

Due to problems associated with the original mix design supplied to NDOT, the decision was made to use solvent extractions and muffle furnace tests performed during the construction of the project to determine the aggregate gradation to be used in the fabrication of laboratory samples. A complete Superpave mixture design was performed on the extracted gradation which resulted in an optimum asphalt content of 5.6% by total weight of mix. The field optimum used during the construction of the project was 5.0% by total with of mix, thus a 0.6% difference in asphalt contents was observed between LMLC and FMLC mixes. With both mixtures having the same gradation, the data in Table 27 show that the 0.6% change in asphalt content did not have a statistically significant effect on the air-void contents between the mixtures compacted in the gyratory compactor. This conclusion violates engineering judgment if one considers that during the mixture design, specimens at 5.0% asphalt binder content had significantly higher air-voids than those at 5.6% (Volume I report). The only possible cause for this discrepancy is that the FMLC mixtures sampled at the time of construction may have had a different gradation than that determined by NDOT extractions. This ideology holds some merit if one recalls that all of the FMLC mixtures sampled at the time of construction were "Bulk Sampled" and were not an average representation of the FMLC material which could differ from the extractions samples.

To explore this hypothesis, reflux extractions were performed on the "Bulk Sampled" FMLC material and a comparison of the two samples is shown in Table 28. These results verified the assumptions that the bulk sampled material had a slightly different gradation than that determined from the extracted samples. The FMLC material had approximately 0.7% more number 200 material which may help explain the reduction in air-voids associated with this mix.

Hveem Mixture

Tables 29, 30, and 31 present all the statistical comparisons for the Hveem LMLC, FMLC, and cores tested in the gyration study.

<u>LMLC Mixtures:</u> Table 29 indicates that air-void of the LMLC mixtures at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ are statistically different which is visually verified when observing Figure 4. Furthermore, the data show that the air-void contents among all gyration levels and cores sampled in years 0 and 1 are statistically different.

<u>FMLC Mixtures:</u> Table 30 indicates that the air-voids of the FMLC mixtures at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ gyration levels are statistically different which is visually verified when observing Figure 4. As with the LMLC mix, the data also show that the air-void contents among all

gyration levels and cores sampled in years 0 and 1 are statistically different.

Cores (FMLC): Similar to the Superpave cores, the Hveem specimens experienced a decrease in air-void contents of approximately 3.3% in the first year of traffic loading. This trend is expected due to densification of the mixture under traffic loads.

LMLC vs. FMLC Mixtures: Table 31 compares air-void contents of LMLC and FMLC mixtures at gyration levels of $N_{initial}$, $N_{design,\ and}$ $N_{maximum}$. The data indicate that the air-void contents at all 3 gyration levels of the FMLC mixtures were statistically higher than those measured in the LMLC mixtures. Reflux extractions were performed on the field mixtures and a comparison of LMLC and FMLC asphalt contents and gradations for the Hveem mixture are shown in Table 32. This comparison indicate that both mixtures have identical asphalt contents, however the field mixture has approximately 2.6% less minus 200 material while the rest of the gradation was remained relatively the same. Due to the significant amount of fines present in the LMLC mix, it makes sense that statistically lower air-voids were present in the gyratory compacted LMLC specimens with all other things being equal.

Comparison of Superpave and Hveem Cores (FMFC)

Cores obtained at various sampling times from both the Superpave and Hveem sections are compared in Table 33. The overall trend indicates that the Superpave cores had statistically higher air-void contents than the Hveem cores up to this point in the life of the project. This observation would indicate either: a) the Superpave mixture is less resistant to densification under traffic loading than the Hveem mixture, or b) during the construction of the project, the Hveem mixture was compacted to a lower air-void level then the Superpave.

Plastic Strains Comparison

The second goal of the gyration study was to compare the plastic stain values at the gyration levels of $N_{initial}$, N_{design} ,and $N_{maximum}$. A test temperature of 49.3 °C was selected using SHRPbind Version 2.0 software, which represented pavement temperature at 50 mm below the surface.

Table 34 presents a summary of the average plastic strains for each mixture tested in the

RSCH test in Contract 2827 along with standard deviations and coefficient of variation. This table illustrates the variability among gyration levels under the RSCH test.

Superpave Mixture

Tables 35, 36, and 37 present all the statistical comparisons for the Superpave LMLC, FMLC, and cores tested in the gyration study.

LMLC Mixtures: Table 35 indicates that the plastic strains of the LMLC mixture at $N_{initial}$ were statistically larger than those obtained at N_{design}, and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference in the plastic strain levels at the N_{design} and $N_{maximum}$ gyration levels. If one considers that the air-void levels presented in the previous section for these gyration levels were statistically different, it could be concluded that once the air-void level falls below approximately 4 percent, changes in plastic strains for the LMLC mixtures were minimal.

Table 35 also indicates that the plastic strains at the $N_{initial}$ gyration level were statistically the same as those measured in cores sampled in years 0 and 1. The plastic strains at the N_{design} and $N_{maximum}$ gyration levels, however, were statistically different than the strains in the cores sampled in years 0 and 1.

FMLC Mixtures: Table 36 indicates that the plastic strains of the FMLC mixture at $N_{initial}$ were statistically larger than those obtained at the N_{design}, and $N_{maximum}$ gyration levels. Even though air-voids between the N_{design} and $N_{maximum}$ gyration levels were statistically different, the RSCH test results for these gyration levels showed no statistical differences.

Table 36 also indicates that the plastic strains at the $N_{initial}$ gyration level were statistically the same as those measured in cores sampled in years 0 and 1. The plastic strains at the N_{design} and $N_{maximum}$ gyration level however, the strains were statistically different than the cores sampled in years 0 and 1. For both LMLC and FMLC mixes, cores sampled in years 0 and 1 appear to have similar performance in the RSCH test to the mix at the $N_{initial}$ gyrations level.

Cores (FMFC): A comparison of plastic strains for the cores sampled in years 0 and 1 indicate that their performance in the RSCH test were statistically the same as shown in Table 35. When considering the drop in air-voids of almost 3.3%, one would conclude that the mixtures performance under the RSCH test is insensitive to large changes in air-void contents. As with contract 2751, the core sampling records were reviewed to ensure that sampling was performed at the same location in years 0 and 1. It was determined that again, cores were sampled in different locations (4 miles apart) within the test section which may help explain how the strain could remain relatively unchanged though the air-void content was reduced by almost 40% from year 0 to year 1.

<u>LMLC vs. FMLC Mixtures:</u> Table 37 presents mean comparisons of plastic strain values between LMLC and FMLC mixes at the various gyration levels. At $N_{initial}$ and N_{design} there appears to be no difference in performance under the RSCH test. Conversely, the performances of the LMLC and FMLC mixes were statistically different at the $N_{maximum}$ gyration level. This difference in RSCH performance observed at the $N_{maximum}$ was most likely a function of the differences in air-voids levels between the LMLC and FMLC mixes as shown in Table 23.

Hveem Mixture

Tables 38, 39, and 40 present all statistical comparisons of plastic strains obtained from the RSCH test for the Superpave LMLC, FMLC, and cores tested in the gyration study.

<u>LMLC Mixtures:</u> Table 38 indicates that plastic strains of the LMLC mixture at $N_{initial}$ were statistically larger than those obtained at the N_{design}, and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference in the plastic strains at N_{design} and $N_{maximum}$. If one considers that the air-void levels presented in the previous section for these gyration levels were statistically different, it could be concluded that once the air-void level fell below 2 percent, changes in the plastic strains of the LMLC mixtures are minimal. At the $N_{maximum}$ gyration level, the lab mixture had approximately 0.03% air-voids, which is an indication of extreme over compaction.

The data in Table 38 also indicate that plastic strains at the $N_{initial}$ gyration level were statistically different than strains in cores at years 0. While the performance of years 0 and 1 cores are statistically the same. The performance of the mixtures at the N_{design} and $N_{maximum}$ gyration levels were statistically different than cores sampled in years 0 and 1.

FMLC Mixtures: All statistical comparisons preformed for the FMLC mixtures are shown in Table 39. The plastic strains measured at the 3 gyration levels were statistically different. This indicates that the FMLC continually became more resistant to shear deformation even when air-void levels fell below 3%. As concluded from Table 39, the $N_{initial}$ gyration level plastic strain values were the same as cores sampled in year 0, however they statistically differ from cores tested in year 2. At both the N_{design} and $N_{maximum}$ gyration levels, the RSCH performance was statistically different from cores in both years 0 and 1

Referring to the data summary shown in Table 24, it can be noted that even though air-voids of the cores fell by approximately 3.4% from year 0 to year 1, there was a statistically significant reduction in the shear resistance of year 1 cores. At the average air-void level of 4.4% that was present in year 1 cores, it is highly unlikely that over compaction would cause the reduction in shear resistance observed between year 0 and year 1 RSCH test results. After an investigation of NDOT core sampling records, its was determined that cores sampled at year 1 were taken from a different part of the test section than those sampled immediately after construction. Making conclusions based on comparison of these cores must be done with caution, as it appears that the mixtures have completely different shear resistance properties.

LMLC vs. FMLC Mixtures: Table 40 presents a comparison of plastic strains as measured by the RSCH test between LMLC and FMLC mixtures at the three compaction levels. At $N_{initial}$ and N_{design} gyration levels, there appears to be a significant difference in the performance of mixtures. Conversely, their shear resistance at the $N_{maximum}$ gyration level were statistically the same which would indicate that at this degree of compaction, the mixtures have attained a relatively constant shear resistant.

Comparison of Superpave and Hveem Cores (FMFC)

RSCH test results for the Hveem and Superpave cores sampled in years 0 and 1 are compared in Table 41. The overall trend indicates that the Superpave cores have statistically significant lower plastic strains than the Hveem mixtures up to this point in the life of the project.

General Overview of Results

Numerous comparisons have been presented which can become easily confusing to the reader. This section will attempt to sum up the general trend of the data presented for contract 2827.

1. For Superpave LMLC and FMLC mixtures, air-void and plastic strains appear to be statistically the same.
2. Care must be taken when reviewing core data due to sampling location differences between years 0 and 1.
3. Superpave cores appear to have greater shear resistance in the RSCH test than the Hveem cores tested up to this point in the life of the project.
4. For both Superpave and Hveem mixtures, in most cases the FMLC mixtures have more shear resistance than the LMLC mixtures.
5. In the RSCH test, at equal gyration levels, the Hveem LMLC mixtures outperform the Superpave LMLC mixtures.
6. In the RSCH test, at equal gyration levels, the Superpave FMLC mixtures outperform the Hveem FMLC mixtures.
7. The Hveem LMLC mixture appears to be "over compacted" at the $N_{maximum}$ gyration level.

At the $N_{initial}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Superpave FMLC - (Plastic Strain = 3.460%)
2. Superpave LMLC - (Plastic Strain = 4.451%)
3. Hveem FMLC - (Plastic Strain = 5.131%)
4. Hveem LMLC - (Plastic Strain = 7.356%)

At the N_{design} compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem LMLC - (Plastic Strain = 0.880%)
2. Superpave FMLC - (Plastic Strain = 1.011%)
3. Superpave LMLC - (Plastic Strain = 1.243%)
4. Hveem FMLC - (Plastic Strain = 1.631%)

At the $N_{maximum}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem LMLC – (Plastic Strain = 0.761%)
2. Superpave FMLC – (Plastic Strain = 0.832%)
3. Hveem FMLC – (Plastic Strain = 0.985%)
4. Superpave LMLC – (Plastic Strain = 1.167%)

In general the rankings indicate that at the higher air-void levels associated with the $N_{initial}$ gyration level, the Hveem mixture performed considerably worse in the RSCH test than did the Superpave mixture. However at the lower air-void levels associated with the N_{design} and $N_{maximum}$ compaction levels, the Hveem and Superpave mixtures performed similarly.

Contract 2880

Tables 42 through 45 summarize the volumetric and RSCH test results obtained for the Superpave and Hveem mixtures using PG 64-22 and AC-20P binders. Figures 5 through 8 present percent plastic strains versus air-voids for LMLC and FMLC Superpave and Hveem mixtures using the PG 64-22 and AC-20P binders.

These figures and tables summarize the entire 2880 contract with regards to each mixtures resistance to permanent deformation as evaluated by the RSCH test. The following sections explore Tables 42 through 45 in details using statistical comparisons to illustrate the major findings.

Due to the nearly unlimited number of possible statistical comparisons associated with this contract, the researchers chose to remain within a mixture type and compare only, LMLC, FMLC, and LMLC vs. FMLC. Future analyses will compare the performance of the different types of mixtures.

Air-voids Comparison

The first goal of the gyration study was to compare air-void contents calculated at the gyration levels of $N_{initial}$, N_{design} ,and $N_{maximum}$. To greatly simplify the comparison process, this section will be divided into a number of subsections.

Superpave PG 64-22 Mixture

Tables 46, 47, and 48 present all the statistical comparisons for the Superpave PG 64-22 LMLC and FMLC material tested in the gyration study.

<u>LMLC Mixtures:</u> Table 46 indicates that the air-voids of the LMLC mixtures at the $N_{initial}$ gyration level were statistically different than those measured at N_{design} and $N_{maximum}$. Furthermore, this table shows that specimens compacted at N_{design} and $N_{maximum}$ had statistically similar air-voids. This reduction in rate of compaction between the N_{design} and $N_{maximum}$ gyration levels would suggest that the mixtures may have reached their compaction limits at these gyration levels.

Reviewing Table 42 and Figure 5, it can be observed that all LMLC specimens compacted to $N_{maximum}$ did not reach the 4% air-void level. This would indicate that samples prepared during the gyration study did not appear to have the same compaction characteristics as the LMLC mixtures prepared during the mix design which reached air-void levels of approximately 2.5% at $N_{maximum}$. The only logical explanation for this behavior was that material changes (ie: stock pile gradings) must have occurred from the time of the original mix design was performed in August to when the project was bulk sampled in September. Table 49 presents sieve analysis results for the rock dust stock stockpile performed in August (original mix design material) and December of 1998 (bulk sampled material). This table indicates that there was approximately a 3.6 % increase in minus number 200 material observed in the rock dust stockpile between the two sampling periods. Using this information with the University of Nevada adhesion correction procedure, it was determined that the adjusted blend used to fabricated all gyration study samples needed significantly less minus 200 material than that used in the original mix design corrected blend. Table 50 presents the difference between the adhesion adjusted combined blends used in August for the original mixture design and that used to fabricate LMLC specimens in the gyration study using the bulk sampled material.

This significant reduction in minus number 200 material used to fabricate the gyration study test specimens may be one of the causes of the excessively high air-void contents at the N_{design}

and $N_{maximum}$ gyration levels observed in the LMLC mix. Moreover, in this "post construction LMLC mix", one makes the assumption that all minus 200 materials adhering to the aggregate is reintroduced into the mixture during the mixing process. If this assumption does not hold true, the "post construction LMLC mix" would have less filler material than the original mix design, thus eluding to the possible reason for the high air-void levels.

<u>FMLC Mixtures:</u> Table 47 indicates that for the FLMC mixtures, air-voids were statistically different at $N_{initial}$, $N_{design,}$ and $N_{maximum}$.

<u>LMLC vs. FMLC Mixtures:</u> Comparing the LMLC and FMLC air-void contents as shown in Table 48, it can be concluded at all 3 gyration levels the LMLC had statistically different air-void contents than observed in the FMLC compacted mixtures. Reflux extractions were performed on the FMLC material and compared the gradations. These tests indicated that both the LMLC and the FMLC mixtures had very similar asphalt contents and gradations, which makes the mean comparison results previously presented somewhat puzzling. One would expect mixtures having similar gradations and asphalt contents to compact to approximately the same level under equal compactive efforts.

It can be stated that the overall trend indicates that in general, the LMLC material has higher air-voids than the FMLC material at an equal compactive effort. However these differences in air-voids may be a function the change in the rock dust stockpiles outlined earlier in this section.

Superpave AC-20P Mixture

Tables 51, 52, and 53 present all the statistical comparisons of air-void contents for the compacted Superpave AC-20P LMLC and FMLC material tested in the gyration study.

<u>LMLC and FMLC Mixtures:</u> Tables 51 and 52 indicate that for both LMLC and FMLC mixtures, air-void levels at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ are statistically different.

<u>LMLC vs. FMLC Mixtures:</u> Comparing the LMLC and FMLC mixtures, it is concluded from Table 53 that at the N_{design} and $N_{maximum}$ gyration levels, the lab and field mixes have statistically equal air-voids. Conversely at $N_{initial}$, the LMLC and FMLC mixtures have statistically different air-voids.

The overall trend indicates again that in general, the LMLC and FMLC materials have equal air-void contents at equal compactive efforts.

Hveem PG 64-22 Mixture

Tables 54, 55, and 56 present all the statistical comparisons for the Hveem PG 64-22 LMLC and FMLC material tested in the gyration study.

LMLC Mixtures: Upon review of Table 54 for the LMLC mixtures, it can be concluded that air-void levels at $N_{initial}$, $N_{design,\ and}$ $N_{maximum}$ are statistically different.

FMLC Mixtures: Table 55 indicates that the air-voids of the FMLC mixtures at $N_{initial}$ are statistically different than those measured at N_{design} and $N_{maximum}$. FMLC mixtures at N_{design} and $N_{maximum}$ have statistically the same air-voids.

LMLC vs. FMLC Mixtures: A comparison of the LMLC and FMLC mixtures in Table 56 showed that at N_{design} and $N_{maximum}$ gyration levels, the two mixtures have statistically different air-voids. Conversely at the $N_{initial}$ gyration level, both mixtures have statistically the same air-voids.

Hveem AC-20P Mixture

Tables 57, 58, and 59 present all statistical comparisons for the Hveem AC-20P LMLC and FMLC material tested in the gyration study.

LMLC and FMLC Mixtures: Tables 57 and 58 indicate that for both LMLC and FMLC materials, air-voids at $N_{initial}$ are statistically different than those measured at N_{design} and $N_{maximum}$ gyration levels. Both LMLC and FMLC mixtures at N_{design} and $N_{maximum}$ have statistically the same air-voids.

LMLC vs. FMLC Mixtures: Comparing the LMLC and FMLC mixtures (Table 59) showed that at all three gyration levels, the LMLC had statistically higher and different air-voids than the FMLC mixtures.

Plastic Strains Comparison

The second goal of the gyration study was to compare the plastic strains from the RSCH test at the gyration levels of $N_{initial}$, N_{design} ,and $N_{maximum}$. A test temperature of 50.0 °C was selected to match the temperature used previously to test WesTrack specimens in the RSCH test.

Table 60 presents a summary of average plastic strains for each mixture tested in the RSCH test in Contract 2880 along with standard deviations and coefficient of variation.

Superpave PG 64-22 Mixture

Tables 61, 62, and 63 present all the statistical comparisons for the Superpave PG 64-22 LMLC and FMLC mixtures tested in the gyration study.

<u>LMLC Mixtures:</u> Table 61 indicates that for the LMLC mixture, plastic strains at $N_{initial}$ were statistically larger than those obtained at the N_{design} and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference in plastic strains at the N_{design} and $N_{maximum}$ gyrations. If one considers that the air-void levels presented in the previous section for these two gyration levels were statistically the same, it make sense that the performance of the mixtures in the RSCH test are also statistically the same.

<u>FMLC Mixtures:</u> Table 62 indicates that for the FMLC mixture, plastic strains at $N_{initial}$ were statistically the same as those obtained at $N_{design,}$ which were both different than strains observed at the $N_{maximum}$ gyrations. As presented in the previous section, air-void contents between $N_{initial}$ and N_{design} differed by approximately 5.8%. It would appear that the PG 64-22 was somewhat insensitive to air-void changes as shown visually in Figure 5, which indicates that the slope or rate of change in plastic strain increase with an air-void increase for this mixture was minimal.

<u>LMLC vs. FMLC Mixtures:</u> Table 63 presents mean comparisons of plastic strains for LMLC and FMLC mixes at the various gyration levels. At $N_{initial}$ compaction level, there appears to be a statistical difference in performance in the RSCH test between the LMLC and FMLC mixtures. Conversely, their performance was statistically the same at the N_{design} and $N_{maximum}$ gyration level

Superpave AC-20P Mixture

Tables 64, 65, and 66 present all statistical comparisons for the Superpave AC-20P LMLC and FMLC mixtures tested in the gyration study.

<u>LMLC Mixtures:</u> Table 64 indicates that for the LMLC mixtures, plastic strains at $N_{initial}$, $N_{design,}$ and $N_{maximum}$ were statistically the same. The air-void levels represented by these respective

gyration levels range from 9.2% down to2.4%. Again, it would appear that the AC-20P mix was somewhat insensitive to air-void changes as shown visually in Figure 6. This figure shows that the slope or rate of change in plastic strain increase with an air-void increase for this mixture was minimal.

FMLC Mixtures: Table 65 indicates that for the LMLC mixture, plastic strains at $N_{initial}$ were statistically larger than those obtained at the N_{design} and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference of the plastic strains at N_{design} and $N_{maximum}$. If one considers that the air-void levels presented at the previous section for these two gyration levels were statistically the same, it makes sense that the RSCH performance was also statistically the same.

LMLC vs. FMLC Mixtures: Table 66 presents mean comparisons of plastic strains between LMLC and FMLC mixes at the various gyration levels. At all three gyration levels, the RSCH shear resistance of the two mixtures is statistically the same between the two mixes.

Hveem PG 64-22 Mixture

Tables 67, 68, and 69 present all statistical comparisons for the Hveem PG 64-22 LMLC and FMLC mixtures tested in the gyration study.

LMLC Mixtures: Table 67 indicates that for the LMLC mixtures, plastic strains at $N_{initial}$ were statistically larger than those obtained at N_{design} and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference in the plastic strain levels at N_{design} and $N_{maximum}$.

FMLC Mixtures: As with the LMLC mixtures, Table 68 indicates that for the FMLC mixtures, plastic strains at $N_{initial}$ were statistically larger than those obtained at the N_{design} and $N_{maximum}$ gyration levels. Again, this table also indicates that there was no significant difference between the plastic strain levels at N_{design} and $N_{maximum}$.

LMLC vs. FMLC Mixtures: Table 69 presents mean comparisons of plastic strains between LMLC and FMLC mixture at the various gyration levels. At all three gyration levels, the RSCH shear resistance of the two mixtures is statistically the same for the LMLC and FMLC mixtures.

Hveem AC-20P Mixture

Tables 70, 71, and 72 present all the statistical comparisons for the Hveem AC-20P LMLC and FMLC mixtures tested in the gyration study.

<u>LMLC Mixtures:</u> Table 70 indicates that for the LMLC mixtures, plastic strains at $N_{initial}$ were statistically larger than those obtained at the N_{design} and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference in performance of the mixtures compacted at N_{design} and $N_{maximum}$ gyration levels

<u>FMLC Mixtures:</u> Table 71 indicates that for the FMLC mixtures, plastic strains at $N_{initial}$ were statistically larger than those obtained at the N_{design} and $N_{maximum}$ gyration levels. Furthermore, there was no significant difference of the plastic strain levels at N_{design} and $N_{maximum}$.

<u>LMLC vs. FMLC Mixtures:</u> Table 72 presents mean comparison of RSCH performance between LMLC and FMLC mixes at the various gyration levels. At all three gyration levels, the RSCH performance of the two mixtures is statistically the same.

General Overview of Results

In general, the following statements can be made regarding data present in the gyration study for contract 2880:

1. For Superpave and Hveem mixtures, the AC-20P mixtures have more resistance to permanent deformation than the PG 64-22 mixtures.

2. Hveem mixtures outperformed the Superpave mixtures in the RSCH test when using both PG64-22 and AC-20P asphalt binders.

3. In general, at equal air-void levels the FMLC mixtures have less resistance to permanent deformations than the LMLC mixtures for all types of mixtures tested in the study. This conclusion is visually verified in Figures 5 through 8.

4. Cores (FMFC) must be tested to complete the gyration study. These results will enable conclusions to be made about actual field performance of the mixtures.

At the $N_{initial}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Superpave AC-20P LMLC - (Plastic Strain = 2.784%)
2. Hveem AC-20P FMLC - (Plastic Strain = 2.947%)
3. Hveem AC-20P LMLC - (Plastic Strain = 2.988%)
4. Superpave PG 64-22 FMLC - (Plastic Strain = 3.891%)
5. Hveem PG 64-22 LMLC - (Plastic Strain = 4.034%)

6. Superpave AC-20P FMLC - (Plastic Strain = 4.354%)
7. Hveem PG 64-22 FMLC - (Plastic Strain = 4.859%)
8. Superpave PG 64-22 LMLC - (Plastic Strain = 8.849%)

At the N_{design} compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem AC-20P LMLC - (Plastic Strain = 0.538%)
2. Hveem AC-20P FMLC - (Plastic Strain = 0.793%)
3. Hveem PG 64-22 FMLC - (Plastic Strain = 0.838%)
4. Hveem PG 64-22 LMLC - (Plastic Strain = 0.966%)
5. Superpave AC-20P LMLC - (Plastic Strain = 1.456%)
6. Superpave AC-20P FMLC - (Plastic Strain = 1.483%)
7. Superpave PG 64-22 FMLC - (Plastic Strain = 2.468%)
8. Superpave PG 64-22 LMLC - (Plastic Strain = 2.523%)

At the $N_{maximum}$ compaction level, the RSCH tests ranked the mixtures from best to worst as follows:

1. Hveem AC-20P LMLC - (Plastic Strain = 0.541%)
2. Hveem PG 64-22 FMLC - (Plastic Strain = 0.541%)
3. Hveem PG 64-22 LMLC - (Plastic Strain = 0.704%)
4. Hveem AC-20P FMLC - (Plastic Strain = 0.728%)
5. Superpave AC-20P LMLC - (Plastic Strain = 1.149%)
6. Superpave AC-20P FMLC - (Plastic Strain = 1.217%)
7. Superpave PG 64-22 FMLC - (Plastic Strain = 1.688%)
8. Superpave PG 64-22 LMLC - (Plastic Strain = 1.802%)

It appears, in general, and based on the above rankings, that at the lower air-voids associated with N_{design} and $N_{maximum}$ gyration levels, the Hveem mixtures outperformed the Superpave mixtures in both the LMLC and FMLC mixes. However at the higher air-voids associated with the $N_{initial}$ compaction levels, the Superpave and Hveem mixtures performed similarly.

CONCLUSIONS

For detailed conclusions regarding analysis performed within individual contracts, the reader is referred to the appropriate sections of this report on contracts 2751, 2827, and 2880.

As observed from testing in all contracts, in general it appears that LMLC and FMLC mixtures perform significantly different in the RSCH test. This difference in performance is at first alarming, however one must keep in mind the fact that no correction was made for air-void differences between samples at the various gyration levels.

In contract 2751 an over densification problem was observed in both Superpave and Hveem FMLC mixtures. Cores taken from the Hveem and Superpave sections, however, do not indicate the presence of over compaction, which is an indicator that the gyratory compactor may not simulate the compaction mechanism that a mixture experiences in the field. It appears that from the limited data produced in this research effort, that the gyratory compacted specimens have more shear resistance in the RSCH test than field core tested to date.

As previously discussed for contracts 2751 and 2827, errors in sampling cores for years 1 and 2 for each respective contract brought up an interesting question. For both contracts, samples in different years were taken in completely different areas within the same test section, and significant differences in air-void content and RSCH performances were observed. If these sections were constructed uniformly, no significant differences should have been present between the various sampling locations within the same test section. The variability in the cores taken from a single test section illustrates a problem, which has plagued the construction industry for years.

Reviewing the RSCH test results, a trend of increased variability in the test results of coarse graded mixtures was noted in all three contracts, which resulted in excessive coefficients of variations (COV). As shown in Tables 15, 34, and 53 the coefficients of variation were upwards of 25% for many of the mixtures tested. If one considers that most newly constructed HMA pavements have air-void contents in the 6-8% range, this put serious doubts on the applicability of the RSCH test for QA/QC testing where repeatability of the test procedures is critical.

For contract 2880, the RSCH test results on the LMLC and FMLC mixtures, indicate that the Hveem designed samples have the most resistance to permanent deformation. Furthermore, the Hveem mixtures manufactured using the AC-20P binder appeared to exhibit the best performance in the RSCH test. Because no cores have been tested from this contract at the present time, it would be premature to make conclusions about the overall performance of the individual test sections on contract 2880. Currently, the researchers are testing cores from the 2880 contract and this report will be updated once the data are available.

REFERENCES

1. Sebaaly, P.E., McNamara, W.M., and Epps, J.A., "Evaluation of Rutting Resistance of Superpave and Hveem Mixtures - Volume I: Introduction and Background," Research Report Number 1393-2, Nevada DOT, Crason City, Nevada, June, 2000.

2. American Association of State Highway and Transportation Officials, "June 1997 Interim Edition - AASHO Provisional Standards," Provisional Standard TP4-93[1], American Association of State Highway and Transportation Officials, Washington D.C, 1994.

3. Sousa, J.B., Tayebali, A., Harvey, J.H, Hendricks, P., and Monismith, C.L., "Sensitivity of Strategic Highway Research Program A-003A Testing Equipment to Mix Design Parameters for Permanent Deformation and Fatigue", Transportation Research Board 1384, Transportation Research Board, Washington D.C., 1993.

4. Hand, A., "Relationship Between Laboratory Measured HMA Material and Mixture Properties and Pavement Performance at WesTrack," Dissertation of Doctor of Philosophy, University of Nevada, Reno, 1998.

Table 1 Gyration Study Test Matrix For Contract 2751.

Mix Type	Binder Type	LMLC			FMLC			FMFC	FMFC	FMFC
		$N_{initial}$	N_{design}	$N_{maximum}$	$N_{initial}$	N_{design}	$N_{maximum}$	Yr. = 0	Yr. = 1	Yr. = 2
Superpave	PG 64-28	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps
Hveem	PG 64-28	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps

Table 2 Gyration Study Test Matrix For Contract 2827.

Mix Type	Binder Type	LMLC			FMLC			FMFC	FMFC
		$N_{initial}$	N_{design}	$N_{maximum}$	$N_{initial}$	N_{design}	$N_{maximum}$	Yr. = 0	Yr. = 1
Superpave	PG 64-34	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps
Hveem	PG 64-34	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps

Table 3 Gyration Study Test Matrix For Contract 2880.

Mix Type	Binder Type	LMLC			FMLC			FMFC
		$N_{initial}$	N_{design}	$N_{maximum}$	$N_{initial}$	N_{design}	$N_{maximum}$	(Cores)
Superpave	PG 64-22	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	N/A
	AC-20P	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	N/A
Hveem	PG 64-22	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	N/A
	AC-20P	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	3 Reps	N/A

Table 4 Contract 2751 Superpave "Coarse" LMLC, FMLC, and Cores Volumetric/ RSCH Test Results.

	LMLC N_{inital}				LMLC N_{design}				LMLC N_{max}				
Sample Number	NI2a	NI2B	Ni6	Average	ND1B	ND2A	ND2B	Average	NM1A	NM1b	NM2A	Average	
BSG	2.232	2.238	2.228	2.233	2.329	2.31	2.315	2.318	2.338	2.343	2.348	2.343	
Rice	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.387	
% Air Voids	6.49	6.24	6.66	6.47	2.43	3.23	3.02	2.89	2.05	1.84	1.63	1.84	
Plastic Strain @ 5000Cycles	5.638	4.792	3.421	4.617	1.557	2.706	2.289	2.184	1.538	1.44	1.89	1.623	

	FMLC N_{inital}				FMLC N_{design}				FMLCN_{max}				
Sample Number	Sa1	Sa2	Sa3	Average	Sa1	Sa2	Sa3	Average	Sa1	Sa2	Sa3	Average	
BSG	2.191	2.187	2.182	2.19	2.365	2.362	2.371	2.366	2.382	2.384	3.379	2.715	
Rice	2.371	2.371	2.371	2.37	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371	
% Air Voids	7.59	7.76	7.97	7.77	0.25	0.38	0.00	0.21	0	0	0	0	
Plastic Strain @ 5000Cycles	3.146	2.961	2.788	2.965	0.964	0.738	0.897	0.866	0.477	1.368	0.680	0.842	

	Cores Yr = 0					Cores Yr =1				Cores Yr =2			
Sample Number	C1	C2	C3	C4	Average	C17	C18	C20	Average	C8	C9	C10	Average
BSG	2.256	2.252	2.241	2.231	2.250	2.3	2.297	2.311	2.303	2.294	2.299	2.292	2.295
Rice	2.371	2.371	2.371	2.371	2.371	2.408	2.408	2.408	2.408	2.401	2.401	2.401	2.401
% Air Voids	4.85	5.02	5.48	5.90	5.12	4.485	4.610	4.028	4.374	4.456	4.248	4.540	4.415
Plastic Strain @ 5000Cycles	N/A	N/A	5.906	N/A	5.906	2.037	1.746	2.559	2.114	3.706	3.803	3.039	3.516

Table 5   Contract 2751 Hveem Type II LMLC, FMLC, and Cores Volumetric/RSCH Test Results.

	LMLC N_{inital}				LMLC N_{design}				LMLC N_{max}			
Sample Number	Ni1	Ni2	Ni4	Average	Nd1	Nd3	Nd4	Average	Nm1	Nm2	Nm3	Average
BSG	2.184	2.174	2.192	2.183	2.360	2.367	2.367	2.365	2.374	2.367	2.362	2.368
Rice	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409
% Air Voids	9.34	9.76	9.01	9.37	2.03	1.74	1.74	1.84	1.45	1.74	1.95	1.72
Plastic Strain @ 5000Cycles	1.279	1.041	1.191	1.170	0.407	0.446	0.483	0.445	0.567	0.434	0.45	0.484

	FMLC N_{inital}				FMLC N_{design}				FMLC N_{max}			
Sample Number	Ni1	Ni2	Ni3	Average	Nd1	Nd3	Nd4	Average	Nm1	Nm2	Nm3	Average
BSG	2.200	2.19	2.176	2.19	2.379	2.379	2.368	2.375	2.38	2.382	2.385	2.382
Rice	2.382	2.382	2.382	2.382	2.382	2.382	2.382	2.382	2.382	2.382	2.382	2.382
% Air Voids	7.64	8.06	8.65	8.12	0.13	0.13	0.59	0.28	0.08	0	0	0.03
Plastic Strain @ 5000Cycles	0.888	1.063	0.894	0.948	0.324	0.325	0.263	0.304	0.818	0.759	0.610	0.729

	Cores Yr = 0				Cores Yr =1				Cores Yr =2			
Sample Number	C7	C8	C11	Average	C1	C3	C4	Average	C2	C3	C4	Average
BSG	2.251	2.252	2.266	2.256	2.267	2.25	2.262	2.260	2.201	2.207	2.205	2.204
Rice	2.382	2.382	2.382	2.382	2.406	2.406	2.406	2.406	2.407	2.407	2.407	2.407
% Air Voids	5.50	5.46	4.87	5.28	5.78	6.48	5.99	6.08	8.56	8.31	8.39	8.420
Plastic Strain @ 5000Cycles	0.242	0.342	0.318	0.301	0.211	0.211	0.229	0.217	0.249	0.238	0.200	0.229

Table 6 Contract 2751 LMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0002 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.0047(d)	0.0001(d)	0.0001(d)	0.0001 (d)
$LMLCN_{max}$	0.0002 (d)	0.0047(d)	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)
Cores Y0	0.0001 (d)	0.0001(d)	0.0001 (d)	**X**	0.1503 (s)	0.2199 (s)
Cores Y1	0.0001 (d)	0.0001(d)	0.0001 (d)	0.1503 (s)	**X**	0.9999 (s)
Cores Y2	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.2199 (s)	0.9999 (s)	**X**

Table 7 Contract 2751 FMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$FMLCN_{inital}$	**X**	0.0001(d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001(d)	**X**	0.9768 (s)	0.0001 (d)	0.0001(d)	0.0001 (d)
$FMLCN_{max}$	0.0001 (d)	0.9768 (s)	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)
Cores Y0	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**	0.1503 (s)	0.2199 (s)
Cores Y1	0.0001 (d)	0.0001(d)	0.0001 (d)	0.1503 (s)	**X**	0.9999 (s)
Cores Y2	0.0001 (d)	0.0052 (d)	0.0001 (d)	0.2199 (s)	0.9999 (s)	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 8 Contract 2751 Superpave "Coarse" Gradation Comparison of LMLC and FMLC Materials.

Asphalt Content by TWM (%)	6.3	5.4
Sieve Size (US)	% Cumulative Passing	
	Laboratory Mix	Field Mix
1"	100.0	100.0
3/4"	100.0	100.0
1/2"	90.0	85.7
3/8"	60.4	57.1
# 4	27.3	30.3
# 8	19.3	22.5
# 16	14.2	16.7
# 30	8.7	11.7
# 50	7.2	7.3
# 100	5.5	4.8
# 200	4.6	3.0
pan	0.0	0.0

Table 9 Contract 2751 LMLC vs. FMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

LMLC $N_{initial}$ vs. FMLC $N_{initial}$	0.0002 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0001 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0001 (d)

Table 10 Contract 2751 LMLC Hveem Type II Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0162 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.9999 (s)	0.0001 (d)	0.0001 (d)	0.0001 (d)
$LMLCN_{max}$	0.0001 (d)	0.9999 (s)	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)
Cores Y0	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**	0.0788 (s)	0.0001 (d)
Cores Y1	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0788 (s)	**X**	0.0001 (d)
Cores Y2	0.0162 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**

Table 11 Contract 2751 FMLC Hveem Type II Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.9993 (s)
$FMLCN_{des}$	0.0001 (d)	**X**	0.9953 (s)	0.0001 (d)	0.0001 (d)	0.0001 (d)
$FMLCN_{max}$	0.0001 (d)	0.9953 (s)	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)
Cores Y0	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**	0.0788 (s)	0.0001 (d)
Cores Y1	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0788 (s)	**X**	0.0001 (d)
Cores Y2	0.9993 (s)	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 12 Contract 2751 Hveem Type II Gradation Comparison of LMLC and FMLC Materials.

Asphalt Content by TWM (%)	5.6	5.7
Sieve Size (US)	% Cumulative Passing	
	Laboratory Mix	Field Mix
1"	100.0	100.0
3/4"	100.0	100.0
1/2"	90.9	90.6
3/8"	76.2	76.0
# 4	53.6	55.9
# 8	37.3	39.4
# 16	26.2	27.5
# 30	19.2	19.7
# 50	14.0	14.5
# 100	10.7	11.2
# 200	8.6	8.9
pan	0.0	0.0

Table 13 Contract 2751 LMLC vs. FMLC Hveem Type II Mix Air Void Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC i_{nitial}	0.0004 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0001 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0001 (d)

Table 14 Contract 2751 Superpave "Coarse" and Hveem Type II Core Air Void Mean Comparison Results.

Core	SPYO	SPY1	SPY2	HVY0	HVY1	HVY2
SPYO	**X**	0.1503 (s)	0.2199 (s)	0.9999 (s)	0.0133 (d)	0.0001 (d)
SPY1	0.1503 (s)	**X**	0.9999 (s)	0.0289 (d)	0.0001 (d)	0.0001 (d)
SPY2	0.2199 (s)	0.9999 (s)	**X**	0.0466 (d)	0.0093 (d)	0.0072 (d)
HVY0	0.9999 (s)	0.0289 (d)	0.0466 (d)	**X**	0.0788 (s)	0.0001 (d)
HVY1	0.0133 (d)	0.0001 (d)	0.0093 (d)	0.0788 (s)	**X**	0.0001 (d)
HVY2	0.0001 (d)	0.0001 (d)	0.0072 (d)	0.0001 (d)	0.0001 (d)	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 15   Contract 2751 Summary of RSCH Test Results.

Mixture Type	Gyration	Average Plastic Strain (%)	St. Dev.	COV
Superpave - LMLC	$N_{initial}$	4.617	1.119	24.2
	N_{design}	2.184	0.582	26.6
	$N_{maximum}$	1.623	0.237	14.4
Superpave - FMLC	$N_{initial}$	2.965	0.179	6.0
	N_{design}	0.866	0.116	13.4
	$N_{maximum}$	0.842	0.467	55.5
Hveem - LMLC	$N_{initial}$	1.170	0.120	10.3
	N_{design}	0.445	0.038	8.5
	$N_{maximum}$	0.484	0.073	15.0
Hveem - FMLC	$N_{initial}$	0.948	0.099	10.5
	N_{design}	0.304	0.036	11.7
	$N_{maximum}$	0.729	0.107	14.7
SP Cores - Yr. = 0	N/A	5.906	N/A	N/A
SP Cores - Yr. = 1	N/A	2.114	0.412	19.5
SP Cores - Yr. = 2	N/A	3.516	0.416	11.8
HV Cores - Yr. = 0	N/A	0.301	0.052	17.4
HV Cores - Yr. = 1	N/A	0.217	0.010	4.8
HV Cores - Yr. = 2	N/A	0.229	0.026	11.2

Table 16 Contract 2751 LMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$LMLCN_{inital}$	**X**	0.0442 (d)	0.0385 (d)	*	0.052 (d)	0.2243 (s)
$LMLCN_{des}$	0.0442 (d)	**X**	0.231 (d)	*	0.8732 (s)	0.037 (d)
$LMLCN_{max}$	0.0385 (d)	0.231 (d)	**X**	*	0.1656 (s)	0.0053 (d)
Cores Y0	*	*	*	**X**	*	*
Cores Y1	0.047	0.8732 (s)	0.1656 (s)	*	**X**	0.0141 (d)
Cores Y2	0.2243 (s)	0.037 (d)	0.0053 (d)	*	0.0141 (d)	**X**

Table 17 Contract 2751 FMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$FMLCN_{inital}$	**X**	0.002 (d)	0.0086 (d)	*	0.0531 (s)	0.1351 (s)
$FMLCN_{des}$	0.002 (d)	**X**	0.9365 (s)	*	0.0272 (d)	0.0052 (d)
$FMLCN_{max}$	0.0086 (d)	0.9365 (s)	**X**	*	0.0247 (d)	0.0019 (d)
Cores Y0	*	*	*	**X**	*	*
Cores Y1	0.0531 (s)	0.0272 (d)	0.0247 (d)	*	**X**	0.0141 (d)
Cores Y2	0.1351 (s)	0.0052 (d)	0.0019 (d)	*	0.0141 (d)	**X**

Table 18 Contract 2751 LMLC vs. FMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC Ni_{nitial}	0.1243 (s)
LMLC N_{des} vs. FMLC N_{des}	0.0562 (s)
LMLC N_{max} vs. FMLC N_{max}	0.0825 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 19 Contract 2751 LMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$LMLCN_{inital}$	**X**	0.0053 (d)	0.0024 (d)	0.0022 (d)	0.005 (d)	0.004 (d)
$LMLCN_{des}$	0.0053 (d)	**X**	0.4768 (s)	0.0211 (d)	0.006 (d)	0.0021 (d)
$LMLCN_{max}$	0.0024 (d)	0.4768 (s)	**X**	0.0281 (d)	0.022 (d)	0.0172 (d)
Cores Y0	0.0022 (d)	0.0211 (d)	0.0281 (d)	**X**	0.1037 (s)	0.1252 (s)
Cores Y1	0.005 (d)	0.006 (d)	0.022 (d)	0.1037 (s)	**X**	0.5147 (s)
Cores Y2	0.004 (d)	0.0021 (d)	0.0172 (d)	0.1252 (s)	0.5147 (s)	**X**

Table 20 Contract 2751 FMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1	Cores Y2
$FMLCN_{inital}$	**X**	0.0039 (d)	0.0604 (s)	0.0021 (d)	0.0057 (d)	0.0041 (d)
$FMLCN_{des}$	0.0039 (d)	**X**	0.0135 (d)	0.9321 (s)	0.0422 (d)	0.0465 (d)
$FMLCN_{max}$	0.0604 (s)	0.0135 (d)	**X**	0.0093 (d)	0.0062 (d)	0.0071 (d)
Cores Y0	0.0021 (d)	0.9321 (s)	0.0093 (d)	**X**	0.1037 (s)	0.1252 (s)
Cores Y1	0.0057 (d)	0.0422 (d)	0.0062 (d)	0.1037 (s)	**X**	0.5147 (s)
Cores Y2	0.0041 (d)	0.0465 (d)	0.0071 (d)	0.1252 (s)	0.5147 (s)	**X**

Table 21 Contract 2751 LMLC vs. FMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC Ni_{nitial}	0.0716 (s)
LMLC N_{des} vs. FMLC N_{des}	0.0093 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0368 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 22 Contract 2751 Superpave "Coarse" and Hveem Type II Core Plastic Strain Mean Comparison Results.

	SPYO	SPY1	SPY2	HVY0	HVY1	HVY2
SPYO	**X**	*	*	*	*	*
SPY1	*	**X**	0.0141 (d)	0.0156 (d)	0.0153 (d)	0.0152 (d)
SPY2	*	0.0141 (d)	**X**	0.005 (d)	0.0093 (d)	0.0072 (d)
HVY0	*	0.0156 (d)	0.005 (d)	**X**	0.1037 (s)	0.1252 (s)
HVY1	*	0.0153 (d)	0.0093 (d)	0.1037 (s)	**X**	0.5147 (s)
HVY2	*	0.0152 (d)	0.0072 (d)	0.1252 (s)	0.5147 (s)	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 23 Contract 2827 Suprepave "Coarse" LMLC, FMLC, and Cores Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni1	Ni2	Ni4	Average	Nd1	Nd2	Nd3	Average	Nm2	Nm3	Nm4	Average
BSG	2.159	2.161	2.164	2.161	2.326	2.309	2.323	2.319	2.352	2.349	2.345	2.349
Rice	2.412	2.412	2.412	2.412	2.412	2.412	2.412	2.412	2.412	2.412	2.412	2.412
% Air Voids	10.49	10.41	10.28	10.39	3.57	4.27	3.69	3.84	2.49	2.61	2.78	2.63
Plastic Strain @ 5000Cycles	5.722	4.126	3.504	4.451	1.186	1.52	1.024	1.243	1.058	1.289	1.155	1.167

	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni1a	Ni1b	Ni2a	Average	Nd1a	Nd1b	Nd2a	Average	Nm1b	Nm2a	Nm2b	Average
BSG	2.178	2.172	2.182	2.177	2.346	2.336	2.338	2.340	2.380	2.379	2.356	2.372
Rice	2.417	2.417	2.417	2.417	2.417	2.417	2.417	2.417	2.417	2.417	2.417	2.417
% Air Voids	9.89	10.14	9.72	9.92	2.94	3.35	3.27	3.19	1.53	1.57	2.52	1.88
Plastic Strain @ 5000Cycles	3.241	4.018	3.121	3.460	0.940	0.925	1.168	1.011	0.806	0.946	0.744	0.832

	Cores Yr = 0				Cores Yr =1				Cores Yr =2
Sample Number	C15	C16	C19	Average	C10	C11	C12	Average	
BSG	2.203	2.203	2.196	2.201	2.274	2.273	2.269	2.272	
Rice	2.420	2.420	2.420	2.42	2.411	2.411	2.411	2.411	
% Air Voids	8.97	8.97	9.26	9.06	5.68	5.72	5.89	5.77	
Plastic Strain @ 5000Cycles	2.539	3.003	3.303	2.948	3.486	2.213	2.892	2.864	

Table 24   Contract 2827 Hveem Type II LMLC, FMLC, and Cores Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni1	Ni2	Ni3	Average	Nd1	Nd2	Nd4	Average	Nm2	Nm3	Nm4	Average
BSG	2.142	2.146	2.167	2.152	2.321	2.331	2.323	2.325	2.369	2.371	2.379	2.373
Rice	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371	2.371
% Air Voids	9.66	9.49	8.60	9.25	2.11	1.69	2.02	1.94	0.08	0.00	0.00	0.03
Plastic Strain @ 5000Cycles	6.546	7.673	7.85	7.356	0.999	0.825	0.816	0.880	0.554	0.815	0.914	0.761
	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni1	Ni2	Ni3	Average	Nd1	Nd2	Nd4	Average	Nm4	Nm2	Nm3	Average
BSG	2.060	2.062	2.08	2.067	2.274	2.275	2.265	2.271	2.300	2.311	2.295	2.302
Rice	2.348	2.348	2.348	2.348	2.348	2.348	2.348	2.348	2.348	2.348	2.348	2.348
% Air Voids	12.27	12.18	11.41	11.95	3.15	3.11	3.53	3.27	2.04	1.58	2.26	1.96
Plastic Strain @ 5000Cycles	6.027	5.643	3.724	5.131	1.732	1.383	1.778	1.631	1.176	0.793	0.985	0.985
	Cores Yr = 0				Cores Yr =1				Cores Yr =2			
Sample Number	C2	C3	C4	Average	C1	C4	C5	Average				
BSG	2.177	2.165	2.159	2.167	2.268	2.260	2.263	2.264				
Rice	2.348	2.348	2.348	2.348	2.367	2.367	2.367	2.367				
% Air Voids	7.28	7.79	8.05	7.71	4.18	4.52	4.39	4.37				
Plastic Strain @ 5000Cycles	5.01	3.396	5.785	4.730	8.053	10.834	7.047	8.645				

Table 25 Contract 2827 LMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)	0.1402 (s)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.0035 (d)	0.0001 (d)	0.0001 (d)
$LMLCN_{max}$	0.0001 (d)	0.0035 (d)	**X**	0.0011 (d)	0.0001(d)
Cores Y0	0.1402 (s)	0.0001 (d)	0.0011 (d)	**X**	0.0001 (d)
Cores Y1	0.0001 (d)	0.0001 (d)	0.0001(d)	0.0001 (d)	**X**

Table 26 Contract 2827 FMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)	0.1202 (s)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)
$FMLCN_{max}$	0.0001 (d)	0.0001 (d)	**X**	0.0001 (d)	0.0001 (d)
Cores Y0	0.1202 (s)	0.0001 (d)	0.0001 (d)	**X**	0.0001 (d)
Cores Y1	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**

Table 27 Contract 2827 LMLC vs. FMLC Superpave "Coarse" Mix Air Void Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC Ni_{nitial}	0.8752 (s)
LMLC N_{des} vs. FMLC N_{des}	0.456 (s)
LMLC N_{max} vs. FMLC N_{max}	0.2507 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 28 Contract 2827 Superpave "Coarse" Gradation Comparison of LMLC and FMLC Materials.

Asphalt Content by TWM (%)	5.6	5.0
Sieve Size (US)	% Cumulative Passing	
	Laboratory Mix	Field Mix
1"	100.0	100.0
3/4"	98.8	98.6
1/2"	76.8	76.5
3/8"	56.8	57.4
# 4	37.6	37.3
# 8	24.1	25.1
# 16	15.9	16.3
# 30	10.7	11.0
# 50	8.0	8.5
# 100	6.1	6.9
# 200	4.8	5.5
pan	0.0	0.0

Table 29 Contract 2827 LMLC Hveem Type II Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1
$LMLCN_{inital}$	**X**	0.0001(d)	0.0001(d)	0.0001(d)	0.0001(d)
$LMLCN_{des}$	0.0001(d)	**X**	0.0001(d)	0.0001(d)	0.0001(d)
$LMLCN_{max}$	0.0001(d)	0.0001(d)	**X**	0.0001(d)	0.0001(d)
Cores Y0	0.0001(d)	0.0001(d)	0.0001(d)	**X**	0.0001(d)
Cores Y1	0.0001(d)	0.0001(d)	0.0001(d)	0.0001(d)	**X**

Table 30 Contract 2827 FMLC Hvem Type II Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.0013 (d)	0.0001 (d)	0.0121 (d)
$FMLCN_{max}$	0.0001 (d)	0.0013 (d)	**X**	0.0001 (d)	0.0001 (d)
Cores Y0	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**	0.0001 (d)
Cores Y1	0.0001 (d)	0.0121 (d)	0.0001 (d)	0.0001 (d)	**X**

Table 31 Contract 2827 LMLC vs. FMLC Hveem Type II Mix Air Void Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC i_{nitial}	0.0001 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0001 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0001 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 32 Contract 2827 Hveem Type II Gradation Comparison of LMLC and FMLC Materials.

Asphalt Content by TWM (%)	5.6	5.7
Sieve Size (US)	% Cumulative Passing	
	Laboratory Mix	Field Mix
1"	100.0	100.0
3/4"	98.7	98.8
1/2"	85.1	88.3
3/8"	74.6	79.2
# 4	62.4	65.6
# 8	40.3	41.7
# 16	24.4	23.4
# 30	16.1	13.1
# 50	11.3	8.6
# 100	8.8	6.2
# 200	7.0	4.4
pan	0.0	0.0

Table 33 Contract 2827 Superpave "Coarse" and Hveem Type II Cores Air Void Mean Comparison Results.

	SPYO	SPY1	HVY0	HVY1
SPYO	**X**	0.0001 (d)	0.0007 (d)	0.0001 (d)
SPY1	0.0001 (d)	**X**	0.0001 (d)	0.0001 (d)
HVY0	0.0007 (d)	0.0001 (d)	**X**	0.0001 (d)
HVY1	0.0001 (d)	0.0001 (d)	0.0001 (d)	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 34 Contract 2827 Summary of RSCH Test Results.

Mixture Type	Gyration	Average Plastic Strain (%)	St. Dev.	COV
Superpave - LMLC	$N_{initial}$	4.451	1.144	25.7
	N_{design}	1.243	0.253	20.3
	$N_{maximum}$	1.167	0.116	9.9
Superpave - FMLC	$N_{initial}$	3.460	0.487	14.1
	N_{design}	1.011	0.136	13.5
	$N_{maximum}$	0.832	0.103	12.5
Hveem - LMLC	$N_{initial}$	7.356	0.707	9.6
	N_{design}	0.880	0.103	11.7
	$N_{maximum}$	0.761	0.186	24.4
Hveem - FMLC	$N_{initial}$	5.131	1.234	24.0
	N_{design}	1.631	0.216	13.2
	$N_{maximum}$	0.985	0.192	19.4
SP Cores - Yr. = 0	N/A	2.948	0.384	13.1
SP Cores - Yr. = 1	N/A	2.864	0.384	14.5
HV Cores - Yr. = 0	N/A	4.730	1.219	25.8
HV Cores - Yr. = 1	N/A	8.645	1.962	22.7

Table 35 Contract 2827 LMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1
$LMLCN_{inital}$	**X**	0.0347 (d)	0.037 (d)	0.1402 (s)	0.1229 (s)
$LMLCN_{des}$	0.0347 (d)	**X**	0.6705 (s)	0.0049 (d)	0.0341 (d)
$LMLCN_{max}$	0.037 (d)	0.6705 (s)	**X**	0.0101 (d)	0.0401 (d)
Cores Y0	0.1402 (s)	0.0049 (d)	0.0101 (d)	**X**	0.8854 (s)
Cores Y1	0.1229 (s)	0.0341 (d)	0.0401 (d)	0.8854 (s)	**X**

Table 36 Contract 2827 FMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1
$FMLCN_{inital}$	**X**	0.0089 (d)	0.0087 (d)	0.2302 (s)	0.2715 (s)
$FMLCN_{des}$	0.0089 (d)	**X**	0.1492 (s)	0.0072 (d)	0.00325 (d)
$FMLCN_{max}$	0.0087 (d)	0.1492 (s)	**X**	0.0075 (d)	0.0286 (d)
Cores Y0	0.2302 (s)	0.0072 (d)	0.0075 (d)	**X**	0.8854 (d)
Cores Y1	0.2715 (s)	0.00325 (d)	0.0286 (d)	0.8854 (d)	**X**

Table 37 Contract 2827 LMLC vs. FMLC Superpave "Coarse" Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC Ni_{nitial}	0.2707 (s)
LMLC N_{des} vs. FMLC N_{des}	0.255 (s)
LMLC N_{max} vs. FMLC N_{max}	0.0202 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 38 Contract 2827 LMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$	Cores Y0	Cores Y1
$LMLCN_{inital}$	**X**	0.0034 (d)	0.0031 (d)	0.0439 (d)	0.3227 (s)
$LMLCN_{des}$	0.0034 (d)	**X**	0.4014 (s)	0.031 (d)	0.0186 (d)
$LMLCN_{max}$	0.0031 (d)	0.4014 (s)	**X**	0.0309 (d)	0.0185 (d)
Cores Y0	0.0439 (d)	0.031 (d)	0.0309 (d)	**X**	0.0449 (d)
Cores Y1	0.3227 (s)	0.0186 (d)	0.0185 (d)	0.0449 (d)	**X**

Table 39 Contract 2827 FMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$	Cores Y0	Cores Y1
$FMLCN_{inital}$	**X**	0.0354 (d)	0.0259 (d)	0.7093 (s)	0.0697 (s)
$FMLCN_{des}$	0.0354 (d)	**X**	0.0184 (d)	0.0441 (d)	0.024 (d)
$FMLCN_{max}$	0.0259 (d)	0.0184 (d)	**X**	0.0309 (d)	0.0203 (d)
Cores Y0	0.7093 (s)	0.0441 (d)	0.0309 (d)	**X**	0.0449 (d)
Cores Y1	0.0697 (s)	0.024 (d)	0.0203 (d)	0.0449 (d)	**X**

Table 40 Contract 2827 LMLC vs. FMLC Hveem Type II Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{nitial} vs. FMLC i_{nitial}	0.0465 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0137 (d)
LMLC N_{max} vs. FMLC N_{max}	0.2204 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 41 Contract 2827 Superpave "Coarse" and Hveem Type II Core Plastic Strain Mean Comparison Results.

	SPYO	SPY1	HVY0	HVY1
SPYO	**X**	0.8854 (s)	0.0425 (d)	0.0297 (d)
SPY1	0.8854 (s)	**X**	0.0997 (s)	0.0237 (d)
HVY0	0.0425 (d)	0.0997 (s)	**X**	0.0449 (d)
HVY1	0.0297 (d)	0.0237 (d)	0.0449	**X**

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 42   Contract 2880 Superpave PG 64-22 LMLC amd FMLC Mix Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni2	Ni3	Ni4	Average	Nd1	Nd7	Nd8	Average	Nm2	Nm3	Nm8	Average
BSG	2.195	2.187	2.201	2.194	2.282	2.298	2.287	2.289	2.301	2.311	2.305	2.306
Rice	2.419	2.419	2.419	2.419	2.419	2.419	2.419	2.419	2.419	2.419	2.419	2.419
% Air Voids	9.26	9.59	9.01	9.29	5.66	5.00	5.46	5.37	4.88	4.46	4.71	4.69
Plastic Strain @ 5000Cycles	8.395	9.540	8.611	8.849	3.136	2.155	2.278	2.523	1.908	1.46	2.039	1.802

	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni1	Ni3	Ni4	Average	Nd2	Nd3	Nd4	Average	Nm1	Nm2	Nm4	Average
BSG	2.185	2.200	2.190	2.192	2.345	2.338	2.327	2.337	2.372	2.372	2.381	2.375
Rice	2.445	2.445	2.445	2.45	2.445	2.445	2.445	2.445	2.445	2.445	2.445	2.445
% Air Voids	10.63	10.02	10.43	10.36	4.09	4.38	4.83	4.43	2.99	2.99	2.62	2.86
Plastic Strain @ 5000Cycles	2.852	4.032	4.788	3.891	2.829	2.106	2.454	2.463	1.476	1.847	1.742	1.688

Table 43 Contract 2880 Superpave AC-20P LMLC and FMLC Mix Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni2	Ni3	Ni4	Average	Nd1	Nd6	Nd7	Average	Nm1	Nm3	Nm4	Average
BSG	2.194	2.174	2.193	2.187	2.291	2.295	2.303	2.296	2.352	2.351	2.352	2.352
Rice	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409	2.409
% Air Voids	8.92	9.76	8.97	9.22	4.90	4.73	4.40	4.68	2.37	2.41	2.37	2.38
Plastic Strain @ 5000Cycles	3.689	2.01	2.653	2.784	1.448	1.642	1.278	1.456	0.812	1.259	1.376	1.149
	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni2	Ni3	Ni4	Average	Nd1	Nd2	Nd3	Average	Nm1	Nm2	Nm4	Average
BSG	2.186	2.191	2.190	2.189	2.348	2.329	2.342	2.340	2.371	2.351	2.363	2.362
Rice	2.436	2.436	2.436	2.44	2.436	2.436	2.436	2.436	2.436	2.436	2.436	2.436
% Air Voids	10.26	10.06	10.10	10.14	3.61	4.39	3.86	3.95	2.67	3.49	3.00	3.05
Plastic Strain @ 5000Cycles	4.342	4.486	4.234	4.354	1.314	1.673	1.462	1.483	0.881	1.467	1.303	1.217

Table 44 Contract 2880 Hveem PG 64-22 LMLC and FMLC Mix Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni3	Ni4	Ni6	Average	Nd2	Nd5	Nd6	Average	Nm2	Nm5	Nm6	Average
BSG	2.198	2.179	2.192	2.190	2.337	2.320	2.320	2.326	2.351	2.345	2.353	2.350
Rice	2.464	2.464	2.464	2.464	2.464	2.464	2.464	2.464	2.464	2.464	2.464	2.464
% Air Voids	10.80	11.57	11.04	11.13	5.15	5.84	5.84	5.61	4.59	4.83	4.50	4.64
Plastic Strain @ 5000Cycles	4.098	5.098	2.905	4.034	0.832	1.07	0.997	0.966	0.622	0.834	0.657	0.704

	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni1	Ni2	Ni3	Average	Nd1	Nd3	Nd4	Average	Nm2	Nm3	Nm4	Average
BSG	2.218	2.2	2.213	2.210	2.375	2.383	2.374	2.377	2.399	2.397	2.394	2.397
Rice	2.487	2.487	2.487	2.49	2.487	2.487	2.487	2.487	2.487	2.487	2.487	2.487
% Air Voids	10.82	11.54	11.02	11.12	4.50	4.18	4.54	4.41	3.54	3.62	3.74	3.63
Plastic Strain @ 5000Cycles	5.191	4.402	4.984	4.859	0.968	0.606	0.939	0.838	0.516	0.551	0.557	0.541

Table 45 Contract 2880 Hveem AC-20P LMLC and FMLC Mix Volumetric/ RSCH Test Results.

	$LMLCN_{inital}$				$LMLCN_{design}$				$LMLCN_{max}$			
Sample Number	Ni4	Ni5	Ni6	Average	Nd1	Nd2	Nd3	Average	Nm4	Nm5	Nm6	Average
BSG	2.18	2.191	2.185	2.185	2.369	2.372	2.369	2.370	2.386	2.373	2.373	2.377
Rice	2.462	2.462	2.462	2.462	2.462	2.462	2.462	2.462	2.462	2.462	2.462	2.462
% Air Voids	11.45	11.01	11.25	11.24	3.78	3.66	3.78	3.74	3.09	3.61	3.61	3.44
Plastic Strain @ 5000Cycles	2.091	4.036	2.836	2.988	0.537	0.509	0.569	0.538	0.66	0.442	0.521	0.541

	$FMLCN_{inital}$				$FMLCN_{design}$				$FMLCN_{max}$			
Sample Number	Ni1	Ni2	Ni4	Average	Nd1	Nd2	Nd3	Average	Nm1	Nm2	Nm3	Average
BSG	2.226	2.237	2.230	2.231	2.404	2.395	2.403	2.401	2.420	2.428	2.414	2.421
Rice	2.466	2.466	2.466	2.47	2.466	2.466	2.466	2.466	2.466	2.466	2.466	2.466
% Air Voids	9.73	9.29	9.57	9.53	2.51	2.88	2.55	2.65	1.87	1.54	2.11	1.84
Plastic Strain @ 5000Cycles	3.219	2.825	2.797	2.947	0.638	0.977	0.765	0.793	0.590	0.774	0.819	0.728

Table 46 Contract 2880 Superpave PG 64-22 LMLC Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.3744 (s)
$LMLCN_{max}$	0.0001 (d)	0.3744 (s)	**X**

Table 47 Contract 2880 Superpave PG 64-22 FMLC Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.0001 (d)
$FMLCN_{max}$	0.0001 (d)	0.0001 (d)	**X**

Table 48 Contract 2880 Superpave PG 64-22 LMLC vs. FMLC Mix Air Void Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.0068 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0348 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0001 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 49 Comparison of Rock Dust Stock Pile Gradations - Pre vs. Post Construction Sampled Material.

Sieve Size (US)	Cumulative Percent Passing		% Difference
	Original Mix Design	Bulk Sampled Material	
1"	100.0	100.0	0.0
3/4"	100.0	90.1	9.9
1/2"	100.0	100.0	0.0
3/8"	100.0	100.0	0.0
#4	98.2	99.0	-0.8
#8	69.1	74.5	-5.4
#16	44.4	49.5	-5.1
#30	30.4	34.9	-4.5
#50	22.5	26.6	-4.1
#100	17.6	21.4	-3.8
#200	14.2	17.8	-3.6
Pan	0.0	0.0	0.0

Table 50 Comparison of Adhesion Corrected Combined Gradations - Pre vs. Post Construction Sampled Material.

Sieve Size (US)	Cumulative Percent Passing		% Difference
	Original Mix Design	Bulk Sampled Material	
1"	100.0	100.0	0.0
3/4"	99.6	99.5	0.1
1/2"	83.2	84.6	-1.4
3/8"	69.5	70.0	-0.5
#4	38.8	38.2	0.6
#8	23.1	23.0	0.1
#16	14.6	14.0	0.6
#30	9.6	8.8	0.8
#50	6.4	5.5	0.9
#100	4.3	2.8	1.5
#200	2.8	1.4	1.4
Pan	0.0	0.0	0.0

Table 51 Contract 2880 Superpave AC-20P LMLC Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.0001 (d)
$LMLCN_{max}$	0.0001 (d)	0.0001 (d)	**X**

Table 52 Contract 2880 Superpave AC-20P FMLC Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.0445 (d)
$FMLCN_{max}$	0.0001 (d)	0.0445 (d)	**X**

Table 53 Contract 2880 Superpave AC-20P LMLC vs. FMLC Mix Air Void Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.0421 (d)
LMLC N_{des} vs. FMLC N_{des}	0.2949 (s)
LMLC N_{max} vs. FMLC N_{max}	0.432 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 54 Contract 2880 Hveem PG 64-22 LMLC Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.0244 (d)
$LMLCN_{max}$	0.0001 (d)	0.0244 (d)	**X**

Table 55 Contract 2880 Hveem PG 64-22 FMLC Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.1943 (s)
$FMLCN_{max}$	0.0001 (d)	0.1943 (s)	**X**

Table 56 Contract 2880 Hveem PG 64-22 LMLC vs. FMLC Mix Air Void Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.9999 (s)
LMLC N_{des} vs. FMLC N_{des}	0.0012 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0157 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 57 Contract 2880 Hveem AC-20P LMLC Mix Air Void Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$LMLCN_{des}$	0.0001 (d)	**X**	0.9997 (s)
$LMLCN_{max}$	0.0001 (d)	0.9997 (s)	**X**

Table 58 Contract 2880 Hveem AC-20P FMLC Mix Air Void Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0001 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.1326 (s)
$FMLCN_{max}$	0.0001 (d)	0.1326 (s)	**X**

Table 59 Contract 2880 Hveem AC-20P LMLC vs. FMLC Mix Air Void Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.0001 (d)
LMLC N_{des} vs. FMLC N_{des}	0.0054 (d)
LMLC N_{max} vs. FMLC N_{max}	0.0001 (d)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 60 Contract 2880 Summary of RSCH Test Results.

Mixture Type	Gyration	Average Plastic Strain (%)	St. Dev.	COV
Superpave PG 64-22 - LMLC	$N_{initial}$	8.849	0.608	6.9
	N_{design}	2.523	0.534	21.2
	$N_{maximum}$	1.802	0.304	16.8
Superpave PG 64-22 - FMLC	$N_{initial}$	3.891	0.976	25.1
	N_{design}	2.463	0.362	14.7
	$N_{maximum}$	1.688	0.191	11.3
Superpave AC-20P - LMLC	$N_{initial}$	2.784	0.847	30.4
	N_{design}	1.456	0.182	12.5
	$N_{maximum}$	1.149	0.298	25.9
Superpave AC-20P - FMLC	$N_{initial}$	4.354	0.126	2.9
	N_{design}	1.483	0.180	12.2
	$N_{maximum}$	1.217	0.302	24.8
Hveem PG 64-22 - LMLC	$N_{initial}$	4.034	1.098	27.2
	N_{design}	0.966	0.122	12.6
	$N_{maximum}$	0.704	0.114	16.1
Hveem PG 64-22 - FMLC	$N_{initial}$	4.859	0.409	8.4
	N_{design}	0.838	0.201	24.0
	$N_{maximum}$	0.541	0.022	4.1
Hveem AC-20P - LMLC	$N_{initial}$	2.988	0.981	32.8
	N_{design}	0.530	0.030	5.6
	$N_{maximum}$	0.541	0.110	20.4
Hveem AC-20P - FMLC	$N_{initial}$	2.947	0.236	8.0
	N_{design}	0.793	0.171	21.6
	$N_{maximum}$	0.728	0.121	16.7

Table 61 Contract 2880 Superpave PG 64-22 LMLC Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0002 (d)	0.0004 (d)
$LMLCN_{des}$	0.0002 (d)	**X**	0.13013 (s)
$LMLCN_{max}$	0.0004 (d)	0.13013 (s)	**X**

Table 62 Contract 2880 Superpave PG 64-22 FMLC Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.1136 (s)	0.0348 (d)
$FMLCN_{des}$	0.1136 (s)	**X**	0.0456 (d)
$FMLCN_{max}$	0.0348 (d)	0.0456 (d)	**X**

Table 63 Contract 2880 Superpave PG 64-22 LMLC vs. FMLC Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.0034 (d)
LMLC N_{des} vs. FMLC N_{des}	0.8809 (s)
LMLC N_{max} vs. FMLC N_{max}	0.6165 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 64 Contract 2880 Superpave AC-20P LMLC Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.1071 (s)	0.0659 (s)
$LMLCN_{des}$	0.1071 (s)	**X**	0.2165 (s)
$LMLCN_{max}$	0.0659 (s)	0.2165 (s)	**X**

Table 65 Contract 2880 Superpave AC-20P FMLC Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0001 (d)	0.0009 (d)
$FMLCN_{des}$	0.0001 (d)	**X**	0.2752 (s)
$FMLCN_{max}$	0.0009 (d)	0.2752 (s)	**X**

Table 66 Contract 2880 Superpave AC-20P LMLC vs. FMLC Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.0798 (s)
LMLC N_{des} vs. FMLC N_{des}	0.8641 (s)
LMLC N_{max} vs. FMLC N_{max}	0.17951 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 67 Contract 2880 Hveem PG 64-22 LMLC Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0387 (d)	0.0332 (d)
$LMLCN_{des}$	0.0387 (d)	**X**	0.0571 (s)
$LMLCN_{max}$	0.0332 (d)	0.0571 (s)	**X**

Table 68 Contract 2880 Hveem PG 64-22 FMLC Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0007 (d)	0.0029 (d)
$FMLCN_{des}$	0.0007 (d)	**X**	0.1237 (s)
$FMLCN_{max}$	0.0029 (d)	0.1237 (s)	**X**

Table 69 Contract 2880 Hveem PG 64-22 LMLC vs. FMLC Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.3234 (s)
LMLC N_{des} vs. FMLC N_{des}	0.4076 (s)
LMLC N_{max} vs. FMLC N_{max}	0.1261 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

Table 70 Contract 2880 Hveem AC-20P LMLC Mix Plastic Strain Mean Comparison Results.

	$LMLCN_{inital}$	$LMLCN_{des}$	$LMLCN_{max}$
$LMLCN_{inital}$	**X**	0.0494 (d)	0.0481 (d)
$LMLCN_{des}$	0.0494 (d)	**X**	0.971 (s)
$LMLCN_{max}$	0.0481 (d)	0.971 (s)	**X**

Table 71 Contract 2880 Hveem AC-20P FMLC Mix Plastic Strain Mean Comparison Results.

	$FMLCN_{inital}$	$FMLCN_{des}$	$FMLCN_{max}$
$FMLCN_{inital}$	**X**	0.0002 (d)	0.0007 (d)
$FMLCN_{des}$	0.0002 (d)	**X**	0.6196 (s)
$FMLCN_{max}$	0.0007 (d)	0.6196 (s)	**X**

Table 72 Contract 2880 Hveem AC-20P LMLC vs. FMLC Mix Plastic Strain Mean Comparison Results.

LMLC Ni_{ni} vs. FMLC N_{ini}	0.9501 (s)
LMLC N_{des} vs. FMLC N_{des}	0.1191 (s)
LMLC N_{max} vs. FMLC N_{max}	0.1206 (s)

Notes: Any Value less than 0.05 indicates a statistical difference which is denoted by (d)
(s) - Denotes statistically the same

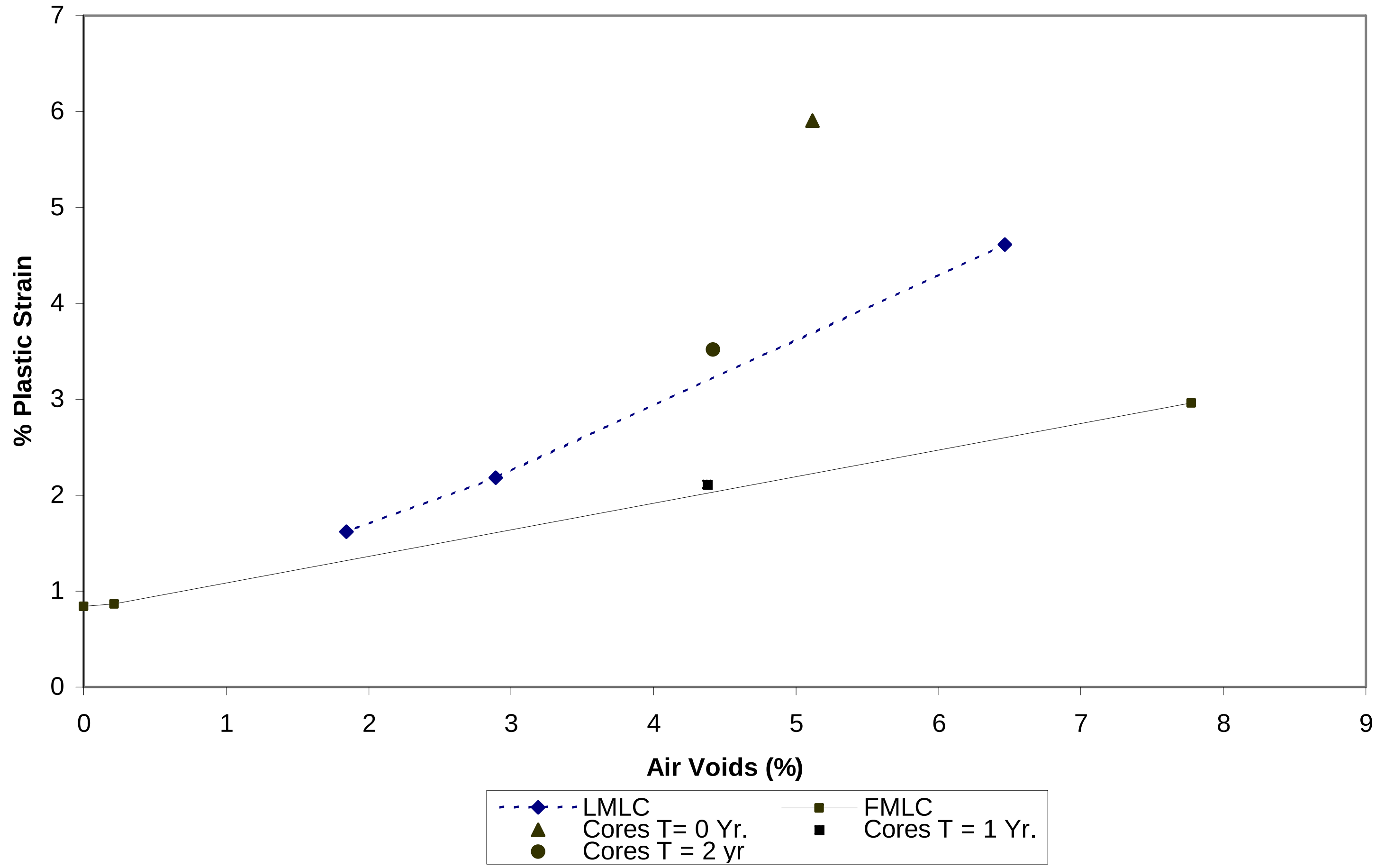

Figure 1 Contract 2751 Superpave " Coarse " LMLC, FMLC, and cores RSCH at 5000 load cycles.

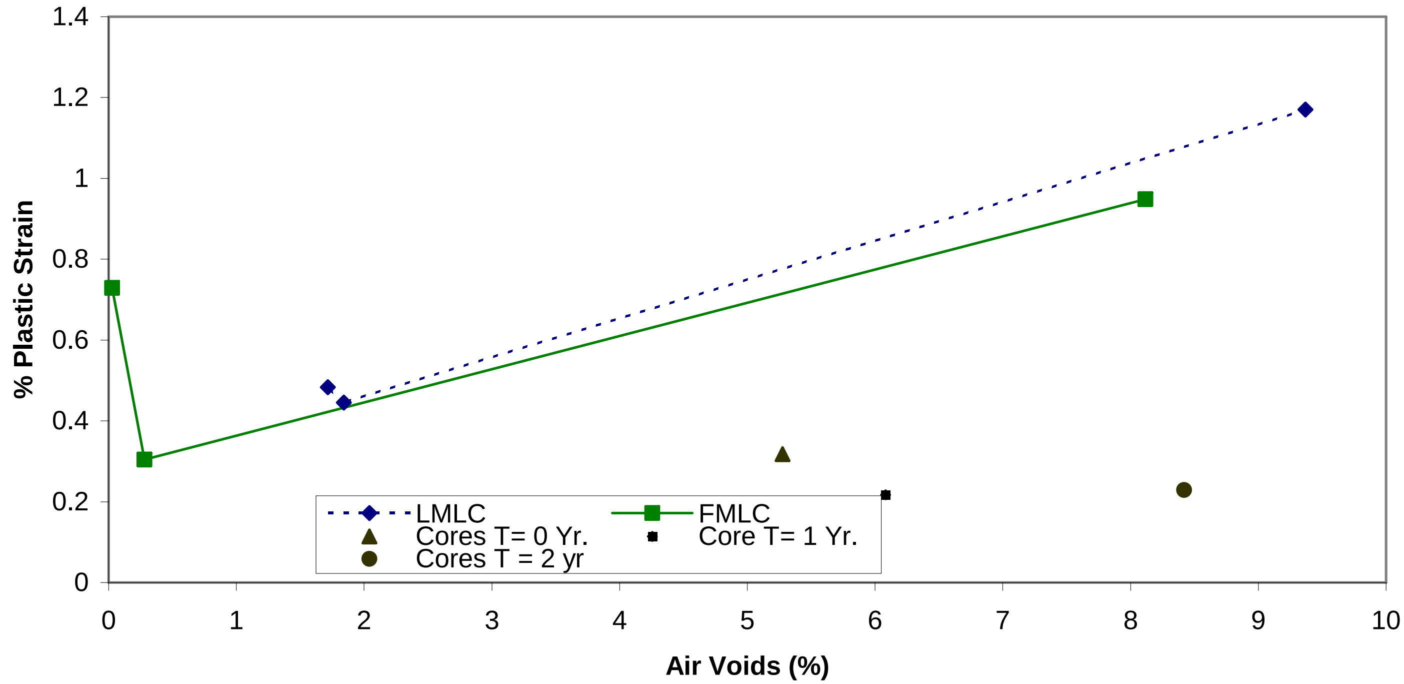

Figure 2 Contract 2751 Hveem type II LMLC, FMLC and cores RSCH at 5000 load cycles.

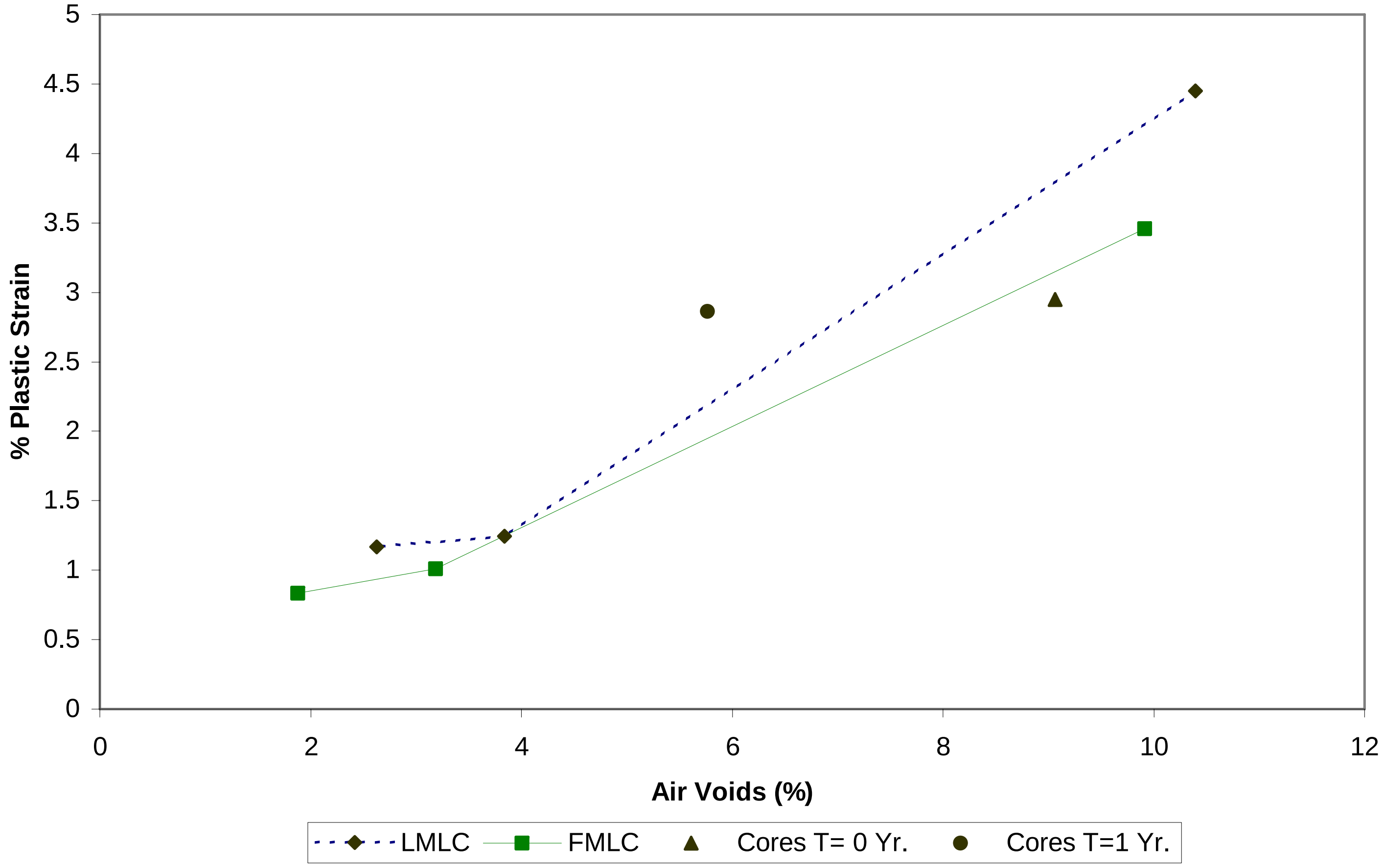

Figure 3 Contract 2827 Superpave “Coarse” LMLC, FMLC, and cores RSCH at 5000 load cycles.

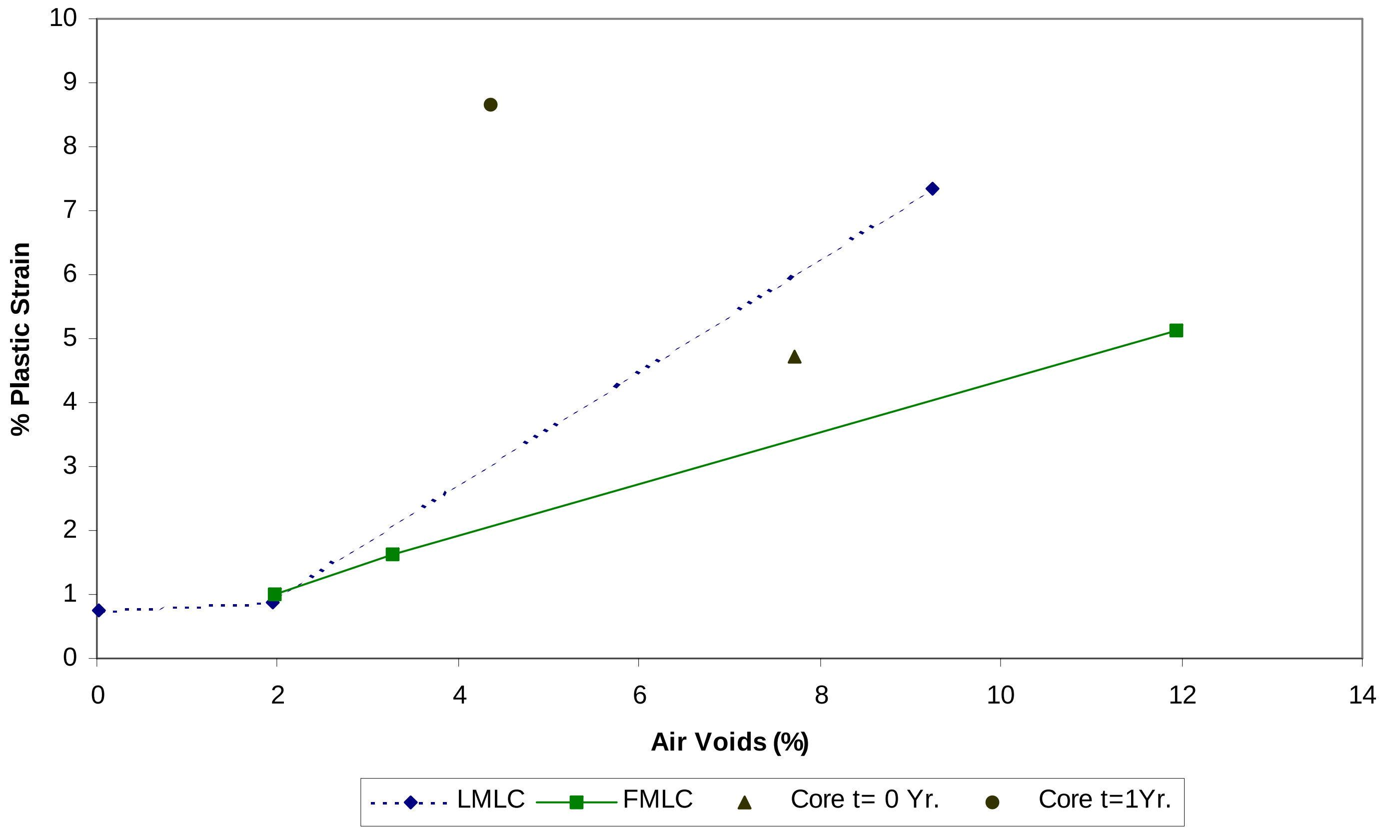

Figure 4 Contract 2827 Hveem type II LMLC, FMLC, and cores RSCH at 5000 load cycles.

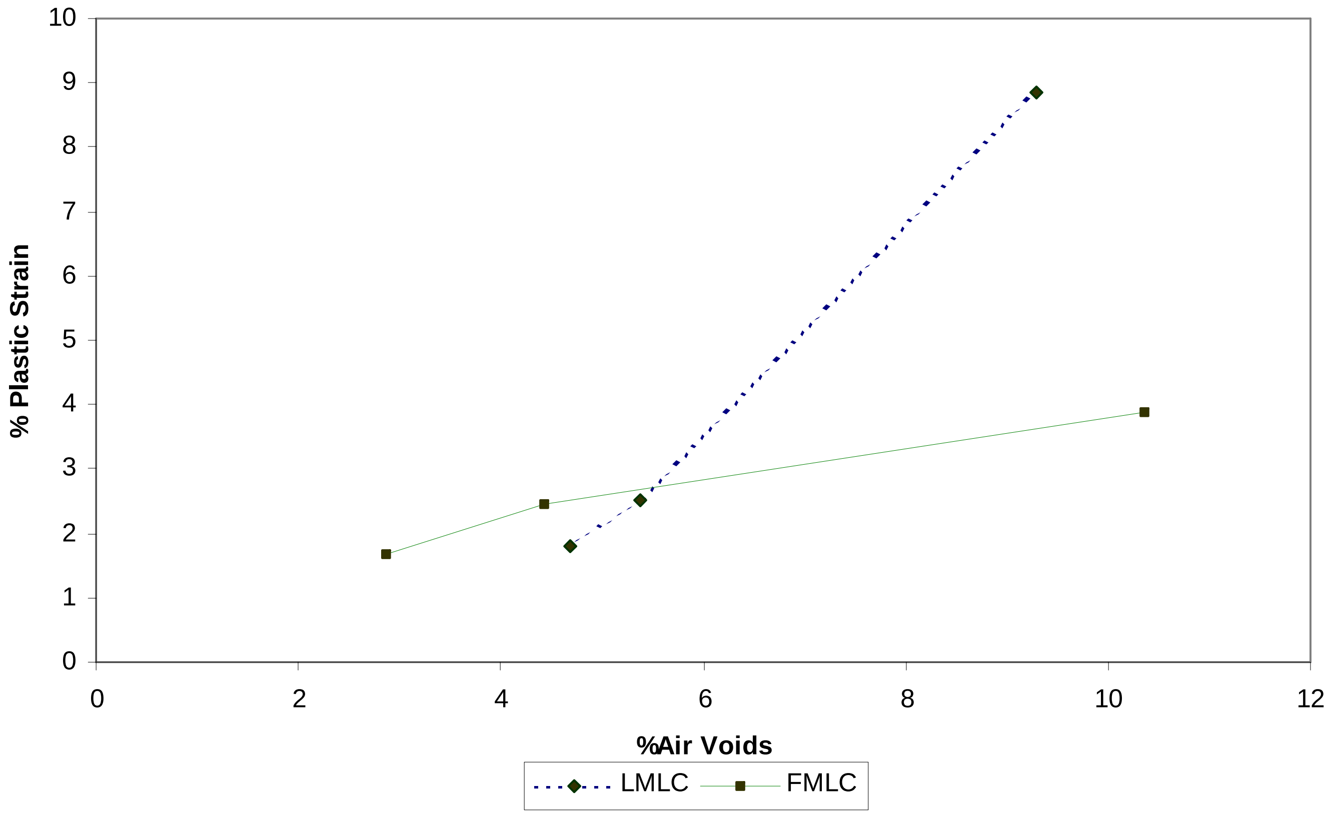

Figure 5 Contract 2880 Superpave PG64-22 LMLC and FMLC RSCH at 5000 load cycles.

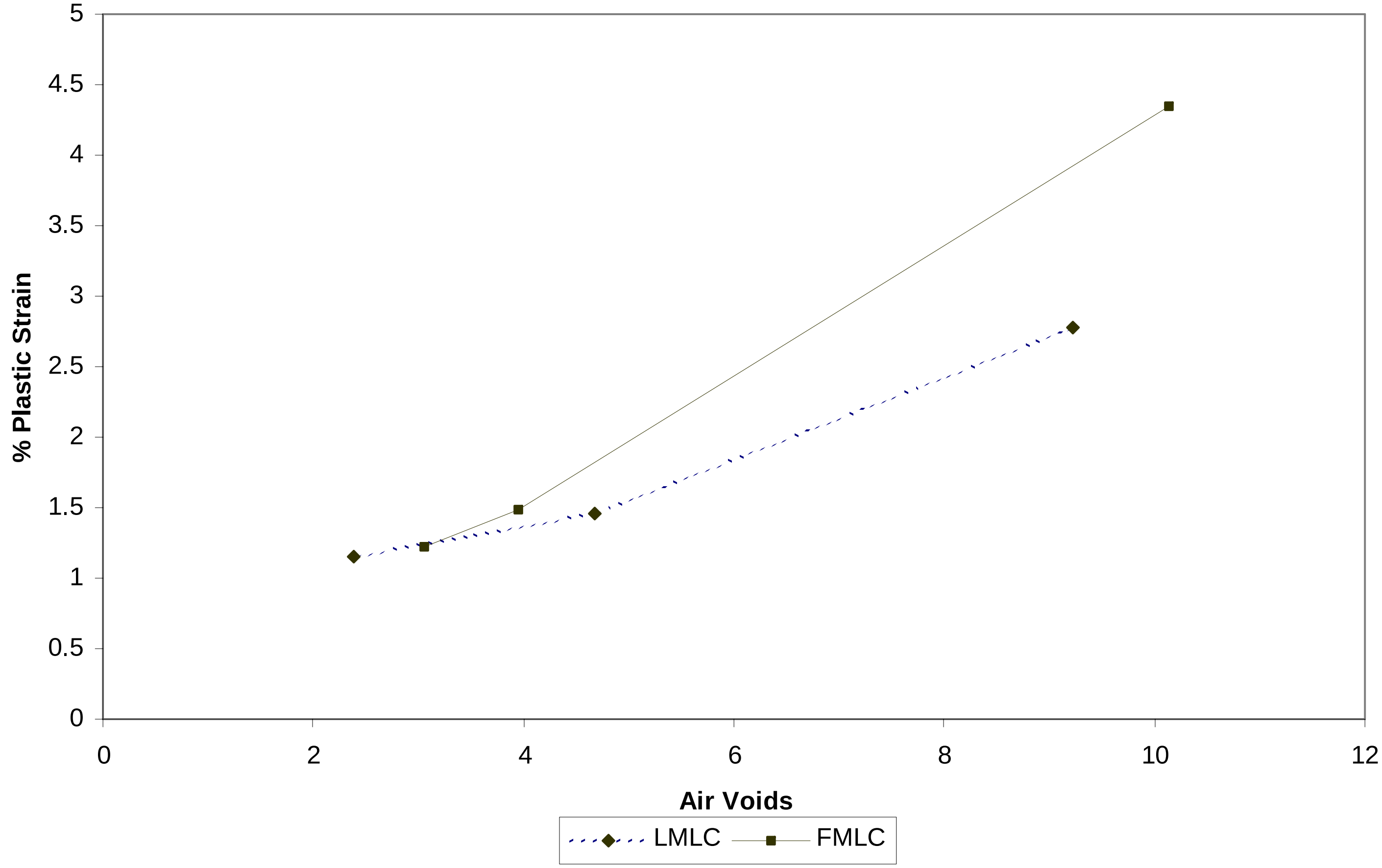

Figure 6 Contract 2880 Superpave AC-20P LMLC and FMLC RSCH at 5000 load cycles.

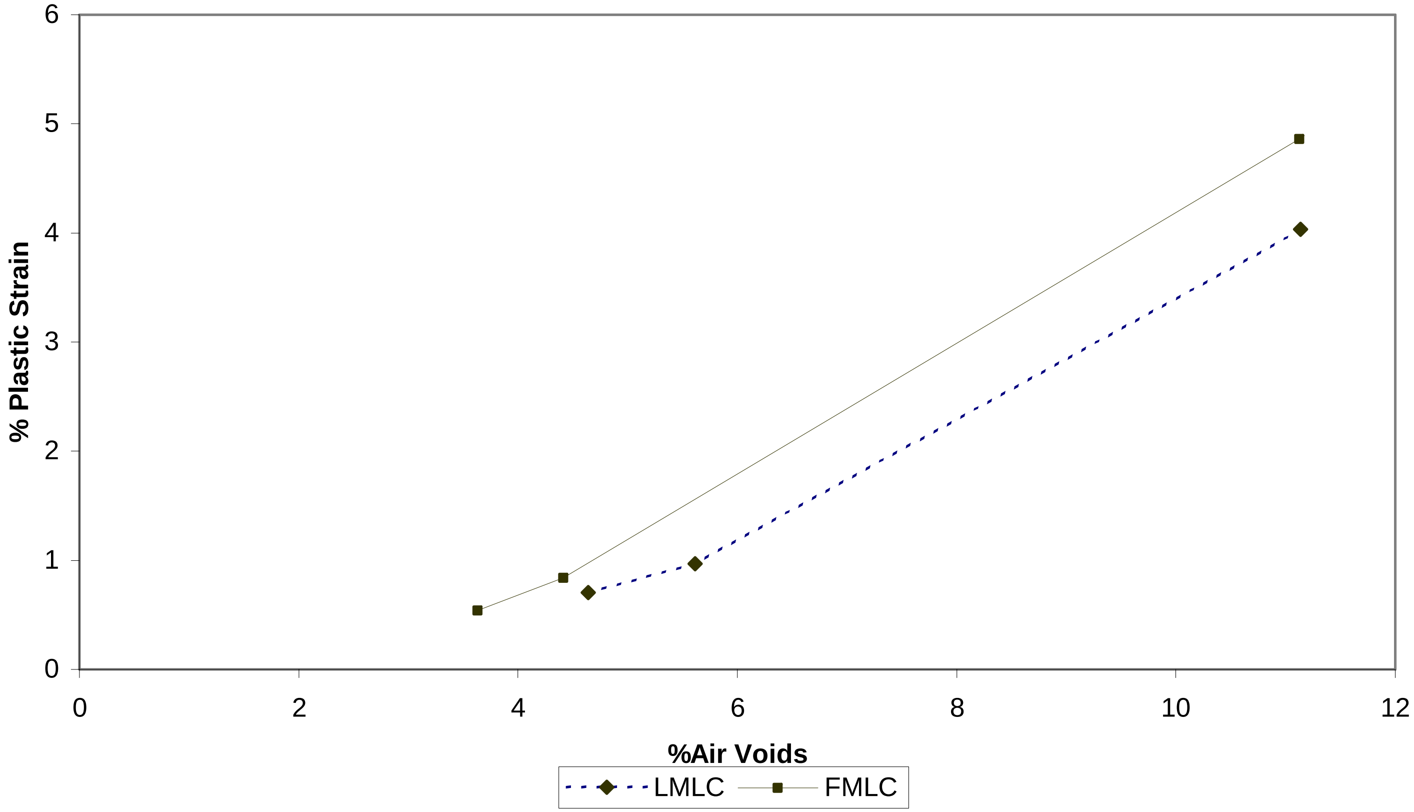

Figure 7 Contract 2880 Hveem PG64-22 LMLC and FMLC RSCH at 5000 load cycles.

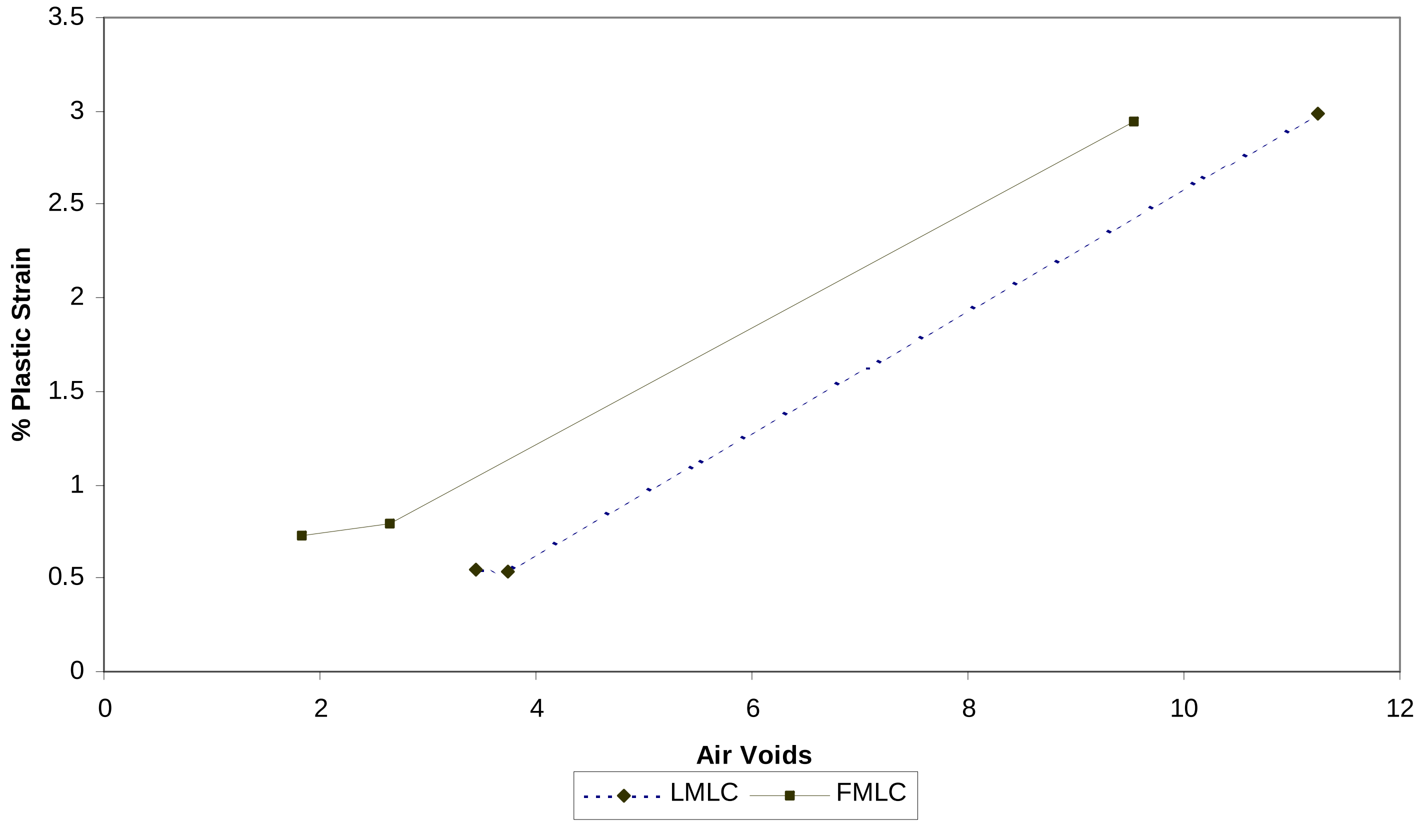

Figure 8   Contract 2880 Hveem AC-20P LMLC and FMLC RSCH at 5000 load cycles.

Kenny C. Guinn, Governor

Jeff Fontaine, P.E. Director
Prepared by Research Division
Alan Hilton, Research Division Chief
(775) 888-7803
ahilton@dot.state.nv.us
1263 South Stewart Street
Carson City, Nevada 89712