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# Evaluation of the Influence of Variation of Superpave HMA Mixtures Physical Properties on Pavement Performance

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**Abstract:** For numerous years, researchers have investigated hot-mix asphalt (HMA) plant production and the relationship between measured quality control/quality acceptance (QC/QA) parameters and field performance. After 12 years of service, this study presents a statistical evaluation of the relationship between HMA plant QC/QA data, roadway density, and field performance, as measured by international roughness index (*IRI*), rutting, and random cracking. Three Louisiana Superpave projects constructed in 1999 utilizing wearing and binder course mixtures were evaluated. Results indicated that, as Superpave Gyratory Compaction levels increased, roadway density variability increased. Generally, QC test results were less variable than QA test results and voids filled with asphalt (*VFA*) showed the highest variability between measured volumetric parameters. Statistical analysis indicated that the coarse aggregate portion (19.0 mm, 9.5 mm, and 4.75 mm sieves) and the 0.075 mm sieve had an effect on voids in the mineral aggregate (*VMA*), *VFA*, and air voids ($V_a$). The percentage of asphalt cement significantly affected rutting and random cracking; the top size aggregate at or near the nominal maximum size aggregate, the 4.75 mm, and the 0.075 mm sieves had an effect on rutting, random cracking, and *IRI* for the HMA mixtures evaluated.

***Key words**: Field performance; Quality acceptance; Quality control; Superpave hot mix asphalt; Variability.*

## Introduction

The Superpave system, which includes a mix design procedure, asphalt binder and aggregate specifications, was the result of a $50 million research effort by the Strategic Highway Research Program (SHRP) for the purpose of developing performance-based tests and specifications for asphalt cement binders and HMA mixtures [1]. Since the implementation of SHRP, research findings from major projects have identified the need for additional evaluation of the relationship between Superpave specifications and pavement performance. Some of the most prominent projects in the mid-1990s emphasized the need to improve the structural design practice of HMA pavements, develop improved performance tests for HMA, and define relationships among material properties and pavement performance with the use of accelerated pavement testing on a full-scale test track.

In order to define these relationships, a facility known as WESTRACK was designed and constructed to perform accelerated pavement testing [2]. In fulfilling this goal, one of the major objectives was the development of performance models, which define the influence of HMA variables on pavement performance. WESTRACK concluded that with high asphalt content and lower air voids, there was a higher potential for rutting and reduced fatigue cracking; whereas, with lower asphalt contents and higher air voids, there was a greater tendency for fatigue cracking and reduced rutting. Fine-graded mixes above and through the restricted zone outperformed coarse-graded mixtures. The fine mixes exhibited less fatigue cracking and permanent deformation and were also less sensitive to deviations from target values in asphalt cement content and air void parameters. The research team recommended that additional laboratory and accelerated pavement testing be conducted to determine the effects of other asphalt binders, including polymer-modified, aggregate types, and gradations [2].

The Alabama Department of Transportation (ADOT) collected asphalt content, air void content, and mat density data for Superpave mixtures in order to develop statistics for a statistically based QC/QA program [3]. Data were analyzed to determine accuracy and variability, to compare contractor and Alabama DOT test results, and to assess the effects of maximum aggregate size and equivalent single axle loads (ESALs). It was determined that there are significant differences between contractors and Alabama DOT's test results. It was also reported that the accuracy and variability of the contractors' measurements were consistently better than the accuracy and variability of Alabama DOT measurements. In addition, as the maximum aggregate size increased, the level of mat density increased, and the variability decreased [3].

The Georgia Department of Transportation (GDOT) performed a statistical analysis to determine the extent of differences between contractor and GDOT test results for aggregate gradation and asphalt cement content [4]. This analysis was part of the National Cooperative Highway Research Program (NCHRP) Project 10-58(02). Analysis of data showed that there were significant differences between the contractors' test results and GDOT QA measurements. In general, the variation or variances were more likely to be significant than the measured differences in mean values. It was concluded that, when the variances differed significantly, QA variance was higher than the contractors' variance [4].

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Mohammad et al. [5] investigated the variability of mechanical properties of HMA mixtures due to production, characterized and compared the mechanical properties of roadway cores and laboratory compacted samples, and developed a relationship between modulus/stiffness from in-situ non-destructive testing (NDT) such as falling weight deflectometer (FWD), light falling weight deflectometer (LFWD), and a portable seismic pavement analyzer (PSPA) and mechanistic evaluation using Indirect Tensile Strength (ITS), Indirect Tensile Resilient Modulus (ITMr), Frequency Sweep at Constant Height (FSCH), and Loaded Wheel Tracking (LWT) tests. Results from this study indicated that, in general, the coefficients of variation of mechanistic properties were higher for laboratory-compacted samples than for roadway cores. Results from the FSCH test for laboratory samples were significantly higher than for roadway cores. Good correlations were observed between roadway cores and laboratory compacted samples in terms of complex shear moduli and indirect tensile resilient moduli. A methodology was developed for the prediction of laboratory resilient modulus from in-situ PSPA test parameter. Field test results indicated that the LFWD test may be used as an alternative for the FWD test in pavement structural evaluation [5].

This paper presents a comparison and statistical evaluation of HMA plant QC/QA data, roadway density, and field performance after 12 years of service, as measured by IRI, rutting, and random cracking. Three of nine initial Louisiana Superpave projects constructed in 1999 utilizing wearing and binder course mixture types were evaluated.

## Objectives

The objectives of this study were as follows:

- Evaluate the variation of Superpave HMA mixtures produced and how it influences pavement performance,
- Ascertain if there is a relationship between measured key quality characteristics (i.e., mixture volumetrics, gradation, asphalt cement content, Superpave Gyratory Compaction (SGC) densification, and roadway density) and mixture performance properties, such as random cracking, rutting, and *IRI*, as determined by data collected by the Automatic Road Analyzer (ARAN), and
- Determine the statistical variability between QC/QA during production of the HMA mixtures.

## Scope

Three Superpave projects constructed in 1999 were selected for evaluation in this study. The three projects selected consisted of a Level 1, Level 2, and a Level 3 HMA mixture design criteria. The contractors' QC data along with the Louisiana Department of Transportation and Development (LADOTD) quality acceptance data were used for evaluation of the selected projects. The collected data included HMA job mix formula (JMF), plant production data (air voids ($V_a$), *VMA*, *VFA*, gradation), percent tensile strength ratio (*TSR*), and roadway density expressed as a percentage of theoretical maximum density. In addition, measured ARAN performance data (rutting, *IRI* smoothness, and random cracking) were obtained for the specific job site location from the Louisiana's Pavement Management System (PMS).

## Experimental Program

The following section describes HMA mixture design, materials, statistical evaluation, and field performance measurement methodologies.

### Mixture Design

Table 1 provides a summary of the three projects selected for this study. A styrene butadiene styrene (SBS) polymer modified asphalt cement (PAC) 40HG meeting LADOTD specifications was used to produce the HMA mixtures evaluated in this study. Under Louisiana's current Superpave binder specification, the previously specified PAC 40HG would grade as a PG 70-22M, where the "M" designation indicates an elastomeric polymer modified asphalt cement because specifications require force ductility ratio and elastic recovery testing.

HMA mix design procedures required the contractor to submit Superpave JMFs. In most cases, the JMFs are developed in the contractor's laboratory, but in some cases, the JMF is designed utilizing actual plant-produced HMA mixtures. During Louisiana's Superpave infancy, LADOTD required the contractor to perform five independent sets of testing per 1,000 tons of HMA mixture on specific parameters as set forth by the specifications for JMF validation. In addition, LADOTD would perform five independent sets of testing for quality acceptance. The parameters in these 10 tests would then be averaged to become the actual JMF based on plant-produced HMA mixtures. This plant produced and validated JMF would then be used for all QC/QA testing.

### Statistical Analysis: HMA Production and Performance Parameters

Statistical analysis was performed using various techniques to determine basic statistical properties. In addition, an analysis of variance (ANOVA) was used to determine if there were any statistical differences between QC/QA data. Statistical analysis was performed on plant-produced wearing and binder course mixtures. Analysis was performed on QA and QC test parameters to determine the variability of these test parameters for each mix types being produced through the hot mix plant facility. In addition, the variability of roadway density was quantified. The mean and coefficient of variation (% C.V.) statistical calculations were selected to assess parameters' variability.

Statistical analyses of the test results were carried out using the Statistical Analysis System (SAS) software. A multiple comparison procedure using the Fisher's Least Significant Difference (LSD) with a 95 percent confidence interval was used to statistically analyze the test results. These comparison procedures ranked the results in groups designated with the letters "A," "B," or "A/B." The letter "A" was used to rank the grouping with the highest mean of the parameters evaluated followed by other letters in the appropriate descending order. Letter designation such as "B" for one grouping, when compared to a letter designation of "A" for the other grouping, signifies that the "B" grouping is significantly different from the

**Table 1.** Superpave Mixture Types JMF Percentages.

| | US 61 | | LA 121 | | US 90 | |
|---|---|---|---|---|---|---|
| Mixture Identification | Binder | Wearing | Binder | Wearing | Binder | Wearing |
| NMAS[1], mm | 25 | 19 | 19 | 19 | 25 | 19 |
| Thickness, mm | 50 | 40 | 50 | 40 | 50 | 40 |
| Level | 2 | | 1 | | 3 | |
| ESAL x $10^6$ | 10 - 30 | | < 10 | | > 30 | |
| $N_{\text{initial}}$ | 8 | 8 | 8 | 8 | 9 | 9 |
| $N_{\text{design}}$ | 109 | 109 | 96 | 96 | 126 | 126 |
| $N_{\text{final}}$ | 174 | 174 | 152 | 152 | 204 | 204 |
| % *VMA* | 13.1 | 13.2 | 14.2 | 14.1 | 13.1 | 14.2 |
| % *VFA* | 70 | 69 | 71 | 70 | 70 | 70 |
| % VOIDS | 3.9 | 4.1 | 4.2 | 4.3 | 3.9 | 4.2 |
| % $G_{mm}$, $N_{\text{initial}}$ | 86.0 | 85.9 | 86.1 | 85.2 | 86.0 | 84.7 |
| % $G_{mm}$, $N_{\text{design}}$ | 96.1 | 95.9 | 95.9 | 95.8 | 96.1 | 95.8 |
| % $G_{mm}$, $N_{\text{final}}$ | 97.5 | 97.4 | 97.5 | 97.4 | 97.5 | 97.5 |
| Gyratory Slope | 8.91 | 8.88 | 9.04 | 9.82 | 8.91 | 9.70 |
| % *TSR* | ** | ** | ** | 92 | ** | 86 |
| % Asphalt Cement | 4.3 | 4.0 | 4.4 | 4.7 | 4.3 | 4.5 |
| Sieve | Gradation (% passing) | | | | | |
| 37.5 mm | 100 | 100 | 100 | 100 | 100 | 100 |
| 25.0 mm | 97 | 100 | 100 | 100 | 97 | 100 |
| 19.0 mm | 86 | 97 | 98 | 98 | 84 | 94 |
| 12.5 mm | 73 | 85 | 84 | 83 | 60 | 76 |
| 9.5 mm | 66 | 71 | 64 | 62 | 46 | 60 |
| 4.75 mm | 40 | 44 | 35 | 32 | 29 | 34 |
| 2.36 mm | 22 | 29 | 25 | 23 | 21 | 23 |
| 1.18 mm | 16 | 21 | 16 | 18 | 15 | 15 |
| 0.600 mm | 13 | 16 | 15 | 14 | 12 | 12 |
| 0.300 mm | 10 | 10 | 9 | 8 | 9 | 9 |
| 0.075 mm | 5.0 | 5.0 | 4.3 | 3.8 | 4.9 | 6.0 |

[1]NMAS – Nominal Maximum Aggregate Size
** Not Available

**Table 2.** Dependent/Independent Variables for Volumetric/aggregate Gradation Step-wise Statistical Analysis.

| Dependent Variables | Independent Variables |
|---|---|
| *VFA* | %AC |
| *VMA* | *VFA* |
| *VA* | Aggregate Gradations |
| $RV_a$ (Roadway Density) | |

**Table 3.** Dependent/Independent Variables for Physical Properties/pavement Performance Parameters Step-wise Statistical Analysis.

| Dependent Variables | Independent Variables |
|---|---|
| Rutting | %AC |
| Random Cracking | *VFA* |
| *IRI* | Aggregate Gradations |
| | *VMA* |
| | $V_a$ |
| | $RV_a$ (Roadway Density) |

other grouping. A double-letter designation, “A/B,” indicates that the mean of the parameter evaluated is not significant for either grouping.

A stepwise regression analysis was also performed to determine the independent variables that statistically influence the dependent variables (*VMA*, *VFA*, $V_a$, and air voids in the field ($RV_a$)). The procedure combines the forward and backward stepwise regression methods. The regression starts with no variables in the model. The *F* statistics are calculated for each independent variable. The variable with the most significance level greater than 0.25, is entered into the model first. All variables are entered individually with this entry criterion. The significance of each variable included is rechecked in each step throughout the analysis and the variable is removed if it does not yield an *F* statistic at a level of significance greater than 0.05 (95 percent Confidence Level). The process is completed when no more variables outside the model had a level of significance greater than 0.25 to enter and 0.05 to be removed.

Table 2 indicates the dependent and independent variables used to determine the gradation sieves that significantly affected volumetrics for wearing course and binder course for the HMA mixtures evaluated. Table 3 presents the dependent and independent variables used to determine what physical properties of the wearing course and binder course significantly affected pavement performance parameters (rutting, random cracking, and *IRI*) for the HMA mixtures evaluated.

## Field Performance Evaluation

Field performance of pavements was evaluated using data acquired from LADOTD's PMS, in which the *IRI*, rut-depth measurements, and crack data are regularly monitored. Visual data were collected by the ARAN developed by Roadware Group, Inc. and independently analyzed for inclusion into Louisiana's pavement management inventory. ARAN is a vehicle that is specially designed to collect accurate and repeatable data for pavement management programs. ARAN is capable of measuring and recording up to 36 different characteristics ranging from pavement roughness and rutting to multi-camera imagery while traveling at posted speed limits [6-7].

### *International Roughness Index*

The *IRI* is a standard roughness measurement related to those obtained by road meters installed on vehicles or trailers. The *IRI* is a mathematical model applied to a measured profile. The model simulates a quarter-car system (QCS) traveling at a constant speed of 80 kilometer per hour (km/h). The *IRI* is computed as the cumulative movement of the suspension of the QCS divided by the traveled distance [8].

### *Rut Depth Measurement*

Field rut depth data collection for this case study was performed by ARAN using two-vehicle mounted subsystems. In 1995 and 1998, data were collected by the ARAN Smart Rutbar, which uses ultrasonic transducers to measure the transverse roadway cross section. Ultrasonic transducers are spaced at 100mm across the measuring device. Up to 37 transducers are used to cover a 3.65m wide lane. In 2000 and 2003, three-laser and five-laser point systems were utilized to collect rutting measurements. This change

**Table 4.** US 61 Statistical Analyses: JMF Wearing & Binder Course Validation.

| | US 61 WC | | US 61 BC | | | US 61 WC | | US 61 BC | |
|---|---|---|---|---|---|---|---|---|---|
| | Contractor | DOTD | Contractor | DOTD | | Contractor | DOTD | Contractor | DOTD |
| | | | | | Sieve | Percent Passing | | | |
| *% VMA* | 13.1 | 13.2 | 14 | 13.9 | 37.5 mm | 100 | 100 | 100 | 100 |
| %CV | 1.36 | 0 | 0.78 | 1.14 | %CV | 0 | 0 | 0 | 0 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| *% VFA* | 69 | 69 | 66 | 68 | 25.0 mm | 100 | 100 | 96 | 97 |
| %CV | 1.29 | 0 | 0.82 | 0.81 | %CV | 0 | 0 | 0.47 | 0.86 |
| GROUPING | A | A | B | A | GROUPING | A | A | B | A |
| % $V_a$ | 4 | 4.1 | 4.7 | 4.5 | 19.0 mm | 97 | 97 | 87 | 87 |
| %CV | 4.45 | 0 | 2.13 | 2.88 | %CV | 0 | 0 | 0.96 | 1.32 |
| GROUPING | A | A | A | B | GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{initial}}$ | 85.9 | 85.8 | 84.9 | 85.1 | 12.5 mm | 85 | 85 | 70 | 70 |
| %CV | 0.26 | 0 | 0.24 | 0.69 | %CV | 0 | 0 | 0.79 | 1.75 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| %$G_{mm}$, $N_{\text{design}}$ | 96 | 95.9 | 95.3 | 95.5 | 9.5 mm | 71 | 71 | 60 | 61 |
| %CV | 0.19 | 0 | 0.1 | 0.14 | %CV | 0 | 0 | 1.67 | 2.01 |
| GROUPING | A | A | B | A | GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{final}}$ | 97.4 | 97.3 | 96.8 | 97 | 4.75 mm | 45 | 45 | 32 | 32 |
| %CV | 0.23 | 0 | 0.21 | 0.11 | %CV | 0 | 0 | 3.44 | 2.21 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| SGC Slope | 8.88 | 8.91 | 9.2 | 9.13 | 2.36 mm | 29 | 29 | 20 | 21 |
| %CV | 0.4 | 0 | 2.42 | 4.64 | %CV | 0 | 0 | 2.68 | 4.02 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % AC | 4 | 4 | 4.1 | 4.2 | 1.18 mm | 21 | 21 | 16 | 17 |
| %CV | 0 | 0 | 0.04 | 0.15 | %CV | 0 | 0 | 2.83 | 3.3 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| | | | | | 0.600 mm | 16 | 16 | 13 | 13 |
| | | | | | %CV | 0 | 0 | 0 | 4.09 |
| | | | | | GROUPING | A | A | A | A |
| | | | | | 0.300 mm | 10 | 10 | 8 | 9 |
| | | | | | %CV | 0 | 0 | 0 | 5.08 |
| | | | | | GROUPING | A | A | B | A |
| | | | | | 0.075 mm | 5 | 5 | 4.3 | 4.4 |
| | | | | | %CV | 0 | 0 | 3.05 | 4.95 |
| | | | | | GROUPING | A | A | A | A |

**Table 5.** LA 121 Statistical Analyses: JMF Wearing & Binder Course Validation.

| | LA 121 WC | | LA 121 BC | | | LA 121 WC | | LA 121 BC | |
|---|---|---|---|---|---|---|---|---|---|
| | Contractor | DOTD | Contractor | DOTD | | Contractor | DOTD | Contractor | DOTD |
| | | | | | Sieve | Percent Passing | | | |
| % *VMA* | 13.9 | 13.9 | 13.3 | 13.3 | 37.5 mm | 100 | 100 | 100 | 100 |
| %CV | 1.61 | 1.73 | 1.41 | 1.11 | %CV | 0 | 0 | 0 | 0 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % *VFA* | 73 | 72 | 73 | 72 | 25.0 mm | 100 | 100 | 100 | 100 |
| %CV | 1.68 | 4.28 | 1.15 | 1.16 | %CV | 0 | 0 | 0 | 0 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % $V_a$ | 3.8 | 3.9 | 3.6 | 3.7 | 19.0 mm | 98 | 98 | 98 | 99 |
| %CV | 3.92 | 12.16 | 4.39 | 4.27 | %CV | 0 | 0 | 1.44 | 1.16 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{initial}}$ | 85.8 | 85.7 | 86.7 | 86.4 | 12.5 mm | 83 | 83 | 86 | 84 |
| %CV | 0.2 | 0.29 | 0.3 | 0.26 | %CV | 0 | 1.84 | 3.26 | 2.71 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{design}}$ | 96.2 | 96.1 | 96.4 | 96.3 | 9.5 mm | 62 | 63 | 66 | 66 |
| %CV | 0.15 | 0.49 | 0.16 | 0.16 | %CV | 0 | 3.04 | 3.47 | 3.93 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{final}}$ | 97.8 | 97.7 | 97.9 | 97.8 | 4.75 mm | 32 | 34 | 37 | 37 |
| %CV | 0.15 | 0.44 | 0.09 | 0.17 | %CV | 0 | 5.29 | 3.82 | 3.67 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| SGC Slope | 9.69 | 9.66 | 9.01 | 9.16 | 2.36 mm | 23 | 23 | 26 | 26 |
| %CV | 1.48 | 2.83 | 2.57 | 1.81 | %CV | 0 | 3.61 | 5.08 | 3.24 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | A |
| % AC | 4.9 | 4.8 | 4.7 | 4.6 | 1.18 mm | 18 | 18 | 24 | 19 |
| %CV | 5.37 | 3.13 | 3.51 | 1.54 | %CV | 0 | 3.11 | 2.32 | 3.34 |
| GROUPING | A | A | A | A | GROUPING | A | A | A | B |
| | | | | | 0.600 mm | 14 | 14 | 16 | 16 |
| | | | | | %CV | 0 | 3.24 | 4.42 | 3.51 |
| | | | | | GROUPING | A | A | A | A |
| | | | | | 0.300 mm | 8 | 8 | 10 | 10 |
| | | | | | %CV | 0 | 0 | 4.56 | 5.71 |
| | | | | | GROUPING | A | A | A | A |
| | | | | | 0.075 mm | 3.8 | 3.9 | 4.8 | 4.3 |
| | | | | | %CV | 0 | 2.95 | 4.42 | 6.27 |
| | | | | | GROUPING | A | A | A | B |

was implemented because point lasers are faster than ultrasonic transducers in the collection of data and can record the transverse profile at 10 mm intervals along the roadway. Beginning in 2005, data were collected using the ARAN laser transverse profiler, Laser XVP, vehicle mounted subsystem. This laser transverse profiler uses dual synchronized mounted scanning lasers to measure the transverse roadway profile allowing a more accurate measurement of rutting in addition to measuring each wheel path independently. This technology allows transverse profile measurement up to 3.96 m lane widths.

### *Crack Data Measurement*

Transverse, random, fatigue, block, and longitudinal crack data were obtained by ARAN video imagery technology. For this study, only random cracking is reported. Random cracking was the only type cracking analyzed because LADOTD includes both longitudinal and transverse cracking in the random cracking values. In addition, these type cracks are generally influenced by the quality of HMA mixtures. Generally, fatigue cracking and block cracking are usually attributed to base failures and soil cement base course treatments in Louisiana. It is for this reason that block cracking and fatigue cracking were not included in this study. Prior to the year 2000, video imagery was collected utilizing videocassette recorder (VCR) imagery. After the year 2000, digital imagery was utilized because of quicker image retrieval. The crack data video imagery was independently analyzed using computer software developed by Roadware Group, Inc. and then the resulting distress values for each pavement distress (i.e. longitudinal cracking, transverse cracking, rutting, etc.) were included into LADOTD’s PMS database. The pavement distress data for this study was obtained from this database.

## Results and Analysis

### Statistical Analysis: HMA Production and Performance Parameters

Table 4 presents the JMF validation data and results of the statistical analysis for the wearing and binder course HMA mixtures for Route US 61. This table presents the contractor's and LADOTD's validation data for the wearing and binder course HMA mixtures. As shown in Table 4, there were no statistical differences noted for the parameters and gradations for the wearing course mixture evaluated. It is shown that the *%VMA* for the wearing course mixture was produced near the minimum specification limit of 13.0 percent and that the wearing course HMA mixture percent air voids met the design parameter of 4.0 percent. Table 4 indicates that there are several volumetric and gradation parameters showing a statistical difference in the binder course between the contractor's and DOTD's validation data. These properties include statistical differences in *%VFA*, $\%V_a$, $\%G_{mm}$ @ $N_{\text{design}}$, the 25.0 mm sieve, and the 0.300 mm sieve. The *%VMA* for the binder course mixture was produced well above the minimum specification limit of 12.0 percent as indicated in Table 4.

Table 5 shows the JMF validation data and results of the statistical analysis for the wearing and binder course HMA mixtures for Route LA 121. This table compares the contractor's and LADOTD's validation data for the wearing and binder course HMA mixtures in this project. As shown in Table 5, there were no statistical differences noted for the parameters and gradations for the wearing course mixture in this project. The %*VMA* for the wearing course mixture was produced at 13.9 percent, which is above the minimum specification limit of 13.0 percent. It was noted that the wearing course HMA mixture percent air voids was produced

**Table 6.** US 90 Statistical Analyses: JMF Wearing & Binder Course Validation.

| | US 90 WC | | US 90 BC | |
|---|---|---|---|---|
| | Contractor | DOTD | Contractor | DOTD |
| % *VMA* | 15.3 | 15.3 | 13.1 | 13.5 |
| %CV | 1.27 | 1.99 | 3.28 | 3.28 |
| GROUPING | A | A | A | A |
| % *VFA* | 71 | 71 | 73 | 70 |
| %CV | 2.82 | 2.31 | 4.2 | 4.16 |
| GROUPING | A | A | A | A |
| % $V_a$ | 4.5 | 4.4 | 3.6 | 4.1 |
| %CV | 8.18 | 8.22 | 14.6 | 11.63 |
| GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{initial}}$ | 84.5 | 84.1 | 85.7 | 84.8 |
| %CV | 0.56 | 0.98 | 1.05 | 0.72 |
| GROUPING | A | A | A | A |
| %$G_{mm}$, $N_{\text{design}}$ | 95.5 | 95.6 | 96.4 | 95.9 |
| %CV | 0.38 | 0.4 | 0.54 | 0.49 |
| GROUPING | A | A | A | A |
| % $G_{mm}$, $N_{\text{final}}$ | 97.2 | 97.2 | 98 | 97.6 |
| %CV | 0.35 | 0.32 | 0.41 | 0.44 |
| GROUPING | A | A | A | A |
| SGC Slope | 9.84 | 10 | 9.35 | 9.68 |
| %CV | 4.17 | 5.66 | 4.1 | 2.85 |
| GROUPING | A | A | A | A |
| % AC | 4.4 | 4.7 | 4.2 | 3.9 |
| %CV | 3.48 | 2.34 | 1.98 | 3.85 |
| GROUPING | B | A | A | B |

| | US 90 WC | | US 90 BC | |
|---|---|---|---|---|
| | Contractor | DOTD | Contractor | DOTD |
| Sieve | Percent Passing | | | |
| 37.5 mm | 100 | 100 | 100 | 100 |
| %CV | 0 | 0 | 0 | 0 |
| GROUPING | A | A | A | A |
| 25.0 mm | 100 | 100 | 96 | 96 |
| %CV | 0 | 0 | 0.57 | 1.71 |
| GROUPING | A | A | A | A |
| 19.0 mm | 95 | 94 | 84 | 85 |
| %CV | 0.95 | 2.18 | 3.12 | 3.19 |
| GROUPING | A | A | A | A |
| 12.5 mm | 77 | 78 | 61 | 61 |
| %CV | 1.49 | 3.79 | 5.68 | 5.91 |
| GROUPING | B | A | A | A |
| 9.5 mm | 59 | 63 | 48 | 47 |
| %CV | 3.49 | 4.2 | 6.84 | 7.25 |
| GROUPING | A | A | A | A |
| 4.75 mm | 34 | 36 | 30 | 29 |
| %CV | 3.81 | 3.64 | 7.82 | 5.63 |
| GROUPING | A | A | A | A |
| 2.36 mm | 22 | 23 | 21 | 20 |
| %CV | 3.84 | 3.67 | 8.25 | 5 |
| GROUPING | A | A | A | A |
| 1.18 mm | 15 | 15 | 15 | 15 |
| %CV | 3.75 | 4.71 | 8.71 | 5.65 |
| GROUPING | A | A | A | A |
| 0.600 mm | 11 | 11 | 13 | 12 |
| %CV | 4.14 | 6.43 | 7.1 | 3.67 |
| GROUPING | A | A | A | A |
| 0.300 mm | 8 | 8 | 9 | 9 |
| %CV | 5.45 | 6.52 | 9.52 | 0 |
| GROUPING | A | A | A | A |
| 0.075 mm | 5.3 | 5.2 | 4.9 | 5 |
| %CV | 3.64 | 7.47 | 8.18 | 7.89 |
| GROUPING | A | A | A | A |

slightly below the design parameter of 4.0 percent. Table 5 indicates that there were two parameters in the binder course mixture with a statistical difference between the JMF and the QA data (i.e., the 1.18 mm and the 0.075 mm sieves). While the standard deviation of the 0.075mm parameter was consistent between the JMF and the QA data, the mean values reported were 4.8 and 4.3, respectively. The wearing course and binder course HMA mixtures had a 19.0 mm nominal maximum aggregate size (NMAS).

Table 6 presents the comparison of the JMF validation data and results of the statistical analysis for Route US 90 wearing and binder course HMA mixtures. This table compares the contractor's and LADOTD's validation data for the wearing and binder course HMA mixtures. There were two parameters shown in Table 6 with statistical differences noted for the wearing course mixture. These parameters were the percent asphalt cement content and the 12.5mm sieve gradation. It is shown in Table 6 that the mean value for the 12.5mm sieve is relatively close between the contractor and LADOTD at 77 and 78 percent, respectively. However, the standard deviation of the test results is higher for the LADOTD data than the contractor at 2.95 and 1.14, respectively. It is noted that the *%VMA* for the wearing course mixture was produced 2.3 percent higher than the minimum specification limit of 13.0 percent. It is also indicated that the wearing course HMA mixture percent air voids was 0.5 percent higher than the design parameter of 4.0 percent. Table 6 also indicates that there was one parameter showing a statistical difference between the contractor's and LADOTD's binder course validation data, the percent asphalt cement content.

Table 7 presents the results of the stepwise statistical analysis of the physical properties for the wearing and binder course layers that significantly affect volumetrics. In general, the percent asphalt cement, and the percent passing the 19.0 mm, 9.5 mm, and 0.075 mm sieves significantly affected plant volumetrics (*VMA*, *VFA*, $V_a$). Table 7 shows that *VFA* was a significant variable for roadway air voids, $RV_a$, *VMA*, $V_a$, and the percent passing the 1.18 mm sieve had also an influence on roadway air voids for the binder course mixture. It is noted that the percent passing the 0.300 mm sieve was significant in terms of *VMA* for the binder course mixture. In addition, the percent passing the 1.18 mm sieve was a significant variable in terms of *VMA*. The percent passing the 4.75 mm sieve was significant for the *VFA* and $V_a$ for the binder course mixture.

Table 8 indicates the results of the stepwise statistical analysis of the physical properties for the wearing and binder course layers that significantly affect pavement performance parameters as defined by rutting, random cracking, and *IRI*. In general, it is shown that the roadway air voids $RV_a$, the percent passing the 19.0 mm and 9.5 mm sieves significantly affected pavement performance parameters in terms of *IRI*, random cracking, and rutting. In addition, it is noted that *VFA* significantly affected random cracking.

## Roadway Density Statistics

Table 9 presents the roadway statistics for all projects evaluated in this study. It is shown that the average densities as a percentage of the theoretical maximum density for both mix types were 92.5, 93.4, and 94.2 for US 61, LA 121, and US 90, respectively. It is also shown that the standard deviation and % C.V. for LA 121 wearing and binder course, which is a Level 1 mix design, was the most

**Table 7.** Aggregates Properties that Significantly Affect Mix Volumetrics at 95% Confidence Level

| Pavement Layer \ Volumetric Properties | *VFA* | *VMA* | $V_a$ | $RV_a$ |
|---|---|---|---|---|
| Wearing Course | %P19.0<br>%P0.075<br>%AC | %P9.5<br>%P0.075<br>%P1.18 | %P0.075<br>%AC | *VFA*<br>%P0.300 |
| Binder Course | %P19.0<br>%P9.5<br>%P4.75 | %P1.18<br>%P0.075<br>%AC | %P19.0<br>%P9.5<br>%P4.75 | *VFA*<br>*VMA*<br>$V_a$<br>%P1.18 |

%P19.0: Percent passing 19.0 mm sieve,
%P9.5: Percent passing 9.5 mm sieve,
%P4.75: Percent passing 4.75 mm sieve,
%P1.18: Percent passing 1.18 mm sieve,
%P0.300: Percent passing 0.300 mm sieve,
%P0.075: Percent passing 0.075 mm sieve,
$RV_a$: Roadway Air Voids,
$V_a$: Plant Air Voids

**Table 8.** Physical Properties that Significantly Affect Pavement Performance at 95% Confidence Level.

| Pavement Layer \ Performance Parameter | Rutting | Random Cracking | *IRI* |
|---|---|---|---|
| Wearing Course | %P4.75<br>$RV_a$<br>%P19.0 | $RV_a$<br>%P0.075<br>*VFA* | $RV_a$<br>%P9.5<br>%AC |
| Binder Course | %P2.38<br>%P9.5<br>%P1.18<br>%P19.0 | %P19.0<br>$RV_a$ | %P9.5<br>%P19.0<br>$RV_a$ |

% P19.0: Percent passing 19.0 mm sieve
%P9.5: Percent passing 9.5 mm sieve
%P4.75: Percent passing 4.75 mm sieve
%P1.18: Percent passing 1.18 mm sieve
%P2.36: Percent passing 2.36 mm sieve
%P200: Percent passing 0.075 mm sieve
$RV_a$: Roadway Air Voids

**Table 9.** Roadway Density Statistics.

| | Mixture Types | Average % Density | Standard Deviation | % C.V. |
|---|---|---|---|---|
| US 61 | Binder Course | 92.5 | 1.46 | 1.57 |
| | Wearing Course | 92.4 | 0.87 | 0.94 |
| | Both Mixtures | 92.5 | 1.29 | 1.39 |
| LA 121 | Binder Course | 93.1 | 1.18 | 1.27 |
| | Wearing Course | 93.8 | 1.01 | 1.08 |
| | Both Mixtures | 93.4 | 1.15 | 1.23 |
| US 90 | Binder Course | 93.7 | 3.62 | 3.87 |
| | Wearing Course | 94.6 | 1.72 | 1.82 |
| | Both Mixtures | 94.2 | 2.67 | 2.83 |
| All Projects | All Mix Types | 93.3 | 2.01 | 2.15 |

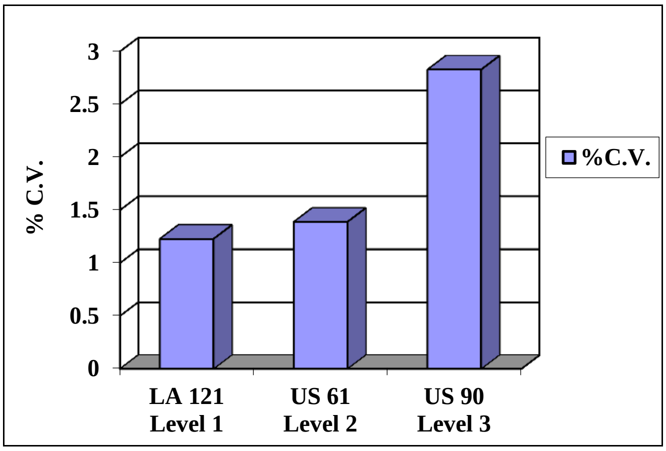



**Fig. 1.** Roadway Density, % C.V.

consistent and had the lowest variability. Table 9 shows that US 90 had the highest roadway density and highest variability in terms of standard deviation and % C.V. of all HMA mixtures evaluated.

Fig. 1 shows the combined % C.V. for both mixtures for each project evaluated. As shown in this figure, as the SGC levels increased, the roadway density variability also increased. Metcalf et al. examined and reported the statistical analysis of HMA data collected from 1987 to 1995 as acquired from Louisiana's Material's Test Data (MATT) reporting system [9]. The purpose of the MATT reporting system is to archive all materials and construction data. Louisiana was one of the first states to study the statistical variability of asphaltic concrete and in 1971 developed and adopted a statistically-based specification using historical data. Metcalf et al. reported that the standard deviation for the percent passing gradation parameters for the 4.75 mm and 0.075 mm sieves as 3.7 percent and 0.90 percent, respectively. The historical records indicate that the roadway density standard deviation from 1987 to 1995 is approximately 1.9 percent.

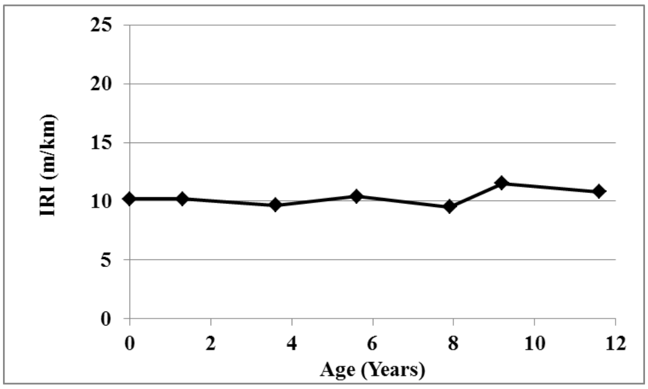
In review of the standard deviations for all mix types and roadway density, the 4.75 mm sieve and the 0.075 mm sieve were all within historical data standard deviations, as reported by Metcalf et al. It was noted that the highest standard deviations recorded for the 4.75 mm sieve and the 0.075 mm sieve were 3.38 percent and 0.54 percent, respectively. The overall roadway density standard deviation was reported as 2.01 percent, which are slightly higher than the historical value, 1.9 percent, reported by Metcalf et al.

## Field Evaluation Performance Tests and Observations

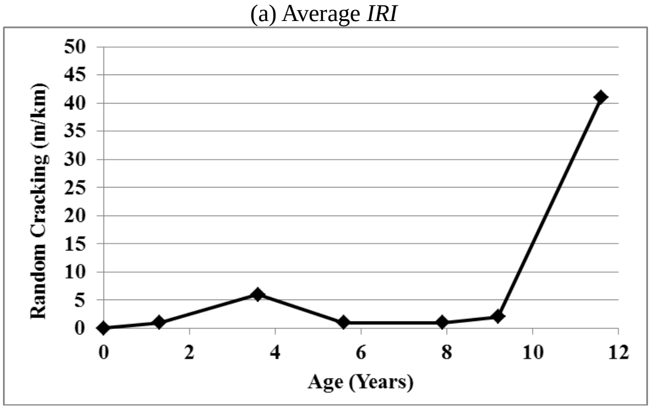
### *Data Analysis*

Comparisons of the field performance of pavements were achieved using data acquired from Louisiana's PMS in which the IRI, rut-depth measurements, and crack data are recorded. The assumed data shown for year zero (just after construction) was assumed that the IRI for each project would have been no worse than the first measured data point after construction. Likewise, it was assumed that there was no cracking or rutting in initial year of construction since these projects were completed in that year.

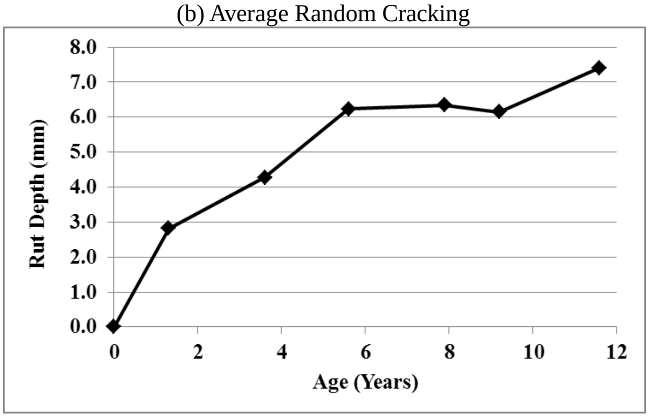
Fig. 2 presents the pavement performance as measured by *IRI*, random cracking, and rutting for Route US 61. Fig. 2(a) presents pavement performance as measured by the average *IRI* in meter per kilometer (m/km). From time of construction to approximately 11.5 years after construction, there was an increase in *IRI* from 10 m/km to 11 m/km, respectively. It is noted that the consistency of the *IRI* over the first 7.5 years is a direct reflection of having virtually no cracking during that time period, as indicated in Fig. 2(b). Fig. 2(b) shows the pavement performance as measured by the average meter per kilometer (m/km) of random cracks. It is noted in Fig. 2(b) that there is a peak in the data. This peak may be a sensitivity error or possibly an error in the interpretation of data in terms of identifying random cracking. The PMS section includes both longitudinal and transverse cracking as random cracking. As shown in Fig. 2(b), from year 7.5 to year 11.5, there was significant cracking, which directly influenced the increase in *IRI*. Fig. 2(b) illustrates that at 11.5 years, the measured value for random cracking was 41 m/km. Fig. 2(c) illustrates the pavement performance as measured by average




(a) Average *IRI*

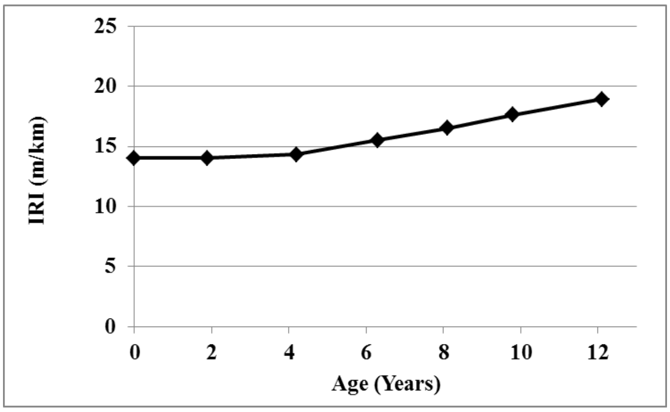



(b) Average Random Cracking



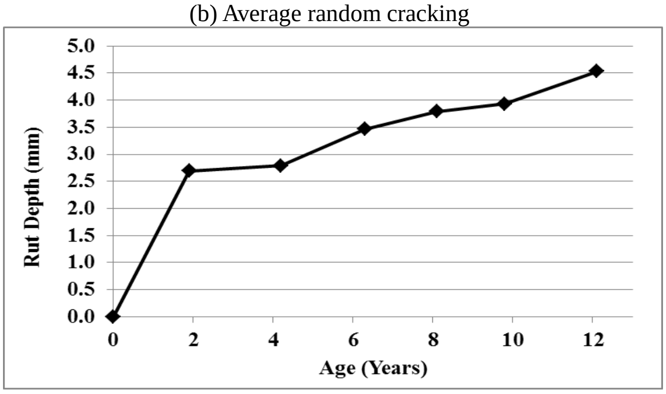

(c) Average rut depth

**Fig. 2.** US 61 Average *IRI*, Random Cracking, and Rutting.



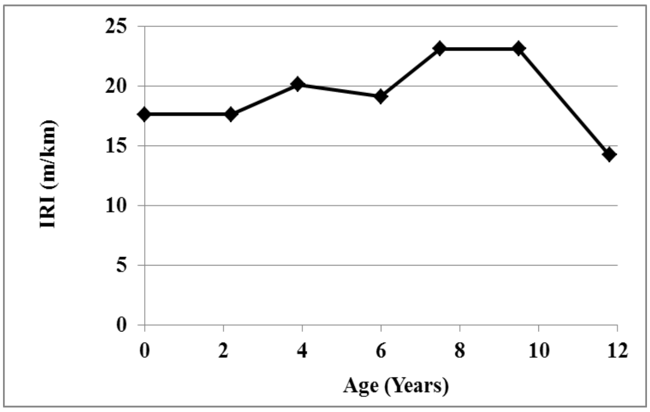

(a) Average *IRI*


(b) Average random cracking



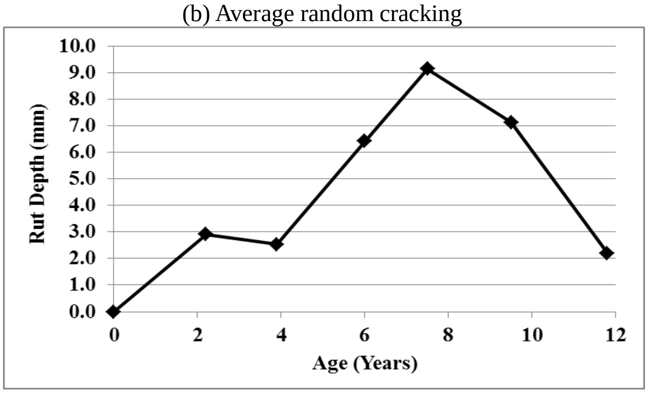

(c) Average rut depth

**Fig. 3.** LA 121 Average *IRI*, Random Cracking, and Rutting.




(a) Average *IRI*


(b) Average random cracking




(c) Average rut depth

**Fig. 4.** US 90 Average *IRI*, Random Cracking, and Rutting.

millimeter (mm) of rutting. It is shown that US 61 has a maximum of 7.41 mm of rutting in year 11.5.

Fig. 3 presents the pavement performance as measured by *IRI*, random cracking, and rutting for Route LA 121. Fig. 3(a) shows the pavement performance as measured by average *IRI*. It is observed that there is an increased rate of change in *IRI* since construction completion from 14 m/km to 19 m/km. The *IRI* increased 5 m/km over the 12-year performance period. It is noted that this project was an in-place cement stabilized base course with a two-lift HMA structural overlay. The increase in *IRI* is consistent with the adverse effects associated with the increase in random cracking due to reflective block cracking due to cement-stabilized base course shrinkage cracking.

Fig. 3(b) illustrates the pavement performance as measured by the average m/km of random cracks. It is observed that there is an increase in rate of change in the random cracking within the project limits over the 12-year evaluation period. This change can be associated with the effects of reflective cracking from cement-stabilized base course shrinkage cracking. In year 12, the measured value for random cracking was 415 m/km, which is a rate of increase of 34.30 m/km per year. It is shown that there is a peak in the data at year 2 and then a decrease in year 4. PMS data indicates that significant patching was performed between year 2 and year 4 which reduced the random cracking value as indicated in year 4. Fig. 3(c) presents pavement performance as measured by the average mm of rutting. The measured rutting value for year twelve was 4.53 mm, as shown in Fig. 3(c).

Fig. 4 presents the pavement performance as measured by *IRI*, random cracking, and rutting for Route US 90. Fig. 4(a) presents pavement performance as measured by average *IRI* in m/km. It is shown that there was an increase in *IRI* of 6 m/km per year for the first 7.5 years after initial construction. For the next two years, there was no change in *IRI*. From year 9.5 to year 12, there was a decrease in *IRI* of 9 m/km. This decrease is the result of this project being reconstructed in year 12. Fig. 4(b) illustrates pavement performance as measured by average m/km of random cracks. At year four, it is noted that there is a spike in the data followed by a decrease. It was determined that this spike is the result of data error and subsequent interpretation of data. In addition, data showed that there was high variability in the measurements, which may account for the unusually high recording. The measured data for year four also indicated much higher values for all cracking types recorded in the PMS. Beginning in year six to year 7.5, there was a steady increase in cracking, 5.7 m/km per year. This was followed by a decrease in random cracking. This is due to maintenance patching activities from year 7.5 to year 12 at the time of reconstruction. Fig. 4(c) presents the pavement performance as measured by average mm of rutting for Route US 90. It is shown that there was a steady increase in rutting from time of construction to year 7.5. The maximum rutting of 9.14 mm was recorded at year 7.5. As shown in Fig. 4(c), there was a decrease in rutting from year 7.5 to year 12 because of maintenance patching activities and reconstruction at year 12.

## Conclusions

This study presents the evaluation of initial Superpave projects in Louisiana completed in 1999. The JMF plant data as measured by LADOTD and the contractor were compared to determine if there was a statistical difference between the two data sets. In addition, this research ascertained if there was a relationship between the production data, roadway density, and actual field performance measured by random cracking, rutting, and *IRI*. Key findings can be drawn from the analyses of mixtures as follows:

- It was determined that, as the SGC levels increased, the variability in roadway density increased.
- LA 121 is exhibiting the most random cracking. The increase in random cracking is adversely affecting the *IRI* by causing an increase in *IRI* over time. The increased random cracking was associated with soil cement reflective cracking.
- There were no statistical differences noted in the US 61 wearing course validation data, LA 121 wearing course validation data, and US 90 binder course production data. In general, the contractor’s test results are less variable than LADOTD.
- VFA showed the highest variability between volumetric parameters (*VMA*, *VFA*, and $V_a$) evaluated. In addition, *VFA* significantly affected roadway air voids, $RV_a$.
- Percentage passing the 19.0 mm, 9.5 mm, and 0.075 mm sieves significantly affected *VMA*, *VFA*, and $V_a$.
- It was shown that the roadway air voids, and the percentage passing the 19.0 mm and 9.5 mm sieves significantly affected pavement performance parameters in terms of *IRI*, random cracking, and rutting. In addition, *VFA* significantly affected random cracking.

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