# Evaluation of Field Projects Using Crumb Rubber Modified Asphaltic Concrete

**by**

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LTRC / LOUISIANA STATE UNIVERSITY

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In 1994, the Louisiana Department of Transportation and Development (LADOTD) initiated a research project to evaluate different crumb-rubber modified (CRM) applications in which the long-term pavement performance of the CRM asphalt pavements was compared to that of the control sections built with conventional asphalt mixtures. This report presents a laboratory, construction, and field performance evaluation study of several applications of CRM hot-mix asphalt in Louisiana. Eight CRM asphalt pavement sections were constructed using eight different CRM processes or applications. Five state highway projects were selected to construct these eight CRM sections. A control section was built with conventional asphalt mixtures on each project to compare the field performance of pavement sections built with CRM asphalt mixtures. To evaluate the mixture characteristics of the CRM and conventional mixes, laboratory tests of Marshall stability and flow, indirect tensile strength (ITS) and strain, and indirect tensile resilient modulus ($M_R$) were conducted on field compacted Marshall specimens. Comparisons of the construction and field performance of the pavements were achieved through roadway core air void analysis, rut-depth measurement, international roughness index (IRI), pavement structure numbers measured through the DYNAFLECT system, and Quality Control data. Also, the final field performance evaluation used visual data acquired from Louisiana's Pavement Management Section in which the international roughness index (IRI), rut-depth measurements, and crack data were evaluated. Also, visual inspection of cracks was reported. The result of this study indicated that the conventional mixtures exhibited higher laboratory strength characteristics than the CRM mixtures. The pavement sections constructed with CRM asphalt mixtures showed overall better field performance indices (rut depth, random cracks, and IRI numbers) than corresponding control sections. Both CRM modified, wet and dry, hot mix asphalt (HMA) mix types are performing equally well, if not better, than the conventional mix types evaluated.

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# ABSTRACT

In 1994, the Louisiana Department of Transportation and Development (LADOTD) initiated a research project to evaluate different crumb-rubber modified (CRM) applications in which the long-term pavement performance of the CRM asphalt pavements was compared to that of the control sections built with conventional asphalt mixtures.

This report presents a laboratory, construction, and field performance evaluation study of several applications of CRM hot-mix asphalt in Louisiana. Eight CRM asphalt pavement sections were constructed using eight different CRM processes or applications. Five state highway projects were selected to construct these eight CRM sections. A control section was built with conventional asphalt mixtures on each project to compare the field performance of pavement sections built with CRM asphalt mixtures.

To evaluate the mixture characteristics of the CRM and conventional mixes, laboratory tests of Marshall Stability and flow, indirect tensile strength (ITS) and strain, and indirect tensile resilient modulus ($M_R$) were conducted on field compacted Marshall specimens.

Comparisons of the construction and field performance of the pavements were achieved through roadway core air void analysis, rut-depth measurement, international roughness index (IRI), pavement structure numbers measured through the DYNAFLECT system, and Quality Control/Quality Acceptance (QC/QA) data[1]. Also, the final field performance evaluation used visual data acquired from Louisiana's Pavement Management Section in which the international roughness index (IRI), rut-depth measurements, and crack data were evaluated. Also, visual inspection of cracks was reported.

The result of this study indicated that the conventional mixtures exhibited higher laboratory strength characteristics than the CRM mixtures. The pavement sections constructed with CRM asphalt mixtures showed overall better field performance indices (rut depth, random cracks, and IRI numbers) than corresponding control sections. Both CRM modified, wet and dry, hot mix asphalt (HMA) mix types are performing equally well, if not better, than the conventional mix types evaluated.

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# IMPLEMENTATION STATEMENT

Based on the findings of this research, it is recommended that HMA and asphalt cement binder specifications be developed and implemented to allow the use of the CRM wet process in HMA. The CRM wet process has proven to be an excellent method for reducing crack propagation due to random cracking through actual pavement performance and its use should increase the life-cycle of HMA pavements. This process also indicated the ability to be self-healing in the wheel paths based on visual inspection of LA 15. Random and transverse cracks were evident between and on each side of the wheel paths, but not visible in the wheel paths themselves. This process will be able to compete with Louisiana's current practice of using paving fabrics and grids to reduce pavement reflective cracking.

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# INTRODUCTION

The use of crumb-rubber modifier (CRM) in hot-mix asphalt mixtures can be traced back to the 1840s when natural rubber was introduced into bitumen to increase its engineering performance [1]. Since the 1960s, researchers and engineers have used shredded automobile tires in hot-mix asphalt (HMA) mixtures for pavements.

In the 1960s, Charles H. McDonald pioneered the development of the wet process (or reacted) crumb rubber modified asphalt cement binders in the United States. In 1963, McDonald first used CRM asphalt cement binders for a patching material in which he termed the operation as a "band-aid" repair technique in Phoenix, Arizona. The CRM asphalt binder was spray applied and then covered with a "localized chip seal" placed by hand over a small pavement area. The first "large area" spray application was done in 1967 which produced poor results because of the asphalt distributor's inability to spray high viscosity materials as seen in CRM asphalt cement binders. By changing the mixture components used in the modification of CRM asphalt cement binders and also by altering the asphalt distribution equipment, successful "large area" spray applications were placed in Arizona in the 1970s. These “large area” spray applications became known as stress-absorbing membranes (SAM). In 1972, Arizona DOT placed its first stress–absorbing membrane interlayer (SAMI) as part of a project to evaluate techniques to reduce reflection cracking. Arizona first placed hot-mix asphalt containing CRM asphalt cement was in 1975. Arizona DOT uses CRM asphalt binders for SAMIs and hot mix asphalt today. Arizona DOT and local governments in Arizona primarily use CRM asphalt cement binders in open-graded and gap-graded HMA mixtures. The use of CRM asphalt cement binders in open-graded friction courses is now the most popular use of this type of binder by the Arizona DOT [2].

Not until the late 1980s did the use of recycled tire crumb rubber in HMA mixtures became popular. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) specified that all asphalt pavement projects funded by federal agencies must use certain percentages of scrap tires [3, 4]. Although this mandate was later suspended from the ISTEA legislation, it has greatly encouraged the research and application of CRM asphalt in HMA pavement.

The processes of applying crumb-rubber in asphalt mixtures can be divided into two broad categories: a dry process and a wet process. In the dry process, crumb rubber is added to the aggregate before the asphalt binder is charged into the mixture. In the wet process, asphalt cement is pre-blended with the rubber at high temperature (177 – 210 $^{o}$C) and specific blending conditions. Crumb rubber particles in the dry process are normally coarser than those in the wet process and are considered as part of the aggregate gradations (called "rubber-filler") whereas, in wet process, fine crumb rubber powders react with asphalt binders (called "asphalt-rubber") and improve the binder properties. Common dry process methods include the PlusRide™, chunk rubber, and generic dry. Common wet process methods include the Arizona, McDonald, Ecoflex, and Rouse continuous blending methods [1].

The Federal Highway Administration (FHWA) and many state agencies have conducted numerous field studies for the feasibility of using recycled rubber tire products in HMA pavements. The National Cooperative Highway Research Programs (NCHRP) "Synthesis of Highway Practice 198 – Uses of Recycled Rubber Tires in Highways" provides comprehensive review of the use of recycled rubber tires in highways based on a review of nearly 500 references and on information recorded from state highway agencies' responses to a 1991 survey of current practices [5]. Florida DOT began constructing demonstration projects of asphalt pavement with CRM wet processes in 1989 and has reported satisfactory pavement performance [6]. They concluded that the addition of CRM would increase the asphalt film thickness, binder resiliency, viscosity, and shear strength. Virginia DOT constructed pavements containing CRM asphalt mixtures produced by two wet processes, McDonald and Rouse, and compared the pavement performance to that of conventional asphalt mixtures. Maupin [7] reported that the mixes containing asphalt rubber performed at least as well as conventional mixes. In Virginia mixes, the inclusion of asphalt rubber in HMA pavements increased construction costs by 50 to 100 percent as compared to the cost of conventional mixes [7]. Troy et al [8] conducted research on CRM pavements in Nevada. In their study, they evaluated a CRM binder using the Superpave binder testing protocols and conducted the mix design using the Hveem procedure. They concluded that the conventional sample geometry in Superpave binder test protocols cannot be used to test the CRM binders and that the Hveem compaction is inadequate for mixtures containing CRM binders.

The Louisiana Department of Transportation and Development (LADOTD) initiated a research project to evaluate different procedures of CRM applications in 1994 in which the long-term pavement performance of the CRM asphalt pavements was compared to that of the control sections built with conventional asphalt mixtures [9]. Huang et al. evaluated conventional and CRM asphalt mixtures through laboratory engineering performance tests such as indirect tensile strength (ITS) and indirect tensile resilient modulus ($M_R$) tests [10]. Marshall Stability and Flow tests were also conducted during the mixture design. Huang et al also compared field performance through the pavement structural non-destructive test of DYNAFLECT and long-term pavement performance measurement, such as roadway core density, International Roughness Index (IRI), rutting, and fatigue cracking. The conventional mixtures exhibited higher laboratory strength characteristics than the CRM mixtures. Also, the pavement sections constructed with CRM asphalt mixtures showed overall better performance indices (rut depth, fatigue cracks, and international roughness index numbers) than the corresponding control sections [10].

This report presents the laboratory, construction, and field performance evaluation study of several applications of crumb-rubber modified (CRM) hot-mix asphalt after eight to twelve years of field performance.

# OBJECTIVE

The objective of this study was to evaluate the mixture characteristics, construction, and long term field performance of asphalt pavements constructed with eight different CRM applications as opposed to the control sections built with conventional HMA mixtures.

# SCOPE

The scope of the study included the laboratory mixture characterization, construction, and field performance evaluation of eight CRM applications as follows:

- Arizona wet process incorporated into a gap-graded mixture;
- Arizona wet process incorporated into a stress absorbing membrane interlayer (SAMI);
- Arizona wet process incorporated into an open-graded friction course (OGFC);
- PlusRide™ dry process utilizing a gap-graded aggregate structure;
- Rouse powdered rubber wet process incorporated into a typical dense-graded mixture;
- A terminal-blended material formulated by Neste Wright in a dense-graded mixture;
- Rouse dry-powdered rubber process blended into a dense-graded aggregate structure;
- Generic CRM dry process incorporated into a gap-graded mixture.

Conventional and CRM asphalt mixtures were evaluated through laboratory engineering performance tests such as indirect tensile strength (ITS) and indirect tensile resilient modulus ($M_R$) tests. In addition, Marshall stability and flow tests were conducted during the mixture design.

Comparisons of construction and pavement field performance were achieved through QC/QA analysis, pavement structural non-destructive test of DYNAFLECT, and long-term pavement performance measurements, such as roadway core density, International Roughness Index (IRI), rutting and fatigue cracking. Also, visual inspection of cracks is reported.

# METHODOLGY

## Experimental Design

Figure 1 indicates the crumb rubber pavement test sections located on five various state routes throughout Louisiana.

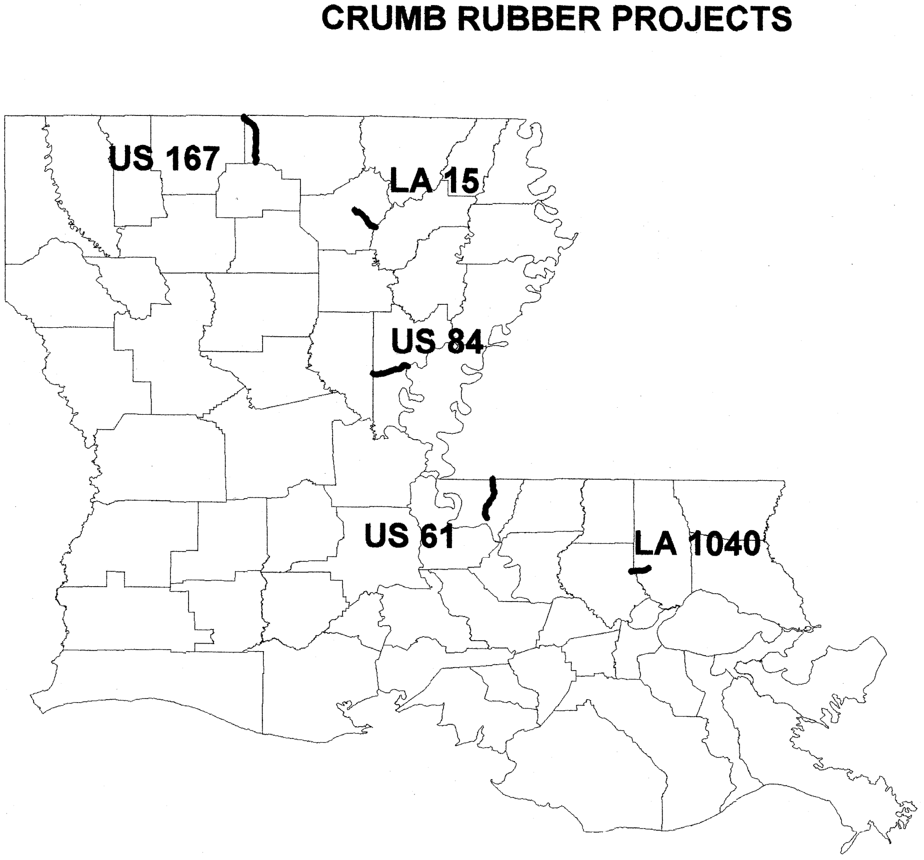

**Figure 1**
**Locations of crumb-rubber modified asphalt pavement**

Table 1 represents an informational project summary for each location.

## Table 1
## Project information summary sheet

| Project No. | Contractor | Traffic Data | | Work Order Date | Final Inspection Date | Description | Begin C.S.L.M. | END C.S.L.M. |
|---|---|---|---|---|---|---|---|---|
| | | Year/ADT | % Truck | | | | | |
| 019-05-0024 US 61 | F.G.Sullivan,Jr. | 1992/4000 | 20 | 10/12/ 1992 | 10/21/1993 | 1" OGFC (17.5% Arizona Wet) w/ AR Modified SAMI | 8.350 | 9.350 |
| | | | | | | CRM (17.5% Arizona Wet) Gap-Graded | 9.350 | 13.850 |
| | | | | | | Polymer Modified Gap-Graded Wearing | 13.850 | 14.850 |
| | | | | | | Conventional Dense-Graded | 14.850 | 15.850 |
| 832-23-0009 LA 1040 | Barber Bros. Contracting Co., Inc. | 1993/7500 | 9 | 2/21/1994 | 12/23/1994 | CRM (3% PlusRide, Dry) (832-23-0009) Gap-Graded | 0.000 | 1.360 |
| | | | | | | CRM (3% PlusRide, Dry) (853-10-0012) Gap-Graded | 0.000* | 3.057 |
| | | | | | | Conventional Dense-Graded | 3.057 | 4.800 |
| 022-06-0041 US 84 | D&J Construction Co., Inc. | 1994/8800 | 21 | 8/01/1994 | 8/08/1995 | CRM (5% Neste Wright, Wet) Dense-Graded | 3.669 | 5.658 |
| | | | | | | Conventional Dense-Graded | 5.658 | 7.784 |
| 026-10-0018 LA 15 | D&J Construction Co., Inc. | 1994/6250 | 10 | 10/17/1995 | 10/31/1995 | Conventional Dense-Graded | 0.000 | 1.726 |
| | | | | | | CRM (10% Rouse, Wet) Dense-Graded | 1.726 | 3.726 |
| | | | | | | CRM (17.5% Arizona Wet) Gap-Graded | 3.726 | 5.726 |
| 023-11-0028 US 167 | D&J Construction Co., Inc. | 1994/6200 | 15 | 5/15/1996 | 2/19/1997 | CRM (1% Rouse, Dry) Dense-Graded | 0.709 | 2.709 |
| | | | | | | CRM (2% Generic, Dry) Gap-Graded | 2.709 | 4.709 |
| | | | | | | Conventional Dense-Graded | 4.709 | 7.421 |

*New stationing at Parish Line.

Each project was constructed with one or two CRM asphalt sections and a control section comprised of a conventional HMA mixture (table 2). Also, US 61 was constructed with an additional pavement section comprised of a polymer gap-graded wearing course mixture.

| Route | CRM Section 1 | CRM Section 2 | Control Section | Additional Section |
|---|---|---|---|---|
| US 61 | 1.0" OGFC<br>17.5% Arizona Wet<br>& Asphalt Rubber<br>Modified SAMI | 1.5" Gap-graded WC<br>17.5% Arizona Wet | 1.5" Dense-graded<br>Conventional Type 8F WC<br>PAC 40HG | 1.5" Gap-graded<br>Wearing Course<br>PAC 40HG |
|  | Existing roadway | Existing roadway | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG | Existing roadway |
| LA 15 | 1.5" Dense-graded WC<br>10% Rouse Wet | 1.5" Gap-graded WC<br>17.5% Arizona Wet | 1.5" Dense-graded<br>Conventional Type 8F WC<br>PAC 40HG |  |
|  | 2.0" Dense-graded BC<br>10% Rouse Wet | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG |  |
| US 84 | 1.5" Dense-graded WC<br>5% Neste Wright Wet |  | 1.5" Dense-graded<br>Conventional Type 8F WC<br>PAC 40HG |  |
|  | 2.0" Dense-graded BC<br>5% Neste Wright Wet |  | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG |  |
| US 167 | 1.5" Gap-graded WC<br>2% Generic Dry | 1.5" Dense-graded WC<br>1% Rouse Dry | 1.5" Dense-graded<br>Conventional Type 8F WC<br>PAC 40HG |  |
|  | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG | 2.0" Dense-graded BC<br>1% Rouse Dry | 2.0" Dense-graded<br>Conventional Type 8 BC<br>PAC 40HG |  |
| LA 1040 | 1.5" Gap-graded WC<br>3% PlusRide™ Dry |  | 1.5" Dense-graded<br>Conventional Type 3 WC<br>AC 30 |  |
|  | 2.0" Dense-graded<br>Conventional Type 3 BC<br>AC 30 |  | 2.0" Dense-graded<br>Conventional Type 3 BC<br>AC 30 |  |

**Table 2**
**CRM test sections**

Table 3 presents a summary of experimental designs for the eight CRM applications as categorized by the CRM procedures. As indicated, six CRM products, which include dry and wet processes, were incorporated into eight CRM applications. The eight CRM applications were incorporated into various pavement sections and constructed on five different projects throughout the state as shown in figure 1.

**Table 3**
**Experimental design of CRM-HMA pavements**

| Process | CRM Products | CRM Applications | Route | Mix Function | Control Section Mixes |
|---|---|---|---|---|---|
| Wet | 17.5% Arizona Wet, (ISI) | SAMI | US 61 | Interlayer | N/A |
| | | OGFC | US 61 | WC | Dense-graded<br>Types 8F WC & 8 BC<br>PAC 40HG |
| | | Gap-graded | US 61 | WC | Dense-graded<br>Types 8F WC & 8 BC<br>PAC 40HG |
| | | | LA 15 | WC | Dense-graded<br>Type 8F<br>PAC 40HG |
| | 10% Rouse Wet | Dense-graded | LA 15 | WC, BC | Dense-graded<br>Types 8F WC & 8 BC<br>PAC 40HG |
| | 5% Neste Wright Wet | Dense-graded | US 84 | WC, BC | Dense-graded<br>Types 8F WC & 8 BC<br>PAC 40HG |
| Dry | 1% Rouse Dry | Dense-graded | US 167 | WC,BC | Dense-graded<br>Types 8F WC & 8 BC<br>PAC 40HG |
| | 2% Generic Dry | Gap-graded | US 167 | WC | Dense-graded<br>Type 8F<br>PAC 40HG |
| | 3% Plusride™ Dry | Gap-graded | LA 1040 | WC | Dense-graded<br>Type 3<br>AC 30 |

Note: WC – wearing course; BC – binder course; SAMI – Stress Absorbing Membrane Interlayer; ISI – International Surfacing Inc.; OGFC – Open-graded Friction Course

A detailed description of the CRM asphalt pavement in the five field projects follows:

- In US 61, comparisons were made between the polymer modified gap-graded wearing course mixtures, two alternative applications of Arizona Wet processed CRM mixtures, and a conventional polymer modified dense-graded wearing course mixture. The two alternative CRM sections were:
  - Gap-graded wearing course mixture blended with 17.5 percent Arizona Wet Process;
  - Gap-graded wearing course mixture (open-graded friction course (OGFC)) blended with 17.5 percent Arizona Wet process placed on the top of stress-

    absorbing membrane interlayer (SAMI) blended with 17.5 percent Arizona Wet CRM.

- In LA 15, the control section consisted of dense-graded conventional wearing and binder mixtures. The control section was compared with:
    - CRM mixtures with 10 percent Rouse Wet Process on the wearing and binder mixtures that had similar gradations as the control mixtures;
    - Gap-graded CRM wearing mixtures with 17.5 percent Arizona Wet Process on the top of the same conventional binder mixture as the control section.
- In US 84, the comparison was made between the conventional dense-graded mixtures (control section) and the CRM mixtures with the similar gradations and processed with 5 percent Neste Wright Wet Process.
- In US 167, the control section consisted of conventional dense-graded wearing and binder mixtures. The control section was compared with:
    - Gap-graded CRM wearing mixture processed with 2 percent Generic Dry Process on the top of the same conventional binder mixture;
    - CRM dense-graded wearing and binder mixtures processed with 1 percent Rouse Dry, which had similar gradations to the control section mixtures.
- In LA 1040, the comparison was made between the control section that had conventional dense-graded wearing and binder mixtures and the CRM section that replaced the conventional wearing course mixture with a gap-graded CRM mixture processed with 3 percent PlusRide™ Dry.

## Material Properties and Mixture Design

### Asphalt Cement

Two types of original asphalt cement, a conventional viscosity graded AC 30 and an SB polymer modified asphalt cement PAC 40HG, were used to produce conventional asphalt mixtures. Three types of CRM were blended into the conventional AC 30 asphalt cement at different percentages to form six different asphalt rubber (wet) applications.

Table 4 presents the properties of the conventional, polymer-modified, and CRM asphalt cements as tested.

**Table 4**
**Conventional asphalt cement and asphalt-rubber cement properties**

| Description | AC 30 | AC 10 + 17.5% Arizona Wet | AC 30 + 10% Rouse | AC 30 + 5% NW | PAC 40HG | AASHTO Method |
|---|---|---|---|---|---|---|
| Original Binder | | | | | | |
| Rotational Viscosity: Brookfield, Pa·s 135 ºC | 0.463 | 5.475 | 3.10 | 1.112 | 1.05 | TP48 |
| Dynamic Shear Rheometer, DSR, G*/sinδ, kPa | | | | | | |
| 64 ºC | 1.7274 | | 3.1 | 2.9 | | TP5 |
| 70 ºC | 0.8405 | | 2.4 | 1.6 | 1.9 | TP5 |
| 76 ºC | | 3.3 | 0.9 | 0.88 | 1.0 | TP5 |
| 82 ºC | | 2.8 | | | | |
| RTFO (TFO for Asphalt Rubber) | | | | | | |
| % Loss | | 0.34 | 0.1 | 0.011 | 0.187 | TP240 |
| 64 ºC | | | 6.6 | 4.4 | | TP5 |
| 70 ºC | 2.2942 | 6.7 | 3.2 | 2.2 | 3.2 | TP5 |
| 76 ºC | | 4.8 | 1.7 | 1.3 | 1.9 | TP5 |
| 82 ºC | | 3.8 | | | | |
| PAV | | | | | | |
| DSR, G*·sinδ, kPa, @10 rad/s, (25 ºC) | 3628 | 3564 | 2123 | 1353 | 3175 | TP5 |
| BBR Creep Stiffness, S, Mpa | 238 | | | | 99 | TP5 |
| BBR Creep Slope, m value | 0.310 | | | | 0.452 | TP5 |

## Aggregate

Three types of aggregates (limestone, sandstone and crushed gravel) were used to make the HMA mixtures in this study. These aggregates are commonly used in highway construction in Louisiana. They all met the Louisiana contract specifications [11] for these projects.

## CRM Product

Five types of CRM were considered in this research. A 16-mesh CRM made by International Surfacing Inc. (ISI), a Rouse-80 powder, and a Neste Wright powder were used in the terminal blending wet process. A 16-mesh generic crumb rubber and a PlusRide™ shredded rubber were used in the dry process. Also, the same Rouse-80 powder material used in the wet process was also used as a dry process on US 167.

Table 5 presents the gradations of these CRM products and their applications in this research.

**Table 5**
**CRM powder (chunk) gradations and applications**

| Products | | ISI | Rouse | Generic | Neste Wright | PlusRide™ |
|---|---|---|---|---|---|---|
| Applications | | Arizona Wet Gap-graded (US 61 WC, LA 15 WC)<br>Arizona Wet SAMI (US 61)<br>Arizona Wet OGFC (US 61) | Rouse Wet Dense-graded (LA 15 WC, BC)<br>Rouse Dry Dense-graded (US 167) | Generic Dry Gap-graded (US 167) | Neste Wright Wet Dense-graded (US 84 WC & BC) | PlusRide™ Dry Gap-graded (LA 1040 WC) |
| Percent Passing (%) | ¼” | | | | | 100 |
| | #4 | | | | | 80 |
| | #8 | 100 | | | | |
| | #10 | 97 | | 100 | | 41 |
| | #16 | 50 | | 85 | | |
| | #20 | | | | 100 | 23 |
| | #30 | 10 | | 43 | | |
| | #40 | | 100 | | 80 | |
| | #50 | 5 | 99 | 10 | | |
| | #80 | | 94 | | | |
| | #100 | | 83 | | | |
| | #200 | | | 3 | | |

## Mixture Design

The Marshall Design procedure was used to determine the optimum asphalt content of the asphalt mixtures. The design criteria were set by the “Louisiana Standard Specifications for Roads and Bridges” in addition to the special provisions set for these projects [11].

Table 6 presents the gradations and the mix design properties for US 61 wearing and binder course mixtures. It is shown that the flow properties and the percent asphalt cement (%AC) for the CRM wearing course is higher than the conventional mixes. The OGFC had the lowest stability, and the highest VMA and air voids. The OGFC had the least amount of material passing the 200 sieve, while the polymer gap-graded had the highest, 3.3 and 11.0, respectively.

**Table 6**
**US 61 job mix formulas and volumetric properties**

| | Wearing Course | | | | Binder Course | |
|---|---|---|---|---|---|---|
| | **Polymer Gap-Graded** | **17.5% Arizona Wet CRM Gap-Graded** | **17.5% Arizona Wet CRM OGFC** | **Conventional Dense-Graded** | **Conventional Dense-Graded** | |
| **Spec. Gravity** | 2.298 | 2.231 | 2.089 | 2.444 | 2.436 | |
| **Theo. Gravity** | 2.368 | 2.312 | 2.302 | 2.529 | 2.521 | |
| **% Theor. Gravity** | 97.0 | 96.3 | 90.7 | 96.6 | 96.6 | |
| **% VMA** | 17.1 | 18.1 | 27.6 | 13.1 | 12.6 | |
| **% VFA** | 82 | 81 | 66 | 74 | 73 | |
| **% VOIDS** | 3.0 | 3.5 | 9.3 | 3.4 | 3.4 | |
| **Stability (LBS)** | 2115 | 2050 | 1010 | 2191 | 2060 | |
| **Flow (1/100)** | 11 | 24 | 32 | 10 | 10 | |
| **% AC** | 6.3 | 8.4 | 9.0 | 4.1 | 3.9 | |
| | | | | | | |
| **Sieve** | **Gradation Analysis** | | | | | |
| **¾”** | 100 | 100 | 100 | 100 | 100 | |
| **½”** | 93 | 93 | 91 | 94 | 98 | |
| **3/8”** | 71 | 71 | 65 | 81 | 86 | |
| **No. 4** | 35 | 35 | 23 | 60 | 59 | |
| **No.10** | 21 | 19 | 9 | 38 | 39 | |
| **No. 40** | 14 | 10 | 5 | 22 | 22 | |
| **No. 80** | 12 | 7 | 4 | 9 | 9 | |
| **No. 200** | 11.0 | 5.3 | 3.3 | 6.0 | 6.2 | |

Figure 2 illustrates the 0.45 power curve gradation charts for the US 61 wearing and binder course mixtures. Figure 2a shows that the conventional dense-graded mixture is above the maximum density line; hence, it is a fine mixture. The polymer gap-graded mixture lies below the maximum density line as well as the remaining wearing courses; therefore they are all coarse mixes. This figure also illustrates that the OGFC is the coarsest wearing course. Figure 2b indicates that the conventional dense-graded binder course mixture is a fine mixture because the gradation band lies above the maximum density line.

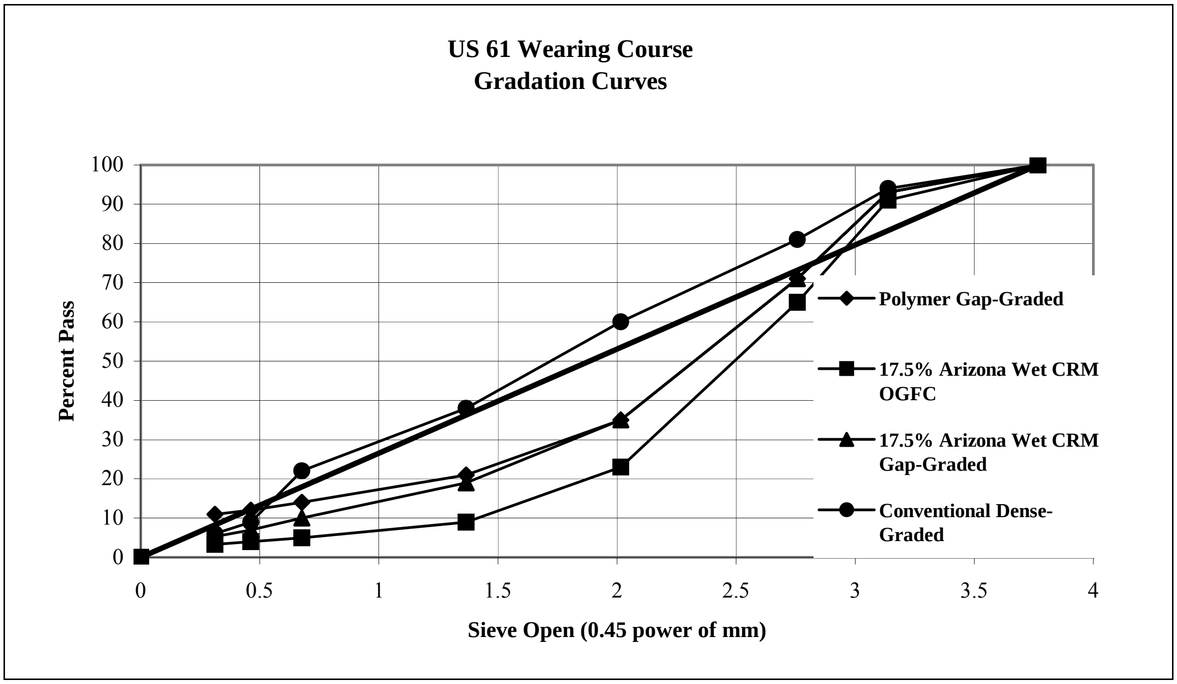

Figure 2a US 61 wearing course

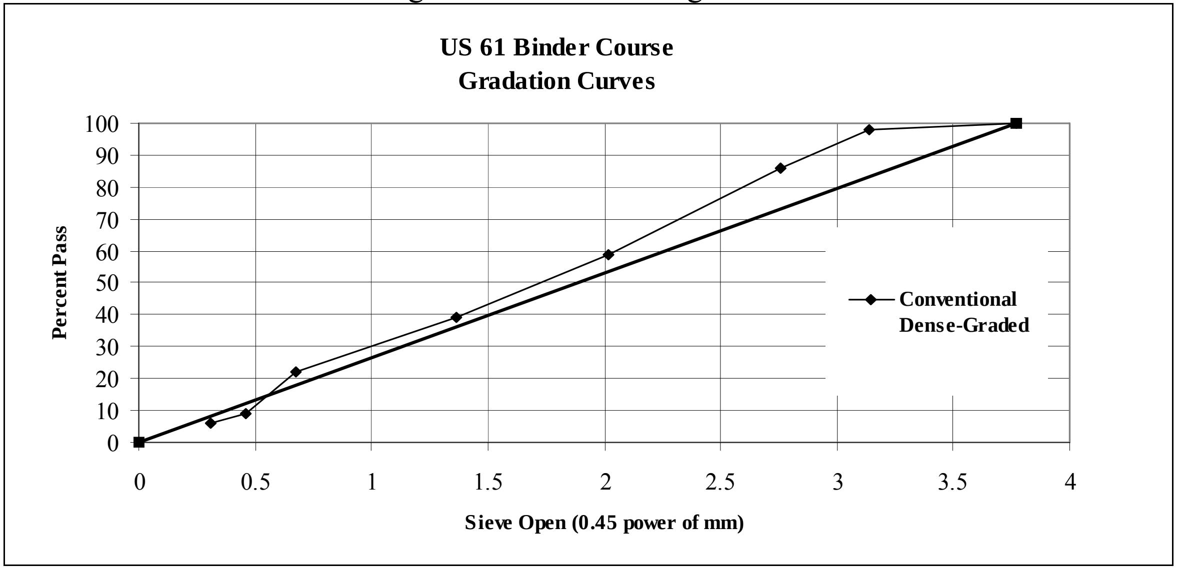

Figure 2b US 61 binder course

**Figure 2**
**US 61 wearing and binder course gradation curves**

Table 7 presents the gradations and the mix design properties for LA 1040 wearing and binder course mixtures. The %AC for the 3 percent PlusRide Dry CRM is higher than the conventional dense-graded wearing course mixture.

Figure 3 indicates the 0.45 power curve gradation charts for the LA 1040 wearing and binder course mixtures. Figure 3a shows that the conventional dense-graded mixture is a fine mixture. The gap-graded wearing course gradation band is below the maximum density line therefore it is a coarse mixture.

Figure 3b shows the 0.45 power curve gradation chart for the LA 1040 binder course mixture. This figure indicates the conventional dense-graded binder course used is a fine mixture.

**Table 7**
**LA 1040 job mix formulas and volumetric properties**

| | **Wearing Course** | | | | **Binder Course** | |
|---|---|---|---|---|---|---|
| | **Control Conventional Dense-Graded** | **3% PlusRide Dry CRM Gap-Graded** | | | **Conventional Dense-Graded** | |
| **Spec. Gravity** | 2.316 | 2.176 | | | 2.332 | |
| **Theo. Gravity** | 2.415 | 2.246 | | | 2.430 | |
| **% Theor. Gravity** | 95.9 | 97.0 | | | 96.0 | |
| **% VMA** | 15.6 | 19.1 | | | 16.2 | |
| **% VFA** | 73 | 84 | | | 75 | |
| **% VOIDS** | 4.1 | 3.0 | | | 4.0 | |
| **Stability (LBS)** | 2030 | 1600 | | | 2018 | |
| **Flow (1/100)** | 11 | 26 | | | 11 | |
| **% AC** | 5.5 | 8.2 | | | 5.4 | |
| | | | | | | |
| **Sieve** | **Gradation Analysis** | | | | | |
| **¾”** | 100 | 100 | | | 100 | |
| **½”** | 97 | 98 | | | 97 | |
| **3/8”** | 91 | 72 | | | 83 | |
| **No. 4** | 57 | 32 | | | 59 | |
| **No.10** | 37 | 22 | | | 38 | |
| **No. 40** | 21 | 14 | | | 21 | |
| **No. 80** | 9 | 12 | | | 9 | |
| **No. 200** | 5.7 | 10.2 | | | 5.7 | |

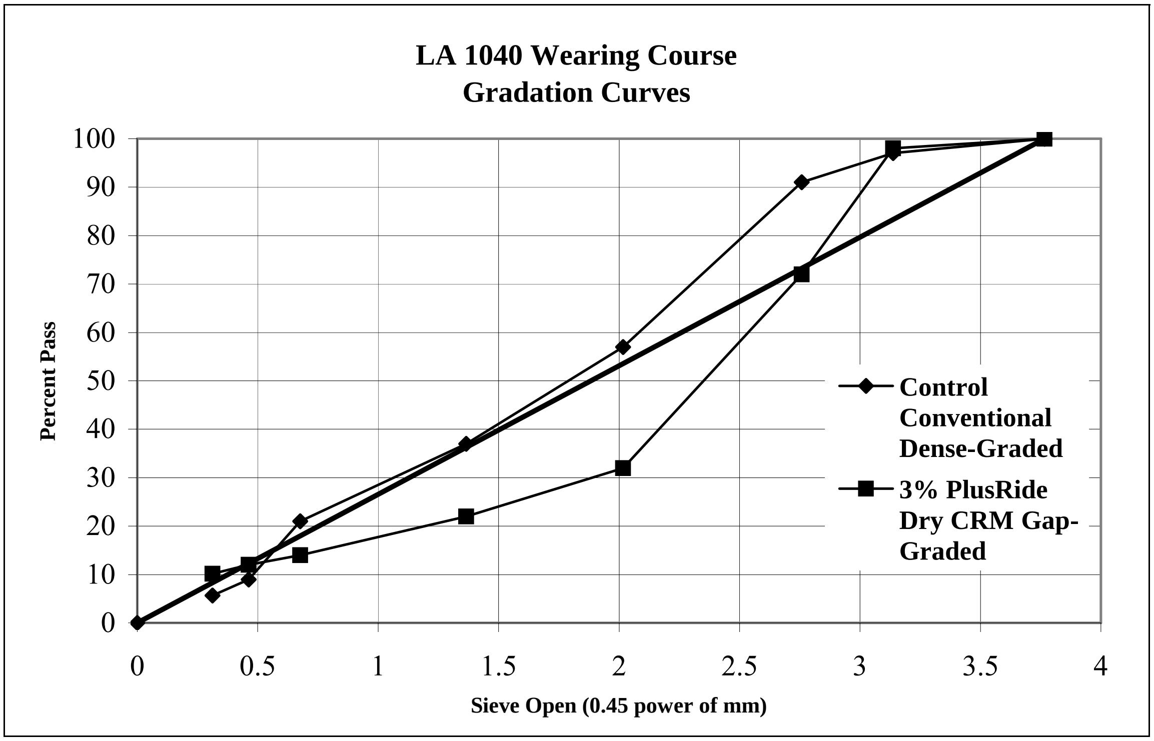

Figure 3a LA 1040 wearing course

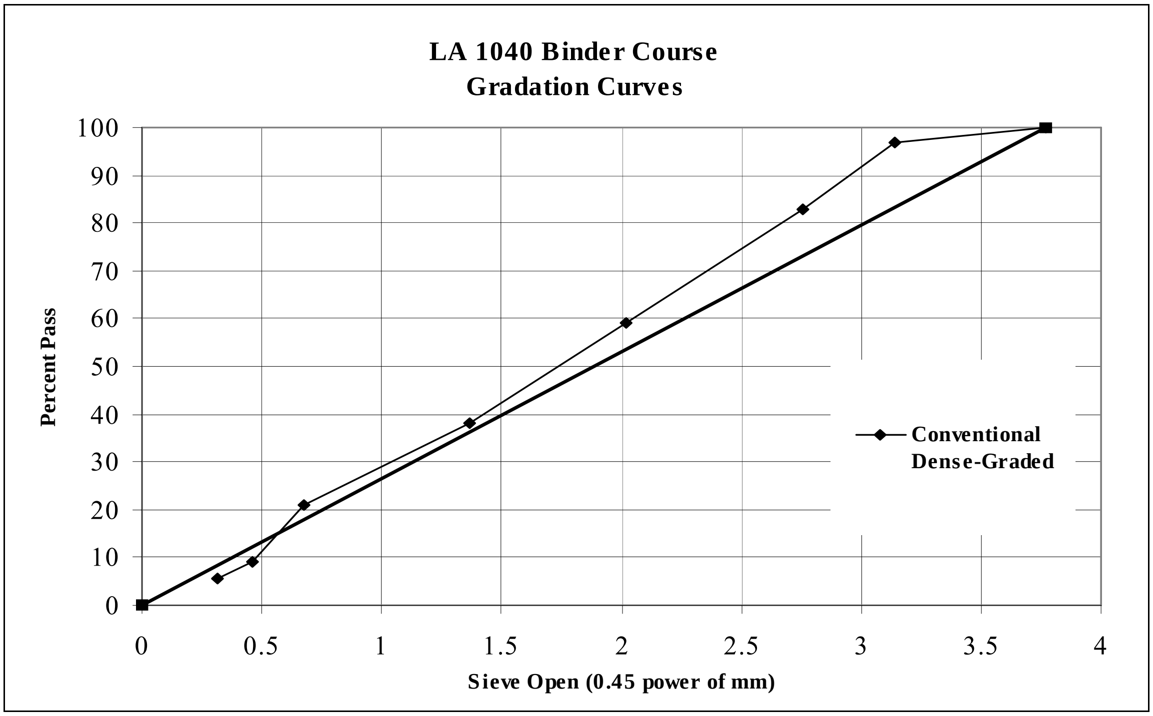

Figure 3b LA 1040 binder course

**Figure 3**
**LA 1040 wearing and binder course gradation curves**

Table 8 presents the gradations and the mix design properties for US 84 wearing and binder course mixtures. It is shown in this table that the %AC for the 5 percent Neste Wright Wet CRM wearing and binder course mixtures are similar with the conventional wearing and binder course mixes.

Figure 4 illustrates the US 84 wearing and binder course 0.45 power curve gradation charts. Figure 4a shows both dense-graded wearing courses used are fine mixtures. Figure 4b indicates that both dense-graded binder courses used were fine mixtures because the gradation bands for each are above the maximum density line.

**Table 8**
**US 84 job mix formulas and volumetric properties**

| | **Wearing Course** | | | | **Binder Course** | |
|---|---|---|---|---|---|---|
| | **Control Conventional Dense-Graded** | **5% Neste Wright Wet CRM Dense-Graded** | | | **Conventional Dense-Graded** | **5% Neste Wright Wet CRM Dense-Graded** |
| **Spec. Gravity** | 2.401 | 2.394 | | | 2.326 | 2.318 |
| **Theo. Gravity** | 2.480 | 2.477 | | | 2.424 | 2.420 |
| **% Theor. Gravity** | 96.8 | 96.6 | | | 96.0 | 95.8 |
| **% VMA** | 12.1 | 12.4 | | | 15.7 | 16.4 |
| **% VFA** | 74 | 73 | | | 74 | 74 |
| **% VOIDS** | 3.2 | 3.4 | | | 4.0 | 4.2 |
| **Stability (LBS)** | 2300 | 2400 | | | 2000 | 2000 |
| **Flow (1/100)** | 8 | 10 | | | 11 | 10 |
| **% AC** | 4.1 | 4.2 | | | 5.2 | 5.4 |
| | | | | | | |
| **Sieve** | **Gradation Analysis** | | | | | |
| **¾”** | 100 | 100 | | | 100 | 100 |
| **½”** | 94 | 94 | | | 92 | 94 |
| **3/8”** | 90 | 90 | | | 85 | 88 |
| **No. 4** | 64 | 64 | | | 62 | 64 |
| **No.10** | 39 | 39 | | | 41 | 41 |
| **No. 40** | 21 | 21 | | | 21 | 20 |
| **No. 80** | 12 | 12 | | | 13 | 13 |
| **No. 200** | 6.0 | 6.0 | | | 6.0 | 6.0 |

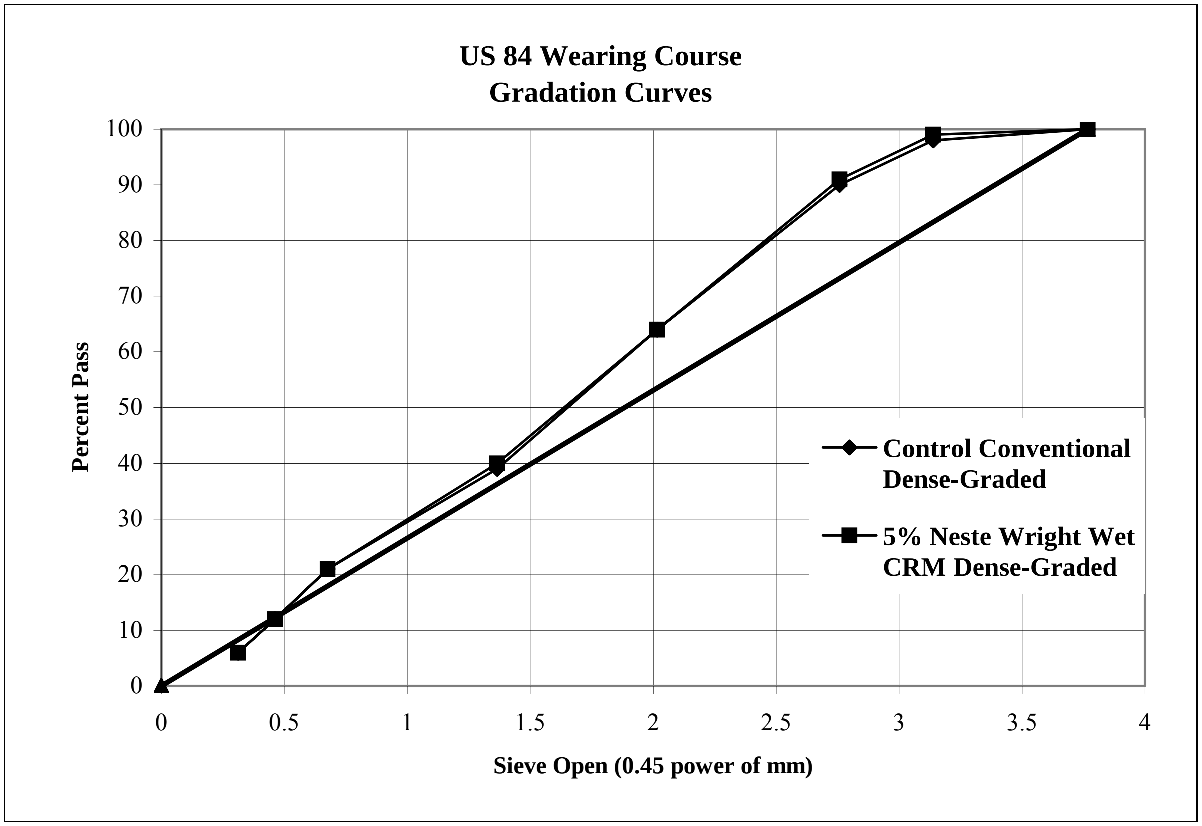

Figure 4a US 84 wearing course

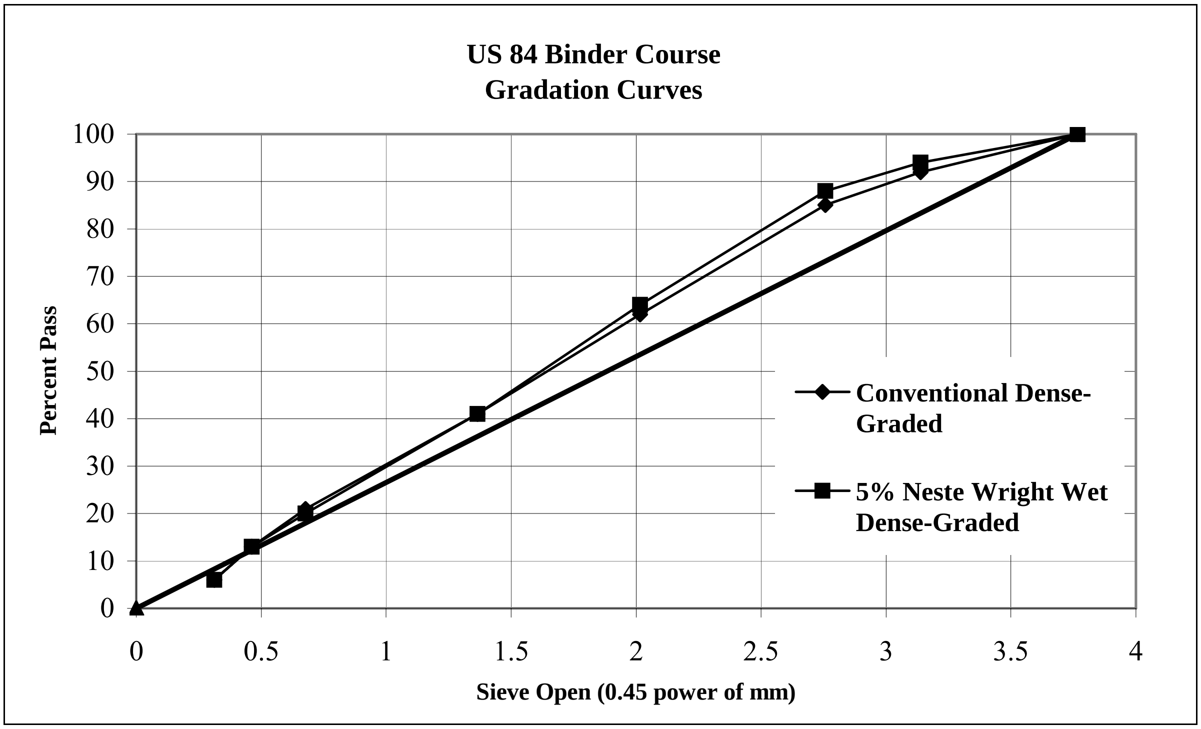

Figure 4b US 84 binder course

**Figure 4**
**US 84 wearing and binder course gradation curves**

Table 9 presents the gradations and the mix design properties for US 167 wearing and binder course mixtures. It indicates that the %AC or the 1 percent Rouse dry CRM dense-graded wearing and binder course mixtures are similar to the conventional dense-graded wearing and binder course mixes. Also, it shows that the 2 percent CRM Generic dry gap-graded wearing course mix has a higher percentage of asphalt cement than does the conventional wearing course.

**Table 9**
**US 167 job mix formulas and volumetric properties**

| | **Wearing Course** | | | | **Binder Course** | |
|---|---|---|---|---|---|---|
| | **Control Conventional Dense-Graded** | **1% Rouse Dry CRM Dense-Graded** | **2% CRM Generic Dry Gap-Graded** | | **Conventional Dense-Graded** | **1% Rouse Dry CRM Dense-Graded** |
| **Spec. Gravity** | 2.420 | 2.380 | 2.283 | | 2.428 | 2.399 |
| **Theo. Gravity** | 2.512 | 2.474 | 2.353 | | 2.528 | 2.498 |
| **% Theor. Gravity** | 96.3 | 96.2 | 97.0 | | 96.0 | 96.0 |
| **% VMA** | 13.8 | 14.0 | 16.3 | | 13.2 | 14.4 |
| **% VFA** | 73 | 73 | 82 | | 70 | 73 |
| **% VOIDS** | 3.7 | 3.8 | 3.0 | | 4.0 | 4.0 |
| **Stability (LBS)** | 2000 | 2000 | 2000 | | 2300 | 2100 |
| **Flow (1/100)** | 11 | 10 | 16 | | 9 | 13 |
| **% AC** | 4.3 | 4.4 | 6.0 | | 3.9 | 3.6 |
| | | | | | | |
| **Sieve** | **Gradation Analysis** | | | | | |
| **1½”** | 100 | 100 | 100 | | 100 | 100 |
| **1”** | 100 | 100 | 100 | | 97 | 100 |
| **¾”** | 100 | 100 | 100 | | 85 | 100 |
| **½”** | 100 | 98 | 97 | | 67 | 98 |
| **3/8”** | 95 | 91 | 74 | | 62 | 87 |
| **No. 4** | 58 | 66 | 31 | | 36 | 64 |
| **No.10** | 35 | 42 | 21 | | 22 | 42 |
| **No. 40** | 22 | 22 | 11 | | 11 | 22 |
| **No. 80** | 12 | 12 | 8 | | 4 | 12 |
| **No. 200** | 6.0 | 6.5 | 5.0 | | 2.5 | 6.0 |

Figure 5 shows the US 167 wearing and binder course 0.45 power curve gradation charts. Figure 5a illustrates that the conventional dense-graded and the 1 percent Rouse dry CRM dense-graded wearing courses are above the maximum density line and therefore are fine mixtures. Figure 5b indicates that the conventional 1 in. nominal maximum aggregate size dense-graded binder course mixture as shown is a coarse mixture because the gradation band goes below the maximum density line.

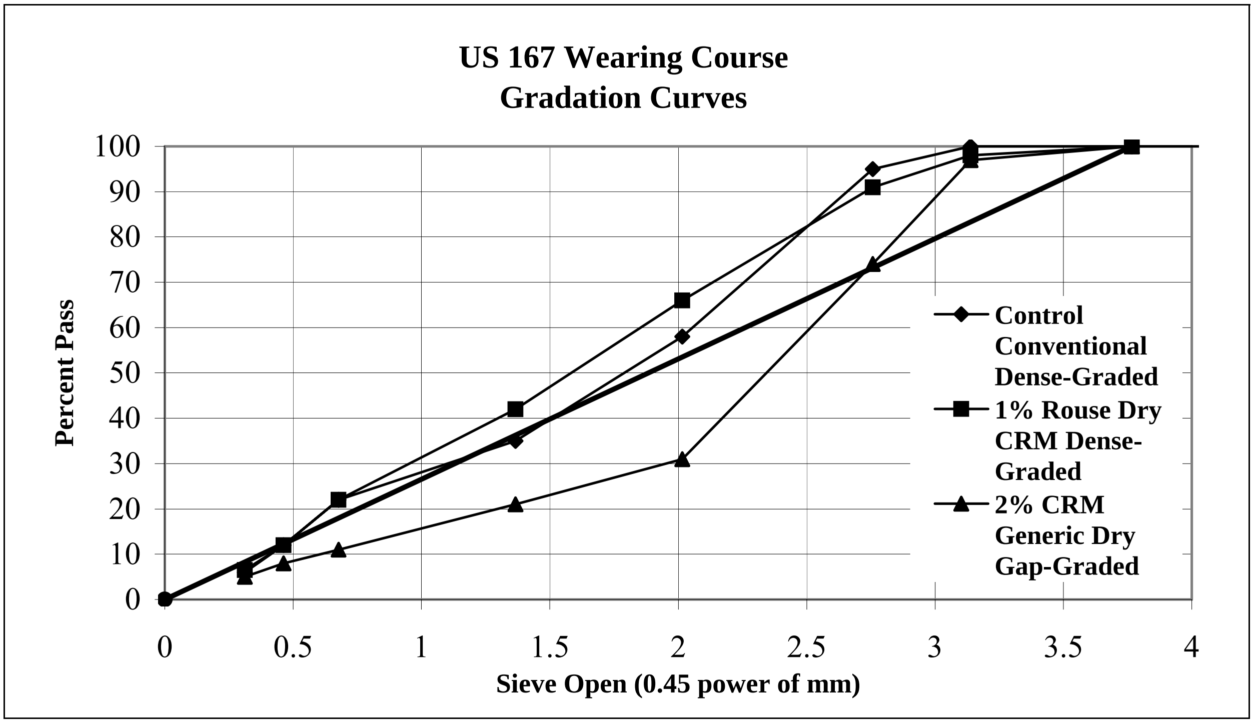

Figure 5a US 167 wearing course

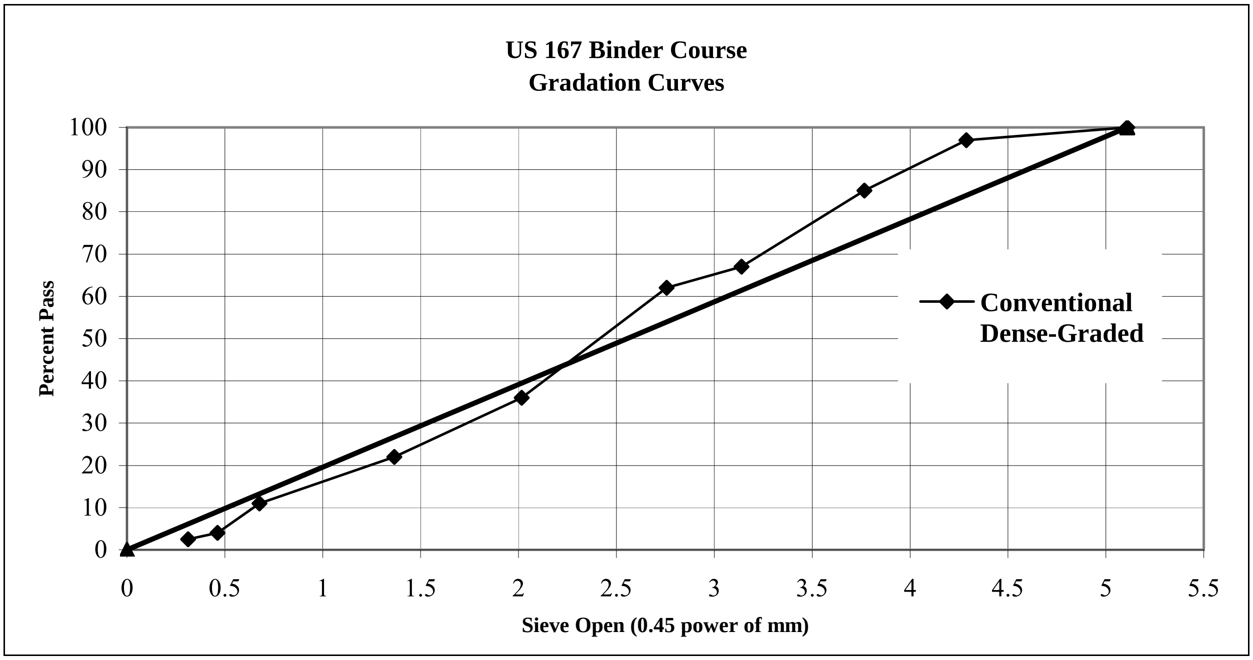

Figure 5b US 167 binder course

**Figure 5**
**US 167 wearing and binder course gradation curves**

Figure 6 shows the 0.45 power curve gradation chart for the ½ in. nominal maximum size 1 percent Rouse dry CRM dense-graded binder course mix used on US 167. This figure indicates that this binder course mix is a fine mixture because the gradation band is located above the maximum density line.

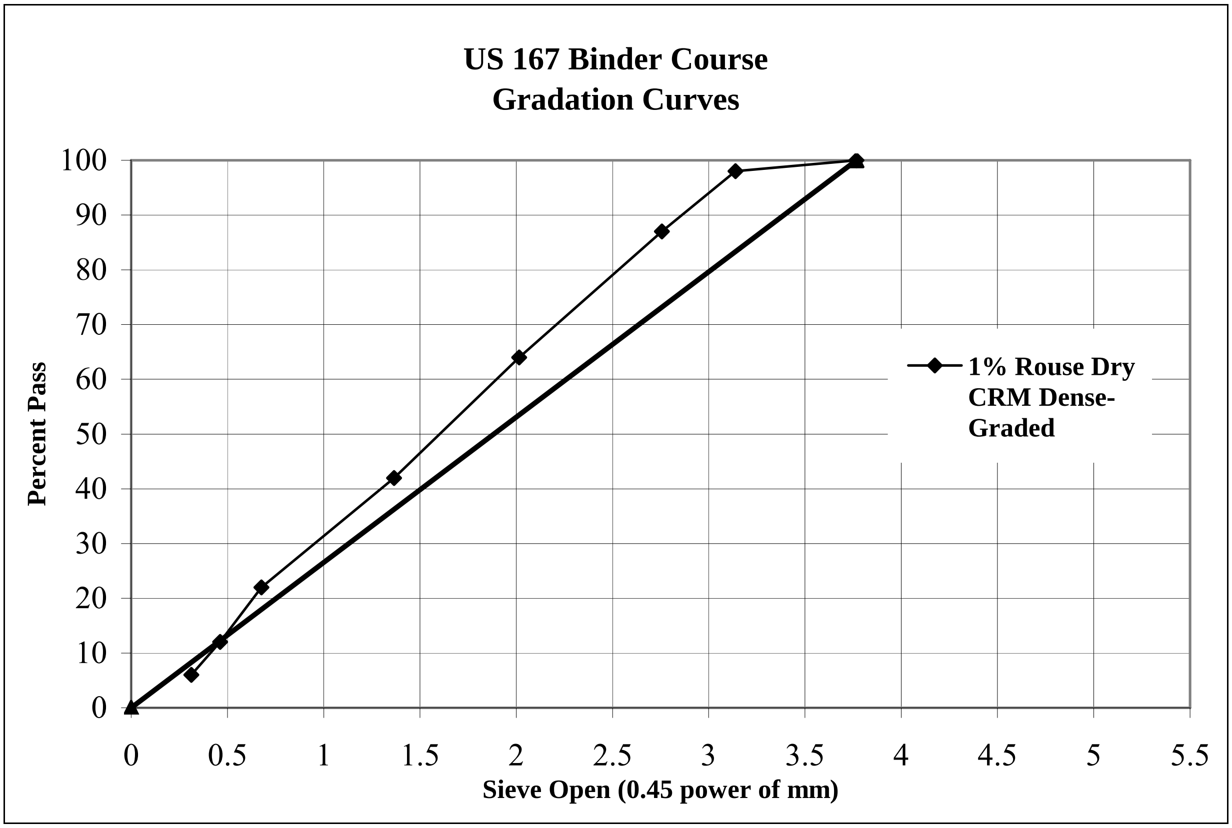

**Figure 6**
**US 167 binder course gradation curves (½ in. nominal maximum size agg.)**

Table 10 presents the gradations and the mix design properties for LA 15 wearing and binder course mixtures. This table shows that the %AC for the 10 percent Rouse wet CRM dense-graded wearing and binder course mixtures are similar with the conventional dense-graded wearing and binder course mixes. Also, it is shown that the 17.5 percent Arizona wet CRM gap-graded wearing course mix has a higher percentage of asphalt cement than does the conventional wearing course.

Figure 7 indicates the 0.45 power curve gradation charts for the LA 15 wearing and binder course mixtures. Figure 7a shows that the conventional dense-graded and the 10 percent Rouse wet CRM dense-graded wearing course mixes are fine mixtures because their gradation bands are above the maximum density line. The 17.5 percent Arizona wet CRM gap-graded wearing course mixture gradation band is below the maximum density line and therefore is a coarse mix. Figure 7b illustrates that both gradation bands for the conventional dense-graded and the 10 percent Rouse wet CRM dense-graded binder courses are above the maximum density line and are therefore fine mixtures.

**Table 10**
**LA 15 job mix formulas and volumetric properties**

| | **Wearing Course** | | | | **Binder Course** | |
|---|---|---|---|---|---|---|
| | **Control Conventional Dense-Graded** | **10% Rouse Wet CRM Dense-Graded** | **17.5% Arizona Wet CRM Gap-Graded** | | **Conventional Dense-Graded** | **10% Rouse Wet CRM Dense-Graded** |
| **Spec. Gravity** | 2.394 | 2.390 | 2.278 | | 2.400 | 2.424 |
| **Theo. Gravity** | 2.481 | 2.480 | 2.356 | | 2.495 | 2.518 |
| **% Theor. Gravity** | 96.5 | 96.4 | 96.7 | | 96.2 | 96.3 |
| **% VMA** | 13.0 | 13.3 | 19.6 | | 14.1 | 13.8 |
| **% VFA** | 73 | 73 | 83 | | 73 | 73 |
| **% VOIDS** | 3.5 | 3.6 | 3.3 | | 3.8 | 3.7 |
| **Stability (LBS)** | 2400 | 2000 | 1140 | | 2100 | 2000 |
| **Flow (1/100)** | 11 | 9 | 17 | | 12 | 10 |
| **% AC** | 4.4 | 4.5 | 7.8 | | 4.4 | 4.3 |
| | | | | | | |
| **Sieve** | **Gradation Analysis** | | | | | |
| **¾”** | 100 | 100 | 100 | | 100 | 100 |
| **½”** | 98 | 100 | 99 | | 98 | 98 |
| **3/8”** | 90 | 91 | 75 | | 90 | 89 |
| **No. 4** | 64 | 64 | 31 | | 64 | 64 |
| **No.10** | 39 | 40 | 20 | | 44 | 41 |
| **No. 40** | 21 | 21 | 10 | | 22 | 21 |
| **No. 80** | 12 | 12 | 7 | | 12 | 12 |
| **No. 200** | 6.5 | 6.0 | 4.9 | | 6.5 | 6.0 |

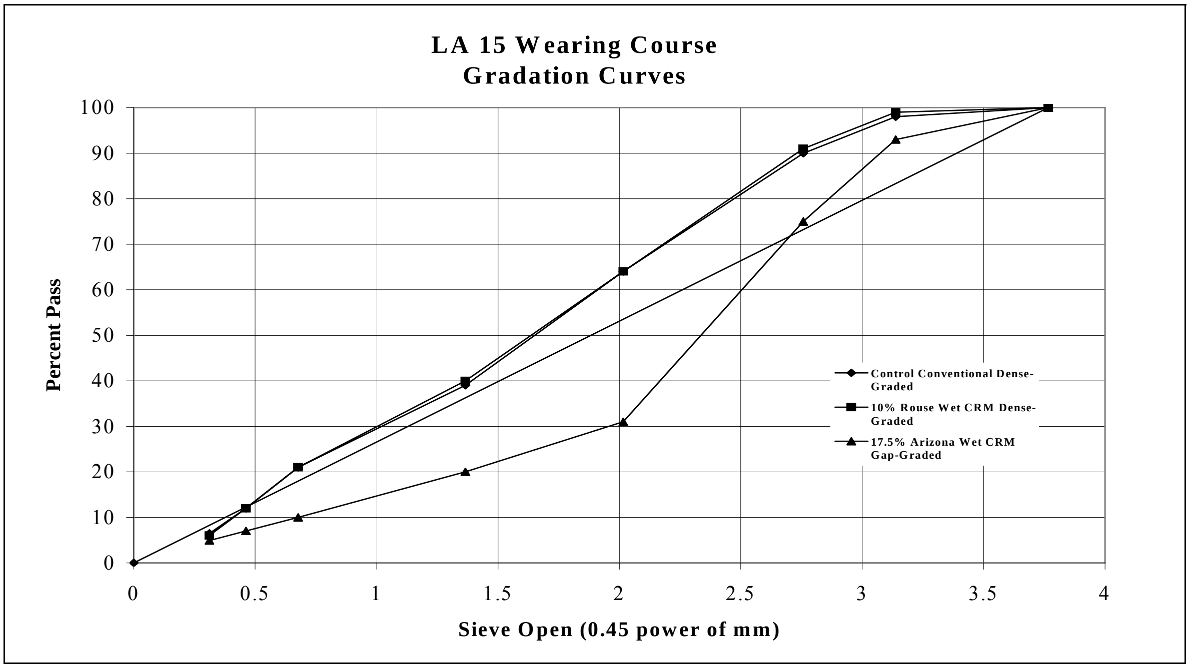

Figure 7a LA 15 wearing course

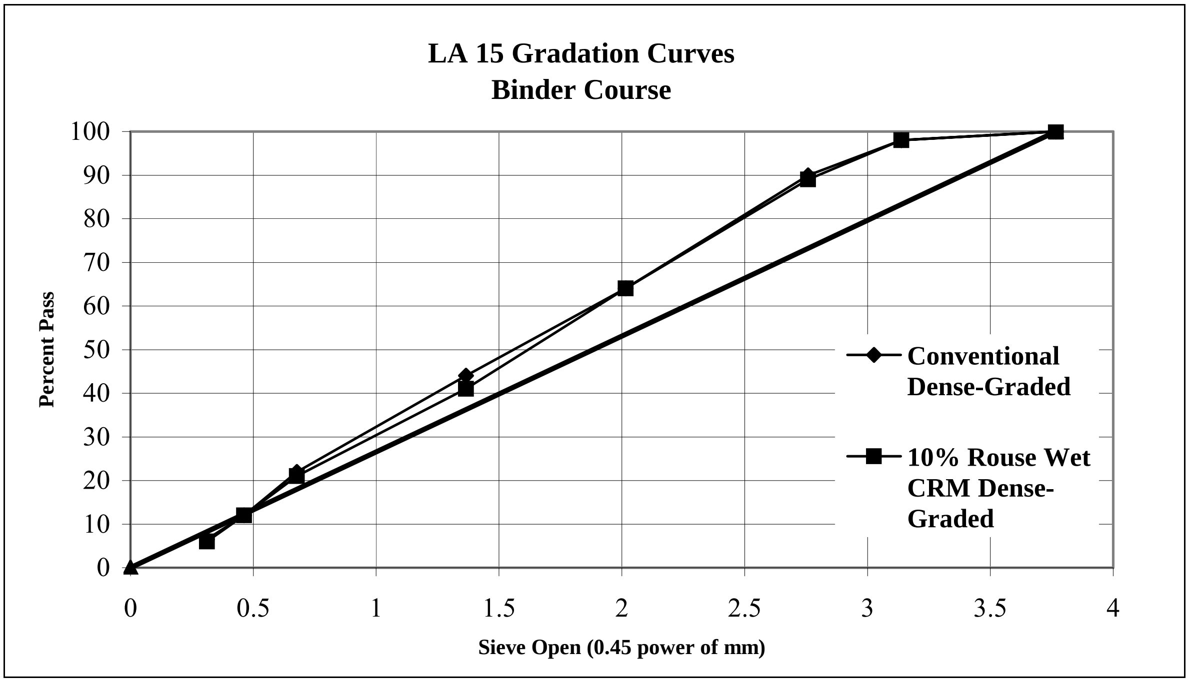

Figure 7b LA 15 binder course

**Figure 7**
**LA 15 wearing and binder course gradation curves**

Except for LA 1040, all projects had at least one CRM test section that had the gradation and other volumetric properties similar to the control section. In the CRM test section of LA 1040 and in one test section of LA 15, gap-graded CRM asphalt mixtures were compared with conventional dense-graded mixtures.

The amount of CRMs added to the mixtures was expressed in the percentage of the total weight of the asphalt cement for wet processes, and in the total weight of mixtures for dry processes. For example, one mega-gram of HMA mixture with 4.5 percent asphalt content and with 10 percent Rouse wet process CRM has a total amount of Rouse CRM powder of 4.5 kg whereas, one mega-gram of HMA mixture in the CRM section with 1 percent Rouse dry process has 20 kg of CRM.

It is shown in tables 6 through 10, that the asphalt contents for CRM asphalt mixtures in mix designs were generally higher than similar mixes without crumb-rubber modifier.

## Laboratory Mixture Characterization

Mixtures in this study were characterized in the laboratory through comparisons of Marshall Stability and flow, indirect tensile strength (ITS), and indirect tensile resilient modulus ($M_R$) tests.

### Marshall Test

The Marshall test was performed during the mix design according to the AASHTO T245-97 procedure. This test is performed at a deformation rate of 51 mm/min (2 in./min) and a temperature of 60 ºC (140 ºF). The properties obtained from this test are the Marshall stability and flow. The Marshall stability of an asphalt mixture is the maximum load the material can carry when tested in the Marshall apparatus. The Marshall flow is the deformation of the specimen when the load starts to decrease. Stability is reported in Newtons (mostly in pounds) and flow is reported in 0.25 mm (0.01 in.) of deformation. Three specimens were tested and an average is reported and used in the analysis.

### Indirect Tensile Strength (ITS) Test

The indirect tensile strength (ITS) and strain test was conducted at 25 ºC according to AASHTO T245 procedure. Test specimen is loaded to failure at a 50.8 mm/min (2 in./min) deformation rate. The load and deformation were continuously recorded and indirect tensile strength and strain were computed as follows:

$$ITS = \frac{2 \cdot P_{ult}}{\pi \cdot t \cdot D} \tag{1}$$

$$\varepsilon_T = 0.0205 \cdot H_T \tag{2}$$

where:

ITS – Indirect tensile strength, kPa
$P_{ult}$ – Peak load, N
T – Thickness of the sample, mm
D – Diameter of the specimen, mm
$\varepsilon$ – Horizontal tensile strain at failure, mm/mm, and
$H_T$ – Horizontal deformation at peak load, mm.

**Indirect Tensile Resilient Modulus ($M_R$) Test**

The indirect tensile resilient modulus test is conducted at temperatures of 5, 25, and 40 ºC according to the modified ASTM D4123 procedure [12]. It is a repeated load indirect tension test for determining the resilient modulus of the asphalt mixtures. The recoverable vertical deformation, δV, and horizontal deformation, δH were used to calculate the indirect tensile resilient modulus, $M_R$ and Poisson's ratio in equations 3 and 4.

$$M_R = \frac{P \cdot (\mu + 0.27)}{t \cdot \delta H} \tag{3}$$

$$\mu = 3.59 \cdot \frac{\delta H}{\delta V} - 0.27 \tag{4}$$

where:

$M_R$ – Resilient Modulus, MPa
P – Applied vertical load, N
t – Sample thickness, mm
μ – Poisson's ratio
δH – Horizontal deformation, mm, and
δV – Vertical deformation

## HMA Plant Production Statistical Analysis

Statistical analysis was performed on the actual hot mix wearing course production Quality Acceptance (QA) test data parameters to determine the variability of these test parameters using various mix types being produced through the hot mix plant facility. The mean, standard deviation, and percent coefficient of variation (% C.V.) statistical calculations were selected to determine parameter variability.

## Field Performance Evaluation of Pavements

### Louisiana Transportation Research Center (LTRC) Data Collection

LTRC monitored pavement densification through pavement coring. In addition, visual observation of cracks, International Roughness Index (IRI), rut depth, and Dynamic Deflection Determination System (DYNAFLECT) tests were performed by LTRC on the pavement sections at five to seven years after construction in this study. This data was previously published in the Transportation Research Record, No. 1789 in 2002 [10].

**International Roughness Index (IRI).** The international roughness index (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 km/hr. The IRI is computed as the cumulative movement of the suspension of the QCS divided by the traveled distance [14].

**Field Rut Depth Measurement.** Field rut depth measurement was performed five to seven years after the pavements were constructed. A vehicle-mounted laser beam profiler was used to measure the roadway profiles. The reported value of rut depth for each test section was an average rut depth of both wheel paths in both traffic directions.

**DYNAFLECT.** The Dynamic Deflection Determination System (DYNAFLECT) is a trailer mounted device that induces a dynamic load on the pavement and measures the resulting slab deflections by using five geophones spaced under the trailer at approximately 300 mm (1 ft.) intervals from the application of the load. The pavement is subjected to 4.45 kN (1000 lbf) of dynamic load at a frequency of 8 Hz. The load is produced by a counter rotation of two unbalanced flywheels. The generated cyclic force is transmitted vertically to the pavement through two steel wheels spaced 508 mm (20 in.) from center-to-center. The dynamic force during each rotation of the flywheels varies from 4.9 to 9.3 kN (1100 to 2100 lbf). Figure 8 presents the deflection basin, which the DYNAFLECT generates.

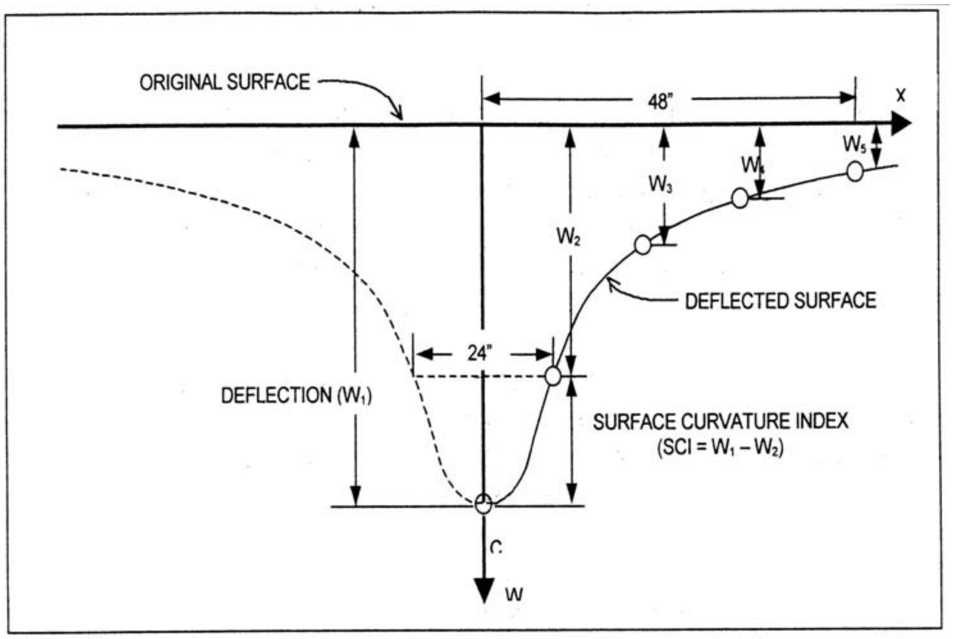

**Figure 8**
**Typical DYNAFLECT Deflection Bowl**

The DYNAFLECT actually measures only half of the deflection bowl. The other half is assumed to be a mirror image of the measured portion. In figure 8, the measurement W1 is the maximum depth of the deflection bowl and occurs near the force wheels. The terms W2, W3, W4, and W5 are the deflections measured by geophones 2 through 5, respectively.

The maximum (first sensor) deflection, W1, provides an indication of the relative strength of the total road section. The Surface Curvature Index, SCI (W1-W2), provides an indication of the relative strength of the upper (pavement) layers of the road section. The Base Curvature Index, BCI (W4-W5), and the fifth sensor value, W5, provide a measure of the relative strength of the foundation. For all four parameters, W1, SCI, BCI, and W5 lower values indicate greater strength. The overall structural number (SN) is determined from a nomograph, utilizing the aforementioned measured values.

### Automated Road Analyzer Visual Data Collection and Analysis

Comparisons of the field performance of pavements were achieved using visual data from 1995, 1997, 2000, 2002, and 2005 acquired from Louisiana's Pavement Management Section, in which the international roughness index (IRI), rut-depth measurements, and crack data was evaluated. Also, visual inspection of cracks after seven to ten years was reported in this study.

Visual data was collected by the Automatic Road Analyzer (ARAN) developed by Roadware Group, Inc. and analyzed for inclusion into Louisiana's pavement management inventory. The data collected by ARAN was analyzed by software developed by Roadware Group, Inc. specifically for ARAN. ARAN is a vehicle that is specially modified to collect accurate and repeatable data for pavement management programs. The ARAN vehicle houses computers and sensors including lasers, inertial measurement units, accelerometers, ultrasonic transducers, digital cameras, and vehicle mounted subsystems. 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 [15, 16].

**Field Rut Depth Measurement**. Field rut depth data collection for this case study was performed by ARAN using two vehicle mounted subsystems.

For 1995 and 1997, data was collected by the ARAN Smart Rutbar which uses ultrasonic transducers to measure the transverse roadway cross section. Ultrasonic transducers are spaced at 100mm (4 in.) across the measuring device. Up to 37 transducers are used to cover a 12 ft. lane. For 2000, 2002, and 2005, data was collected using the ARAN laser transverse profiler, Laser XVP, vehicle mounted subsystem. The laser transverse profiler uses dual synchronized mounted scanning lasers to measure the transverse roadway profile. This technology allows transverse profile measurement up to 13 foot lane widths.

There appears to be a distinction between the vehicle mounted subsystem types as indicated in the analysis of pavement performance for rutting. This may be attributable to the level of accuracy between measuring systems. Documentation for the different measuring systems used indicates the Laser XVP has a higher level of accuracy than the ARAN Smart Bar [15]. For this study, the reported measurement value of rut depth for each test section is the average rut depth.

**Crack Data Measurement.** Transverse, random, alligator, block, and longitudinal crack data was obtained by ARAN video imagery technology. The crack data video imagery was analyzed using computer software developed by Roadware Group, Inc.

For this study, random cracking only was reported. As reported by ARAN, the random cracking value includes all high, medium, and low severity cracking for transverse, block and longitudinal cracking.

The reported value of crack measurements for each test section is the average crack measurement in linear feet.

## Laboratory Mixture Characterization vs. Pavement Performance

Relationships between laboratory mixture characterization and pavement performance were evaluated in this study. In particular ITS tests, strength and strain, were compared with the pavement performance of each test section as measured by random and alligator cracking. Indirect tensile resilient modulus, $M_R$, conducted at temperatures of 5, 25, and 40 ºC, were also compared with random and alligator cracking. It was anticipated that a correlation may exist between the ITS test, $M_R$ conducted at temperatures of 5, 25, and 40 ºC, and the pavement cracking parameters evaluated. In addition, $M_R$ at 40 ºC was compared with the pavement rutting parameter for each test section. It is noted that US 167 is not included in this evaluation because of insufficient data.

## Pavement Condition Index

A modified pavement condition rating index (PCI) was developed to compare the pavement performance of CRM Wet and Dry HMA mixtures versus conventional HMA mixtures. The pavement distress types used for the development of the PCI were IRI, random cracking, and rutting. The values obtained for each distress type were obtained from LADOTD's Pavement Management System's ARAN data. In order to properly rank the projects based on previous observed performance, the factors to be used in the calculated PCI value for each of the pavement distress types should be 40 percent for IRI, 40 percent for Random Cracking, and 20 percent for rutting. Subsequently, distress deduct values were selected for each pavement distress type evaluated. The PCI value was computed using equation 5.

$$\text{PCI} = 100 - \left[0.40(D_1) + 0.40(D_2) + 0.20(D_3)\right] \qquad (5)$$

where:

PCI = Pavement Condition Index
$D_1$ = IRI distress deduct value
$D_2$ = Random Cracking distress deduct value
$D_3$ = Rutting distress deduct value

Table 11 shows the Pavement Condition Index range and deduct values selected for each distress type evaluated in the calculation of the PCI.

### Table 11
### Pavement Condition Index Deduct Values

| **PCI Deduct Values** | | | | | |
|---|---|---|---|---|---|
| **IRI** | | **Random Cracking** | | **Rutting** | |
| Range | Value | Range | Value | Range | Value |
| < 75 | 0 | < 100 | 0 | 0.00 – 0.05 | 0 |
| 75 – 100 | 10 | 100 - 200 | 10 | 0.06 – 0.10 | 10 |
| 101 – 125 | 20 | 201 - 300 | 20 | 0.11 – 0.15 | 20 |
| 126 – 150 | 30 | 301 - 400 | 30 | 0.16 – 0.20 | 30 |
| 151 – 175 | 40 | 401 - 500 | 40 | 0.21 – 0.25 | 40 |
| 176 - 250 | 50 | 501 - 1000 | 50 | 0.26 -0.50 | 50 |
| > 250 | 100 | > 1000 | 60 | > 0.50 | 100 |

A PCI value was computed for each HMA mixture evaluated. Each comparable mixture type‘s PCI values were then averaged to obtain a single value for each evaluation period. For example, the CRM Wet modified HMA sections were average together, all the CRM Dry modified HMA sections were averaged, and the conventional HMA mix types were averaged.

## Cost of Applying CRM

The addition of CRM to asphalt mixtures generally increases the cost of HMA construction significantly. Table 12 lists the unit cost of the HMA concrete for the eight CRM sections in this paper. For LA15 dense mix with 10 percent Rouse wet CRM, the construction cost was similar to the control section with conventional mixtures. For the rest of the CRM sections in this study, the unit costs of CRM asphalt mixtures were 118 percent to 360 percent higher than those of the conventional mixtures.

## Table 12
## Construction Costs of CRM HMA Concrete

| Route | Section | Process Description | Miles of CRM Paving | Tons of CRM | Unit Cost ($/ton mix) | CRM Cost vs. Control (%) |
|---|---|---|---|---|---|---|
| US 61 | OGFC 17.5% AZ Wet | Wet process, batch blending at plant, 17.5% OGFC, 17.5% SAMI | 1.0 | 36.5 | 123 | 360 |
| | Gap 17.5% AZ Wet | Wet process, batch blending at plant, 17.5% | 4.5 | 129 | 69 | 176 |
| LA 15 | Dense 10% Rouse Wet | Wet process, batch or continuous at 10% | 2.0 | 27 | 34 | 100 |
| | Gap 17.5% AZ Wet | Wet process, batch blending at plant, 17.5% | 2.0 | 31.5 | 68 | 200 |
| US 84 | Dense 5% Neste Wright Wet | Terminal blending, 5% | 2.0 | 15 | 40 | 118 |
| US 167 | Dense 1% Rouse Dry | Dry process, 1% by weight, 80 mesh | 2.0 | 54 | 40 | 118 |
| | Gap 2% Generic Dry | Dry process, 2% by weight, 65% retained on #30 sieve | 2.0 | 46 | 47 | 138 |
| LA 1040 | Gap 3% PlusRide™ | Patented dry process, 3% by weight | 4.5 | 177 | 70 | 206 |
| Total | | | 20 | 516 | | |

# DISCUSSION OF RESULTS

## Laboratory Characteristics of Mixtures

Only the wearing course mixtures were evaluated in this study. An average of three specimen results was reported. The air voids for the laboratory test specimens were 4 ± 1 percent.

Figures 9 and 10 present the results of the Marshall Stability and Flow tests. It shows that the conventional mixtures had higher or equal values of Marshall Stability than the crumb-rubber modified asphalt mixtures. Gap-graded CRM mixtures had lower Marshall Stabilities than dense-graded CRM mixtures. The gap-graded CRM mixtures had higher numbers of Marshall Flow than the corresponding conventional control mixes, whereas, the dense-graded CRM mixtures had similar Marshall Flows to the conventional control mixes.

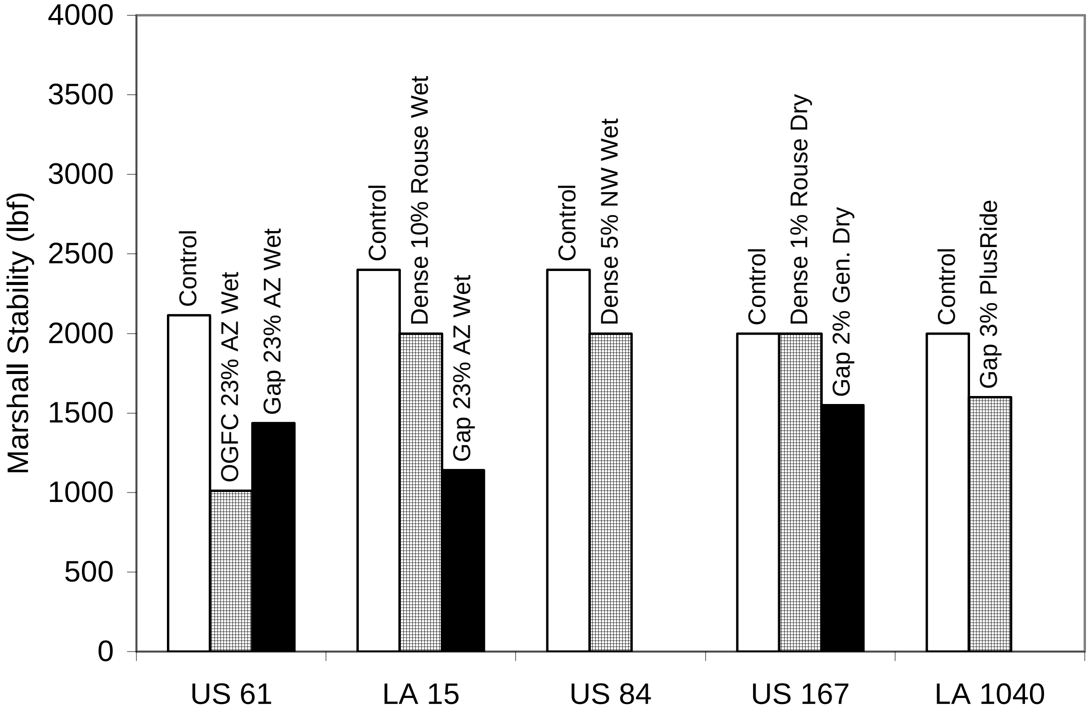

**Figure 9**
**Marshall Stability Test Results**

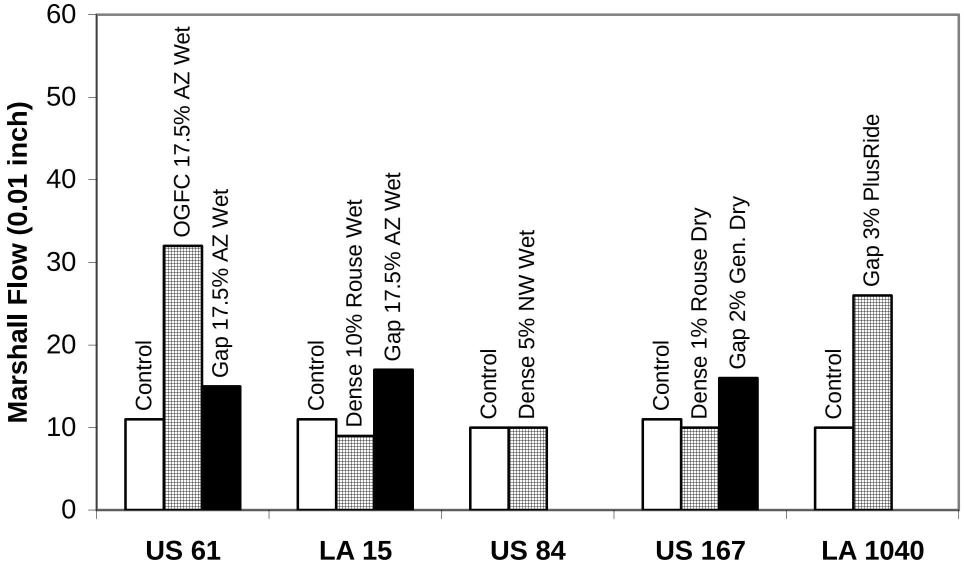

**Figure 10**
**Marshall Flow Test Results**

Figures 11 and 12 present the results of the indirect tensile strength (ITS) and indirect tensile strain tests for the wearing course mixtures. The ITS results for US167 were not available. The conventional mixtures in the control sections exhibited higher indirect tensile strength values than the crumb-rubber modified wearing course mixes. Except for LA1040, the CRM asphalt wearing course mixtures had higher strains than the conventional wearing course mixes. Higher strain indicates the mixes to be more ductile under tension. This characteristic is desired for mixtures to resist fatigue cracks.

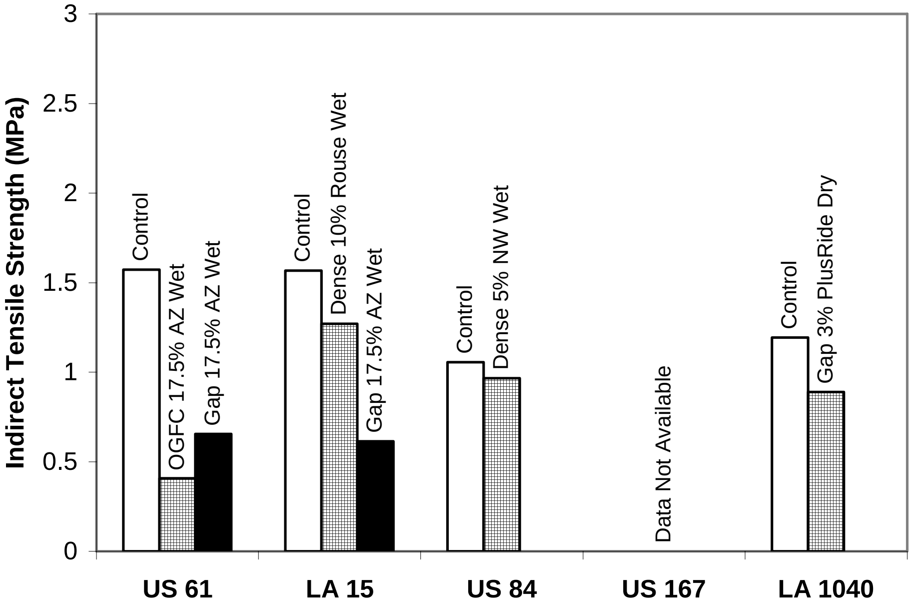

**Figure 11**
**Indirect Tensile Strength Test Results**

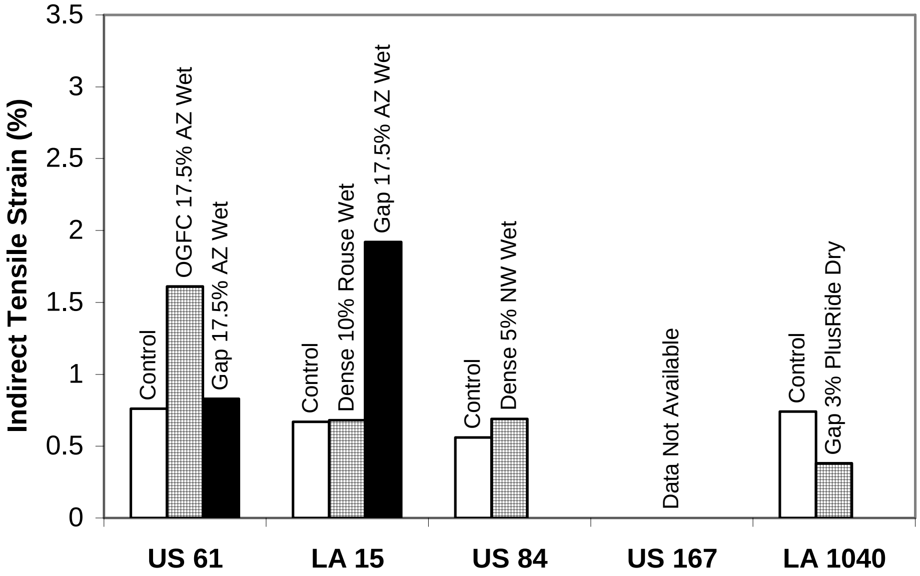

**Figure 12**
**Indirect Tensile Strain Test Results**

Figures 13 through 15 present the results of the indirect tensile resilient modulus (MR) at various testing temperatures, 5 ºC, 25 ºC, and 40 ºC, of the wearing course mixtures for the test sections. The MR results for US167 were not available. A statistical analysis using ANOVA procedure indicated that the conventional wearing course mixtures exhibited significantly higher values of MR than the CRM asphalt mixtures at 5 ºC and 25 ºC. At 40 ºC, the conventional wearing course mixture in US 84 showed significantly higher MR than the CRM asphalt mixtures. The conventional and gap-graded CRM asphalt mixtures showed similar MR values in US61 and LA1040 at a temperature of 40 ºC.

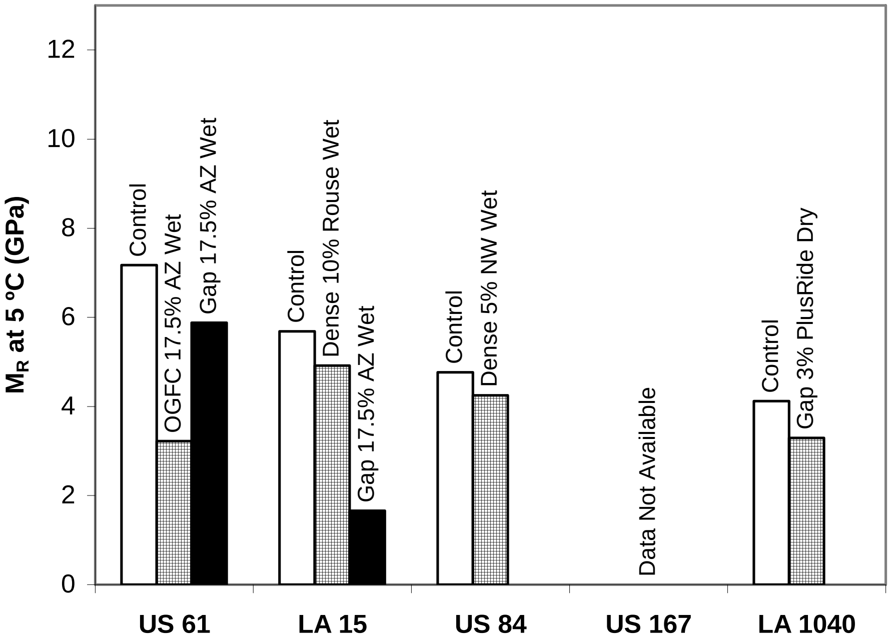

**Figure 13**
**Indirect Tensile Resilient Modulus ($M_R$) Test Results @ 5 ºC**

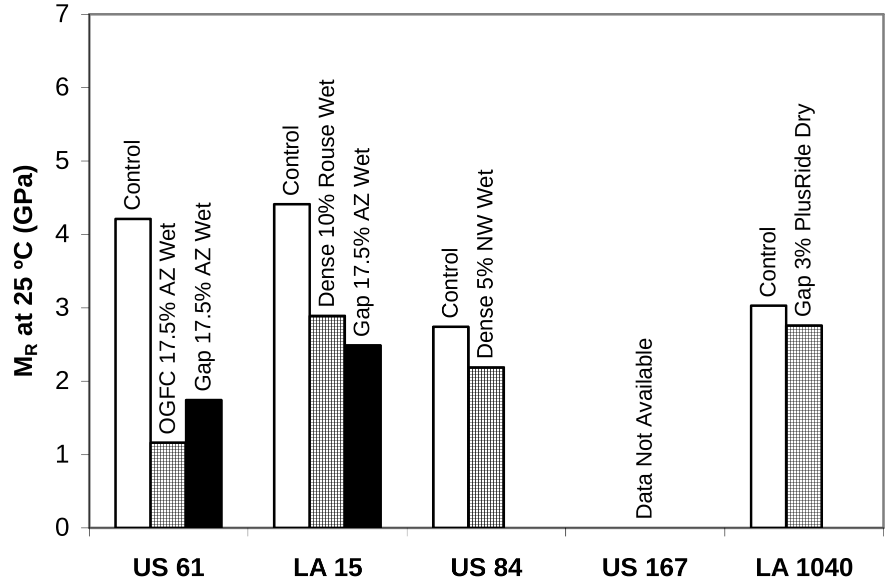

**Figure 14**
**Indirect Tensile Resilient Modulus ($M_R$) Test Results @ 25 ºC**

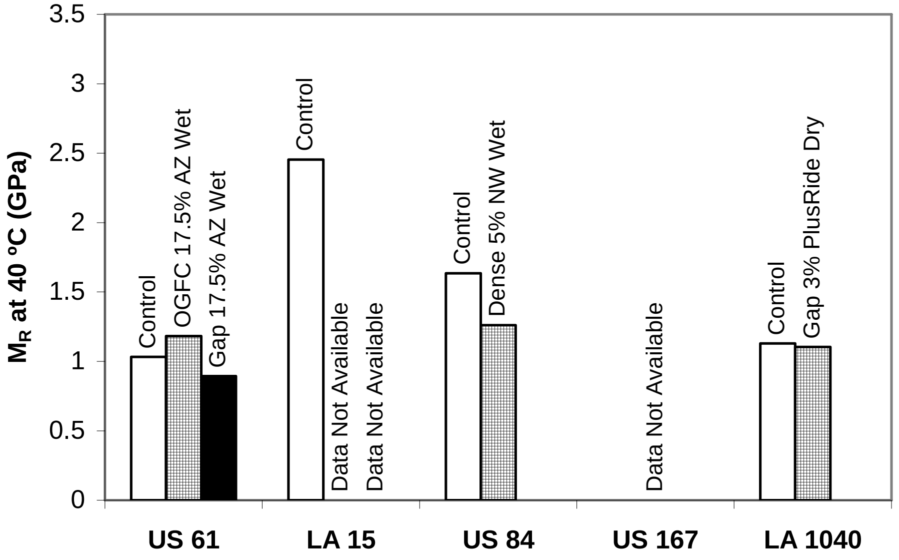

**Figure 15**
**Indirect Tensile Resilient Modulus ($M_R$) Test Results @ 40 ºC**

A statistical analysis using the ANOVA procedure indicated that the conventional wearing course mixtures exhibited significantly higher $M_R$ values than the CRM asphalt mixtures at 5 ºC and 25 ºC. At 40 ºC, the conventional wearing course mixture in US 84 showed significantly higher $M_R$ values than the CRM asphalt mixtures. The conventional and gap-graded CRM asphalt mixtures showed similar $M_R$ values in US61 and LA1040 at a temperature of 40 ºC [10]. The laboratory mixture characterization was previously published in the Transportation Research Record, No. 1789 in 2002 [10].

## HMA Plant Production Statistical Analysis

### Route US 61

Table 13 presents the JMF and QA parameter data and results of the statistical analysis for the polymer gap-graded hot mix asphalt produced for Route US 61. The highest % C.V. computed was for the stability parameter at 22 percent. The % C.V. for stability was followed by the flow and then % A.C., 18 percent and 9.5 percent respectively. It should be noted that the No. 200 sieve had a % C.V. of 6.1 percent and was on the high side of the acceptable gradation tolerance of ± 2.0 percent of the JMF value, 1.7 percent.

Table 14 indicates the JMF and QA parameter data and results of the statistical analysis for the 17.5 percent Arizona wet crumb rubber modified gap-graded hot mix asphalt produced for Route US 61. The highest % C.V. computed was for the % air voids parameter at 39.6 percent. The % C.V. for % air voids was followed by the flow and then stability parameters, at 16 percent and 11 percent respectively. The reported QA data for the No. 200 sieve analysis was outside the acceptable mix gradation tolerance of ± 2.0 percent of the JMF value, 2.3 percent. It is suspected that the high variability of the volumetric parameter, and % air voids were caused by the production differences in the No. 200 sieve.

Table 15 shows the JMF and QA parameter data and results of the statistical analysis for the 17.5 percent Arizona wet crumb rubber modified Open Graded Friction Course (OGFC) hot mix asphalt produced for Route US 61. The highest % C.V. computed was for the stability parameter at 44 percent. The % C.V. for Stability was followed by the % air voids and flow parameters, at 25.8 percent and 21 percent respectively. The reported QA data for the No. 4 sieve is within the acceptable mix gradation tolerance of ± 6 percent of the JMF value, 4 percent.

## Table 13
## Statistical analysis: US 61, polymer gap-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | Mean | Std. Dev | %C.V. |
| **Spec. Gravity** | 2.298 | 2.292 | 0.005 | 0.199 |
| **Theo. Gravity** | 2.368 | 2.369 | 0.002 | 0.076 |
| **% Theor. Gravity** | 97.0 | 96.8 | 0.2 | 0.2 |
| **% VMA** | 17.1 | 17.2 | 0.2 | 0.9 |
| **% VFA** | 82 | 81 | 1 | 1 |
| **% AIR VOIDS** | 3.0 | 3.2 | 0.2 | 5.6 |
| **Stability (LBS)** | 2115 | 2180 | 473 | 22 |
| **Flow (1/100)** | 11 | 12 | 2 | 18 |
| **% AC** | 6.3 | 6.3 | 0.0 | 0.0 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 93 | 92 | 0.0 | 0.0 |
| **3/8”** | 71 | 69 | 1.0 | 1.4 |
| **No. 4** | 35 | 34 | 0.5 | 1.5 |
| **No.10** | 21 | 20 | 0.6 | 3.0 |
| **No. 40** | 14 | 14 | 0.6 | 4.3 |
| **No. 80** | 12 | 12 | 0.6 | 5.0 |
| **No. 200** | 11.0 | 9.3 | 0.6 | 6.1 |

## Table 14

## Statistical analysis: US 61, 17.5% Arizona wet CRM gap-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.231 | 2.227 | 0.0034 | 1.513 |
| **Theo. Gravity** | 2.312 | 2.312 | 0.001 | 0.053 |
| **% Theor. Gravity** | 96.3 | 96.3 | 1.5 | 1.5 |
| **% VMA** | 18.1 | 21.8 | 1.2 | 5.4 |
| **% VFA** | 81 | 83 | 5 | 6 |
| **% AIR VOIDS** | 3.5 | 3.7 | 1.5 | 39.6 |
| **Stability (LBS)** | 2050 | 1491 | 160 | 11 |
| **Flow (1/100)** | 24 | 19 | 3 | 16 |
| **% AC** | 8.4 | 8.3 | 0.4 | 4.7 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 93 | 93 | 1.3 | 1.4 |
| **3/8”** | 71 | 70 | 2.2 | 3.1 |
| **No. 4** | 35 | 34 | 2.2 | 6.4 |
| **No.10** | 19 | 19 | 2.6 | 14.0 |
| **No. 40** | 10 | 9 | 2.2 | 26.2 |
| **No. 80** | 7 | 5 | 1.6 | 28.6 |
| **No. 200** | 5.3 | 3.0 | 0.7 | 24.4 |

## Table 15

## Statistical analysis: US 61, 17.5% Arizona wet CRM OGFC HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | Mean | Std. Dev | %C.V. |
| **Spec. Gravity** | 2.089 | 2.162 | 0.0034 | 1.587 |
| **Theo. Gravity** | 2.302 | 2.315 | 0.007 | 0.309 |
| **% Theor. Gravity** | 90.7 | 93.4 | 1.7 | 1.8 |
| **% VMA** | 27.6 | 25.5 | 1.4 | 5.5 |
| **% VFA** | 66 | 74 | 5 | 7 |
| **% AIR VOIDS** | 9.3 | 6.6 | 1.7 | 25.8 |
| **Stability (LBS)** | 1010 | 1368 | 604 | 44 |
| **Flow (1/100)** | 32 | 18 | 4 | 21 |
| **% AC** | 9.0 | 8.8 | 0.3 | 2.9 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 91 | 93 | 1.0 | 1.0 |
| **3/8”** | 65 | 70 | 2.4 | 3.4 |
| **No. 4** | 23 | 27 | 1.0 | 3.5 |
| **No.10** | 9 | 13 | 1.3 | 10.3 |
| **No. 40** | 5 | 7 | 1.0 | 14.2 |
| **No. 80** | 4 | 5 | 1.0 | 20.2 |
| **No. 200** | 3.3 | 2.8 | 0.6 | 21.7 |

Figure 16 illustrates the % C.V. of volumetric properties (% VFA, % VMA, % air voids) vs. mix types used on the US 61 project. It shows that the conventional dense-graded mix type had the lowest % C.V. for all volumetric properties for all mix types produced on this project. For the % VFA and % VMA properties, the next highest % C.V. shown are of the 17.5 percent Arizona Wet gap-graded crumb rubber modified (CRM) mix type followed by the OGFC. The CRM had the highest % C.V. for the % air voids.

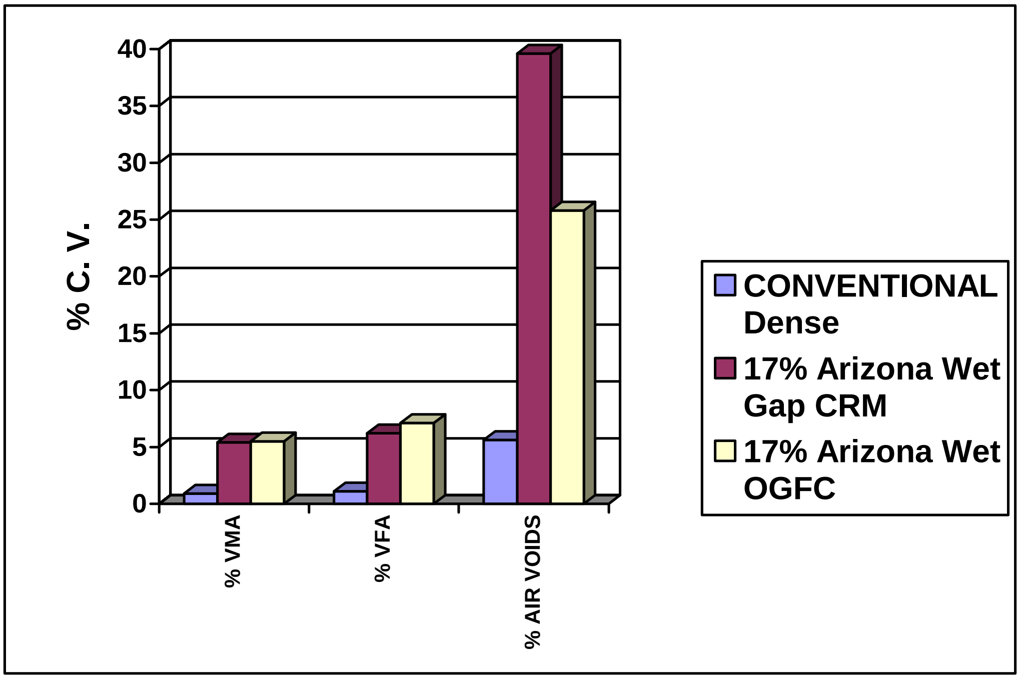

**Figure 16**
**Route US 61, % C.V. vs. mix type**

**Route LA 15**

Table 16 presents the JMF and QA parameter data and results of the statistical analysis for the conventional dense-graded hot mix asphalt produced for Route LA 15. The highest % C.V. represented is for the flow parameter at 22 percent. The % C.V. for flow was followed by the stability and then the % air voids, at 9 percent and 8.3 percent respectively.

Table 17 shows the JMF and QA parameter data and results of the statistical analysis for the 10 percent Rouse Wet CRM Dense-Graded hot mix asphalt produced for Route LA 15. The highest % C.V. represented is for the stability parameter at 22 percent. The % C.V. for stability was followed by the flow and then the % air voids, at 14 percent and 10.0 percent respectively.

## Table 16

## Statistical analysis: LA 15, conventional dense-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | Mean | Std. Dev | %C.V. |
| **Spec. Gravity** | 2.394 | 2.396 | 0.007 | 0.285 |
| **Theo. Gravity** | 2.481 | 2.481 | 0.001 | 0.023 |
| **% Theor. Gravity** | 96.5 | 96.6 | 0.3 | 0.3 |
| **% VMA** | 13.0 | 13.0 | 0.3 | 2.0 |
| **% VFA** | 73 | 74 | 2 | 2 |
| **% AIR VOIDS** | 3.5 | 3.4 | 0.3 | 8.3 |
| **Stability (LBS)** | 2400 | 2766 | 252 | 9 |
| **Flow (1/100)** | 11 | 9 | 2 | 22 |
| **% AC** | 4.4 | 4.4 | 0.0 | 0.9 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 98 | 99 | 0.9 | 0.9 |
| **3/8”** | 90 | 91 | 2.3 | 2.6 |
| **No. 4** | 64 | 62 | 2.6 | 4.2 |
| **No.10** | 39 | 39 | 2.8 | 7.3 |
| **No. 40** | 21 | 22 | 1.9 | 8.8 |
| **No. 80** | 12 | 13 | 1.4 | 10.9 |
| **No. 200** | 6.5 | 7.2 | 0.5 | 6.4 |

**Table 17**

**Statistical analysis: LA 15, 10% Rouse wet CRM dense-graded HMA**

| | **Job Mix Formula (JMF)** | **Quality Assurance (QA)** | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.390 | 2.384 | 0.010 | 0.431 |
| **Theo. Gravity** | 2.480 | 2.480 | 0.001 | 0.030 |
| **% Theor. Gravity** | 96.4 | 96.1 | 0.4 | 0.4 |
| **% VMA** | 13.3 | 13.5 | 0.4 | 2.9 |
| **% VFA** | 73 | 71 | 2 | 3 |
| **% AIR VOIDS** | 3.6 | 3.9 | 0.4 | 10.0 |
| **Stability (LBS)** | 2000 | 2150 | 465 | 22 |
| **Flow (1/100)** | 9 | 9 | 1 | 14 |
| **% AC** | 4.5 | 4.5 | 0.1 | 1.3 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 100 | 100 | 0.0 | 0.0 |
| **3/8”** | 91 | 91 | 1.4 | 1.6 |
| **No. 4** | 64 | 63 | 2.1 | 3.4 |
| **No.10** | 40 | 37 | 1.4 | 3.8 |
| **No. 40** | 21 | 21 | 0.0 | 0.0 |
| **No. 80** | 12 | 12 | 0.7 | 6.1 |
| **No. 200** | 6.0 | 6.2 | 0.6 | 10.3 |

Table 18 presents the JMF and QA parameter data and results of the statistical analysis for the 17.5 percent Arizona wet CRM gap-graded hot mix asphalt produced for Route LA 15. The highest % C.V. represented is for the stability parameter at 28 percent. The % C.V. for stability was followed by the flow and then the % air voids, at 16 percent and 14.6 percent respectively.

## Table 18
## Statistical analysis: LA 15, 17.5% Arizona wet CRM gap-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.278 | 2.262 | 0.014 | 0.618 |
| **Theo. Gravity** | 2.356 | 2.356 | 0.000 | 0.020 |
| **% Theor. Gravity** | 96.7 | 96.0 | 0.6 | 0.6 |
| **% VMA** | 19.6 | 20.2 | 0.5 | 2.5 |
| **% VFA** | 83 | 80 | 2 | 3 |
| **% AIR VOIDS** | 3.3 | 4.0 | 0.6 | 14.6 |
| **Stability (LBS)** | 1140 | 1714 | 484 | 28 |
| **Flow (1/100)** | 17 | 21 | 3 | 16 |
| **% AC** | 7.8 | 7.3 | 0.9 | 12.7 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 99 | 99 | 0.7 | 0.7 |
| **3/8”** | 75 | 75 | 1.4 | 1.9 |
| **No. 4** | 31 | 34 | 2.1 | 6.3 |
| **No.10** | 20 | 23 | 2.8 | 12.3 |
| **No. 40** | 10 | 13 | 0.7 | 5.7 |
| **No. 80** | 7 | 10 | 0.7 | 7.4 |
| **No. 200** | 4.9 | 6.7 | 0.3 | 4.2 |

Figure 17 illustrates the % C.V. of volumetric properties (% VFA, % VMA, % air voids) vs. mix types used on the LA 15 project. It shows that the conventional dense-graded mix type had the lowest % C.V. for all volumetric properties for all mix types produced on this project. For the % VFA and % VMA properties, the next highest % C.V. shown are of the 17.5 percent Arizona wet CRM gap-graded hot mix type followed by the 10 percent Rouse Wet CRM dense-graded hot mix. The 17.5 percent Arizona wet CRM gap-graded hot mix type had the highest % C.V. for the % air voids.

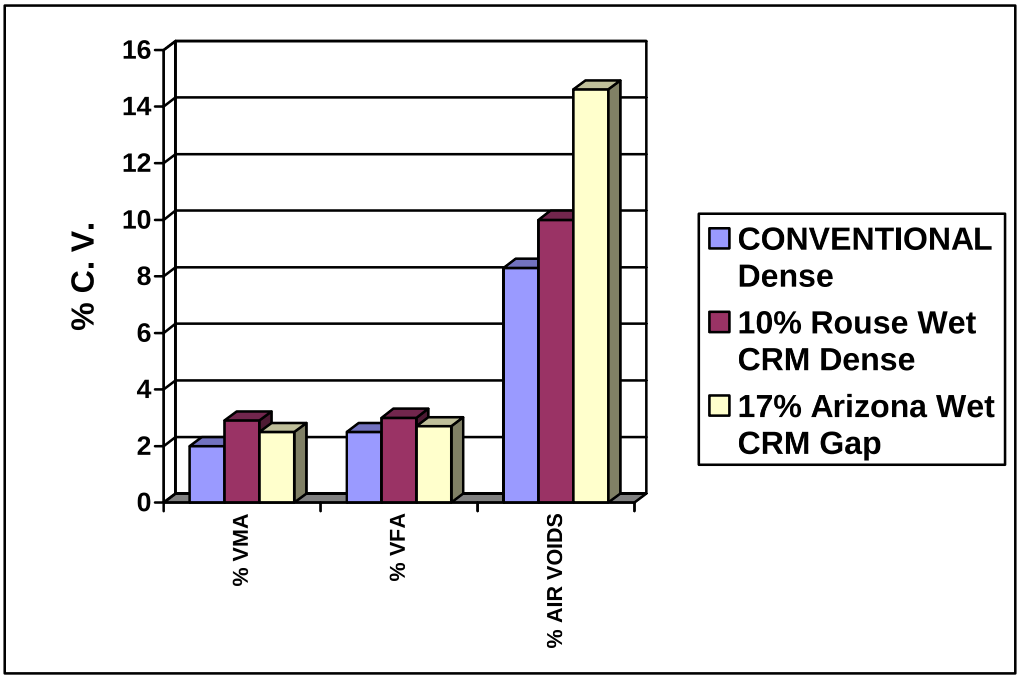

**Figure 17**
**Route LA 15, % C.V. vs. mix type**

In review of the statistical data analysis for this project, it is shown that the contractor had excellent control of plant processes and produced the hot mix types according to the approved Job Mix Formulas.

**Route US 84**

Table 19 presents the JMF and QA parameter data and results of the statistical analysis for the 5 percent Neste Wright CRM dense-graded hot mix asphalt produced for Route US 84. The highest % C.V. represented is for the stability parameter at 11 percent. The % C.V. for stability was followed by the % air voids, at 9.8 percent. There is no reported standard deviation or % C.V. value for the flow parameter because of insufficient data.

Table 20 shows the JMF and QA parameter data and results of the statistical analysis for the conventional dense-graded hot mix asphalt produced for Route US 84. The highest % C.V. represented is for the % air voids parameter at 15.3 percent. The % C.V. for % air voids was followed by the stability, at 9 percent. There was no reported standard deviation or % C.V. value for the flow parameter because of insufficient data.

## Table 19
## Statistical analysis: US 84, 5% Neste Wright CRM dense-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.394 | 2.383 | 0.010 | 0.400 |
| **Theo. Gravity** | 2.477 | 2.477 | 0.001 | 0.036 |
| **% Theor. Gravity** | 96.6 | 96.2 | 0.4 | 0.4 |
| **% VMA** | 12.4 | 12.9 | 0.4 | 2.7 |
| **% VFA** | 73 | 70 | 2 | 3 |
| **% AIR VOIDS** | 3.4 | 3.8 | 0.4 | 9.8 |
| **Stability (LBS)** | 2400 | 3055 | 341 | 11 |
| **Flow (1/100)** | 10 | 9 | * | * |
| **% AC** | 4.2 | 4.1 | 0.1 | 2.8 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 94 | 98 | 0.7 | 0.7 |
| **3/8”** | 90 | 90 | 2.1 | 2.4 |
| **No. 4** | 64 | 63 | 0.7 | 1.1 |
| **No.10** | 39 | 41 | 0.7 | 1.7 |
| **No. 40** | 21 | 22 | 0.7 | 3.3 |
| **No. 80** | 12 | 12 | 0.7 | 6.1 |
| **No. 200** | 6.0 | 5.6 | 0.3 | 5.1 |

* Data not available

**Table 20**

**Statistical analysis: US 84, conventional dense-graded HMA**

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.401 | 2.392 | 0.013 | 0.548 |
| **Theo. Gravity** | 2.480 | 2.480 | 0.001 | 0.034 |
| **% Theor. Gravity** | 96.8 | 96.5 | 0.5 | 0.6 |
| **% VMA** | 12.1 | 12.4 | 0.5 | 3.9 |
| **% VFA** | 74 | 71 | 3 | 5 |
| **% AIR VOIDS** | 3.2 | 3.5 | 0.5 | 15.3 |
| **Stability (LBS)** | 2300 | 2389 | 210 | 9 |
| **Flow (1/100)** | 8 | 14 | * | * |
| **% AC** | 4.1 | 4.1 | 0.1 | 1.3 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 94 | 99 | 0.6 | 0.6 |
| **3/8”** | 90 | 92 | 0.6 | 0.6 |
| **No. 4** | 64 | 63 | 2.1 | 3.3 |
| **No.10** | 39 | 39 | 2.5 | 6.5 |
| **No. 40** | 21 | 20 | 0.6 | 2.9 |
| **No. 80** | 12 | 12 | 0.6 | 4.9 |
| **No. 200** | 6.0 | 6.2 | 0.4 | 5.6 |

* Data not available

Figure 18 illustrates the % C.V. of volumetric properties (% VFA, % VMA, % air voids) vs. mix types used on the US 84 project. It shows that the conventional dense-graded mix type had the highest % C.V. for all volumetric properties for all mix types produced on this project. The figure indicates that the highest % C.V. was for the % air void parameter.

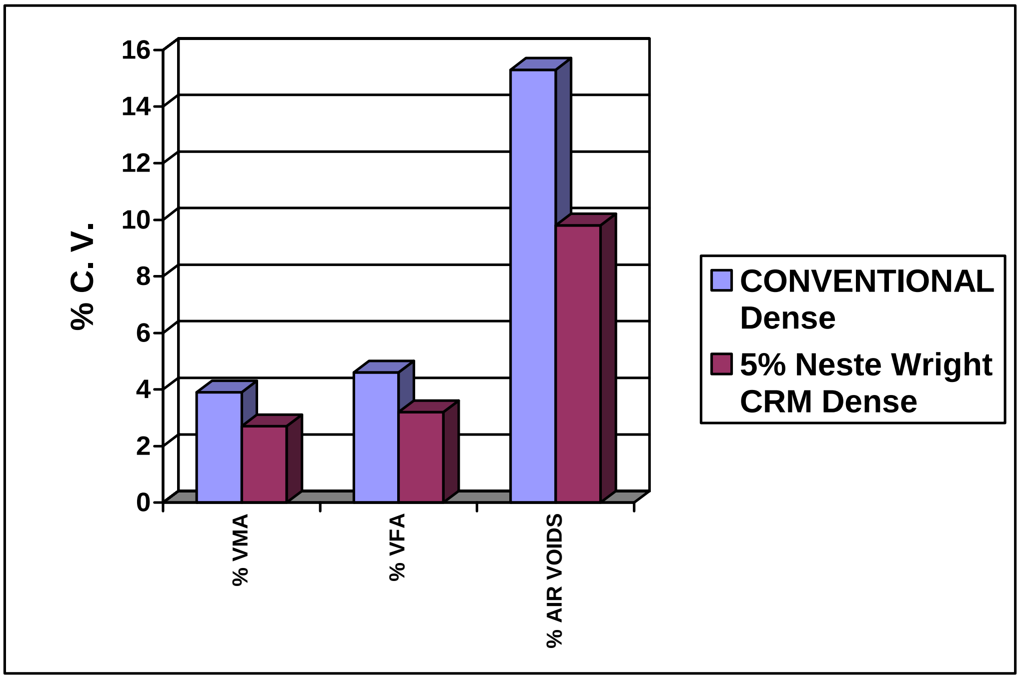

**Figure 18**
**Route US 84, % C.V. vs. mix type**

**Route US 167**

Table 21 presents the JMF and QA parameter data and results of the statistical analysis for the 1 percent Rouse Dry CRM dense-graded hot mix asphalt produced for Route US 167. The highest % C.V. represented is for the stability parameter at 12 percent. The % C.V. for Stability was followed by the % air voids and then flow parameters, at 10.9 percent and 5 percent respectively.

Table 22 indicates the JMF and QA parameter data and results of the statistical analysis for the conventional dense-graded hot mix asphalt produced for Route US 167. The highest % C.V. represented is for the % air voids parameter at 15.0 percent. The % C.V. for % air voids was followed by the stability parameter, at 9 percent. There was no reported standard deviation or % C.V. value for the flow parameter because of insufficient data. It should be noted that the gradation for the No. 40 sieve was within the acceptable mix gradation tolerance of ± 5 percent of the JMF value, 4 percent.

## Table 21

## Statistical analysis: US 167, 1% Rouse dry CRM dense-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | Mean | Std. Dev | %C.V. |
| **Spec. Gravity** | 2.380 | 2.383 | 0.010 | 0.422 |
| **Theo. Gravity** | 2.474 | 2.474 | 0.001 | 0.032 |
| **% Theor. Gravity** | 96.2 | 96.3 | 0.4 | 0.4 |
| **% VMA** | 14.0 | 13.8 | 0.4 | 2.5 |
| **% VFA** | 73 | 74 | 2 | 3 |
| **% AIR VOIDS** | 3.8 | 3.7 | 0.4 | 10.9 |
| **Stability (LBS)** | 2000 | 1968 | 237 | 12 |
| **Flow (1/100)** | 10 | 12 | 1 | 5 |
| **% AC** | 4.4 | 4.4 | 0.0 | 0.0 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 98 | 99 | 1.2 | 1.2 |
| **3/8”** | 91 | 88 | 3.8 | 4.3 |
| **No. 4** | 66 | 62 | 2.3 | 3.7 |
| **No.10** | 42 | 38 | 2.1 | 5.4 |
| **No. 40** | 22 | 21 | 1.0 | 4.7 |
| **No. 80** | 12 | 12 | 0.6 | 4.7 |
| **No. 200** | 6.5 | 5.8 | 1.7 | 29.3 |

**Table 22**

**Statistical analysis: US 167, conventional dense-graded HMA**

| | **Job Mix Formula (JMF)** | **Quality Assurance (QA)** | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.420 | 2.411 | 0.015 | 0.609 |
| **Theo. Gravity** | 2.512 | 2.512 | 0.001 | 0.034 |
| **% Theor. Gravity** | 96.3 | 96.0 | 0.6 | 0.6 |
| **% VMA** | 13.8 | 14.1 | 0.6 | 4.0 |
| **% VFA** | 73 | 72 | 3 | 5 |
| **% AIR VOIDS** | 3.7 | 4.0 | 0.6 | 15.0 |
| **Stability (LBS)** | 2000 | 1899 | 171 | 9 |
| **Flow (1/100)** | 11 | 10 | * | * |
| **% AC** | 4.3 | 4.3 | 0.1 | 2.1 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 100 | 100 | 0.0 | 0.0 |
| **3/8”** | 95 | 96 | 0.6 | 0.6 |
| **No. 4** | 58 | 58 | 1.5 | 2.6 |
| **No.10** | 35 | 32 | 2.1 | 6.6 |
| **No. 40** | 22 | 18 | 0.6 | 3.1 |
| **No. 80** | 12 | 10 | 0.6 | 5.6 |
| **No. 200** | 6.0 | 5.3 | 1.1 | 19.5 |

* Data not available

Table 23 shows the JMF and QA parameter data and results of the statistical analysis for the 2 percent CRM Generic dry gap-graded hot mix asphalt produced for Route US 167. The highest % C.V. presented is for the % air voids parameter at 7.5 percent. The % C.V. for % air voids was followed by the stability parameter, at 5 percent. There was no reported standard deviation or % C.V. value for the flow parameter because there was insufficient data available to perform the analysis. It is noted that although the % C.V. for the parameters as shown in the table appear to be reasonable. The gradation for the 3/8 in. sieve was within the acceptable mix gradation tolerance of ± 6 percent of the JMF value, 3 percent.

**Table 23**

**Statistical analysis: US 167, 2% CRM Generic dry gap-graded HMA**

| | **Job Mix Formula (JMF)** | **Quality Assurance (QA)** | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.283 | 2.257 | 0.007 | 0.303 |
| **Theo. Gravity** | 2.353 | 2.353 | 0.001 | 0.030 |
| **% Theor. Gravity** | 97.0 | 95.9 | 0.3 | 0.3 |
| **% VMA** | 16.3 | 17.2 | 0.3 | 1.6 |
| **% VFA** | 82 | 75 | 2 | 3 |
| **% AIR VOIDS** | 3.0 | 4.1 | 0.3 | 7.5 |
| **Stability (LBS)** | 2000 | 1787 | 93 | 5 |
| **Flow (1/100)** | 16 | * | * | * |
| **% AC** | 6.0 | 6.0 | 0.0 | 0.0 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 97 | 98 | 1.4 | 1.4 |
| **3/8”** | 74 | 77 | 0.0 | 0.0 |
| **No. 4** | 31 | 35 | 2.1 | 6.1 |
| **No.10** | 21 | 21 | 0.0 | 0.0 |
| **No. 40** | 11 | 13 | 1.4 | 10.9 |
| **No. 80** | 8 | 9.5 | 0.7 | 7.4 |
| **No. 200** | 5.0 | 6.0 | 0.1 | 1.2 |

* Data not available

Figure 19 indicates the % C.V. of volumetric properties (% VFA, % VMA, % air voids) vs. mix types used on the US 167 projects. It shows that the conventional dense-graded mix type had the highest % C.V. for all volumetric properties for all mix types produced on this project. The conventional dense-graded mix type was followed by the 1 percent Rouse Dry CRM dense-graded hot mix type and then by the 2 percent CRM Generic Dry gap-graded hot mix asphalt type for all parameters as shown in figure 19. The figure illustrates that the highest % C.V. was for the % air void parameter.

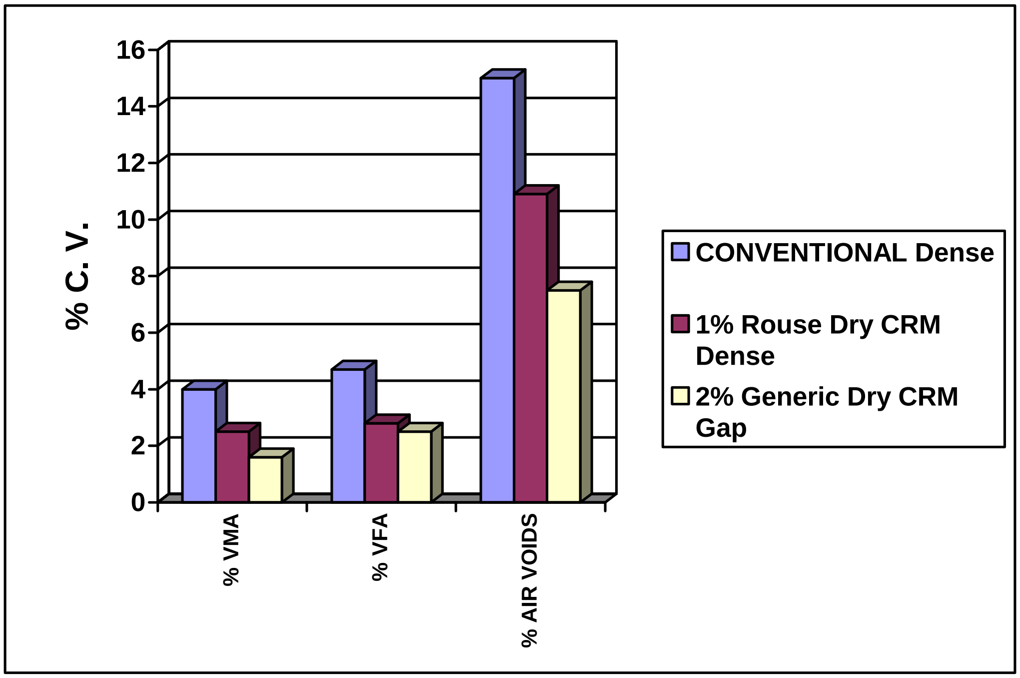

**Figure 19**
**Route US 167, % C.V. vs. mix type**

### Route LA 1040

Table 24 presents the JMF and QA parameter data and results of the statistical analysis for the 3 percent PlusRide gap-graded hot mix asphalt produced for Route LA1040. The highest % C.V. shown is for the % air voids parameter at 27.4 percent. The % C.V. for % air voids was followed by the stability and then flow parameters, at 23 percent and 10 percent respectively. The gradation analysis for the No. 200 sieve was outside the acceptable mix gradation tolerance of ± 2.0 percent of the JMF value, 2.1 percent. The change in the No. 200 sieve is the result of the contractor having difficulty incorporating the required 6 percent lime by volume into the hot mix batch plant. Subsequently, the mix design was modified in the field, but a new JMF was not recorded.

Table 25 shows the JMF and QA parameter data and results of the statistical analysis for the conventional dense-graded hot mix asphalt produced for Route LA 1040. There was no reported standard deviation or % C.V. value for any parameters because there was insufficient data available to perform the required analysis.

## Table 24
## Statistical analysis: LA 1040, 3% PlusRide gap-graded HMA

| | Job Mix Formula (JMF) | Quality Assurance (QA) | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.176 | 2.130 | 0.034 | 1.596 |
| **Theo. Gravity** | 2.246 | 2.243 | 0.005 | 0.205 |
| **% Theor. Gravity** | 97.0 | 94.9 | 1.4 | 1.5 |
| **% VMA** | 19.1 | 20.8 | 1.1 | 5.1 |
| **% VFA** | 84 | 76 | 5 | 7 |
| **% AIR VOIDS** | 3.0 | 5.1 | 1.4 | 27.4 |
| **Stability (LBS)** | 1600 | 1333 | 310 | 23 |
| **Flow (1/100)** | 26 | 27 | 3 | 10 |
| **% AC** | 8.2 | 8.2 | 0.0 | 0.0 |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | 0.0 | 0.0 |
| **½”** | 98 | 97 | 1.6 | 1.6 |
| **3/8”** | 72 | 74 | 3.8 | 5.2 |
| **No. 4** | 32 | 31 | 2.7 | 8.5 |
| **No.10** | 22 | 21 | 2.0 | 9.6 |
| **No. 40** | 14 | 13 | 1.3 | 10.2 |
| **No. 80** | 12 | 10 | 1.2 | 11.5 |
| **No. 200** | 10.2 | 7.9 | 0.8 | 10.0 |

**Table 25**

**Statistical analysis: LA 1040, conventional dense-graded HMA**

| | **Job Mix Formula (JMF)** | **Quality Assurance (QA)** | | |
|---|---|---|---|---|
| | | **Mean** | **Std. Dev** | **%C.V.** |
| **Spec. Gravity** | 2.316 | 2.324 | * | * |
| **Theo. Gravity** | 2.415 | 2.416 | * | * |
| **% Theor. Gravity** | 95.9 | 96.2 | * | * |
| **% VMA** | 15.6 | 15.3 | * | * |
| **% VFA** | 73 | 75 | * | * |
| **% AIR VOIDS** | 4.1 | 3.8 | * | * |
| **Stability (LBS)** | 2030 | 2204 | * | * |
| **Flow (1/100)** | 11 | 10 | * | * |
| **% AC** | 5.5 | 5.5 | * | * |
| | | | | |
| **Sieve** | **Gradation Analysis (Percent Passing)** | | | |
| **¾”** | 100 | 100 | * | * |
| **½”** | 97 | 100 | * | * |
| **3/8”** | 91 | 91 | * | * |
| **No. 4** | 57 | 59 | * | * |
| **No.10** | 37 | 39 | * | * |
| **No. 40** | 21 | 22 | * | * |
| **No. 80** | 9 | 9 | * | * |
| **No. 200** | 5.7 | 5.8 | * | * |

* Data not available

Figure 20 illustrates the % C.V. of volumetric properties (% VFA, % VMA, % air voids) vs. mix types used on the LA 1040 project. There is no graphical representation of the conventional dense-graded mix type as shown in this figure because of insufficient data to calculate the required statistical analysis values. However, it is indicated that the % air voids parameter had the highest % C.V. for the 3 percent PlusRide gap-graded hot mix type.

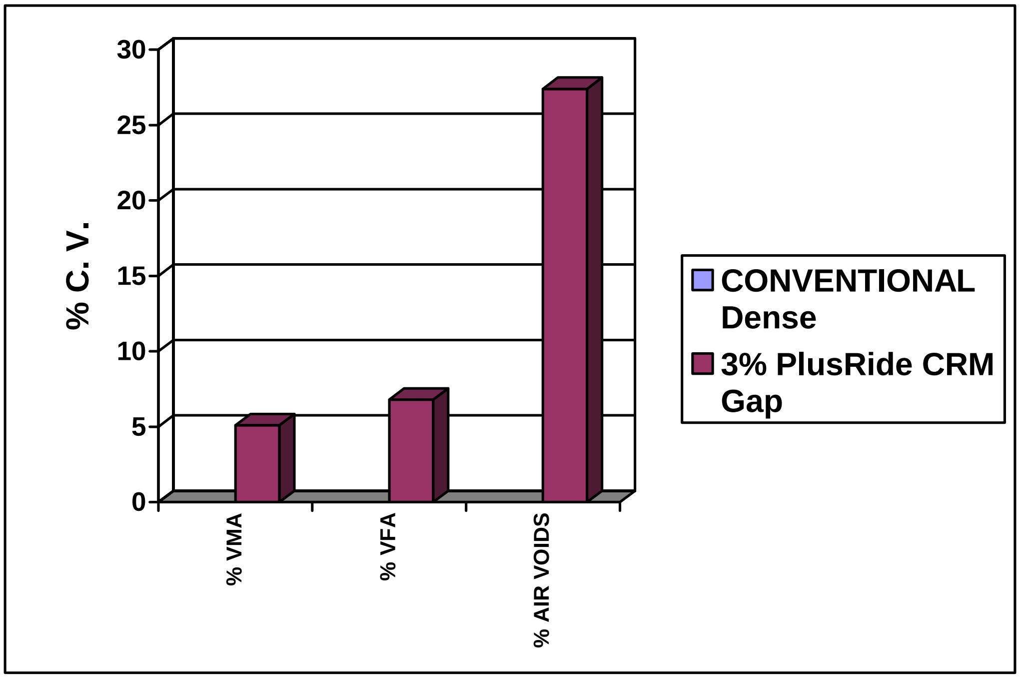

**Figure 20**
**Route LA 1040, % C.V. vs. mix type**

Metcalf et al. examined and reported on the statistical analysis of asphalt concrete data collected from 1987 to 1995 as acquired from Louisiana's Material's Test Data (MATT) reporting system [13]. 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 reported the mean and standard deviations and developed Operating Characteristic (OC) curves for Marshall Stability, gradation, antistrip, density, and profile parameters obtained from the historical data housed in the MATT system. Metcalf documents the standard deviation for the percent passing gradation parameters for the No. 4, No. 40, and No. 200 sieves as 3.7 percent, 2.0 percent, and 0.90 percent, respectively.

In review of the standard deviations for all mix types as shown in tables 13 through 24, the No. 4, No. 40, and No. 200 sieves are all within the historical data standard deviations as reported by Metcalf with the exception of the No. 200 sieve for US 167, 1 percent Rouse dry CRM dense-graded and conventional dense-graded hot mix types, as shown in tables 21 and 22. The standard deviations outside the historical data for US 167 are 1.7 percent and 1.1 percent respectively. The average standard deviations for the No. 4, No. 40, and No. 200 sieves for the remainder of the mix types as shown in tables 13 through 24, excluding table 22, are 0.7 percent, 0.6 percent, and 0.2 percent respectively. Table 25 is not included because of insufficient data. In examining the statistical deviations for all parameters and mix types as depicted in tables 13 through 24, the stability parameter had the highest reported standard deviations for all mixes, low of 93 percent and high of 604 percent. Metcalf documents a high variability of Marshall Stability among hot mix plants with the range of standard deviation from a low of 122 percent and a high of 411 percent. The next highest standard deviation value for all other parameters including the gradation analysis parameters was 5.3 percent.

## LTRC Data Collection Results

The IRI, rut depth, roadway core air voids, and crack observations were taken after the pavements had been in service for five to seven years. Because the traffic data for each project was different, it would be difficult to compare the pavement performance between two projects. Therefore, comparisons were only made for pavement sections within the same project.

### Field Performance Tests and Observations

Figures 21 and 22 present the results of DYNAFLECT testing in regards to structural number and DYNAFLECT Modulus. The DYNAFLECT tests were performed shortly after the pavements were constructed. Pavement sections were labeled by the types of wearing course mixtures. It appeared that the overall structural number (SN) for the US61 pavement sections were similar. The pavement sections in US61 also had the lowest SN in all the five projects. This might be due to the fact that in US61, there was no binder course, and the wearing course mixtures were constructed directly above the existing old pavements (as shown in figure 2). For pavements with dense-graded mixtures, the CRM wet-processed pavements (LA15 and US84) exhibited higher SN values than the control pavement sections. CRM dry-processed pavement (US167 and LA1040) had lower SN values than the control sections. Except for the open-graded friction course (OGFC) with Arizona wet CRM (US61) and the gap-graded mix with PlusRide™ dry CRM, pavement sections constructed with CRM asphalt mixtures exhibited higher modulus values than the control sections.

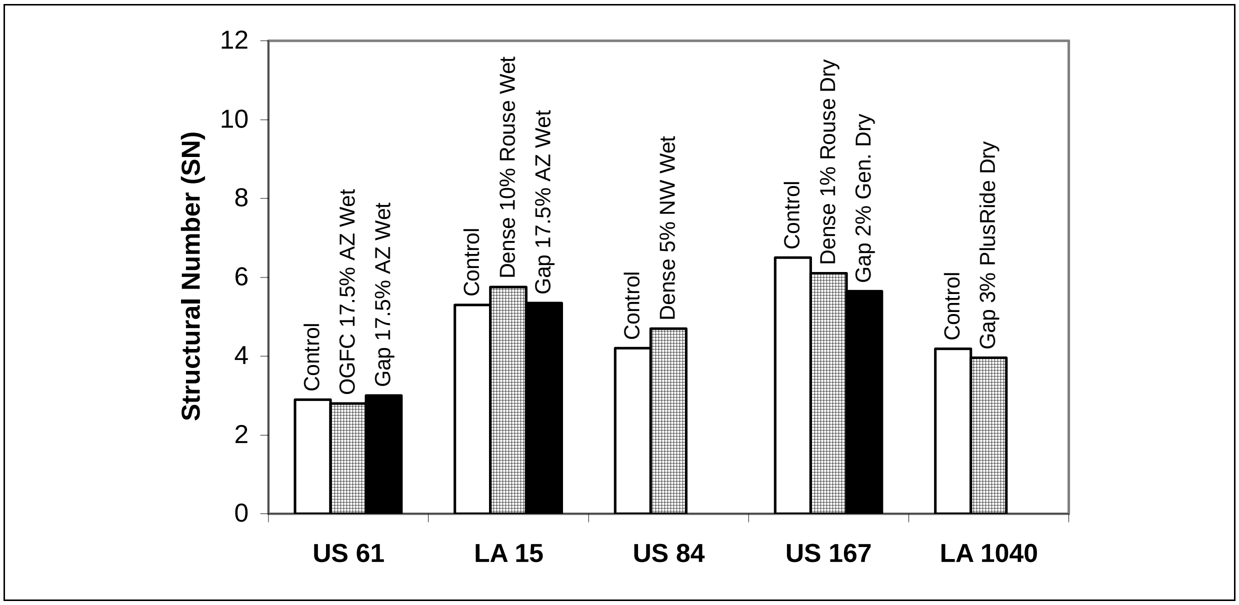

**Figure 21**
**Structural Number Test Results**

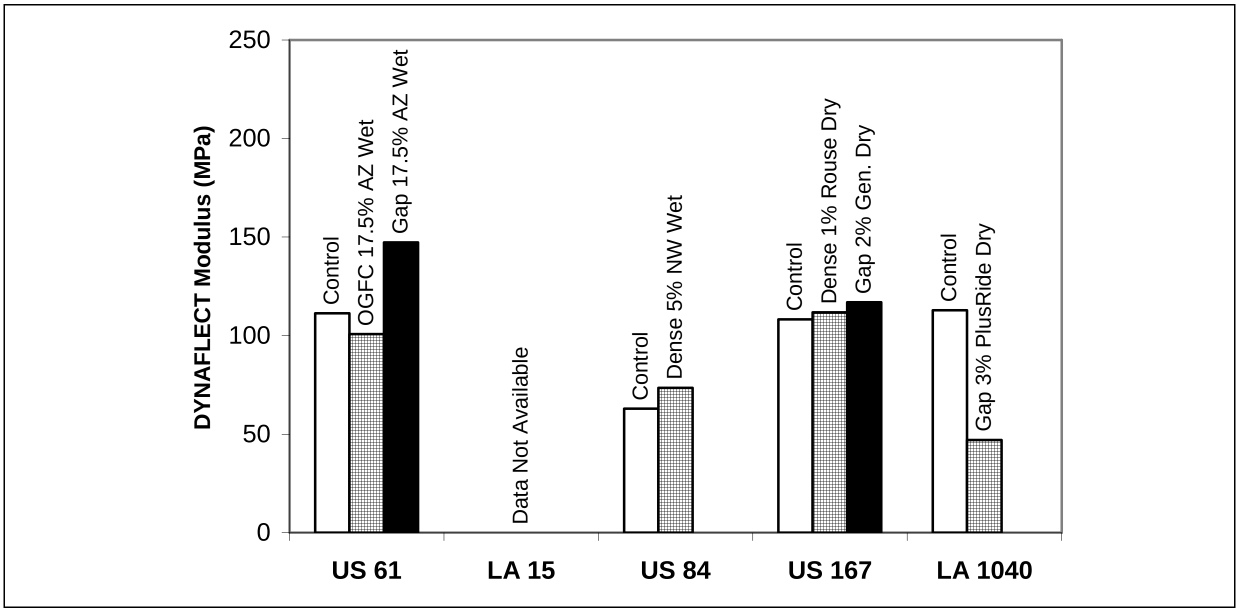

**Figure 22**
**DYNAFLECT Modulus Test Results**

Figure 23 presents the results of IRI as calculated from the measured pavement profiles. The pavement profiles were measured after five to seven years of pavement service. A lower IRI number indicates smoother and a better ride pavement. Newly constructed asphalt pavements normally have IRI values between 40 and 60. An IRI value below 100 is considered as a decent ride whereas, a value above 150 indicates poor ride. Figure 23 shows the control section in US61 had an IRI value close to poor rating. In LA1040, pavement sections constructed with crumb-rubber modified asphalt mixtures exhibited slightly higher IRI than the control section, whereas CRM sections in LA15, US84 and US167 exhibited similar or lower IRI numbers than the control sections. Generally speaking, the CRM sections both dense and Gap graded were constructed to equal or better smoothness levels proving equal "constructability".

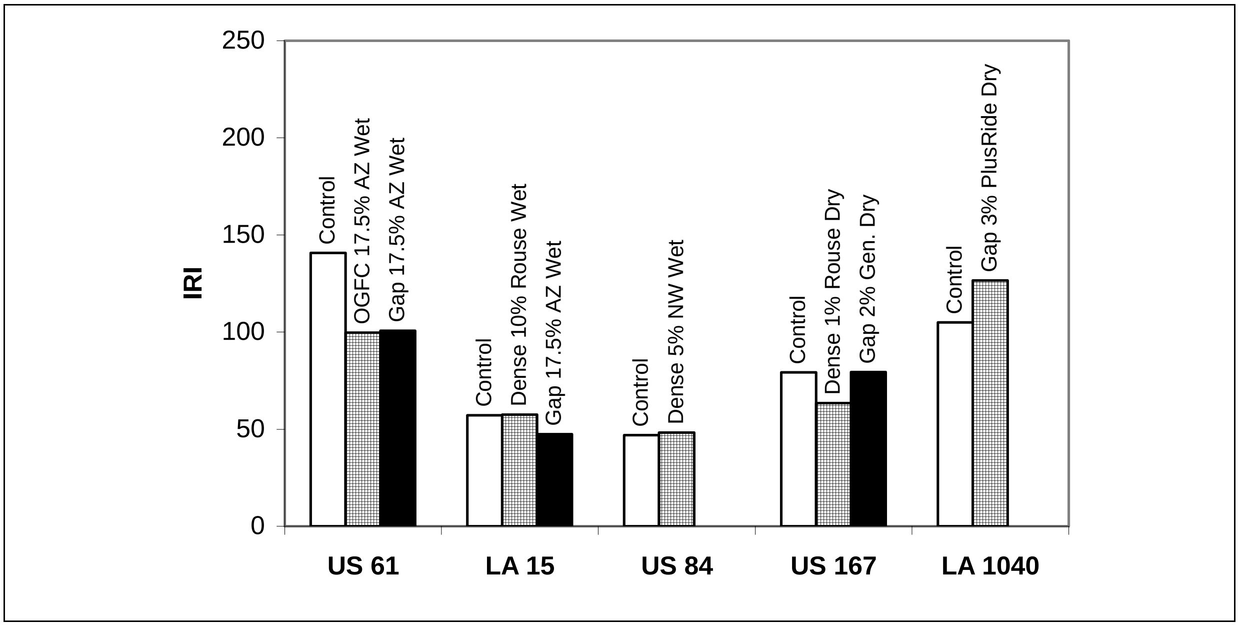

**Figure 23**
**International Roughness Index (IRI)**

Figure 24 presents the average rut depth as calculated from the measured pavement profiles after five to seven years of pavement service. All mixes had less than 6-mm of rutting after seven years of traffic. Except US61, pavement sections constructed with CRM asphalt mixtures exhibited similar or significantly lower rut depth than the control sections. In US61, the pavement section with the gap-graded CRM (17.5% Arizona wet) mixture exhibited higher rut depth than the control section whereas the section built with open-graded CRM (17.5% Arizona wet) mixture showed similar rut depth to the control section; 5.1, 3.4, and 3.4 respectively .

Figure 25 presents the roadway core air voids after six years of pavement service. The bar chart shows the range of air voids within one standard deviation below and above the average air voids from roadway cores. It appeared that except for LA15, the roadway core air voids in the rest of the four projects overlaps with the conventional mixtures within one standard deviation. In LA15, the gap-graded CRM wearing course mix had a significantly lower air voids than the conventional mixtures.

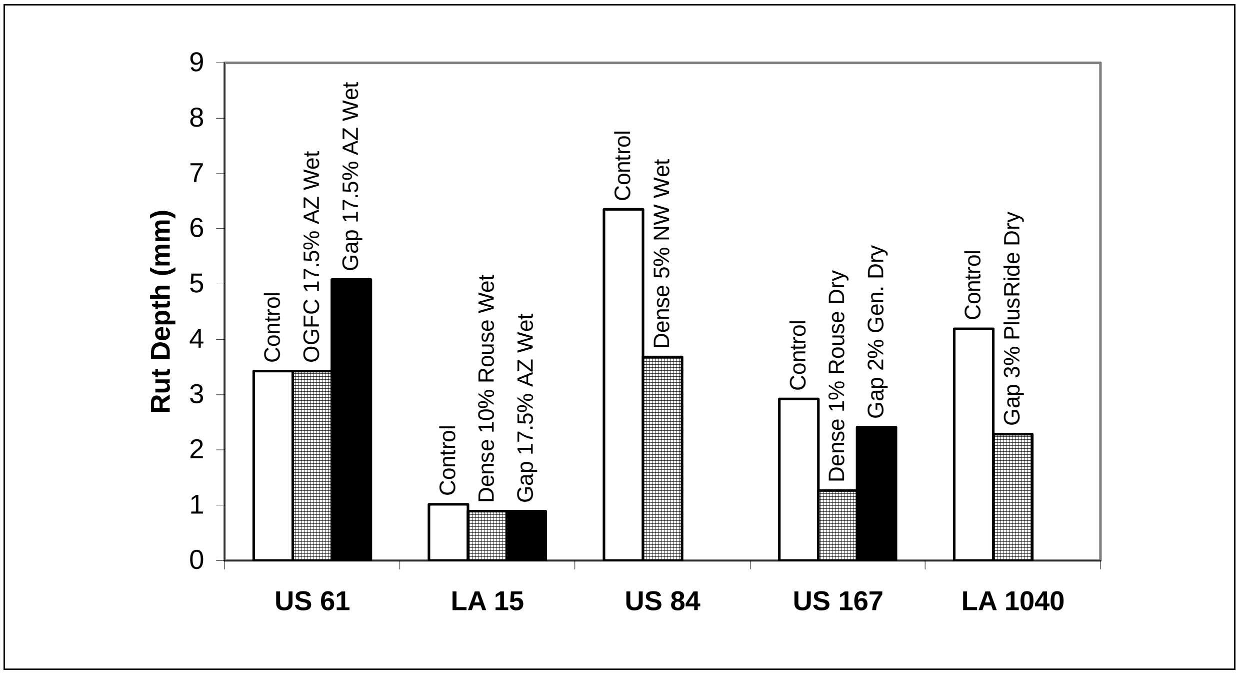

**Figure 24**
**Average Rut Depths of Pavement Sections**

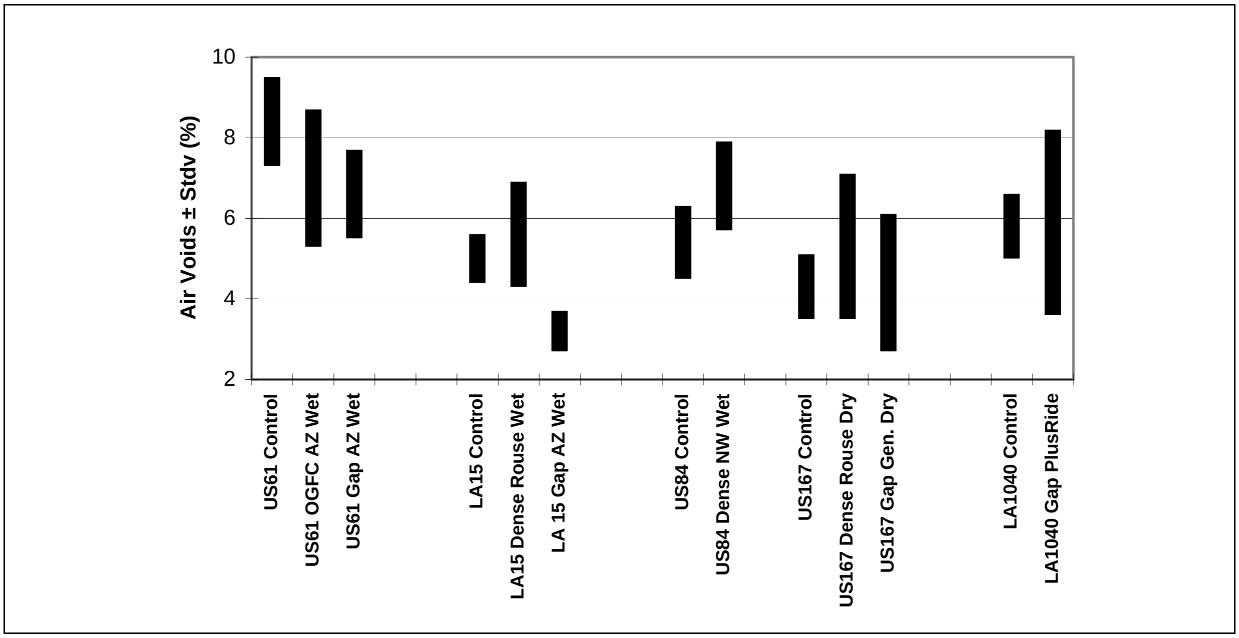

**Figure 25**
**Roadway Core Air Voids (after 5 – 7 years of service)**

## Visual Data Analysis

The field evaluation for these projects is based on data obtained for years 1995, 1997, 2000, 2002, and 2005. However, for Routes US 84, LA 15, and US 167 the 1995 data was before construction of these projects. Therefore, for these projects visual data after time of construction is more accurately reflected from year 1997 and afterwards.

### Field Evaluation Performance Tests and Observations

**Route US 61**. Figure 26 presents the pavement performance as measured by IRI, random cracking, and rutting for Route US 61. Figure 26a indicates the pavement performance as measured by average IRI. This route was rehabilitated using four test sections, and construction was completed in October 1993. This figure shows that the four reconstruction techniques had different rankings in terms of average IRI. This project had unusually long haul time, greater than one hour, which contributed to the rough numbers and further contributing to the roughness measured on the Gap graded sections was the fact that the mixture was extremely stiff containing over 10% minus 200. The conventional mixtures as indicated by data obtained for 1995 had the smoothest IRI, 75.9; the OGFC and CRM gap-graded were similar, 101.0 and 102.2 respectively; and the Polymer gap-graded mix had the highest IRI, 127.4. This ranking was maintained throughout the evaluation period. It can be surmised that the conventional mixtures would have the smoothest IRI since this mixture is commonly used and most familiar to the contractor. IRI measurements indicated that the four test sections performed very well. For the time period evaluated, figure 26a shows an increasing trend with the exception of the polymer gap-graded and OGFC mixtures. The conventional mixture and the CRM gap-graded mixture increased at a similar rate, 2.0 and 2.5 IRI/year respectively. It is indicated that there has been no rate of change in IRI for the OGFC, whereas the polymer gap-graded mixture exhibits a decreasing trend. This may be contributed to the method of IRI measurement used for data collection in years 1995 and 1997. Generally, beginning in 2000, the polymer gap-graded mixture shows no rate of change in IRI.

Figure 26b shows the pavement performance as measured by average linear feet of random cracks. The cracks observed on these section are reflective cracks from the cement treated base. This figure indicates that the four reconstruction test sections have an increasing trend. It is shown that for year 2005 that the conventional mix had the highest linear feet of random cracking, whereas the CRM gap-graded had the lowest, 1641 linear feet and 307 linear feet respectively. For the time period evaluated, the CRM gap-graded mix had the lowest rate of increase of random cracking, 43.8 linear feet per year followed by the OGFC at 82.0 linear feet per year. The polymer gap-graded mixture was similar to the rate of increase of the OGFC at 90.7 linear feet per year. The conventional mixture had the highest rate of increase of random cracking of 234.0 linear feet per year.

Figure 26c illustrates the pavement performance as measured by average inches of rutting. This figure shows that the four reconstruction test sections have an increasing trend in rutting as measured by the ARAN Smart Rutbar for 1995 and 1997. It is indicated that for these time periods the conventional mix had the least amount of rutting. The conventional mix was followed by the OGFC and CRM gap-graded test sections, which were similar. The polymer gap-graded has the highest average rutting for 1995 and 1997. When looking at figure 26c for the 2000, 2002, and 2005 data, it is shown that the polymer gap-graded mix has a rate of increase of 0.01 inches per year, whereas there is no rate of increase for the OGFC mixture for this five-year evaluation period. Also, the conventional and CRM gap-graded mixtures appeared to have a decreasing trend line. It should be noted that the average rutting measurement for the CRM gap-graded mixture is similar at years 2002 and 2005, 0.30 and 0.27 inches respectively. Therefore, generally, the CRM gap-graded mixture has not exhibited rutting over this time period. The average rutting measurement for the conventional mixture for years 2000, 2002, and 2005 are 0.31, 0.37, and 0.29 respectively. The average rutting measurements for year 2000 and 2005 are very similar and it can be stated that generally the conventional mixture has not exhibited rutting over the time period evaluated. At the end of evaluation in 2005, the OGFC and Polymer gap-graded mixtures have similar rutting, 0.21 and 0.23 inches respectively, followed by CRM gap-graded at 0.27 inches. The conventional test section is at 0.29 inches.

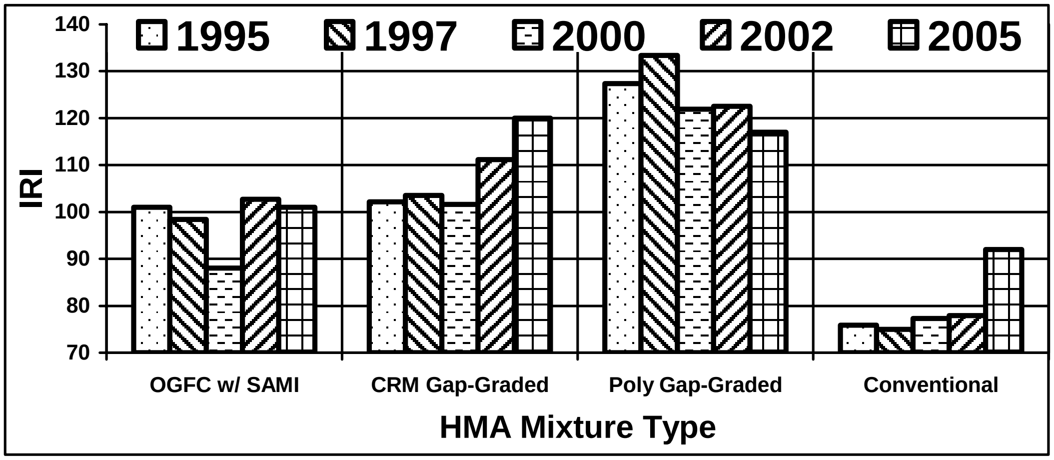

Figure 26a: Average IRI

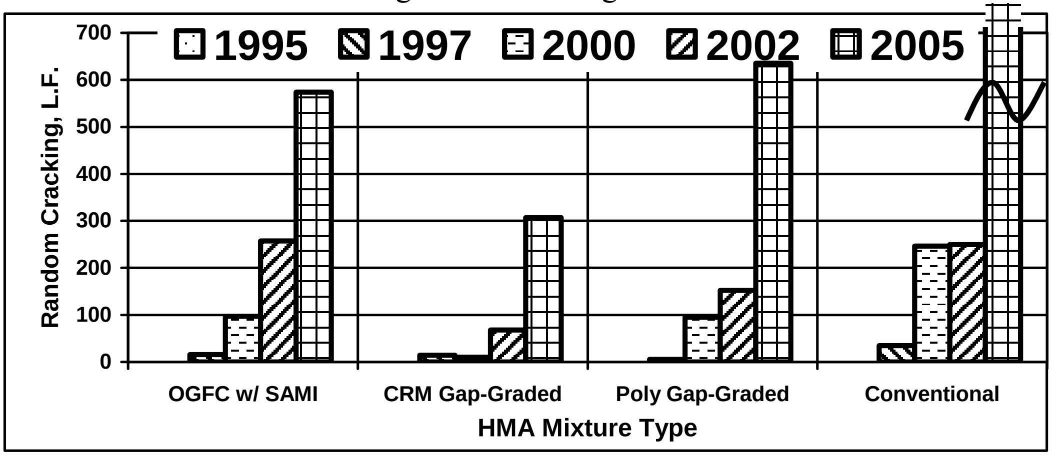

Figure 26b: Average Random Cracking

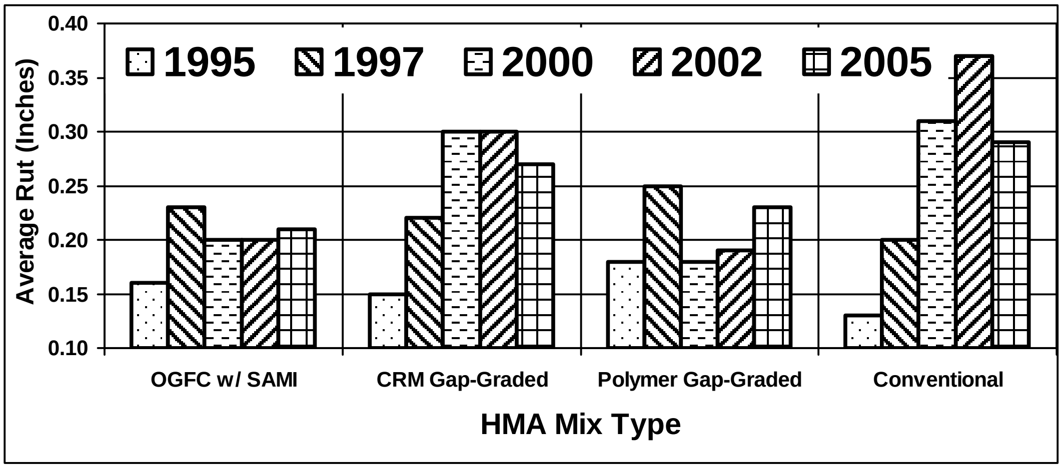

Figure 26c: Average Rut Depth

**Figure 26**
**Route US 61 Average IRI, Random Cracking, and Rutting**

**Route LA 1040.** Visual data provides a summary by control section. This project was divided into two control sections and therefore reported as such. However the typical sections are identical. Figure 27 presents the pavement performance as measured by IRI, random cracking, and rutting for Route LA 1040. This route was reconstructed with two test sections and completed in December 1994. Figure 27a shows the indicated pavement performance as measured by average IRI. The conventional mixtures as indicated by data obtained for 1995 had the smoothest IRI, 103.5; the PlusRide (832-23-0009) gap-graded was 133.0 and the PlusRide (853-10-0012) gap-graded was the highest with an IRI of 142.3. This ranking was maintained throughout the evaluation period. It is noted that both PlusRide gap-graded sections were similar, indicating no increase in IRI during the first seven years after time of construction.

Figure 27a shows that from 2002 to 2005, the PlusRide (832-23-0009) gap-graded and conventional mixtures have begun to show an increased rate of change, 2.6 and 0.8 IRI/year respectively. The other PlusRide (853-10-0012) gap-graded mixture is still exhibiting no rate of change in IRI. Overall, for the 10-year evaluation period, the PlusRide (853-10-0012) gap-graded had the least rate of change followed by the conventional mixture and then the other PlusRide (832-23-009) gap-graded mixtures, 0.0, 0.6, and 0.7 IRI/year respectively.

Figure 27b illustrates the pavement performance as measured by average linear feet of random cracks and indicates that there is an increased trend of random cracking in all test sections. The PlusRide (853-23-0009) gap-graded mixture shows the least increased rate of change followed by the other PlusRide (853-10-0012) gap-graded mixture test section during the evaluation period from time of construction, 28.2 and 39.3 linear feet per year respectively. The conventional mixture had the highest increasing trend of 77.5 linear feet per year.

Figure 27c indicates the pavement performance as measured by average inches of rutting. This figure shows that all test sections have an increasing trend in rutting as measured by the ARAN Smart Rutbar for 1995 and 1997. During these time periods the conventional mix had the least amount of rutting, followed by the PlusRide gap-graded mixtures. At year 2000, there was a significant drop in average rut measurement for all sections, which can be attributed to the change in different measuring systems, from ARAN Smart Bar to Laser XVP. Some patching was required in 1998 to this section. As shown, from 2000 to 2002, no test sections increased. Then there was an increased rate of change for all sections. For the evaluation period between 2000 and 2005, the PlusRide (853-23-0009) gap-graded mixture had the least increased rate of change of 0.01 in. /year. The conventional mix test sections and the other PlusRide (853-10-0012) gap-graded test sections have the same increased rate of change, 0.02 in./year.

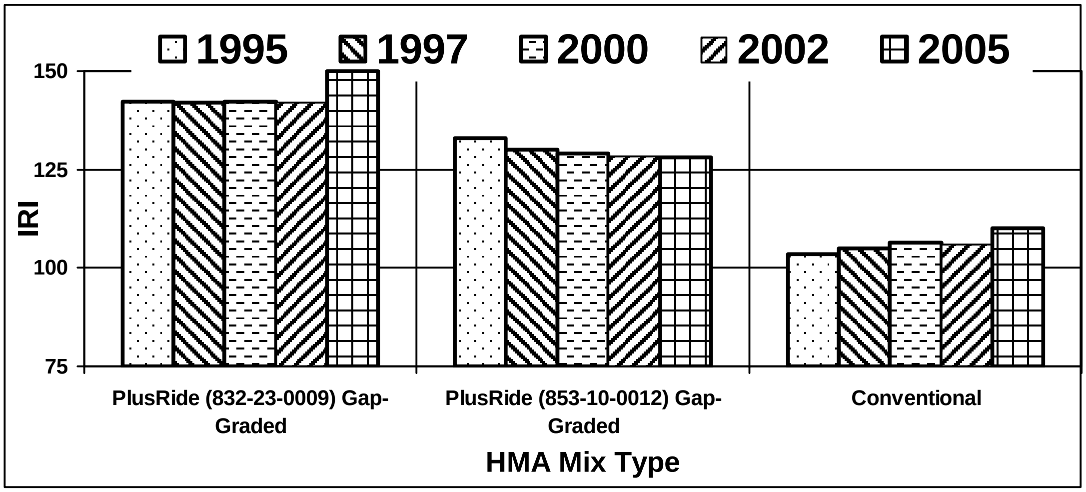

Figure 27a: Average IRI

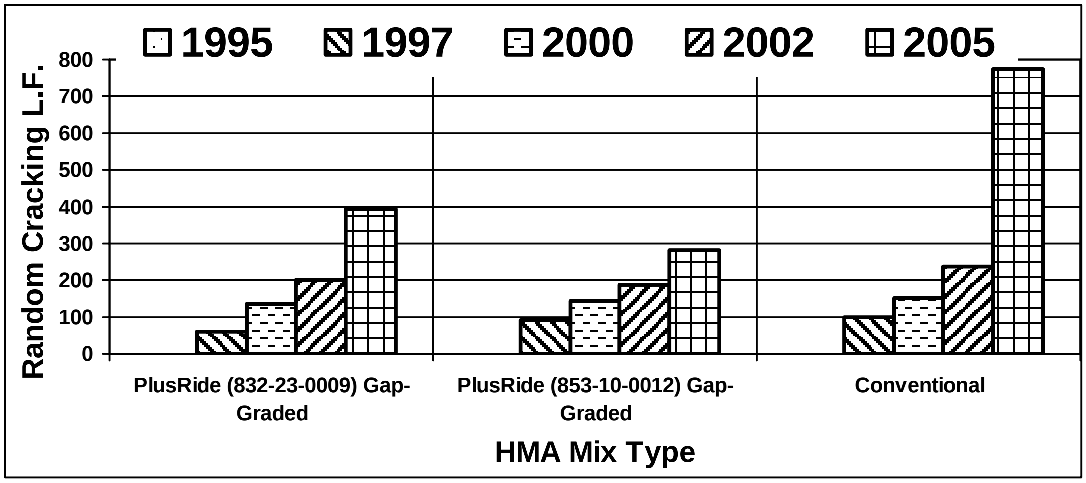

Figure 27b: Average Random Cracking

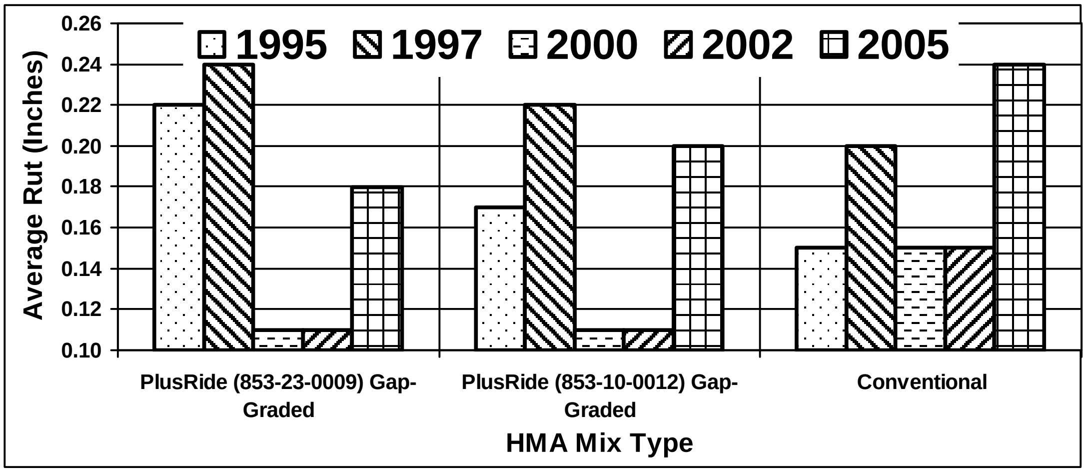

Figure 27c: Average Rut Depth

**Figure 27**
**Route LA 1040 Average IRI, Random Cracking, and Rutting**

**Route US 84**. Figure 28 presents the pavement performance as measured by IRI, random cracking, and rutting for Route US 84. Figure 28a indicates the pavement performance as measured by average IRI. This route was rehabilitated using two test sections. The construction of this route was complete in August 1995. The 1995 average measured values appear to have been made prior to date of construction.

Figure 28a shows that the CRM dense-graded and conventional mix types were similar in terms of IRI in 1997, 50.9 and 51.2 respectively. At year 2000, the average rut measurement decreased for all sections. This can be attributed to the change in different measuring systems, from ARAN Smart Bar to Laser XVP. For the 2000 to 2005 time period, the conventional mix type indicates the least increase in change followed by the CRM dense-graded mix test section, 1.9 and 3.0 IRI/year respectively. At year 2005, both conventional and CRM dense-graded mix test sections had similar measured average IRIs, 58 and 59 respectively.

Figure 28b illustrates the pavement performance as measured by average linear feet of random cracks. This figure shows an increasing trend in linear feet of random cracks for the CRM dense-graded and conventional mix test sections. It is shown that for year 2005 that the conventional mix had the lowest linear feet of random cracking, whereas the CRM dense-graded had the highest, 228 linear feet and 1771 linear feet respectively. This figure shows up to year 2002 the conventional mix type has an increasing trend of 4.8 linear feet per year, whereas the CRM dense-graded mix has an increasing trend of 13.5 linear feet per year. After 2002, the rate of change for the CRM dense-graded mix test section increases significantly, 358.9 linear feet per year. The rate of increase for the conventional mix test section after 2002 is 63.2 linear feet per year.

Figure 28c presents the pavement performance as measured by average inches of rutting for Route US 84. Reconstruction of Route US 84 was complete in August 1995. The average measured values for 1995 as shown in this figure appear to be pre-construction. Figure 28c indicates that the CRM dense-graded section exhibited the least amount of rutting followed by the conventional mix test section. This figure shows that the CRM dense-graded mix test section had the least increased rate of change, 0.01 in. per year. The conventional mix test section increase in rate of change was 0.02 in. per year. The 2005 data indicate the CRM dense-graded mix test section has 0.20 in. of average rutting followed by the conventional test section at 0.35 in.

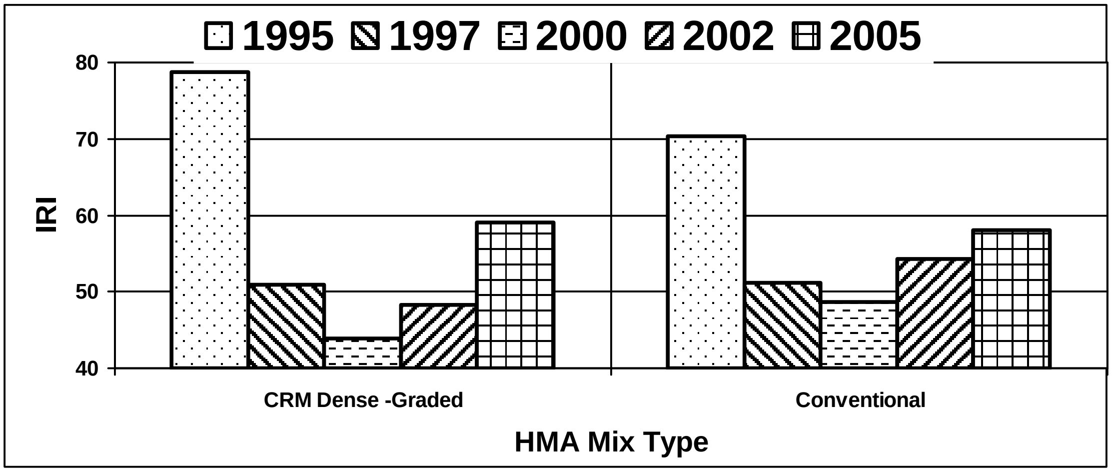

Figure 28a: Average IRI

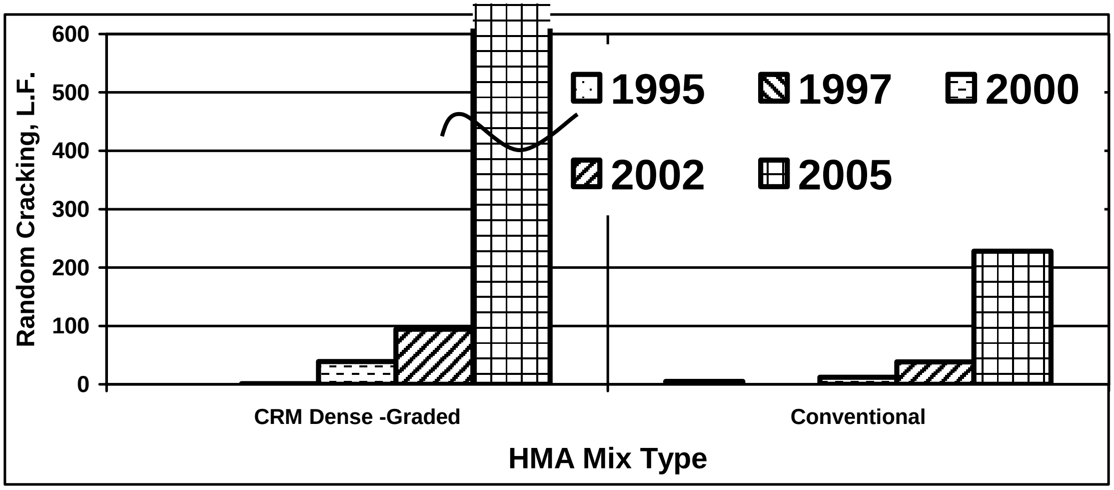

Figure 28b: Average Random Cracking

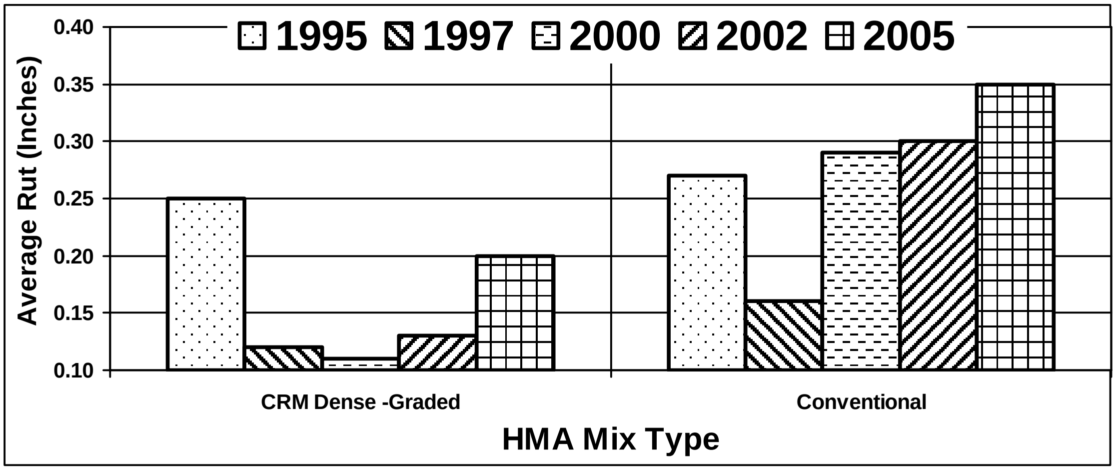

Figure 28c: Average Rut Depth

**Figure 28**
**Route US 84 Average IRI, Random Cracking, and Rutting**

**Route US 167**. Figure 29 presents the pavement performance as measured by IRI, random cracking, and rutting for Route US 167. Figure 29a indicates the pavement performance as measured by average IRI. Reconstruction of this route was complete in February 1997. Three test sections were used to rehabilitate Route US 167. The figure shows that in 1997, the post-construction average IRI measurements for the three mix types were similar. The smoothest section constructed was the 1 percent Rouse dense-graded, 59.3 IRI. The 2 percent Generic gap-graded and the conventional sections were 63.6 and 65.2 IRI, respectively. It is noted that this ranking stayed the same throughout the evaluation time period. Figure 29a showed that there is an increasing trend in average IRI over time for all test sections. The rate of change in IRI for the 1% Rouse dense-graded test section was 1.3 IRI per year. The 2 percent Generic gap-graded and the conventional test sections rate of change was 4.7 and 6.0 IRI per year, respectively.

Figure 29b shows the pavement performance as measured by average linear feet of random cracks. The figure shows that there is an increasing trend in average linear feet of random cracking for all test sections. The 1 percent Rouse dense-graded mix test section had the lowest increased rate of change in random cracking, 16.8 linear feet per year. The conventional mix test section increased at a rate of 25.8 linear feet per year. The 2 percent Generic gap-graded mix section had the highest rate of change, 30.8 linear feet per year.

Figure 29c illustrates the pavement performance as measured by average rut depth. This figure shows a distinction between the rut measuring systems. Data indicate higher rutting levels for all test sections in 1997 than in 2000. The 1997 data were collected with the ARAN Smart Rutbar, and the 2000 data were collected with the Laser XVP, so the discrepancy can be attributed to the difference between the two systems. Between 2000 and 2005, figure 17c indicates no increase in rate of change for the 1 percent Rouse dense-graded test section. The conventional test section and the 2 percent Generic gap-graded mix test sections had the same increased rate of change for the time period evaluated, 0.01 in. per year. The 1 percent Rouse dense-graded had the lowest measure of average rutting, 0.10 in., followed by the 2 percent Generic gap-graded at 0.19 in. The conventional mix test section had the highest average rutting of 0.22 in.

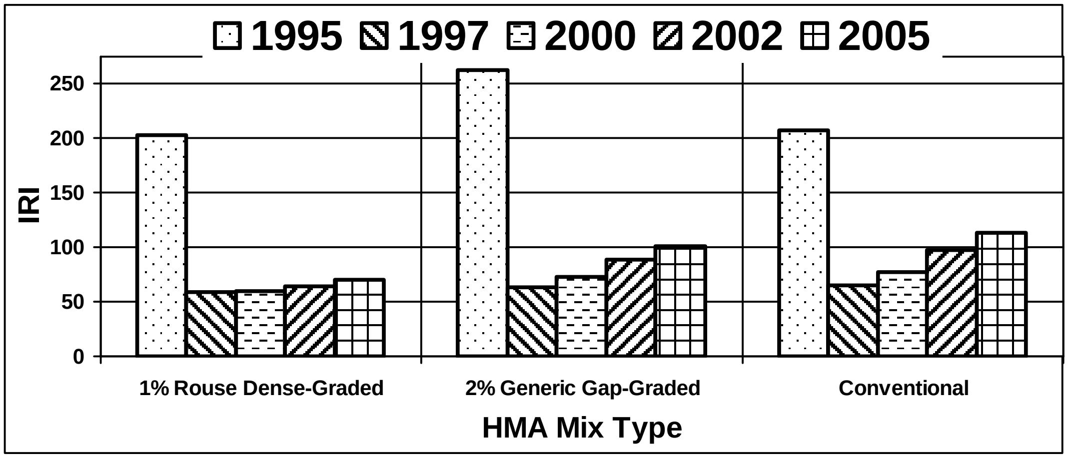

Figure 29a: Average IRI

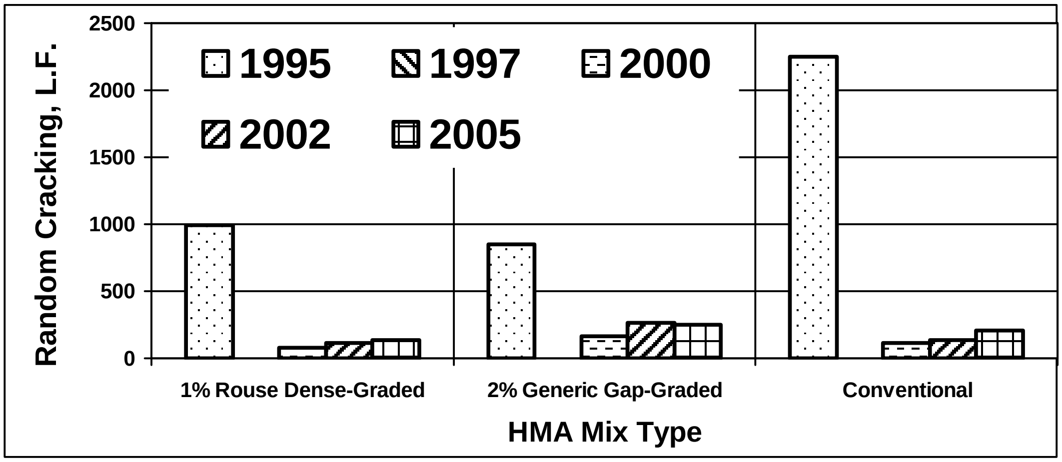

Figure 29b: Average Random Cracking

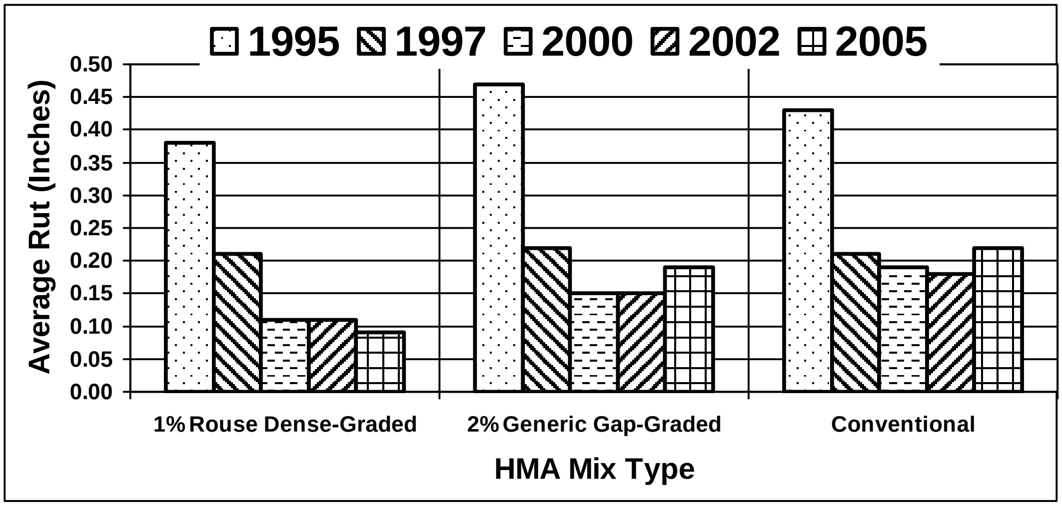

Figure 29c: Average Rut Depth

**Figure 29**
**Route US 167 Average IRI, Random Cracking, and Rutting**

**Route LA 15.** Figure 30 presents the pavement performance as measured by IRI, random cracking, and rutting for Route LA 15. Figure 30a indicates the pavement performance as measured by average IRI for Route LA 15. This route was rehabilitated using three test sections. The rehabilitation of this route was completed in October 1995. The figure shows that the CRM gap-graded section was constructed most smoothly in terms of IRI, 58.5, followed by the Rouse dense-graded section, 66.2. The conventional section was constructed with the highest average IRI value of 77.4. This ranking has stayed the same throughout the evaluation period with the exception of the conventional test section in 2005. This figure shows a decrease in IRI for the conventional mix test section in 2005. It would be reasonable to assume that the 2005 IRI would be no less than the reported measurement in 2002. Therefore, with this assumption, the conventional test section and both CRM sections maintained the same IRI ranking as constructed and had no increase in average IRI over the time period evaluated.

Figure 30b shows the pavement performance as measured by average linear feet of random cracks for Route LA 15. The figure shows an increasing trend for all test sections. Figure 30b indicates that the CRM gap-graded section has the lowest rate of increase at 6.0 linear feet per year, followed by the conventional section, 28.9 linear feet per year. The Rouse dense-graded section had the highest rate of increase, 35.5 linear feet per year. Also, figure 18b indicates that the average random cracking measurement for the CRM gap-graded section was 48 linear feet. The average random cracking measurement for the conventional and the Rouse dense-graded test sections were 231 and 284 linear feet, respectively.

Figure 30c illustrates the pavement performance as measured by average inches of rutting for Route LA 15. It indicates that rutting in the conventional and CRM gap-graded test sections increased slightly between 1997 and 2000. This may be attributed to the densification after traffic at time of initial construction. Figure 30c shows that the average rutting for the Rouse dense-graded, CRM dense-graded, and conventional test sections at year 2005 are 0.11, 0.13, and 0.14 in. respectively. The average rutting increase rate of change for the Rouse dense-graded, CRM dense-graded and conventional test sections for the time period evaluated is 0.004, 0.004, and 0.008 in. per year.

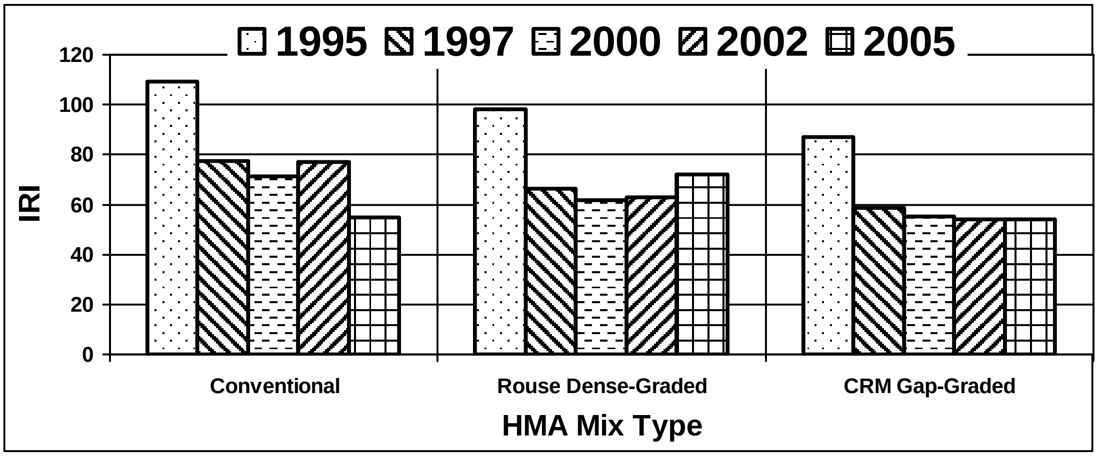

Figure 30a: Average IRI

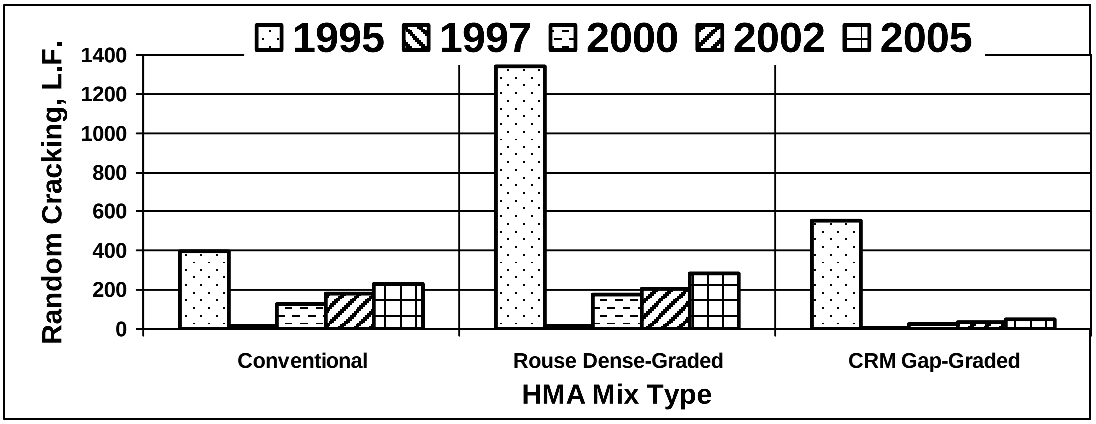

Figure 30b: Average Random Cracking

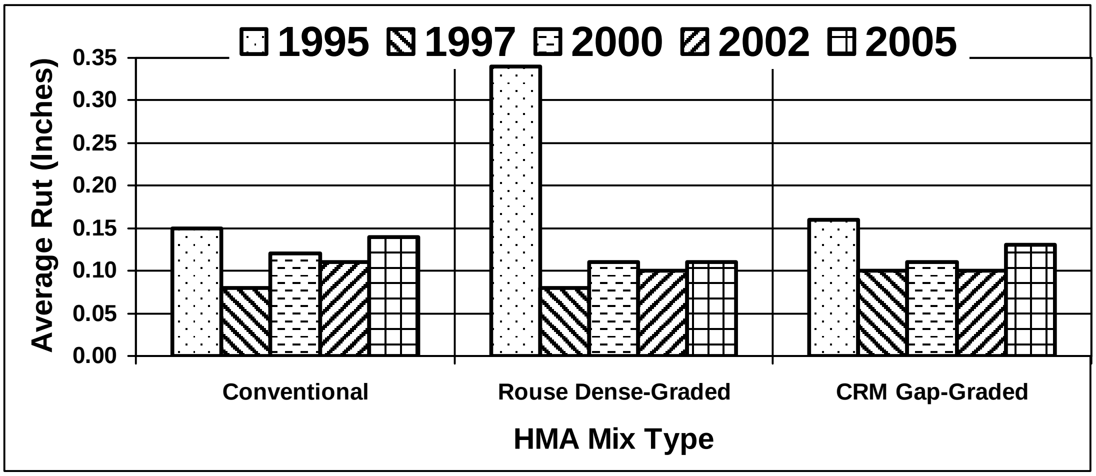

Figure 30c: Average Rut Depth

**Figure 30**
**Route LA 15 Average IRI, Random Cracking, and Rutting**

Table 26 shows the visual data average results for year 2005 for all projects. This table presents the following indices: project number and route (Project No.), year constructed, description, beginning and ending control section log mile (Begin C.S.L.M. and End C.S.L.M., respectively), average IRI (AVG IRI), average linear feet of random cracking (AVG RNDM), average linear feet of transverse cracking (AVG TRNCRK), average linear feet of longitudinal cracking (AVG LNGCRK), average linear feet of block cracking (AVG BLKCRK), and the average square feet of alligator cracking (AVG ALGRCK). It is shown that the CRM 17.5 percent Arizona Wet gap-graded mixtures for Route LA 15 is outperforming all mixture types for the indices indicated.

Table 27 presents a summary of the visual observation of crack development after 7 to 10 years of service for the test sections in this study. The CRM asphalt mixtures pavement sections exhibited less cracking than the control sections.

**Table 26**
**Visual Data Recapitulation for Year 2005**

| Project No. | Description | Begin C.S.L.M. | END C.S.L.M. | AVG IRI | AVG TRNCRK | AVG LNGCRK | AVG BLKCRK | AVG RNDM | AVG ALGCRK | AVG RUT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| 019-05-0024<br>US 61<br>Year 1992 | 1" OGFC w/SAMI | 8.350 | 9.350 | 101 | 346 | 24 | 204 | 574 | 461 | 0.21 |
| | CRM Gap-Graded | 9.350 | 13.850 | 120 | 300 | 8 | 286 | 307 | 232 | 0.27 |
| | Poly. Gap-Graded | 13.850 | 14.850 | 117 | 193 | 2 | 1536 | 635 | 363 | 0.23 |
| | Conventional | 14.850 | 15.850 | 92 | 96 | 9 | 44 | 1641 | 405 | 0.29 |
| 832-23-0009<br>(Lead)<br>LA 1040<br>Year 1993 | Plusride (832-23-0009) Gap-Graded | 0.000 | 1.360 | 150 | 328 | 20 | 30 | 393 | 95 | 0.18 |
| | Plusride (853-10-0012) Gap-Graded | 0.000 | 3.057 | 128 | 240 | 12 | 571 | 282 | 74 | 0.20 |
| | Conventional | 3.057 | 4.800 | 110 | 180 | 23 | 0 | 596 | 296 | 0.24 |
| 022-06-0041<br>US 84<br>Year 1994 | CRM Dense-Graded | 3.669 | 5.658 | 59 | 10 | 0 | 130 | 1771 | 244 | 0.20 |
| | Conventional | 5.658 | 7.784 | 58 | 81 | 18 | 0 | 228 | 1219 | 0.35 |
| 026-10-0018<br>LA 15<br>Year 1994 | Conventional | 0.000 | 1.726 | 55 | 207 | 24 | 0 | 231 | 36 | 0.14 |
| | Rouse Dense-Graded | 1.726 | 3.726 | 72 | 203 | 81 | 0 | 284 | 399 | 0.11 |
| | CRM Gap-Graded | 3.726 | 5.726 | 54 | 46 | 2 | 0 | 48 | 40 | 0.13 |
| 023-11-0028<br>US 167<br>Year 1994 | 1% Rouse Dense-Graded | 0.709 | 2.709 | 70 | 130 | 4 | 0 | 134 | 490 | 0.09 |
| | 2% Rouse Gap-Graded | 2.709 | 4.709 | 101 | 229 | 18 | 0 | 247 | 648 | 0.19 |
| | Conventional | 4.709 | 7.421 | 113 | 202 | 4 | 0 | 206 | 564 | 0.22 |

## Table 27
## Visual Observation of Pavement Cracks after Seven to Ten Years

| Route | Sections | Distress | |
|---|---|---|---|
| | | Block, Transverse, or Shrinkage Cracks | Wheel Path Cracking |
| US 61 | Control | 1/8-1" Wide<br>20-50% Length | Low<br>> 50% Wheel Path |
| | OGFC 17.5% AZ Wet | < 1/8" Wide<br>> 50% Length | Not Visible |
| | Gap 17.5% AZ Wet | < 1/8" Wide<br>20-50% Length | Low<br>< 20% Wheel Path |
| LA 15 | Control | 1/8-1" Wide<br>> 50% Length | Low<br>< 20% Wheel Path<br>(Reflective Crack due to widening) |
| | Dense 10% Rouse wet | 1/8-1" Wide<br>> 50% Length | Low<br>> 50% Wheel Path<br>(Reflective Crack due to widening) |
| | Gap 17.5% AZ Wet | < 1/8" Wide<br>>50% Length<br>(Self-healing in the wheel paths) | Low<br>< 20% (Very Little)<br>(Reflective Crack due to widening) |
| US 84 | Control | 1/8-1" Wide<br>> 50% Length | Low<br>> 50% Wheel Path |
| | Dense 5% Neste Wright | < 1/8" Wide<br>> 50% Length | Low<br>> 50% Wheel Path |
| US 167 | Control | 1/8-1" Wide<br>> 50% Length | Low<br>> 50% Wheel Path |
| | Gap 2% Generic Dry | 1/8-1" Wide<br>> 50% Length | Low<br>> 50% Wheel Path |
| | Dense 1% Rouse Dry | 1/8-1" Wide<br>20-50% Length | Low<br>< 20% Wheel Path |
| LA 1040 | Control | 1/8-1" Wide<br>> 50% Length | Moderate<br>> 50% Wheel Path |
| | Gap 3% PlusRide™ Dry | 1/8-1" Wide<br>> 50% Length | Low<br>20-50% Wheel Path |

Note: %CRM referred to the weight of the asphalt cement in wet processes;
%CRM referred to the total weight of the mixture in dry processes.
*Description of severity levels for wheel path cracking as defined as follows:

**Low**-An area of cracks with no or only a few connecting cracks; cracks are not spalled or sealed; pumping is not evident.

**Moderate**-An area of interconnected cracks forming a complete pattern; cracks may be sealed; pumping is not evident.

**High**-An area of moderately or severely spalled interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; pumping may be evident.

## Indirect Tensile Strength (ITS) Tests

Figure 31 shows the ITS test values as compared with the linear feet of random cracking for all test sections evaluated. This figure indicates a poor correlation between IT strength and strain values, and random cracking. Figure 31a illustrates the IT strength as compared to random cracking. In this figure, there appears to be an increasing trend. It is indicated, generally, that as IT strength increased random cracking increased. Figure 31b shows the IT strain as compared to random cracking. This figure illustrates a decreasing trend. Generally, it is indicated that as IT strain decreased random cracking increased.

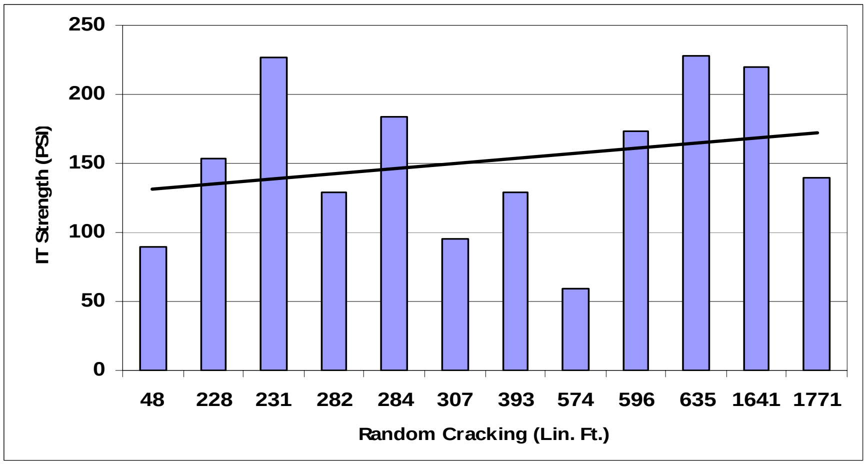

Figure 31a: IT strength vs. random cracking

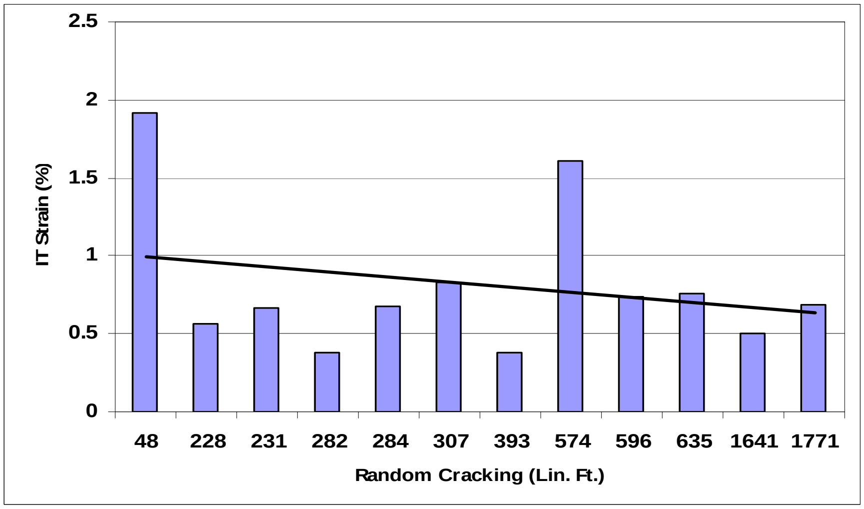

Figure 31b: IT strain vs. random cracking

**Figure 31**
**ITS test vs. random cracking**

Figure 32 illustrates the ITS test values as compared with the square feet of alligator cracking for all test sections evaluated. It is indicated that there is a poor correlation between IT strength and strain values, and alligator cracking for the sections evaluated. Figure 32a shows the IT strength as compared to alligator cracking. In this figure, there appears to be an increasing trend. Generally, it is indicated that as IT strength increased alligator cracking increased. Figure 32b shows the IT strain as compared to random cracking. This figure illustrates a decreasing trend. It is indicated generally, that as IT strain decreased alligator cracking increased.

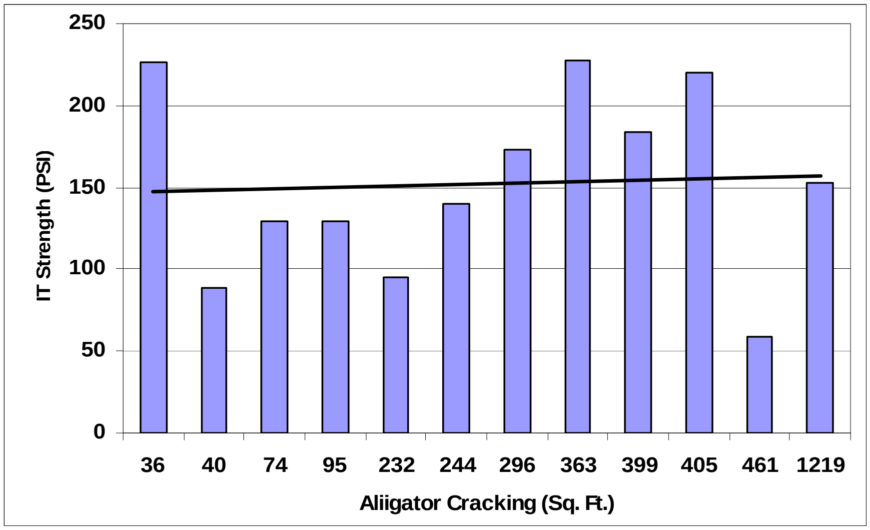

Figure 32a: ITS strength vs. alligator cracking

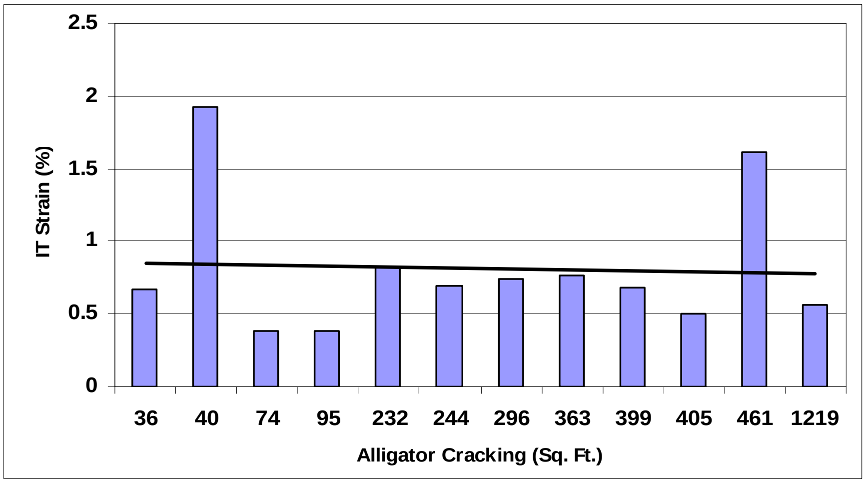

Figure 32b: ITS strain vs. alligator cracking

**Figure 32**
**ITS test vs. alligator cracking**

### Indirect Tensile Resilient Modulus ($M_R$) Test

Figure 33 shows the comparison of the indirect tensile resilient modulus test conducted at temperatures of 5, 25, and 40 ºC and alligator cracking. It is indicated that there is a poor correlation between $M_R$ values at 5, 25, and 40 ºC and alligator cracking for the sections evaluated. Figure 33a shows $M_R$ at 5 ºC as compared to alligator cracking. In this figure, there appears to be an increasing trend. Generally, it is indicated that as $M_R$ increased alligator cracking increased. Figure 33b indicates $M_R$ at 25 ºC as compared to alligator cracking. This figure illustrates a decreasing trend. It is indicated generally, that as $M_R$ decreased alligator cracking increased. Figure 33c illustrates $M_R$ at 40 ºC as compared to alligator cracking. Generally, as $M_R$ at 40 ºC increased alligator cracking increased.

Figure 34 indicates the comparison of the indirect tensile resilient modulus test conducted at temperatures of 5, 25, and 40 ºC and random cracking. It is shown that there is a poor correlation between $M_R$ values at 5, 25, and 40 ºC and random cracking for the sections evaluated. Figure 34a shows $M_R$ at 5 ºC as compared to random cracking. In this figure, there appears to be an increasing trend. Generally, as $M_R$ increased random cracking increased. Figure 34b indicates $M_R$ at 25 ºC as compared to random cracking. An increasing trend is illustrated in this figure. It is indicated generally, that as $M_R$ increased random cracking increased. Figure 34c shows $M_R$ at 40 ºC as compared to random cracking. In figure 34c an increasing trend is illustrated. Generally, as $M_R$ at 40 ºC increased random cracking increased.

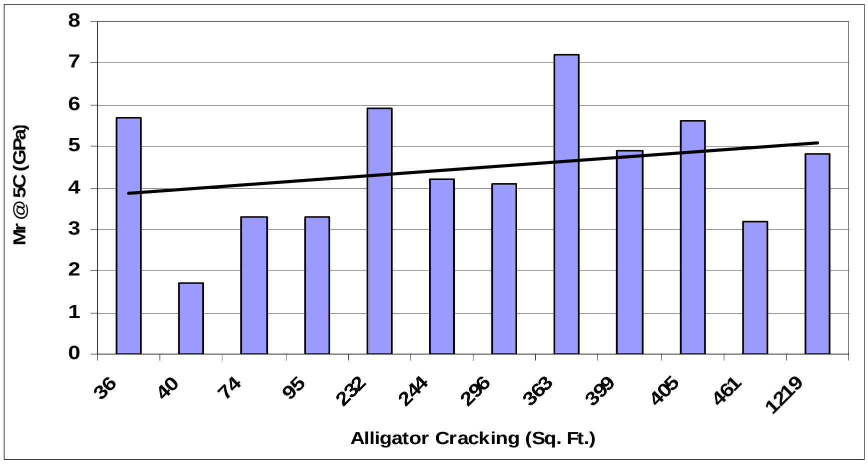

Figure 33a: $M_R$ @ 5 °C vs. alligator cracking

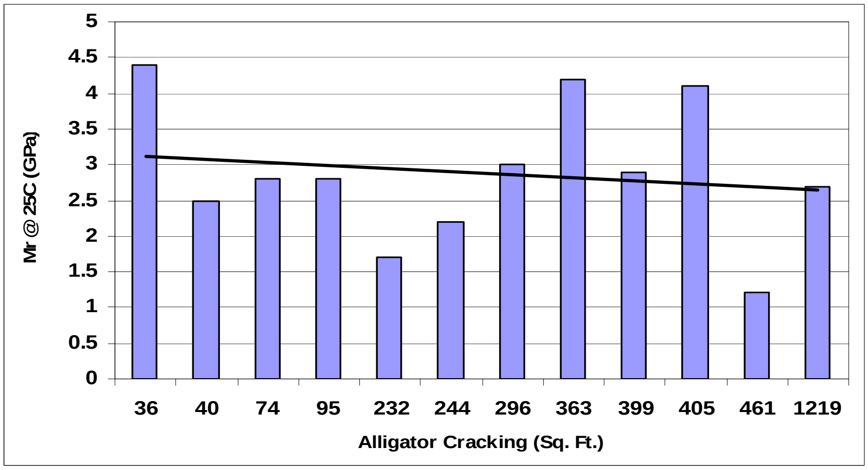

Figure 33b: $M_R$ @ 25 °C vs. alligator cracking

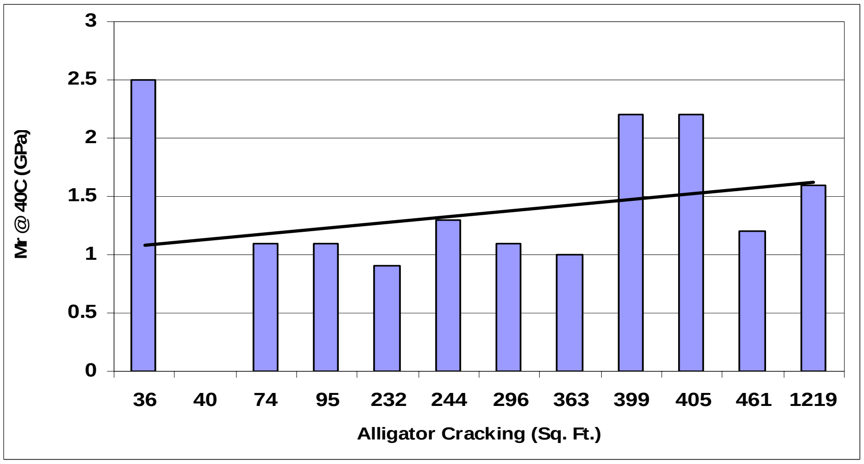

Figure 33c: $M_R$ @ 40 °C vs. alligator cracking

**Figure 33**
**Indirect resilient modulus, $M_R$, vs. alligator cracking**

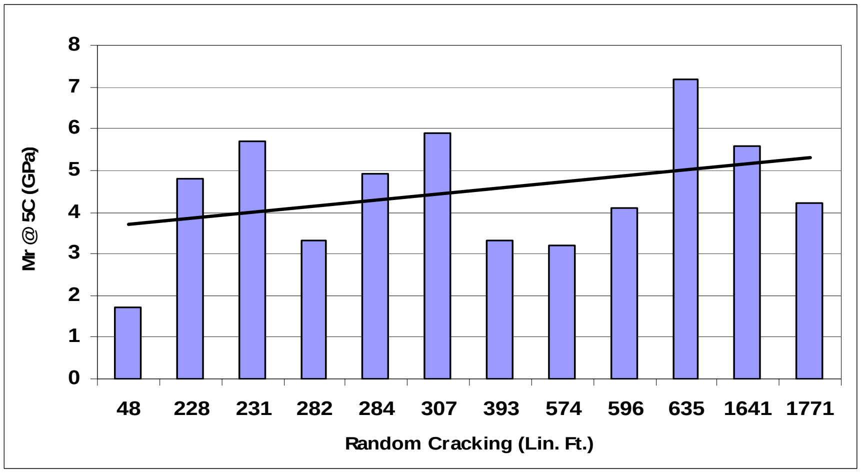

Figure 34a: $M_R$ @ 5 °C vs. random cracking

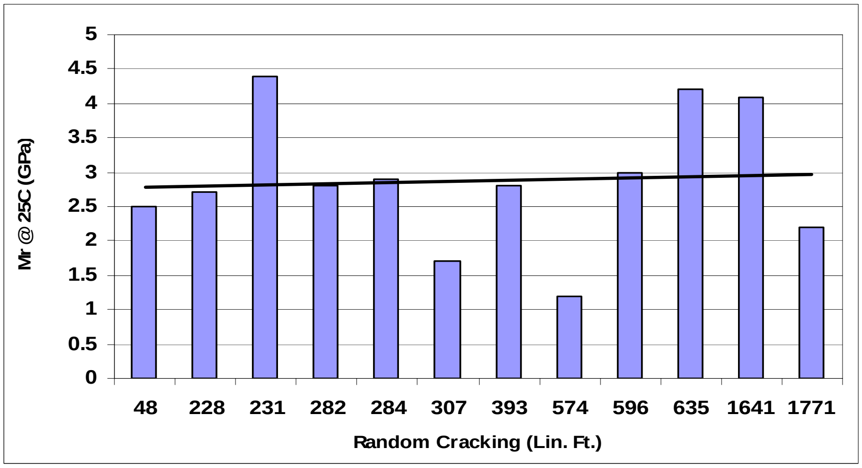

Figure 34b: $M_R$ @ 25 °C vs. random cracking

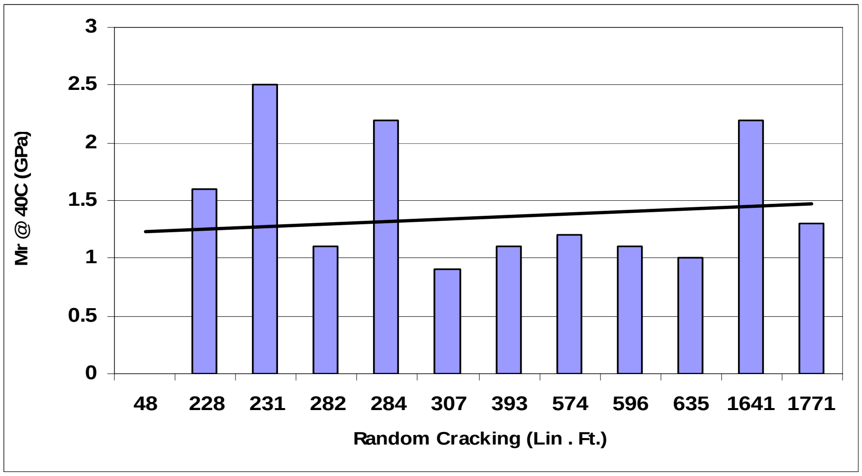

Figure 34c: $M_R$ @ 40 °C vs. random cracking

**Figure 34**
**Indirect resilient modulus, $M_R$, vs. random cracking**

Figure 35 shows a comparison between indirect resilient modulus, $M_R$, measured at 40 °C, and pavement rutting for the test sections evaluated. Generally, it is indicated that there is no correlation or trend between $M_R$ measured at 40 °C and rutting.

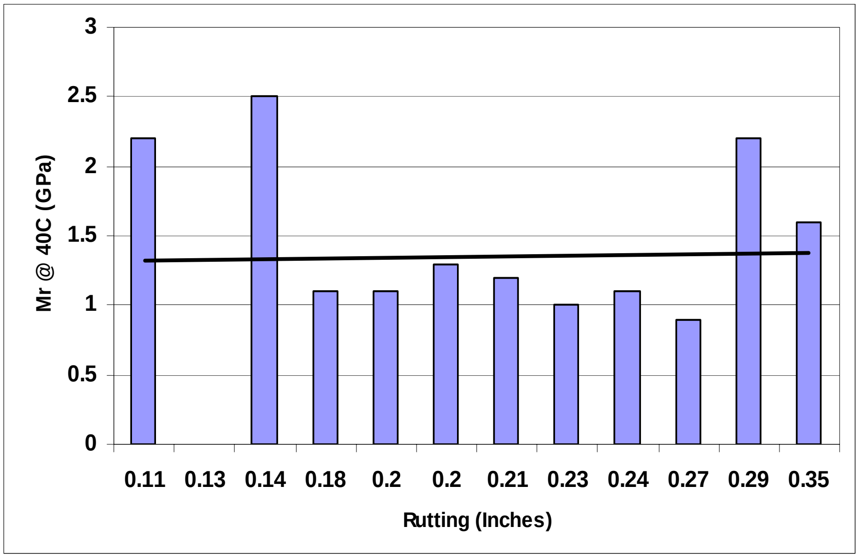

**Figure 35**
**Indirect resilient modulus, $M_R$ @ 40 °C, vs. rutting**

## Pavement Condition Index

Figure 36 illustrates the average PCI for pavement types evaluated. It shows that the average calculated PCI properly ranked the pavement types based on previously observed performance. It depicts that the CRM Wet applied HMA mix types are performing better than CRM dry and conventional HMA mix types, respectively. Figure 24, shows that the CRM wet and dry HMA mixture types are performing as well as or better than the conventional HMA mixture types. Also, the PCI values at the initial evaluation period (3 year average age) were 94, 92, and 89 for the CRM wet, conventional, and CRM dry sections, respectively. However, the PCI value at the 11 year average age for both the CRM wet and CRM dry sections were similar and performed better than the conventional section. The initial lower PCI value of CRM dry section as compared to the other sections is due to construction issues on one of the projects, particularly LA 1040.

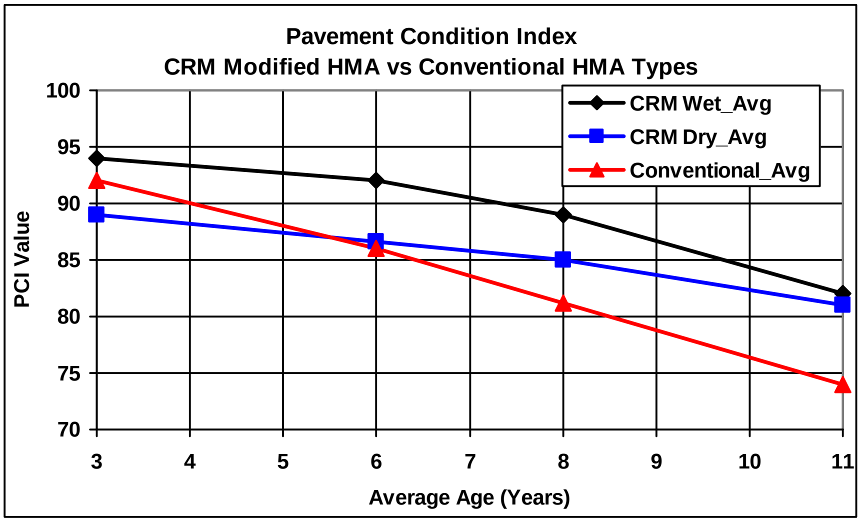

**Figure 36**
**CRM Modified HMA vs. Conventional HMA Mix PCI**

# CONCLUSIONS

Research has been conducted on the evaluation of CRM asphalt pavements in Louisiana. Eight CRM asphalt pavement sections were constructed using eight different CRM processes or applications. Test sections have been compared to conventional sections constructed throughout Louisiana. Laboratory mixture characterization, construction, statistical analysis of plant produced mix parameters, and field performance testing and observation were conducted to evaluate the performance of CRM asphalt pavements. The following can be concluded from this work:

- The CRM wet and dry HMA mixture types are performing equally or better than the conventional HMA mixture types.
- The 17.5 percent Arizona Wet Process Gap-Graded HMA is outperforming all other CRM test section mix types and conventional mixes. .
- Gap-graded CRM mixtures had higher Marshall flows than the control conventional gap- and dense-graded mixtures, whereas the dense-graded CRM mixture had Marshall flows similar to the corresponding control dense-graded mixtures.
- The CRM mixtures had generally lower ITS and $M_R$ than the control mixtures.
- CRM dry-processed pavement with gap-graded mixtures had lower initial structural capacities (DYNAFLECT structural number) than the control sections with dense-graded conventional mixtures.
- After 7 to 10 years of service, the CRM pavement sections exhibited similar or lower IRI than the control sections.
- In this study, the CRM pavement sections generally exhibited similar or lower rut depth than the control sections after seven to ten years in service.
- The CRM pavement test sections generally exhibited similar or less distress cracking (transverse and other random cracks) than the control sections.
- Generally, the use of CRM in asphalt pavement significantly increased the construction cost of HMA mixtures.
- The standard deviations for the No. 4, No. 40, and No. 200 for all mix types. Correlated with previous statistical research on Louisiana's historical data.
- Generally, there was no correlation between $M_R$ at 40 °C and rutting.

# RECOMMENDATIONS

Based on the findings of this research, it is recommended that the CRM wet process be implemented and specifications be amended accordingly. The CRM wet process has proven to be an excellent method for reducing transverse crack propagation in composite pavements. improving actual pavement performance and its use should increase the life-cycle of HMA pavements. This process also indicated the ability to be self-healing in the wheel paths based on visual inspection of LA 15. Random and transverse cracks were evident between and on each side of the wheel paths, but not visible in the wheel paths themselves. This process will be able to compete with Louisiana's current practice of using paving fabrics and grids to reduce crack propagation.

Although analysis indicates that this process is more expensive - approximately twice the cost - than conventional paving mixtures, these prices should significantly decrease based on the increased usage of this process and increase in tonnage for the CRM hot mix. Using the percentage of increase costs vs. the control section for US 61 from table 12 based on a pre 2006 costs for Louisiana's Superpave mixtures, \$50 per ton, the increase to Louisiana costs will be approximately \$3.30 per square yard (2" thick) for this process. When comparing the increase in costs of the CRM wet process with the costs of paving fabrics and grids, the CRM wet process will save Louisiana and it taxpayers approximately \$4.00 per square yard. Also, simply allowing more competition by allowing a new modifiers, CRM, may improve the pricing of the SBS modified liquid that we currently specify.

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# APPENDIX

# Evaluation of Field Projects using Crumb Rubber Modified Asphaltic Concrete

## Chart Data

| **Marshall Stability** | Conventional | CRM1 | CRM2 | Polymer Gap-graded |
|---|---|---|---|---|
| US 61 | 2076 | 1010 | 1436 | 2115 |
| LA 15 | 2400 | 2000 | 1140 | |
| US 84 | 2400 | 2000 | | |
| US 167 | 2000 | 2000 | 1550 | |
| LA 1040 | 2000 | 1600 | | |

| **Marshall Flow** | Conventional | CRM1 | CRM2 | Polymer Gap-graded |
|---|---|---|---|---|
| US 61 | 9 | 32 | 15 | 11 |
| LA 15 | 11 | 9 | 17 | |
| US 84 | 10 | 10 | | |
| US 167 | 11 | 10 | 16 | |
| LA 1040 | 10 | 26 | | |

**ITS(25ºC)** **psi**

| | Control | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 220 | 59 | 95 | 228 |
| LA 15 | 227 | 184 | 89 | |
| US 84 | 153 | 140 | | |
| US 167 | | | | |
| LA 1040 | 173 | 129 | | |

**ITS (MPa)**

| | Control | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 1.518 | 0.4071 | 0.6555 | 1.5732 |
| LA 15 | 1.5663 | 1.2696 | 0.6141 | |
| US 84 | 1.0557 | 0.966 | | |
| US 167 | | | | |
| LA 1040 | 1.1937 | 0.8901 | | |

**ITS Strain**

| | Control | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 0.50 | 1.61 | 0.83 | 0.76 |
| LA 15 | 0.67 | 0.68 | 1.92 | |
| US 84 | 0.56 | 0.69 | | |
| US 167 | | | | |
| LA 1040 | 0.74 | 0.38 | | |

**$M_R$ (5 ºC)** **psi**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 817528 | 466997 | 852253.5 | 1039733 |
| LA 15 | 824178 | 713090 | 239841 | |
| US 84 | 690712 | 615469 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 596909 | 477095 | 0 | |

**$M_R$ (5 ºC)** **Gpa**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 5.640943 | 3.222279 | 5.880549 | 7.174154 |
| LA 15 | 5.686828 | 4.920321 | 1.654903 | |
| US 84 | 4.765913 | 4.246736 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 4.118672 | 3.291956 | | |

**$M_R$ (25 ºC)** **psi**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 597284 | 168591 | 252527.5 | 609926.5 |
| LA 15 | 639561 | 419063 | 360941 | |
| US 84 | 397309 | 317072 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 439059 | 400002 | 0 | |

**$M_R$ (25 ºC)** **Gpa**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 4.12126 | 1.163278 | 1.74244 | 4.208493 |
| LA 15 | 4.412971 | 2.891535 | 2.490493 | |
| US 84 | 2.741432 | 2.187797 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 3.029507 | 2.760014 | | |

**$M_R$ (40 ºC)** **psi**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 288901 | 171539 | 129507 | 149705 |
| LA 15 | 355663 | 315584 | 0 | |
| US 84 | 236956 | 182740 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 163645 | 159957 | 0 | |

**$M_R$ (40 ºC)** **Gpa**

| | Conventional | CRM1 | CRM2 | Polymer Gap-Graded |
|---|---|---|---|---|
| US 61 | 1.993417 | 1.183619 | 0.893598 | 1.032965 |
| LA 15 | 2.454075 | 2.17753 | 0 | |
| US 84 | 1.634996 | 1.260906 | 0 | |
| US 167 | 0 | 0 | 0 | |
| LA 1040 | 1.129151 | 1.103703 | | |

**Dynaflect SN**

| | Control | CRM1 | CRM2 |
|---|---|---|---|
| US 61 | 2.9 | 2.8 | 3 |
| LA 15 | 5.3 | 5.75 | 5.35 |
| US 84 | 4.2 | 4.7 | |
| US 167 | 6.5 | 6.1 | 5.65 |
| LA 1040 | 4.19 | 3.96 | |

**Es (psi)**

| | Control | CRM1 | CRM2 |
|---|---|---|---|
| US 61 | 16125 | 14600 | 21341 |
| LA 15 | | | |
| US 84 | 9122 | 10640 | |
| US 167 | 15680.5 | 16200 | 16954.5 |
| LA 1040 | 16362 | 6814 | |

**Es (MPa)**

| | Control | CRM1 | CRM2 |
|---|---|---|---|
| US 61 | 111.2625 | 100.74 | 147.2529 |
| LA 15 | | | |
| US 84 | 62.9418 | 73.416 | |
| US 167 | 108.1955 | 111.78 | 116.9861 |
| LA 1040 | 112.8978 | 47.0166 | |

**IRI**

| | Control | CRM1 | CRM2 |
|---|---|---|---|
| US 61 | 140.75 | 99.75 | 100.75 |
| LA 15 | 57.25 | 57.5 | 47.5 |
| US 84 | 47 | 48.25 | |
| US 167 | 79.25 | 63.5 | 79.5 |
| LA 1040 | 105 | 126.5 | |

**Rut (mm)**

| | Control | CRM1 | CRM2 |
|---|---|---|---|
| US 61 | 3.429 | 3.429 | 5.08 |
| LA 15 | 1.016 | 0.889 | 0.889 |
| US 84 | 6.35 | 3.683 | |
| US 167 | 2.921 | 1.27 | 2.413 |
| LA 1040 | 4.191 | 2.286 | |

**Air Voids WC**

| | ave-1s | average | ave+1s | | ave | stdv |
|---|---|---|---|---|---|---|
| US61 Control | 7.3 | 8.4 | 9.5 | 9.5 | 8.4 | 1.1 |
| US61 OGFC AZ Wet | 5.3 | 7 | 8.7 | 8.7 | 7 | 1.7 |
| US61 Gap AZ Wet | 5.5 | 6.6 | 7.7 | 7.7 | 6.6 | 1.1 |
| | 0 | 0 | 0 | 0 | | |
| | 0 | 0 | 0 | 0 | | |
| LA15 Control | 4.4 | 5 | 5.6 | 5.6 | 5 | 0.6 |
| LA15 Dense Rouse Wet | 4.3 | 5.6 | 6.9 | 6.9 | 5.6 | 1.3 |
| LA 15 Gap AZ Wet | 2.7 | 3.2 | 3.7 | 3.7 | 3.2 | 0.5 |
| | 0 | 0 | 0 | 0 | | |
| | 0 | 0 | 0 | 0 | | |
| US84 Control | 4.5 | 5.4 | 6.3 | 6.3 | 5.4 | 0.9 |
| US84 Dense NW Wet | 5.7 | 6.8 | 7.9 | 7.9 | 6.8 | 1.1 |
| | 0 | 0 | 0 | 0 | | |
| US167 Control | 3.5 | 4.3 | 5.1 | 5.1 | 4.3 | 0.8 |
| US167 Dense Rouse Dry | 3.5 | 5.3 | 7.1 | 7.1 | 5.3 | 1.8 |
| US167 Gap Gen. Dry | 2.7 | 4.4 | 6.1 | 6.1 | 4.4 | 1.7 |
| | 0 | 0 | 0 | 0 | | |
| | 0 | 0 | 0 | 0 | | |
| LA1040 Control | 5 | 5.8 | 6.6 | 6.6 | 5.8 | 0.8 |
| LA1040 Gap PlusRide | 3.6 | 5.9 | 8.2 | 8.2 | 5.9 | 2.3 |

**Air Voids BC**

| | ave-1s | average | ave+1s | | ave | stdv |
|---|---|---|---|---|---|---|
| US61 Conv. Control | 4.6 | 5.7 | 6.7 | 5.7 | 5.7 | 1.1 |
| LA15 Conv. Control | 4.9 | 6.0 | 7.1 | 7.1 | 6.0 | 1.1 |
| LA15 Dense Rouse Wet | 4.8 | 5.4 | 6.0 | 6.0 | 5.4 | 0.6 |
| LA 15 Conv. Under Gap AZ Wet | 4.3 | 5.0 | 5.7 | 5.7 | 5.0 | 0.7 |
| US84 Conv. Control | 3.9 | 4.5 | 5.2 | 5.2 | 4.5 | 0.6 |
| US84 Dense NW Wet | 4.1 | 4.8 | 5.4 | 5.4 | 4.8 | 0.6 |
| US167 Conv. Control | 4.3 | 6.1 | 7.8 | 7.8 | 6.1 | 1.8 |
| US167 Dense Rouse Dry | 3.4 | 4.6 | 5.7 | 5.7 | 4.6 | 1.1 |
| US167 Conv. Under Gap Gen. Dry | 4.1 | 4.7 | 5.3 | 5.3 | 4.7 | 0.6 |
| LA1040 Conv. Control | 4.5 | 5.2 | 5.9 | 5.9 | 5.2 | 0.7 |
| LA1040 Conv. Under Gap PlusRide | 3.7 | 5.1 | 6.5 | 6.5 | 5.1 | 1.4 |