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16. Abstract

Louisiana Department of Transportation and Development (LADOTD) began the development of Open-Graded Friction Course (OGFC) mixtures in the late 1960s and early 1970s. In the early 1980s, a moratorium was imposed on the use of OGFC mixtures due to some early failure issues and a number of OGFC pavements experiencing end of life failure. However, significant improvements have been noticed in OGFC mixture performance and service life since a new-generation of OGFC mixture was promoted in the U.S. in late 1990s. Inspired by the success of some other state agencies, LADOTD modified the earlier mix design and constructed four new OGFC sections during the last decade to evaluate pavement performance and safety benefits. This paper includes a comprehensive evaluation of Louisiana OGFC mixtures on the basis of their laboratory and field performance. Laboratory work entailed material and mixture design in addition to performing numerous laboratory tests namely permeability, draindown, tensile strength ratio, and loaded wheel test. Field evaluation involved visual inspection, pavement condition survey, skid resistance, and traffic safety. With very few exceptions in the laboratory, the selected OGFC mixtures showed the potential to meet current LADOTD specifications as well as various performance standards established by previous studies. The field analysis indicates that the OGFC test sections showed improved rutting, cracking, and skid performance when compared to typical Superpave roadway sections. It is anticipated that this performance evaluation will support the ongoing use of OGFC mixtures in the state of Louisiana. Additionally, it provides an opportunity to continually improve the current OGFC specification and mix design procedures adopted by LADOTD.

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ABSTRACT

Louisiana Department of Transportation and Development (LADOTD) began the development of Open-Graded Friction Course (OGFC) mixtures in the late 1960s and early 1970s. In the early 1980s, a moratorium was imposed on the use of OGFC mixtures due to some early failure issues and a number of OGFC pavements experiencing end of life failures. However, significant improvements have been noticed in OGFC mixture performance and service life since a new-generation of OGFC mixture was promoted in the U.S. in late 1990s. Inspired by the success of some other state agencies, LADOTD modified the earlier mix design and constructed four new OGFC sections during the last decade to evaluate pavement performance and safety benefits. This paper includes a comprehensive evaluation of Louisiana OGFC mixtures on the basis of their laboratory and field performance. Laboratory work entailed material and mixture design in addition to performing numerous laboratory tests namely permeability, draindown, tensile strength ratio, and loaded wheel. Field evaluation involved visual inspection, pavement condition survey, skid resistance, and traffic safety. With very few exceptions in the laboratory, the selected OGFC mixtures showed the potential to meet current LADOTD specifications as well as various performance standards established by previous studies. The field analysis indicates that the OGFC test sections showed improved rutting, cracking, and skid performance when compared to typical Superpave roadway sections. It is anticipated that this performance evaluation will support the ongoing use of OGFC mixtures in the state of Louisiana. Additionally, it provides an opportunity to continually improve the current OGFC specification and mix design procedures adopted by LADOTD.

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IMPLEMENTATION STATEMENT

The experience obtained from this research study has led to the development of new OGFC mixture specifications for LADOTD which are capable of delivering impressive performance as well as providing a safe traveling surface and improved visibility during inclement weather.

Based on the recommendations of this research, Louisiana's OGFC mix design procedure has been incorporated into the recently developed 501 specifications, Thin Asphaltic Concrete Applications. Some of the highlighted mixture specifications include:

- Performance graded asphalt cement along with fiber additives are required in current practice.
- A maximum limit of 0.472-in. (12-mm) rut depth after 7500 passes in the LWT test.
- The Spray Paver shall be required when placing OGFC mixtures using a polymer based emulsion for the tack coat.
- Require the use of the CoreLok device for determining air voids.

In addition to the new specifications, a design memorandum on the appropriate use of all Asphalt mixtures and treatments was developed, which includes the OGFC mixtures. The memorandum indicates that all new construction on Interstate roadways in urban areas have an OGFC placed as the final lift. Since the beginning of this study, approximately 115,000 tons or 263 lane miles of OGFC mixtures have been placed on various roadways and many more are being planned throughout the state. LTRC will continue to monitor the use and performance of these pavements.

TABLE OF CONTENTS

ABSTRACT III
ACKNOWLEDGMENTS V
IMPLEMENTATION STATEMENT VII
TABLE OF CONTENTS IX
LIST OF TABLES XI
LIST OF FIGURES XIII
INTRODUCTION 1
Background and Literature Review 2
Noise Reduction 3
Improved Safety 4
Mixture Design 6
Production and Construction 7
Limitations of OGFCs 8
OBJECTIVE 9
SCOPE 11
METHODOLOGY 13
Field Project Description 13
US 71, Grant Parish 13
I-20, Ouacita Parish 14
US 61, Ascension Parish 14
US 171, Desoto Parish 14
Materials and Mixture Design 17
Laboratory Testing 19
Permeability Test 19
Draindown Test 20
Loaded Wheel Tracker (LWT) Test 21
Tensile Strength Ratio (TSR) Test 22
Air Void Measurement 22
Field Performance Tests 24
Pavement Friction Properties 24
Distress Condition Survey 25
DISCUSSION OF RESULTS 27
Laboratory Test Results 27
Permeability Test Results 27
Draindown Test Results 28

Loaded Wheel Tracking (LWT) Test Results 28
Tensile Strength Ratio (TSR) Test Results 29
Air Void Measurement 30
Filed Performance Evaluation 31
Distress Condition Survey Results 31
Reflective Crack Measures 35
Accident Reduction 36
Splash and Spray of Rainwater 38
Cost Comparisons 39
CONCLUSIONS 41
RECOMMENDATIONS 43
ACRONYMS, ABBREVIATIONS, AND SYMBOLS 45
REFERENCES 47
APPENDIX 53

LIST OF TABLES

Table 1 Comparison between FHWA and NCAT gradations 7
Table 2 Mixture description and volumetrics 18
Table 3 Friction properties of various roadway sections 32
Table 4 PCI and predicted service life 36
Table 5 Accident reduction 37
Table 6 Cost comparison of OGFC and glass-grid sections 40

LIST OF FIGURES

Figure 1 Locations of OGFC test sections 13
Figure 2 Construction of OGFC 15
Figure 3 LADOTD OGFC test sections 16
Figure 4 Blended aggregate gradations 19
Figure 5 Falling head flexible wall permeameter 20
Figure 6 Loaded wheel tester device 21
Figure 7 Humbolt TSR device 22
Figure 8 CoreLok testing device 23
Figure 9 Locked wheel skid tester 24
Figure 10 Automated pavement data collection unit 25
Figure 11 A screen shot of visidata software 26
Figure 12 Permeability test results 27
Figure 13 Draindown test results 28
Figure 14 LWT test results 29
Figure 15 TSR test results 30
Figure 16 Comparison of air voids 31
Figure 17 MPD results 33
Figure 18 Performance based on PMS data 34
Figure 19 Pattern of accident occurrences 38
Figure 20 Splash and spray comparison: (a) typical superpave (b) OGFC 39

INTRODUCTION

OGFC (open-graded friction course) is a porous, gap-graded asphaltic concrete mixture that contains a high percentage of interconnected air voids. These types of mixtures are also referred to as Permeable Friction Course (PFC) and primarily designed as a thin wearing surface to provide numerous benefits in terms of safety, economy and environment *[1]*. Researchers found that the high air void content coupled with large permeability enhance the effective lateral drainage of rain water to the edge of the pavement. Generally, the OGFC pavement reduces hydroplaning, splash and spray, and improves roadway visibility and the skid resistance of pavement surface under wet weather conditions. Other purported benefits of OGFC mixtures are improved pavement smoothness and lower pavement tire noise *[2-6]*.

In Louisiana, OGFC mixtures were first developed between the late 1960s and early 1970s prior to the initiation of the Federal Highway Safety Program Management Guide, Highway Safety Program 12, and Instructional Memorandum 211-3-73 of 1973 (Skid Accident Reduction Program). Afterwards, LADOTD issued an Engineering Directive to use Plant Mix Seal (another name for OGFC) on all roads with an ADT greater than 4,000 (revised to 3000 in 1980). Many of these surface layers had reached their end-of-life (10-12 years), having lasted much longer than the original life expectancy of five years. However, early failures with some of the OGFCs in the early 1980s due to a reduction in asphalt cement content led to a moratorium on its use in the state of Louisiana.

Initial inspection indicated that the problems encountered with the failed OGFCs were related mainly to moisture and temperature. These problems resulted in early raveling, stripping, and construction difficulties of the OGFC mixtures. The design asphalt content of OGFC's was significantly decreased in late 1970s due to several oil boycotts and subsequent increases in the cost of crude. The decreased asphalt content in combination with the use of base asphalt that oxidized rapidly contributed to these problems. The temperature issues were related to both mix and weather; whereas, the moisture issues were generally associated with a particular aggregate type. To address these issues, changes were made to the specifications, including maximum moisture content for the aggregate, institution of a construction season from May to September, and an increased minimum ambient air temperature. Based on those changes, the moratorium was later lifted.

Construction of a safe and durable highway system in Louisiana has long been a major concern for highway engineers. Substantial efforts have been undertaken to modify the first generation OGFC mixes to overcome the previous failures and to achieve the highest level of performance. Significant improvements have been noticed in mixture performance and service life since a new-generation of OGFC was promoted in the states around the late

1990s based on the mixture design proposed by National Center for Asphalt Technology (NCAT) *[1, 7]*. The new mixtures may contain fibers, polymer-modified asphalt, or asphalt-rubber in addition to a minimum air void content of 18 percent. Inspired by the success of several state agencies, LADOTD constructed four new OGFC roadway sections to evaluate pavement performance and safety benefits. The assessment indicated that OGFC is beneficial for wet weather accident reduction, crack relief over composite pavements, and pavement surface preservation. With positive field performances, OGFC specification and mix design procedures have been developed and included into the latest edition of LADOTD Specifications for Roads and Bridges for thin asphaltic concrete application.

Background and Literature Review

The history of development of OGFC mixes in the United States started with the experimentation of plant mix seal coats during the first half of the twentieth century. According to National Cooperative Highway Research Program (NCHRP), Oregon first began the experimentation of improving the frictional properties of pavement in the 1930s *[6]*. Later California started to use plant mix seal coat mixtures as drainage interlayers and as an alternative to chip seals and slurry seals. In the late 1940s, substantial use of these type of mixtures (later termed as OGFCs) began in the western part of the United States. Despite providing improved frictional properties and reduced potential for hydroplaning and splash/spray, the use of OGFC across the United States did not gain popularity until the FHWA initiated a program to increase the skid resistance on roadways in the 1970s *[7]*. Numerous European countries also began to utilize PFCs (another form of OGFCs) in the late 1970s to early 1980s. Europeans introduced modified binders and fibers to the U.S. version of OGFCs developed between the 1930s and 1970s and improved the performance of those mixtures significantly.

In 1978, NCHRP reported that 15 states in the U.S. were using OGFC extensively and several additional states were considering the use of OGFC mixtures *[8]*. Some state departments of transportation have reported good performance while many others have reported the opposite. A 1998 survey indicated that 19 states were using OGFC at that time *[9]*. The state DOTs that reported good performance with OGFCs had adopted coarser gradations and modified asphalt binders. A recent survey conducted by Clemson University, South Carolina, on the use, specifications, and design of OGFC across the United States indicated that 61 percent of the respondents were using OGFCs on roadways in their jurisdiction *[10]*.

Over the years, numerous researchers in the United States and Europe evaluated the application, performance, and effectiveness of OGFC mixtures. Even though there are minor differences between OGFCs used in the United States and the PFCs or Porous Asphalt (PA) used in other countries, their functions are anticipated to be the same. Consequently, this part of the literature review uses the terms OGFC, PFC, and PA interchangeably and focuses on the overall performance of these types of mixtures. NCHRP published a report that offers valuable resources for the entities interested in the state-of-practice of OGFCs. The report fully documents a comprehensive, critical review of the worldwide literature on design, performance, construction, and maintenance of PFC roadways in addition to survey results from various state departments of transportation *[6]*. Based on the findings of that study, the authors concluded the following:

- The primary benefits of PFCs are associated with improved safety, driver comfort, and environmental. Safety improvement includes the high potential for reduced hydroplaning, pavement glare, and splash/spray. Additionally, it can improve wet weather friction and hence improve traffic safety.
- PFCs can provide driver comfort as it increases driver's confidence during a rain event.
- PFCs offer environmental benefits by providing smoother pavements, which improve fuel economy and reduce pavement noise.
- Design of PFC mixtures should be done through four major steps: (1) selection of appropriate materials, i.e., angular aggregates, modified binders, fibers, etc.; (2) selection of a suitable gradation; (3) selection of optimum binder content; and (4) performance testing, i.e., cantabro abrasion test, stone-on-stone contact test, and draindown test.
- Construction of PFCs requires slight adjustments in hauling, laydown and compaction procedures compared to most hot mix asphalt (HMA) mixtures. PFCs tend to cool down faster; therefore, precaution is needed during transportation. Vibratory and pneumatic rollers are prohibited and only static steel wheel rollers should be used.
- In general, PFCs are not considered to provide structural value to a pavement structure. Literature has shown evidence that PFC's provide cooler temperatures in the underlying layers which result in a net increase in overall pavement stiffness.
- PFCs should not be used in areas exposed to debris and dirt.

Noise Reduction

The power train and the pavement-tire interaction are major sources associated with traffic noise. Power train noise is generated from mechanical devices and, therefore, falls out of the scope of pavement engineering. To investigate pavement-tire noise, the influential factors were found to be: pavement surface type, vehicle speed, layer thickness, traffic condition, texture and roughness of pavement surface, nominal maximum aggregate size, air void contents, and so on *[11]*.

Historically, OGFCs have been found to reduce the pavement-tire noise level due to their good, sound absorption potential. Huber reported an approximately 3 dBA noise reduction with OGFCs in comparison to dense graded HMA at highway speeds *[12]*. This equals a 50 percent reduction in noise pressure. Similarly, Kandahl reported an average noise reduction of 3 to 5 dBA for OGFCs in comparison to regular HMAs *[13]*. Colorado DOT tested 19 pavement surfaces (13 HMA and 6 PCCP) to evaluate the pavement tire noise levels for each surface type. The OGFC section was found to be the quietest with an average noise level of 95.2 dB(A) *[2]*. Similarly, in Ohio, the pavement tire noise for OGFC pavement was 2.8 dB lower than the dense graded asphalt pavement *[14]*.

In 2003, three highway test sections constructed in the central Indiana region were monitored for friction, texture, and noise properties over four years *[3]*. The test sections were constructed with dense-graded asphalt (DGA), stone matrix asphalt (SMA), and PFC mixtures. The authors found the PFC to be the quietest surface followed by Superpave DGA and SMA surfaces. However, a slight increasing trend for noise was observed on the PFC section over time. A similar reduction in pavement-tire noise is reported by Bennert et al. who evaluated different pavement surfaces in New Jersey using the CPX methods at a vehicle speed of 60 mph *[15]*. In another study, Washington State DOT found the OGFC pavements were quieter initially than newly built typical dense graded HMA. However, OGFC pavements continued to lose their initial noise reduction qualities over time *[4]*.

The size of aggregates in OGFC mixtures can be a contributing factor to noise reduction. Research at the Institute for Safe, Quiet and Durable Highways indicated that OGFC mixtures containing smaller sized aggregates generally performed better with respect to noise reduction *[16]*. Similarly, Raaberg et al. concluded that the OGFC mixtures with smaller sized aggregates performed better than OGFC mixtures with larger sized aggregates and dense graded HMA as well. However, OGFC mixtures with smaller aggregates showed durability issues with studded tires *[17]*.

Improved Safety

It has been reported that over 41,000 fatalities and almost 2.5 million injuries occur on United States highways, and nearly 30 percent of those fatalities were influenced by pavement surface condition. Analysis showed that 13.5 percent of fatal crashes and 18.8 percent of all crashes occur under wet weather condition *[18]*. Pavement surfaces should therefore be designed to provide sufficient friction especially in wet weather conditions. Macro-texture, mainly controlled by aggregate gradations and mixture design, has been found to be responsible for hysteresis friction and hydroplaning. The open gradations of

OGFC mixtures create courser surface textures, which result in providing higher macro-textures than the traditional Superpave mixtures. High air void content coupled with higher macro-textures allow quick water drainage, which can effectively improve traffic safety when the pavement is wet *[19]*.

To investigate the effect of OGFC on friction and micro-texture of asphalt pavement, Wang and Flintsch evaluated the Friction Number (FN) and Mean Profile Depth (MPD) of several dense-graded Superpave mixtures, one OGFC, and one SMA surface at the Virginia Smart Road facility over a period of six years *[20]*. The OGFC was found to have highest macro-texture depth (3.75 mm) followed by SMA (2.25 mm) and Superpave (≈ 1.2 mm), respectively. However, the OGFC and SMA mixtures had bigger nominal aggregates, which may contribute to this finding. Additionally, at higher speed, the coarser mixes (OGFC and SMA) were reported to offer higher friction; whereas, no significant difference in friction was noticed at intermediate speed.

Numerous other studies have shown that OGFC pavements provide improved surface friction or at least comparable friction to regular dense graded pavements *[3, 4, 6, 21, 22]*. McDaniel et al. compared a PFC section to adjacent SMA and conventional HMA sections. The Circular Texture Meter (CTM) measurements indicated that the PFC had the highest surface texture depth, more than four times greater than the conventional HMA. The PFC also provided the highest friction value followed by SMA in terms of International Friction Index (FN_{60}) *[23]*.

OGFC mixtures possess a permeable interconnected void structure that allows storm water to pass through the surface layer in a faster pace. This can reduce splash and spray of rain water, pavement glaring from reflected light in addition to providing greater friction due to decreased hydroplaning potential. A long-term study by the British Columbia Ministry of Transportation and Infrastructure indicated that OGFC pavements improved friction and surface drainage in addition to glare and splash reduction *[24]*. In most of the studies, no quantified measure of splash and spray was reported. However, Nicholls quantified approximately 95 percent reduction in splash and spray generated by a vehicle when comparing wet OGFC and dense-graded asphalt pavement surfaces in United Kingdom. This observation was effective for a number of years even though it seemed to be decreasing over time *[25]*. In the U.S., a number of state DOTs presented photographic evidence of this benefit, too. Then again, based upon visual inspection and motorists comments, Pierce et al. and Huddleston et al. reported a significant reduction in splash and spray and improved visibility while driving during rainy weather *[4, 21]*.

Significant improvement in ride quality can be achieved through a thin lift of OGFC. The ride quality comparison by Virginia DOT indicated a consistent improvement of IRI values nearly 50 percent for the new OGFC lift over the original surface *[26]*.

Mixture Design

Different agencies in the U.S. have embraced a wide divergence of mix design practices for OGFCs. A survey by NCAT in 1998 revealed that 76 percent of the participating states had formal mix designs, while 9 percent used a recipe and the rest used a hybrid of those two *[9]*. It is believed that the first widely used OGFC mix design was developed by FHWA in 1974. This design procedure was modified twice, first in 1980 and then again in 1990. The FHWA mix design was based on the evaluation of the surface capacity (determined by oil absorbency test) of the predominant aggregate fraction corresponding to the materials that passed through a 3/8-in. sieve and retained on a No. 4 sieve. Additionally, a draindown test was required to determine the optimum mixing temperature along with a moisture resistance test.

Based on the experience gained in the U.S., Europe, and internal research, NCAT proposed a new OGFC mix design procedure in 2000. This mix-design method included an assessment of both functionality (permeability) and durability *[7]*. There were four primary components in this new mix design: material selection, selection of design gradation, determining optimum binder content, and lastly, evaluation for moisture susceptibility. The mix design recommended a coarser aggregate gradation than the typical ones used in the past. A strong and durable aggregate with LA abrasion values of 30 percent or less was recommended. The aggregate should also be crushed, have minimal flat and elongated particles, and be low in absorption. The criteria for binder selection should be regulated by environment, traffic, and expected functional purposes of the pavement. In general, polymer-modified binders were recommended with a desired addition of fiber stabilizer to resist draindown. The recommended gradations are shown in Table 1 in comparison to FHWA gradations mentioned before *[7]*. One of the important criteria of this mix design is to ensure the stone-on-stone contact of the aggregates. In so doing, the voids in the coarse aggregate in the compacted mixture (VCA_{mix}) have to be less than or equal to the voids in the coarse aggregate calculated from the dry rodded unit weight ($VCA_{drc.}$). Determination of the optimum binder content is based on a series of defined laboratory tests both on samples compacted with a gyratory compactor at 50 gyrations and uncompacted samples. The tests included in this step are determining the air voids, abrasion on aged and unaged samples, and binder draindown. The final step of this mix design is to evaluate the moisture susceptibility using a modified Lottman test method that uses five freeze/thaw cycles instead of one.

Based on the previously mentioned principles, a mix design method was released by ASTM designated as ASTM D 7064-04. To further improve the mix design methods, recently researchers at Texas A&M University proposed several recommendations which are: the use of dimensional analysis to compute air voids and bulk specific gravity, assessment of mixture durability through the Cantabro test, and verification of stone-on-stone contact during the mix design phase. Additionally, the out flow time and an expected permeability value were also suggested to evaluate the drainability of the mixture *[27]*.

Table 1
Comparison between FHWA and NCAT gradations

Sieve Sizes	FHWA Gradations (percent passing)	NCAT Gradations (percent passing)
19 mm (3/4 in)	-	100
12.5 mm (1/2 in)	100	85-100
9.5 mm (3/8 in)	95-100	55-75
4.75 mm (#4)	30-50	10-25
2.36 mm (#8)	5-15	5-10
.075 mm (#200)	2-5	2-4

Production and Construction

The production and construction practice for OGFCs are generally similar to the standard dense graded HMA construction. Storage and mixing of asphalt binder are like typical HMA; however, mixing times may be slightly longer in comparison to HMA mixtures to ensure the fibers to be blended completely in the mix. The storage time for OGFC mixtures has to be limited to minimize the risk of potential drain down. A typical storage time of 2 hours has been reported by state agencies responded to a NCHRP survey *[6]*.

The main concern while transporting OGFCs is to maintain the temperature as the mixture loses temperature faster than compared to typical HMA. Agencies attempt to maintain the appropriate temperatures by limiting hauling time, limiting hauling distance, or specifying a minimum arrival temperature. Placement temperature restrictions for OGFCs are generally more limiting than for the typical dense-graded HMA because of the thinner lift thickness and modified binders used in OGFC.

Compaction of OGFCs is challenging as their usual thin lift thickness tends to cool down quickly. Therefore, compaction needs to be done immediately after the placement *[6]*. The use of Material Transfer Vehicle (MTV) can be beneficial to eliminate both thermal and mixture segregation. For the compaction, steel rollers are recommended only in the static mode. As OGFCs are usually placed in thin lifts (less than about 3 times the NMAS), particles cannot rearrange under vibration. Therefore, vibratory rollers are strictly prohibited to avoid the cracking of aggregates under excessive loading. However, thicker lifts may accommodate vibratory/oscillatory rolling operation *[28]*. Clearing the pavement edge should be acknowledged in OGFC placement as it can clog the pores near the edge and eventually, hamper the drainability functionality of the pavement *[29]*.

Limitations of OGFCs

Even though OGFCs provide numerous advantages on roadways, these mixtures are not free from shortcomings. There has always been a question of the durability of OGFC mixtures. The interconnected voids of OGFC mixtures help surface water to drain quickly but also accelerate the aging process of mixtures as air can pass through the pavement structure easily. However, recent improvements in materials, design and production, appropriate storage, and hauling and placement with a low liquid draindrown quality showed the potential to overcome the premature raveling failures of the past *[26]*.

Maintenance of OGFCs in winter conditions is always a challenge to meet. While new OGFC mixtures have been successfully used in the southern climates, recent surveys indicated that its use in the northern ice and snow climates continues to have problems *[1, 30]*. The porous structure of OGFC surface can allow a faster accumulation of snow and ice in comparison to conventional pavements.

Clogging of pavement pores with time is another major issue with OGFCs. Clogging can reduce both the functional effectiveness, i.e., removal of water from pavement surface and noise reducing capability of OGFC pavements *[3, 19]*. However, regular maintenance treatment can minimize the clogging effectively.

OBJECTIVE

The purpose of this study was to monitor and document the construction and performance of OGFC mixtures in several field projects in the state of Louisiana. This evaluation was focused mainly on long-term performance based on wet weather safety improvement, surface crack resistance, and pavement condition survey. In addition, laboratory performance of OGFC mixtures was evaluated in an effort to determine an appropriate mix-design procedure for Louisiana.

SCOPE

Four OGFC test sections were constructed on US 71, I-20, US 61, and US 171 to evaluate pavement performance and safety benefits on the basis of their laboratory and field performance. Permeability, Draindown, Loaded Wheel Tracking (LWT), and Tensile Strength Ratio (TSR) tests were conducted in the laboratory test factorial in addition to material and mixture design evaluation. Field performance evaluation was performed on the basis of visual inspection, pavement condition survey, friction testing, and traffic safety data analysis.

METHODOLOGY

Field Project Description

Four OGFC test sections were constructed on US 71, I-20, US 61, and US 171 roadways under the scope of this study. The locations of those test sections are shown in the map presented in Figure 1. A sample OGFC pavement surface and regular construction practice are illustrated in Figure 2; whereas, Figure 3 shows the completed OGFC sections as recorded in the LADOTD pavement management system (PMS). Brief descriptions of the selected projects are as follows:

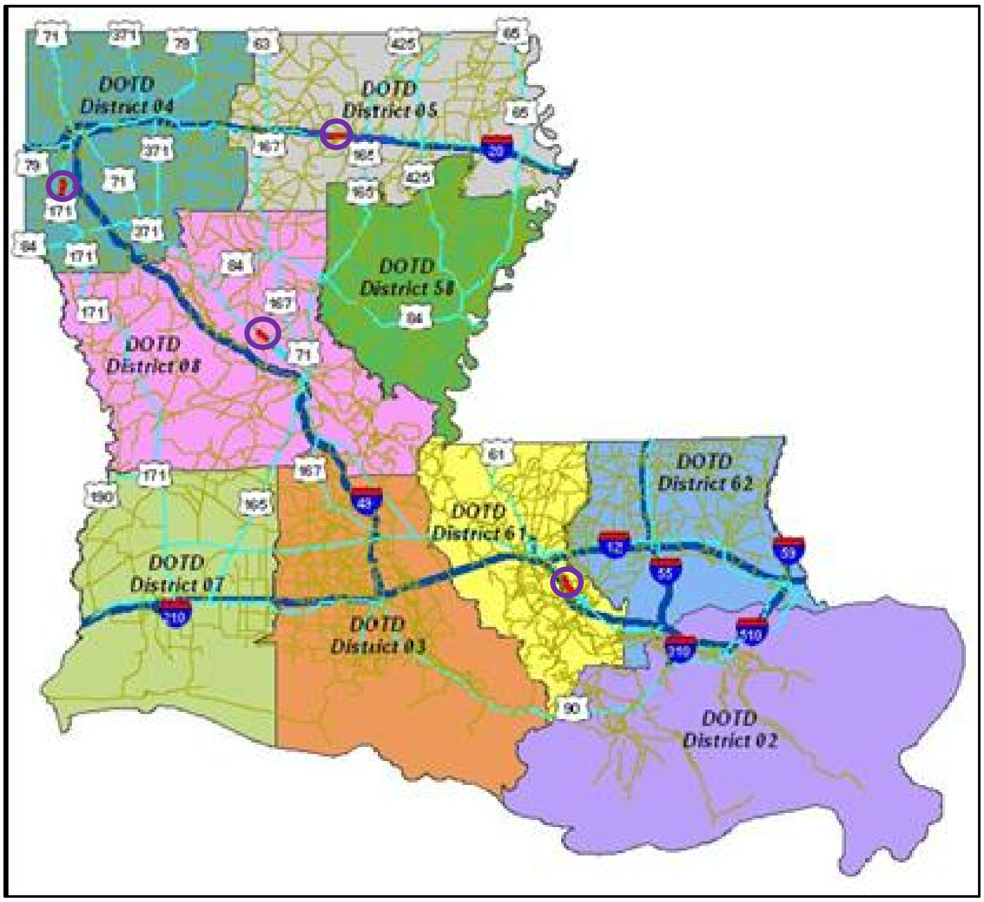

Figure 1
Locations of OGFC test sections

US 71, Grant Parish

This was the first OGFC test section included in this study to assess the improvement in the existing surface characteristics and traffic safety. The 0.157-mile (from Log mile: 4.041 to Log mile: 4.198) long test section was located on US 71, 4.041 miles north of the Rapides Parish line and commences northward. The roadway consists of two 12-ft. travel lanes with two 10-ft. improved hot mix shoulders. Roughly 94.0 tons of OGFC was placed at approximately 3/4 in. compacted thickness over 5-in. asphaltic mixture and 8-in. Portland Cement Concrete (PCC) base. The main reason behind selecting this section was to improve safety due to the growing number of wet weather accidents and fatalities that had occurred prior to the construction. The OGFC section was completed in one day on June 15, 2003.

I-20, Ouacita Parish

The four-lane interstate test section included in this study is located in West Monroe between Britton Road and Vancil Road. This project entailed constructing a 1-in. thick OGFC over 10-in. thick asphalt mixture over 10-in. break and seat Jointed Reinforced Concrete pavement (JRCP). All four lanes and the 4 ft. wide inside shoulder were overlaid. There was approximately 9,500 tons of OGFC material placed in this 5.6 mile (from log mile: 6.11 to log mile: 11.66) section of I-20. This project was also selected to improve the existing surface characteristics and improve safety and was completed in July 2005.

US 61, Ascension Parish

This 5.6-mile long OGFC section was constructed in May 2007 on US 61 located between LA 42 and LA 74 just south of Baton Rouge (from log mile: 6.47 to log mile: 12.02). The project consisted of milling 2-in. of original surface, placing a 2-in. thick SMA and a 3/4-in. thick OGFC. In addition, it had 5-9 in. of asphaltic mixture on top of the 8-in. PCC base. This project was selected to evaluate the mixture's ability to resist reflective cracking predominant in composite pavements. Approximately 10,345 tons of OGFC was placed by Coastal Bridge Contractors Company.

US 171, Desoto Parish

This project is located south of Shreveport constructed on the south bound lane only between the Desoto Parish Line and LA 5 (from log mile: 0.00 to log mile: 4.33). The project consisted of milling 1 in. and placing a 1.25-in. thick OGFC over 10-in. asphaltic concrete and an 8-in. PCC base. The reason behind choosing this test section was to reduce the impact of local flooding occurring at low vertical grades. Approximately 4,540 tons of OGFC was placed on this 4.3 mile divided highway section of US 171. Madden contractors finished the construction in May 2009.

Figure 2
Construction of OGFC

Figure 3
LADOTD OGFC test sections

Materials and Mixture Design

The OGFC mixtures included in this study were designed following the recommendations outlined by NCAT *[7]*. A Superpave gyratory compactor was used with a design gyration level of 50 during the mixture design process. The contractors were required to use a PG 76-22m or higher grade asphalt cement. The design asphalt content was a minimum of 6.5 percent with a maximum draindown of 0.3 percent by total mixture weight. Cellulose fibers or mineral fillers were used with an anticipation of improved draindown of asphalt and better reinforcement against rutting and cracking. It was further specified that the aggregates, coarse and fine, should be 100 percent crushed stone or slag from a source listed on the Qualified Product List (QPL) of LADOTD and also comply with the requirements set forth in subsections 1003.01, 1003.06, and 1003.06(b) of LADOTD Standard Specifications *[31]*. Anti-strip additive at a minimum rate of 0.5 percent by the weight of asphalt was added to prevent stripping. A brief mixture description, volumetrics, and the aggregate gradation blend of the various OGFC mixtures used in this study in comparison to the current LADOTD specifications for OGFC mixtures are presented in Table 2. It can be noticed that the percent voids and the aggregate percent passing No. 8 sieve did not comply with the specifications for the US 171 project. There might be a contract modification however; the authors failed to verify the possible reason behind that.

Voids in coarse aggregate for the compacted mix (VCA_{mix}) and the voids in the same coarse aggregate in a dry-rodded condition (VCA_{drc}) retained on a No. 4 (4.75-mm) sieve were measured to check the stone on stone contact in mixtures. As recommended by NCAT, the VCA_{drc} was determined by compacting the aggregates with a dry-rod as described in AASHTO T 19 method *[7]*. On the other hand, VCA_{mix} was calculated using the following equation:

$$VCA_{mix} = 100 - \left(\frac{G_{mb}}{G_{CA}} \times P_{CA}\right) \tag{1}$$

where,
G_{mb} = Bulk Specific Gravity of the compacted mixture,
G_{CA} = Bulk Specific Gravity of the coarse aggregate fraction, and
P_{CA} = Percent coarse aggregate in the total mixture.

The VCA_{mix} values for US 71, I-20, and US 61 projects were found to be less than the VCA_{drc}, which satisfies the stone on stone contact requirement (Table 2). To enhance the bond between OGFC and the underlying layer, LADOTD chose to utilize a spray-paver to apply the OGFC and tack coat material to the existing surface. Figure 4 provides a graphical representation of blended aggregate gradations used in this study.

Table 2
Mixture description and volumetrics

Mixture Criteria	OGFC Projects				LADOTD Specifications
	US 71	I-20	US 61	US 171	
AC Type	PG 76-22m	PG 76-22m	PG 76-22m	PG 76-22m	PG 76-22m or higher PG grades
Primary Aggregate	Sandstone	Sandstone	Siliceous Limestone	Novaculite	-
Anti-Strip	0.60	0.60	0.80	0.60	0.50 – 1.2
% Fibers	0.10	0.30	0.30	0.20	% Required from draindown test
Volumetric					
% Voids	19.3	21.7	20.5	16.0	18.0 – 24.0
% Design AC	6.6	6.5	6.5	6.5	≥ 6.5
G_{mm}	2.368	2.391	2.418	2.402	-
G_{mb} at N_{des}	2.173	1.872	1.906	2.019	-
% VCA_{mix}	23.0	38.8	40.4	-	-
% VCA_{drc}	23.7	39.4	41.1	-	-
Sieve Sizes	**Percent Passing**				
19 mm (¾ in)	100	100	100	100	100
12.5 mm (½ in)	92	93	95	91	85-100
9.5 mm (3/8 in)	64	68	67	65	55-75
4.75 mm (# 4)	16	21	17	25	10-25
2.36 mm (# 8)	8	8	8	14	5-13
1.18 mm (# 16)	6	6	6	9	-
0.6 mm (# 30)	5	6	5	7	-
0.3 mm (# 50)	4	5	5	5	-
0.15mm (# 100)	3.4	4	4	4	-
75 µm (# 200)	2.3	3.5	3	3	2-4

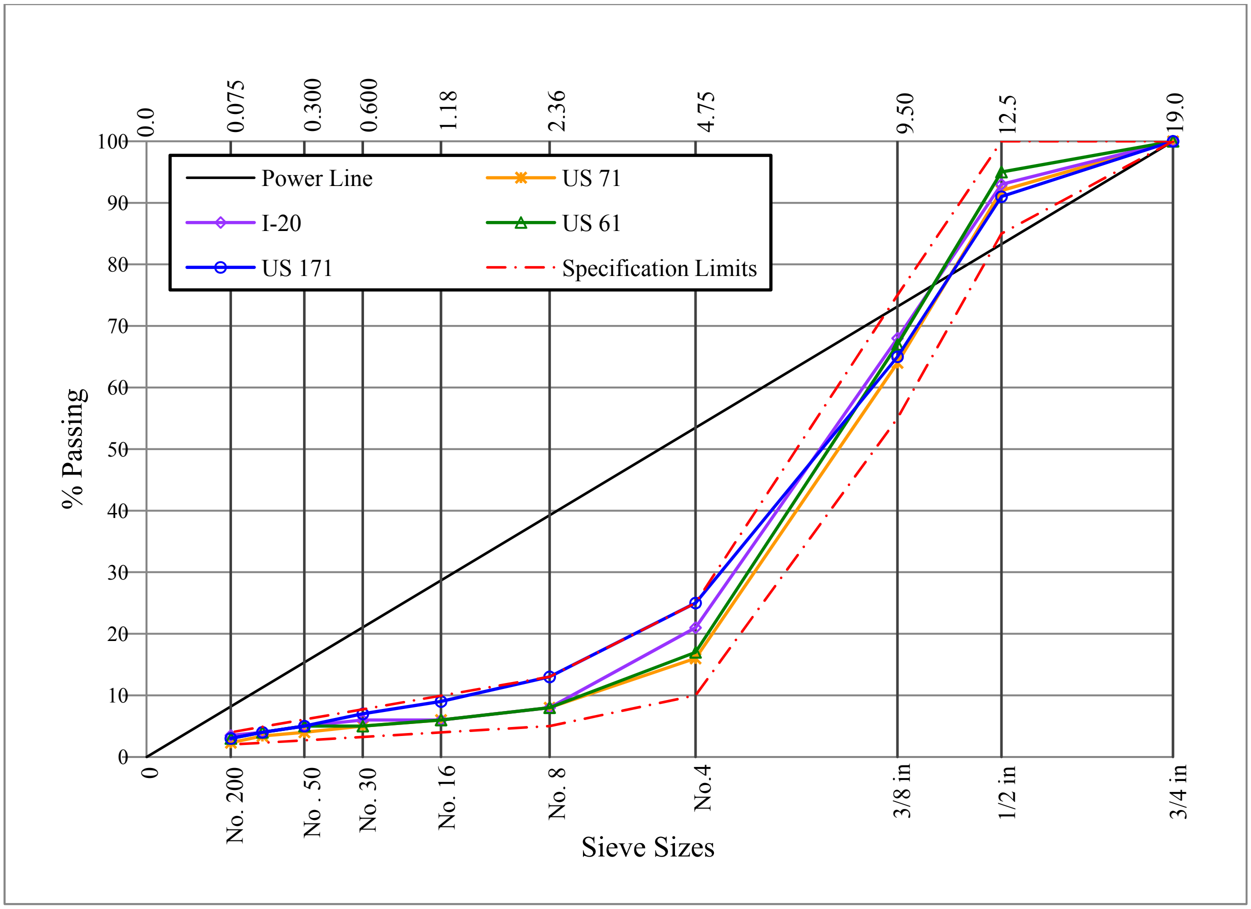

Figure 4
Blended aggregate gradations

Laboratory Testing

Permeability, Draindown, Loaded Wheel Tracking (LWT), and Tensile Strength Ratio (TSR) tests were performed on laboratory-fabricated specimens prepared from plant produced OGFC mixtures that were used in the different field projects.

Permeability Test

Mixtures with high permeability are believed to have greater interconnected voids. The permeability test can determine the drainability of OGFC mixtures, an important characteristic to measure the effectiveness of rapid removal of surface water from roadways during light to moderate rainstorms. A falling head flexible wall permeameter (Figure 5) was utilized to perform the permeability test in accordance with ASTM PS 129 test method. The test was conducted on 6-in. (150-mm) diameter roadway core specimens collected from the aforementioned OGFC projects. A falling-head concept was used to determine the co-efficient of permeability using the following equation:

$$K = \left(\frac{L}{T}\right) \times \left(\frac{d^2}{D^2}\right) \times \ln\left(\frac{H_1}{H_2}\right) \quad (2)$$

where,
K = Coefficient of permeability (mm/s x 10-4),
L = Average thickness of specimen (mm),
D = Average specimen diameter (mm),
d = Average diameter of graduated cylinder (mm),
T = Total time of the test in seconds,
H_1 = Initial height of water (mm), and
H_2 = Final height of water (mm).

Figure 5
Falling head flexible wall permeameter

Draindown Test

The draindown phenomenon is described as the separation of asphalt binder or a combination of binder, fine aggregate, and additives that separates itself from the mixture during production, storage, and placement. Draindown increases the potential for flushing, rutting, and loss of permeability. As OGFC mixtures possess a coarse aggregate skeleton, the typical film thickness for these types of mixtures is about 3 to 4 times higher than the conventional dense-graded mixtures *[32]*. The combination of uniform grading, low filler, and higher asphalt film thickness can increase the potential for the binder to drain off the aggregate particles *[33]*. Therefore, a draindown test is performed to determine the amount of binder mastic that may get separated during production and construction. In this study, draindown tests were conducted on loose OGFC mixes according to AASHTO T 305 test method at a temperature 15°C higher than the mixing temperatures.

Loaded Wheel Tracker (LWT) Test

A Hamburg type LWT tester, as shown in Figure 6 was used in this study in accordance with the AASHTO T 324 test method. The test was conducted by rolling a steel wheel across the surface of the specimen submerged under 50°C water to predict the rutting potential and moisture susceptibility of OGFC mixtures. The test continues until 20,000 wheel passes or 0.79 in. (20 mm) deformation, whichever is reached first. All LWT specimens were compacted to 2.4 in. (60 mm) in thickness even though the actual pavement thicknesses were varied from 0.75 to 1.25 in. The laboratory compactor used for sample preparation was unable to compact the specimens to match the actual pavement thicknesses.

Figure 6
Loaded wheel tester device

Tensile Strength Ratio (TSR) Test

To evaluate the moisture induced damage for OGFC mixtures, TSR tests were conducted as per the AASHTO T 283 method with an exception of air void content of the samples. Being OGFC mixtures, air voids for all specimens were within 17.5 to 20.5 percent. In this test, two sets of 6-in. (150-mm) diameter by 3.5-4.0 in. (90-100 mm) high gyratory compacted cylindrical samples are tested in conditioned and control conditions. A compressive load is applied to failure at a deformation rate of 2 in./min (50.8 mm/min) using a compression test device manufactured by Humbolt (Figure 7). The change in tensile strengths resulting from the saturation and accelerated moisture conditioning are computed and reported as the tensile strength ratio (TSR). Mathematically,

$$TSR\ (\%) = \frac{Tensile\ Strength\ of\ Moisture\ Conditioned\ Sample}{Tensile\ Strength\ of\ Controlled\ Sample} \times 100$$

Figure 7
Humbolt TSR device

Air Void Measurement

In the quest for an appropriate test method to determine the density of OGFC mixtures, LADOTD carried out a round robin testing scheme within its nine district laboratories in addition to the LTRC asphalt laboratory. A CoreLok testing device, as shown in Figure 8 was implemented to compare AASHTO T 331 test method against the conventional AASHTO T 166 method to measure the bulk specific gravity of compacted asphalt mixture specimens *[34]*.

Early research has recommended that the conventional AASHTO T 166 test method is not applicable to compute the density of coarse graded porous mixtures like OGFC, SMA, etc. *[35-37]*. The volumetric error is caused by the free-flow of water from the OGFC samples when determining the saturated surface dry (SSD) weight in the AASHTO T 166 method. The AASHTO T 331 method employs a vacuum sealing device to seal asphalt samples so that sample densities can later be measured by the water displacement method. In this study, an InstroTek CoreLok device was used to seal the samples automatically in specially formulated puncture resistant polymer bags. By removing all the air from the sample, an accurate bulk specific gravity can be measured.

Figure 8
CoreLok testing device

Field Performance Tests

Pavement Friction Properties

One of the major functional benefits of an OGFC mixture is to improve the pavement friction that develops at the contact area of the pavement tire and pavement surface. The friction of the OGFC test sections considered in this study was measured using a Locked Wheel Skid Tester (LWST) device (Figure 9) according to the ASTM E 274 method. This device tests the friction properties of a pavement surface under emergency braking condition for a vehicle without anti-lock brakes. Two types of tires: ribbed and smooth are used in this test method. The smooth tires are more sensitive to macro-texture, hence chosen in this study. The friction force was recorded while a LWST vehicle pulled a two-wheel trailer with a smooth-tire arrangement at 50 mph (80.5 kmph). The coefficient of friction is presented in terms of FN.

Figure 9
Locked wheel skid tester

Since LADOTD does not collect friction data for every single roadway section, friction data for roadway sections adjacent to the OGFC test sections were not available for comparison with the OGFC test sections. However, based on the data availability, three additional asphalt sections on I-10, US 190, and US 171 were selected and compared to the friction performance of I-20, US 61, and US 171 OGFC sections, respectively. These three sections were chosen because they provided a close comparison to the OGFC test sections. The traffic conditions and other details of those companion projects are provided with the results in the corresponding section of this report.

Distress Condition Survey

Every alternate year, LADOTD compiles a comprehensive set of distress data collected by an automated mobile pavement data collection unit (Figure 10). The data generated by this unit can be categorized as: measured data and interpreted data. Measured data include IRI, rutting, faulting that are collected directly. Alternatively, the interpreted data (i.e., fatigue cracking and patching data) are generated from videos of each pavement section. The pavement data are collected continuously and reported for every 0.1 mile segment based on a location reference system consisting of control sections as well as latitude and longitude GPS coordinates. For most cases, data are collected only for the travel lane of the roadways. “Visidata,” a software developed by Roadware, Inc. is used for analysis and presentation of PMS data (Figure 11).

Figure 10
Automated pavement data collection unit

In this study, the evaluation is limited to performance of projects relative to age and not to factors associated with materials and/or construction. The criteria used to evaluate performance include International Roughness Index (IRI), rutting, alligator cracking and random cracking. The IRI was developed by World Bank to characterize a standardized roughness measurement of the longitudinal profile of a roadway. The IRI is a mathematical model computed as the ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance traveled by the vehicle during the measurement (km, mile, etc.).

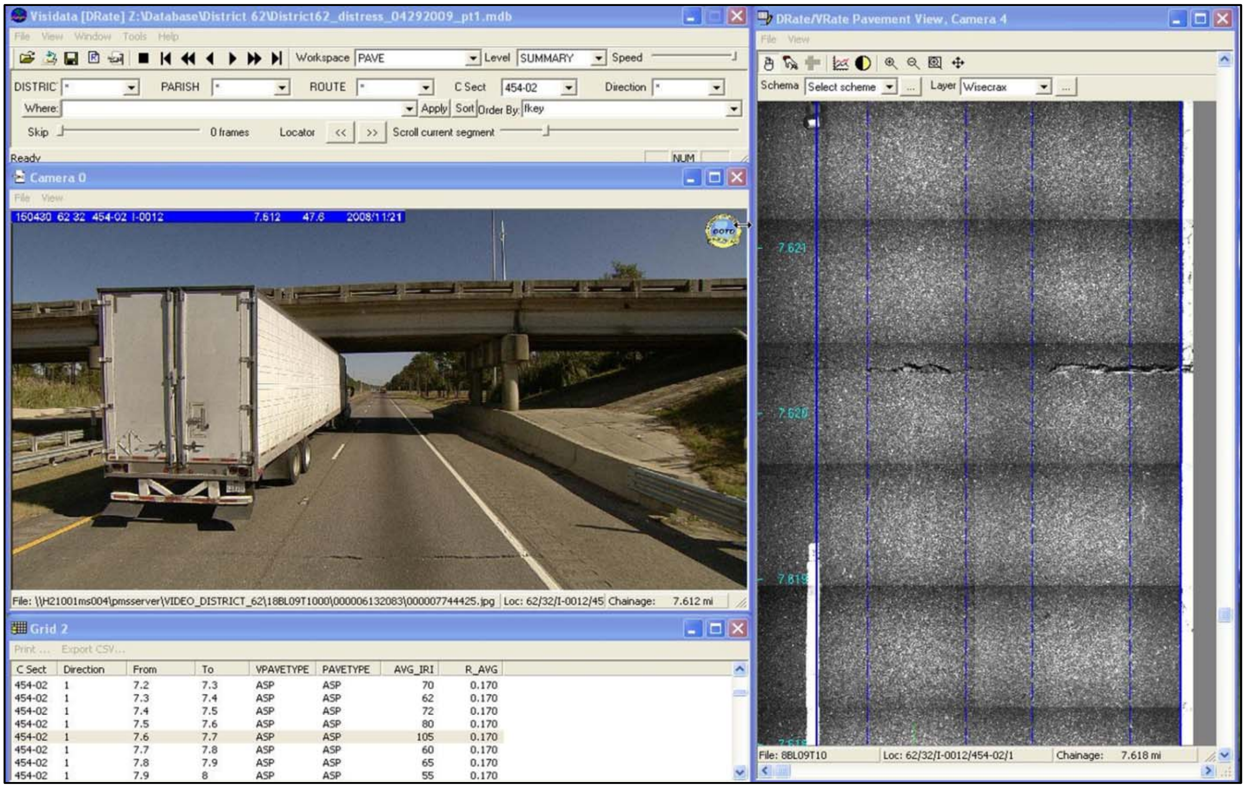

Figure 11
A screen shot of visidata software

The rut depth data used in this study were collected by two different rut measuring systems. For years 2000-2003, a three point rut laser known as Smart Rutbar was used. Rutbar uses ultrasonic transducers spaced at 4 in. (100 mm) across the measuring device to measure the transverse cross section. To cover a 12-ft. wide lane, up to 37 transducers were used. Since 2004, a laser transverse profiler has been used. This profiler uses a dual synchronized mounted scanning laser to measure the transverse profile up to 13 ft. in lane width *[38]*. The reported rut depth is the average rut depth of left and right wheel path over every 0.1-mile segment of the roadway.

The fatigue, or alligator, cracking are defined as the longitudinal cracks that are located within a transverse width of 3 ft. centered at the middle of the wheel path. This type of cracking is reported only for the flexible pavements and not for the composite ones. Any other cracks not classified as fatigue or alligator cracks are considered as random cracks. This includes both longitudinal and transverse cracks.

DISCUSSION OF RESULTS

Drainability, smoothness, and splash and spray were considered as functional performance measures; whereas, rutting, cracking, and tensile strength properties were evaluated for durability of Louisiana OGFC mixtures. Laboratory test results in conjunction with field performance were investigated for the overall evaluation process. In addition, accident data before and after the placement of OGFCs were analyzed to assess the safety benefits.

Laboratory Test Results

Permeability Test Results

The falling head permeability test results are illustrated in Figure 12, where each vertical bar represents an average permeability result of at least three OGFC samples. It can be seen that all OGFC mixtures had at least an average permeability of 450 ft/day (137 m/day). In a previous study, NCAT recommended a minimum permeability value of 328 ft/day (100 m/day) for OGFC mixtures if the mixture is intended to remove the water from pavement surface *[7]*. Alvarez et al. suggested a minimum permeability value of 196.85 ft/day (60 m/day) when the mixture is used mainly for noise reduction *[1]*. Results presented in Figure 12 illustrate that all OGFC mixtures considered in this study exceeded the permeability requirement set by both above mentioned studies.

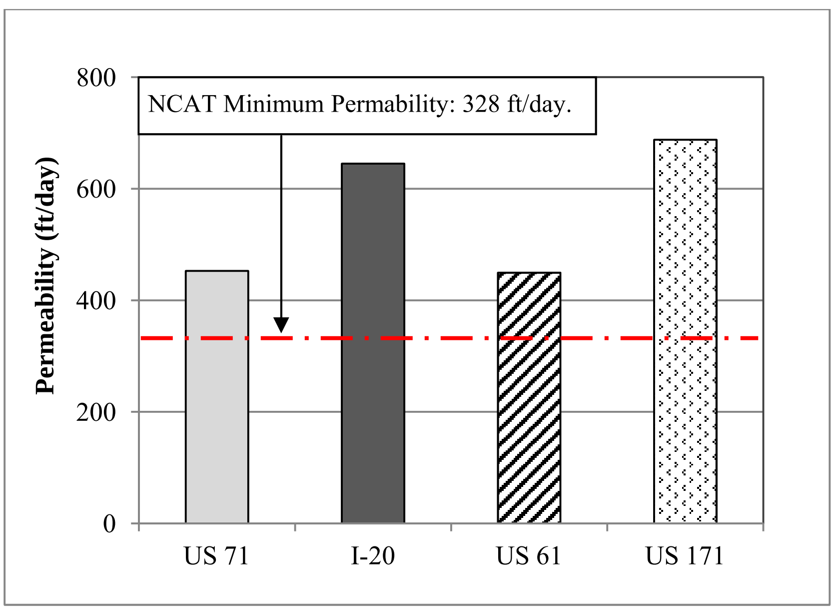

Figure 12
Permeability test results

Draindown Test Results

Results presented in Figure 13 illustrate the draindown results for mixtures considered in this study. It is anticipated that the coarser the aggregate gradation, the higher the potential of binder draindown. As expected, the minimum draindown of .04 percent was observed for US 171 mix that had the highest percentage (25 percent) of aggregate passing the No. 4 sieve. Alternatively, the US 61 mix, which had the second coarser gradation, 17 percent passing No. 4 sieve showed the maximum draindown of 0.12 percent. Notably, all OGFC mixtures showed draindown results well below the LADOTD specification requirement of 0.3 percent. It should also be noted that all mixtures reported contained cellulose fibers by an amount of 0.10 to 0.30 percent of the total aggregate weight. The combination of fibers and SBS modified PG 76-22m binder possibly improved the resistance to draindown. However, no direct correlation was observed between the percent draindown and amount of cellulose fibers added to the mixtures.

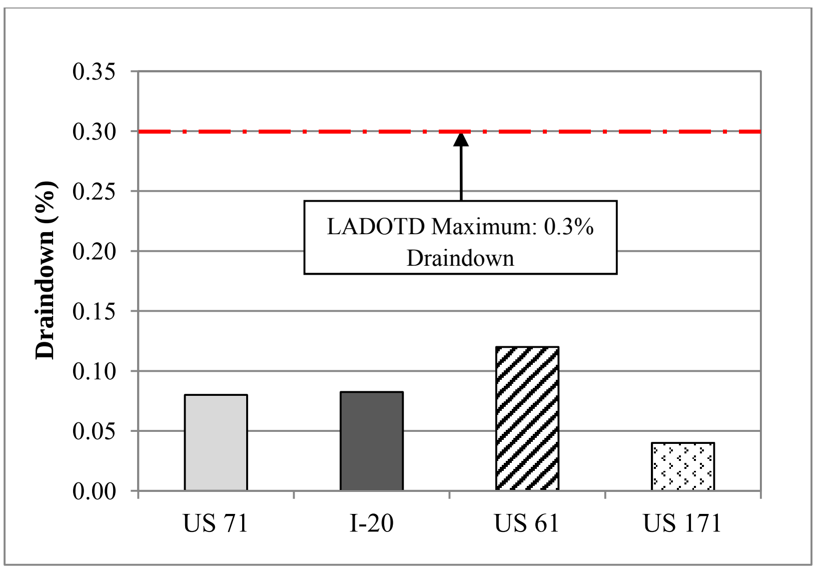

Figure 13
Draindown test results

Loaded Wheel Tracking (LWT) Test Results

The LWT rut depths for US 71, US 61, and US 171mixtures are presented in Figure 14. Each vertical bar in the figure represents the average rut depth of two individual specimens. The results for I-20 could not be included due to the unavailability of data. It was observed that after 20,000 wheel passes, laboratory compacted specimens for US 71 and US 61 test sections experienced 0.13 in. (3.4-mm) and 0.21 in. (5.3-mm) rut depths respectively; whereas, the US 171 specimen failed, lasting only 5,300 total wheel passes, which is an indication of stripping . According to the current LADOTD specification for OGFC mixtures, a maximum rut depth of 0.47 in. (12-mm) after 7,500 passes is acceptable. The rut depths for three OGFC mixtures after 7,500 wheel passes show that both US 71 and US 61 OGFC test specimens passed the specification requirements convincingly; whereas, US 171 failed to meet it (Figure 14). However, the PMS data for the US 171 section has shown comparable rut resistance in the field even though the lab fabricated samples failed to pass LWT specification requirement. In addition, the rut profile of all OGFC mixtures indicated that there was no stripping issue with any of the mixtures at the end of the test.

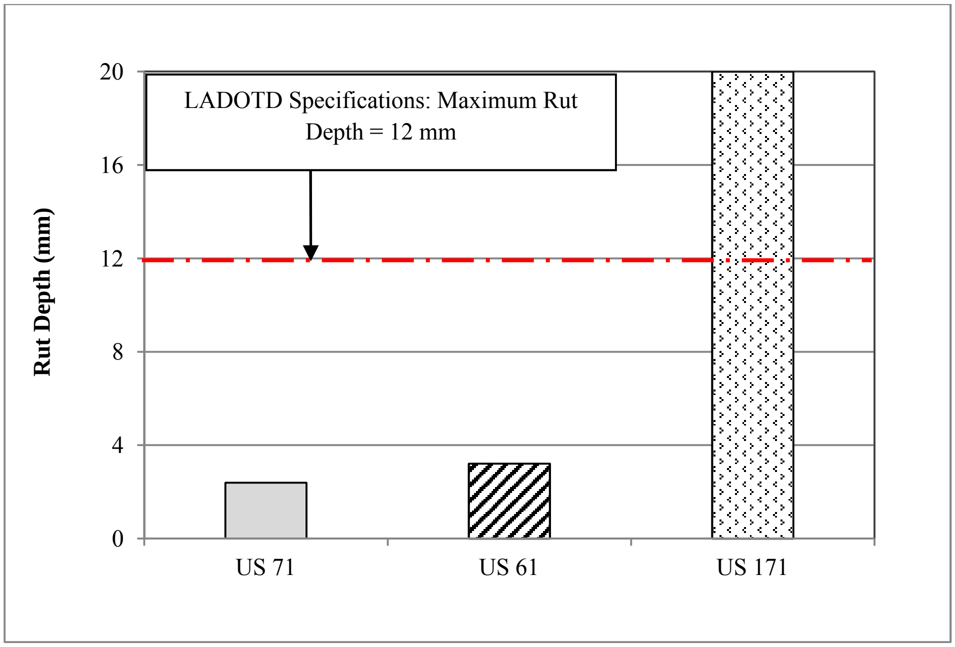

Figure 14
LWT test results

Tensile Strength Ratio (TSR) Test Results

Figure 15 shows the average TSRs reported for different OGFC mixtures. Three specimens were tested per set separately in moisture-conditioned and control conditions. It is evident that both I-20 and US 61 mixtures obtained average TSR values of 95.1 percent and 90.7 percent, respectively. These values are significantly higher than the minimum LADOTD specification requirement of 80 percent retained strength after one freeze-thaw cycle. Alternatively, the mixture from US 171 project failed to meet the existing TSR requirements. The possible reason behind the failing TSR value is unknown at this time. However, construction records indicate that the TSR requirement was waived for the US 171 project. Experience from previous LADOTD projects and other state agencies revealed that the open aggregate structure of OGFC mixtures does not always allow conditioning specimens as described in the AASHTO T 283 test method.

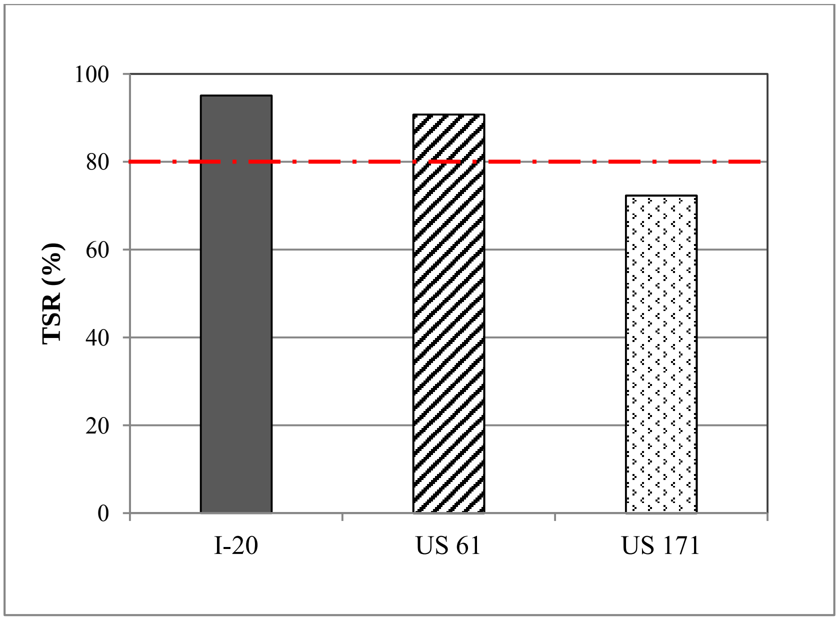

Figure 15
TSR test results

Air Void Measurement

The computed air voids utilizing the bulk specific gravity measured from AASHTO T 166 and CoreLok (AASHTO T 331) methods are presented in Figure 16. For the round robin testing, the OGFC mixture was prepared to obtain an air void content of approximately 18 percent. As seen in Figure 16, no laboratory was able to achieve that result using the AASHTO T 166 method. A maximum air void of 11.6 percent was obtained by District Lab 03. In contrast, air void results from the CoreLok method were within the range of 17.5 to 18.7 percent, which was very close to the target. It appears while taking a saturated surface dry (SSD) weight in the AASHTO T 166 method, any water absorbed into the specimen generally remains there for dense graded mixtures; whereas, the water flows out of the specimen for OGFC mixtures and leads to an erroneous volume measurement. The outcome of this round robin testing concurs with the previous studies and consequently, the AASHTO T 331 test method has been specified instead of the AASHTO T 166 method in the latest edition of the LADOTD specification for OGFC *[35-37]*. Detailed data of the round robin testing scheme are provided in the Appendix.

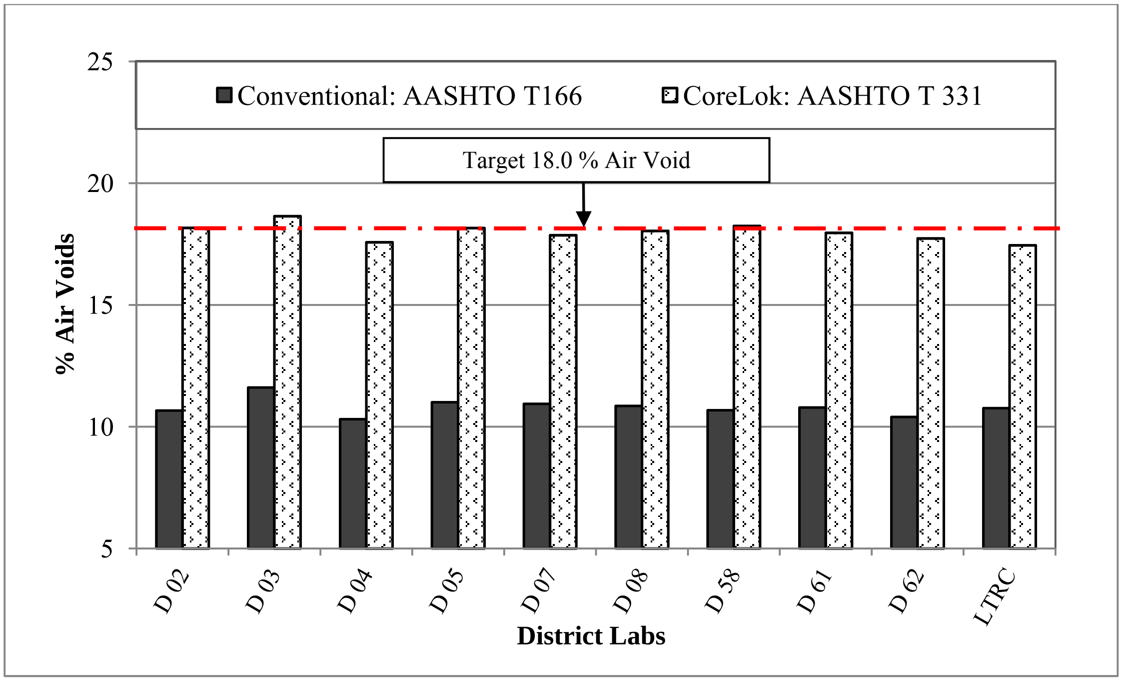

Figure 16
Comparison of air voids

Filed Performance Evaluation

Distress Condition Survey Results

Friction Measurement. The FNs collected from various projects are summarized in Table 3. It is clearly evident that the OGFC sections always obtained higher FN values than their corresponding dense-graded counterparts. Impressively, the I-20 OGFC section has a significantly higher FN value even after 5 years under traffic.

Since the friction performance of the OGFC surfaces is known to be a function of a complex interaction of both macro-texture and micro-texture, Jackson et al. recommended utilizing the MPD value in addition to FN *[38]*. The MPD value represents the macro-texture of the pavement surface, which largely depends on the aggregate gradation and mixture type rather than the aggregate type. Surfaces with higher MPD values should provide greater resistance to sliding, reduce hydroplaning, and help facilitate drainage. Figure 17 presents the current MPDs collected from I-20, US 61, and US 171 test sections in comparison to the typical macro-texture depth of 0.06 to 0.12 in. (1.5 to 3.0 mm) for new OGFC overlays as published in a recent NCHRP study *[39]*. Results indicate that both US 61 and US 171 sections meet the NCHRP recommendation; whereas, I-20 result is slightly below the minimum recommended value (Figure 17). Note that, those typical MPD values are recommended only for the new overlays. The I-20 and US 61 test sections have been under daily traffic for about

5 years. Polishing of the aggregate could have led to a decrease in macro-texture for the I-20 pavement section, which may be the possible reason behind the low MPD results. In another study Kowalski et al., reported a MPD value of 1.4 mm for an OGFC roadway section in Indiana under traffic for 4 years *[3]*. This result is similar to values observed at LADOTD's I-20 test section.

Table 3
Frictional properties of various roadway sections

Test Section	Mix Type	Length (miles)	Year Constructed	Year Tested	Traffic Records		FN	Standard Deviation
					ADT (year)	Percent Truck		
OGFC Test Sections								
US 71	OGFC	Length of this test section was too small to analyze						
I-20	OGFC	5.6	2005	2010	38,000 (in 2010)	18	49.8	5.2
US 61	OGFC	5.6	2007	2010	25,500 (in 2010)	13	36.4	0.8
US 171	OGFC	4.3	2009	2010	7,650 (in 2008)	12	41.5	1.9
Non-OGFC Sections								
I-10	SMA	3.7	2009	2010	32,341 (in 2009)	17	38.4	3.8
US 190	Superpave	4.7	2008	2010	17,200 (in 2010)	14	31.7	1.9
US 171	Superpave	6.5	2009	2010	9,140 (in 2009)	6	36.5	5.6

In a recent study at LTRC, the MPDs of laboratory made OGFC, SMA, and Superpave samples were measured using a Circular Texture Meter (CTM) *[40]*. It was observed that the OGFC mixture had the highest MPD values followed by SMA and Superpave mixtures. For a better representation of both micro- and macro-textures, the IFI friction index F(60) was computed on the basis of the surface friction coefficient measured by a dynamic friction tester at 20 mph (DF_{20}) and MPD data. It was reported that OGFC and SMA mixtures performed better than the Superpave mixtures.

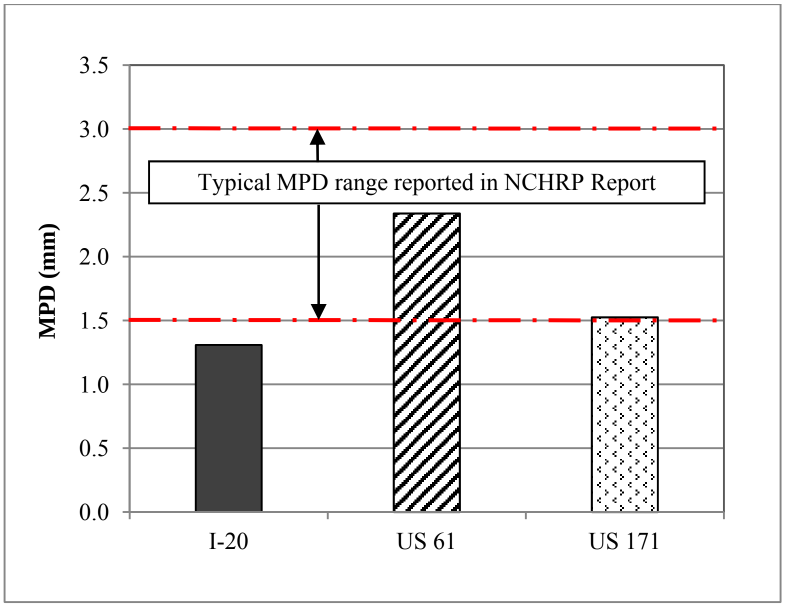

Figure 17
MPD results

Rut, IRI, and Random Cracking. Figure 18 illustrates performance of the four OGFC test sections on the basis of PMS rutting, IRI, and random cracking data. To compare the performance, data associated with early Louisiana Superpave roadways (five Interstates: 15,000–60,000 ADT and four US routes: 8,000–25,000 ADT, constructed in the late 1990s), which have already been reported in a previous study, were also included in the analyses *[41]*. It should be noted that the construction, acceptance, and survey date for the OGFC projects and their Superpave counterparts were different. However, the performance indices are plotted in relation to the age of the pavement to offset this issue. The reported overall values of the performance-criteria for individual projects (Figure 18) are the average values of each 0.1-mile section within the project limits.

Based on the data presented, the overall rutting performance for the US 71, US 61, and US 171 OGFC sections is considerably better than the Superpave US routes. The I-20 OGFC section exceeded the rut depth trends for interstate Superpaves. However, after 4 years under traffic, the rut depth of this section was only 0.15 in., which looks very encouraging. Interestingly, US 171 has shown good rutting performance in the field (0.12 in.) even though the lab fabricated sample for this project did not meet the LWT rut depth requirement.

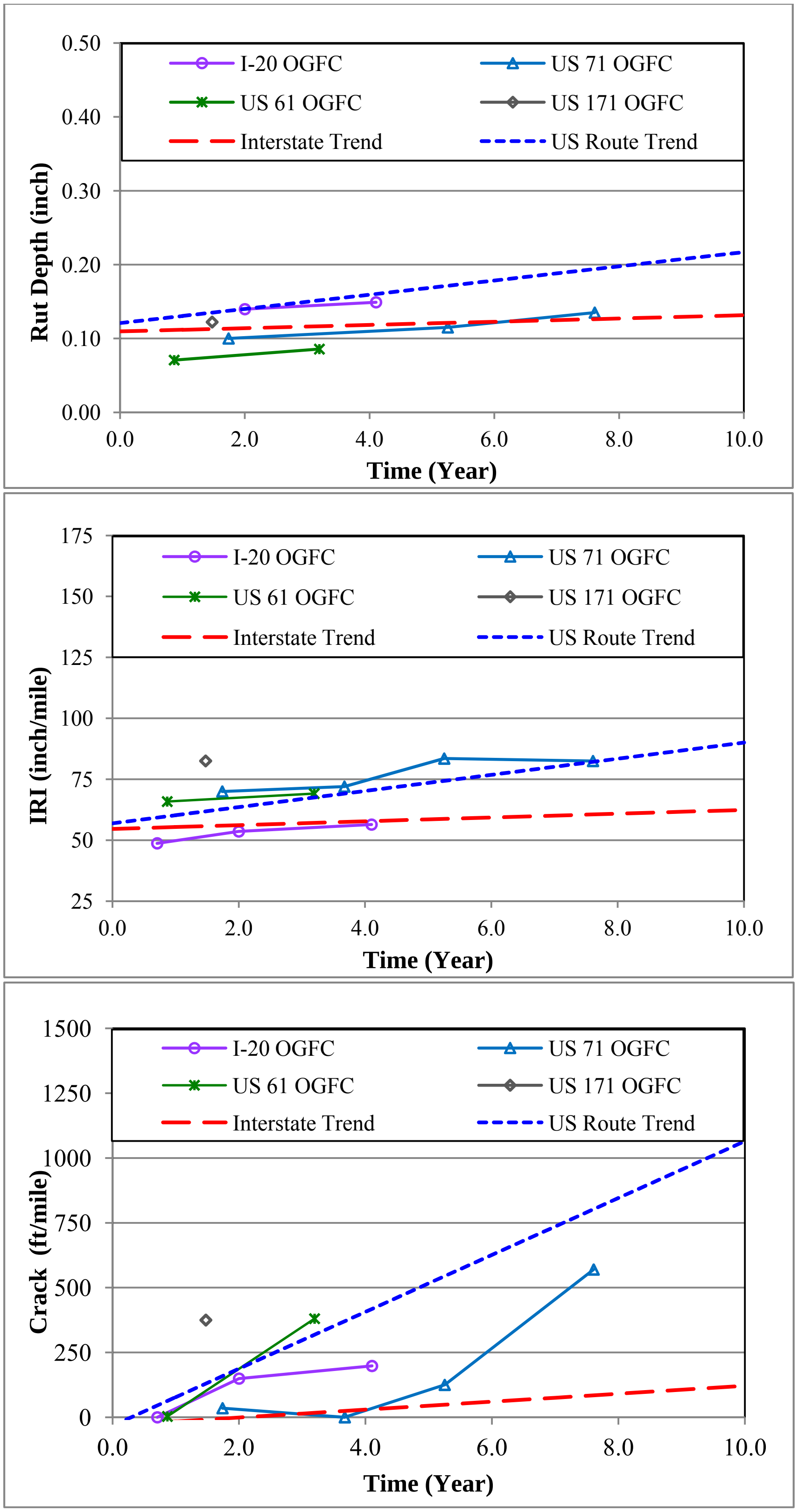

Figure 18
Performance based on PMS data

The IRI for the OGFC sections illustrated in Figure 18 is very comparable to the Superpave trends. Interestingly all roadway sections except US 171 met the LADOTD's IRI requirement of 75 inch/mile for 103 percent bonus pay. The US 171 had an IRI value of 83 inch/mile, which is below the LADOTD requirement for maximum allowable IRI of 85 inch/mile for 100 percent payment for new construction and overlays. It should be noted that the pre-construction data indicated that US 171 section had a high IRI (154 inch/mile) record before construction. The 1.25-in. OGFC overlay was not enough to bring the IRI down below limit of 75 inch/mile yet there was about 46 percent improvement in smoothness after the OGFC overlay.

The cracking data presented in Figure 18 represent a combination of longitudinal and transverse cracks. In general, the amount of cracks for US 71, US 61 and I-20 OGFC sections is lower than general Superpave pavements for the U.S. routes. However, the crack resistance performance for I-20 OGFC section was slightly below the Superpave placed on interstates. All OGFC sections considered here consisted of a 0.75 to 1.25 in. overlay over an existing surface. On the other hand, the Superpave sections have at least 2 in. or thicker wearing course over the existing surface. The pre-construction PMS data indicate that most of the OGFC sections before overlay were in poor condition with considerable amount of rutting. Considering these conditions, the OGFC mixes are found to be performing comparable if not better than conventional Superpave mixes. The slightly higher asphalt content and the presence of coarse material in a larger quantity might have enhanced the overall performance of OGFC sections.

Reflective Crack Measures

A good quality and well-bonded OGFC mixture can also show better cracking performance. A comparative study was performed only on projects within close proximity with US 61 to normalize traffic patterns in order to identify the most effective treatment in controlling reflective cracking on composite pavements. For comparison, three 3.5-in. thick Superpave overlay sections were constructed with roadway reinforcing mesh (fiber-glass grid). Those sections consisted of 2-in. Superpave, glass grid, and 1.5-in. Superpave surface mixture. The traffic counts were 30,600, 31,200, 25,700 on roadway reinforced sections and 25,500 on the OGFC section respectively. All of these sections experienced the same climatic conditions. The PMS data was used to quantify the performances of these sections using a comprehensive Pavement Condition Index (PCI). All the fiber-glass grid sections showed deterioration in the value of PCI after 3 years of service; whereas, the project with OGFC showed no drop in PCI even after 4 years of service (Table 4). Based on the PCI drop, the predicted service lives for the sections with fiber-glass grid were 11, 17, and 8 years respectively. Since there is no performance drop for the OGFC section, the model predicted an infinite service life, which is not practical. However, by observing the performance index it can be concluded that the section with OGFC outperformed the other sections with fiber-glass grid reinforcement.

Table 4
PCI and predicted service life

Route/ Location	Treatment Type	Predicted Service life (years)	PCI @ Years from Construction				
			0	2	4	5	7
US 61 – I	Fiber-Glass Grid	11	97	95	92	-	-
US 61 – II	Fiber-Glass Grid	17	-	94	-	90	87
US 61 – III	Fiber-Glass Grid	8	92	90	-	81	73
US 61 – IV	OGFC	No deterioration	100	100	100	100	-

Accident Reduction

To investigate whether OGFC pavements reduce the occurrence of accidents, especially in wet weather conditions, comparisons were made between accident data on the same roadway section before and after placement of the OGFC mixture (Table 5). Except for the US 171 project, five years pre-construction and post-construction accident data from the Louisiana police report were collected and analyzed to evaluate the traffic safety benefits of OGFCs. The construction of the US 171 section was completed in May 2009; hence, five years post-construction data are yet to be generated and consequently only two years post-construction data were utilized.

The data reflected significant reductions both in fatalities and total accidents regardless of the weather condition for US 71, I-20 corridors. Interestingly, the reduction was the greatest when the wet weather condition was considered. On average, the OGFC on I-20 test section reduced total wet weather accidents by 76 percent over a five-year span and eliminated all fatalities during that period. On the other hand, there was a complete elimination of any type of wet weather accidents and fatalities on US 71 test section for the same duration. Also a 57 percent reduction in total accidents during wet weather condition was noticed for US 171 section. More importantly, no fatality was reported since the construction of that project. Unlike the aforementioned three projects, an increase in accident rate was observed for US

61 in both weather conditions. However, it should be noted that the traffic volume for this roadway increased drastically following the Hurricane Katrina disaster, which might have intensified the occurrence of accidents. The number of all-weather accidents was far greater than that of the wet weather indicating this section to possibly have other accidental causation issues rather than the pavement surface friction.

The pattern of accident occurrences over the period of five years before and after construction of OGFCs, as presented in Figure 19, represents a sudden increase in accident on US 61 in the post Katrina period, just before the construction of OGFC section. This high rate of accidents continued for the next three years, while a remarkable improvement was noticed from the third year after construction onward. Also, for the US 71 and US 171 sections, it is evident that OGFCs were able to keep the accident numbers very low over the period of their service life. Among the four OGFC test sections depicted in figure 19, the most prominent improvement was observed for the I-20 project. Before construction, at least 25 total accidents in a year were recorded. However, the number of total accidents significantly dropped to an impressive 8 accidents per year maximum since the construction of OGFC.

Table 5
Accident reduction

Location	Weather Condition	Nos. of Total Accident/Year		Nos. of Fatality/Year		% Reduction in Total Accidents/ Year	% Reduction in Fatalities/ Year
		Before	After	Before	After		
US 71	Wet Weather	0.6	0.0	0.2	0.0	100	100
	All Weather	2.0	0.2	0.2	0.0	90	100
I-20	Wet Weather	28.6	6.8	0.6	0.0	76	100
	All Weather	66.0	38.0	1.4	0.6	42	57
US 61	Wet Weather	19.4	22.0	0.0	0.5	No Reduction	No Reduction
	All Weather	175.6	191.6	1.2	1.6	No Reduction	No Reduction
US 171	Wet Weather	1.6	0.7	0.0	0.0	57	No Change
	All Weather	8.8	14.7	0.0	0.0	No Reduction	No Change

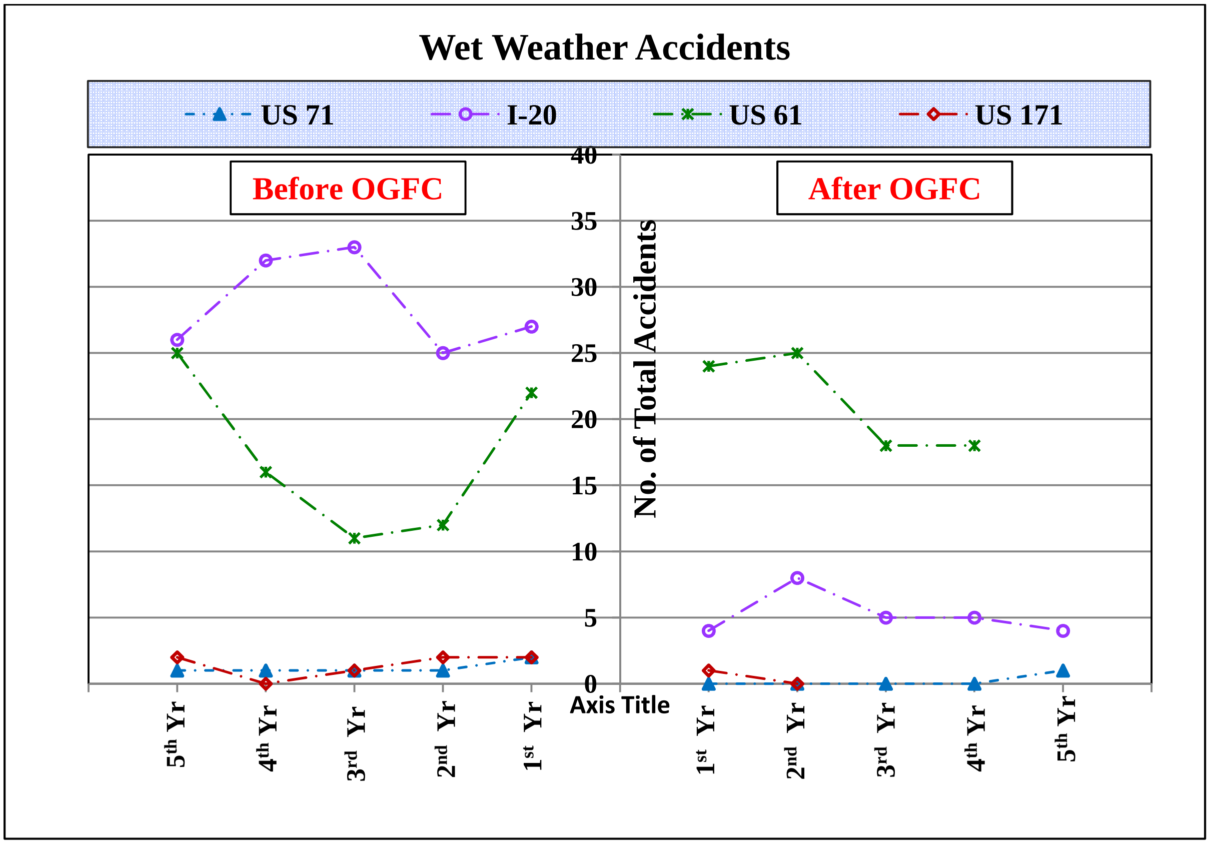

Figure 19
Pattern of accident occurrences

Splash and Spray of Rainwater

Splash and spray of rainwater can be an indicator of drainage capacity in the field. Quantified measurements for splash and spray were not performed in this study. However, the visual observations during rainstorm events indicated that the splash and spray in the OGFC sections were considerably less than the adjacent regular Superpave pavement sections. Figure 19 compares the splash and spray conditions on two adjacent I-20 sections constructed with Superpave WC and OGFC mixtures, respectively. It clearly shows that the OGFC section has almost no splash and spray. However, the improvement was more significant in the presence of heavy vehicles such as tractor/ trailers. Due to the climatic condition, the southern part of Louisiana usually experiences plenty of rainfalls. The reduction in splash and spray may greatly enhance driving conditions during the rainy season.

Figure 20
Splash and spray comparison: (a) typical superpave (b) OGFC

Cost Comparisons

In general, OGFC mixtures are more expensive per ton when compared to regular Superpave mixtures. However, the lower unit weight of OGFC partially offsets its higher costs. In addition, the roadway safety benefits provided by OGFC are hard to ignore and cannot be measured in a monetary value. A comparative materials cost analysis was conducted on four adjacent US 61 projects which included the project considered in this study. These four roadway sections were constructed in an effort to mitigate reflective cracking and maximize pavement performance. The OGFC section in combination with the SMA was compared to Superpave sections that included Fiber-Glass Grids. Only the costs of HMA mixtures placed in binder and wearing courses and the cost of glass-grid reinforcing mesh were considered. Table 6 presents summarized costs per sq. yards for the four projects mentioned previously. The data appear to indicate that the materials cost for OGFC and SMA section per sq. yard was at least $1.98 lower than the companion glass-grid sections. This is almost a 14 percent savings from the cost associated with the asphalt materials used. Also, as mentioned in a previous section of this report, the OGFC section showed a prolonged service life in comparison to glass-grid sections. This indicates a lower life cycle costs for OGFC in comparison to the companion glass-grid sections.

Table 6
Cost comparison of OGFC and glass-grid sections

Route/ Location	Treatment Type	Pavement Structure	Total Cost/ Sq.yd
US 61–I S.P.# 007-08-0030	Fiber-Glass Grid	2” Superpave BC, 1.5-in. Superpave WC, and Glass Grid	$15.17
US 61–II S.P.# 013-04-0036	Fiber-Glass Grid	2” Superpave BC, 1.5” Superpave WC, and Glass-grid	$14.67
US 61–III S.P.# 019-01-0031	Fiber-Glass Grid	2” Superpave BC, 1.5” Superpave WC, and Glass-grid	$14.41
US 61–IV S.P.# 019-01-0031	OGFC	2” SMA and 0.75” OGFC	$12.43

CONCLUSIONS

Based upon the experience obtained from the laboratory and field phases of this study, it can be concluded that Louisiana OGFC mixtures are capable of delivering impressive performance as well as providing a safe traveling surface. The following findings and conclusions are shown based on the outcome of the study:

- Test sections across the state paved with OGFC have proven to save lives. Accident data analyses indicated that OGFC mixtures significantly improved the wet weather accident rate for all test sections except US 61. An increase in the traffic volume in the post hurricane Katrina period might have intensified the rate of accidents on US 61 corridor. However, I-20 data indicated a 76 percent reduction in wet weather accidents and a 100 percent reduction in fatalities.
- The pavement design guide for LADOTD has been changed to require OGFCs for new overlay sections of all Interstate highway surfaces and for any surface being corrected for safety reason whenever a thin lift asphaltic concrete is constructed. According to current LADOTD specifications, OGFCs are allowed for any traffic level and can be substituted for other thin lift asphaltic concrete applications.
- OGFC pavements always showed better friction properties than their Superpave counterparts. Additionally, OGFC mixtures were able to show very good macro-texture in terms of MPD results.
- Five year pavement distress data indicate that the performance and projected life of OGFC sections are comparable to the typical Superpave sections.
- The OGFC-SMA combination provided a superior reflective crack relief section for composite pavements. In comparison to the companion glass-grid sections, the OGFC was found to save 14 percent of the materials costs.
- The material and mixture design guidelines provided in the latest version of LADOTD specifications for OGFC mixtures seem to work very well with reasonable permeability, draindown, LWT, and TSR tests.
- The CoreLok (AASHTO T 331) appeared to be the more accurate method for determining bulk specific gravity and air voids of a compacted OGFC specimen. This test has been added to the latest version of LADOTD specifications as the required method to measure the air voids of OGFC specimen.

RECOMMENDATIONS

Based on the outcome of this study, the authors highly recommend the implementation of OGFCs for any roadway surface having wet weather safety concern. In addition, it is recommended that all new construction on Interstate roadways in urban areas have an OGFC placed as the final lift.

LADOTD OGFC specifications should require a maximum of 0.472-in. (12-mm) rut depth after 7500 passes in the LWT test. For interstate and high volume traffic areas, the mixture shall be placed using the Spray Paver device, using a polymer based emulsion for the tack coat. The use of the CoreLok device should be included in the specification for determining air voids.

The authors recommend that LTRC continuously monitor all future OGFC projects, analyze their LWT rut data, and provide further feedback to designers and provide recommendations (if needed) for future LADOTD specifications.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
HMA	Hot Mix Asphalt
OGFC	Open Graded Friction Course
FHWA	Federal Highway Administration
DOT	Department of Transportation
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
NCHRP	National Cooperative Highway Research Program
LWT	Loaded Wheel Tester
TSR	Tensile Strength Ratio
PMS	Pavement Management System
IRI	International Roughness Index
FN	Friction Number
MPD	Mean Profile Depth
lb.	Pound(s)
m	Meter(s)
cm	Centimeter(s)
ft.	Foot (feet)
in.	Inch(es)
mph	Miles per hour
kmph	Kilometer per hour
PFC	Permeable Friction Course
PA	Porous Asphalt
MTV	Material Transfer Vehicle
SSD	Saturated Surface Dry
DGA	Dense-graded Asphalt
CTM	Circular Texture Meter
SMA	Stone Matrix Asphalt
PCI	Pavement Condition Index
PCC	Portland Cement Concrete
JRCP	Jointed Reinforced Concrete Pavement
LWST	Locked Wheel Skid Tester

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APPENDIX

Table 7
Bulk specific gravity and air void data

District Labs	Bulk Specific Gravity (G_{mb})				Maximum Specific Gravity (G_{mm})	Air Voids (%)
	Sample 1	Sample 2	Sample 3	Average		
AASHTO T 166 Method						
D 02	2.125	2.194	2.183	2.167	2.426	10.66
D 03	2.127	2.154	2.152	2.144	2.426	11.61
D 04	-	2.174	2.178	2.176	2.426	10.31
D 05	2.141	2.175	2.161	2.159	2.426	11.01
D 07	2.149	2.173	2.160	2.161	2.426	10.94
D 08	2.146	2.171	2.171	2.163	2.426	10.85
D 58	2.157	2.177	2.167	2.167	2.426	10.68
D 61	2.149	2.172	2.172	2.164	2.426	10.79
D 62	2.158	2.183	2.180	2.174	2.426	10.40
LTRC	2.174	2.158	2.163	2.165	2.426	10.76
CoreLok Method						
D 02	1.961	1.987	2.008	1.985	2.426	18.16
D 03	1.959	1.987	1.975	1.974	2.426	18.65
D 04	1.972	1.994	2.033	2.000	2.426	17.57
D 05	1.956	-	2.015	1.986	2.426	18.16
D 07	1.979	1.983	2.016	1.993	2.426	17.86
D 08	1.962	1.987	2.016	1.988	2.426	18.04
D 58	1.958	1.986	2.006	1.983	2.426	18.25
D 61	1.968	1.990	2.013	1.990	2.426	17.96
D 62	1.976	1.993	2.018	1.996	2.426	17.73
LTRC	1.998	2.024	1.986	2.003	2.426	17.45

Louisiana superpave performance models used in this study:

- Interstate Rut Trend Line: $y = 0.0022x + 0.1095$
- Interstate IRI Trend Line: $y = 0.7813x + 54.619$
- Interstate Crack Trend Line: $y = 15.31x - 31.747$
- US Route Rut Trend Line: $y = 0.0096x + 0.1209$
- US Route IRI Trend Line: $y = 3.3107x + 56.934$
- US Route Crack Trend Line: $y = 109.71x - 32.09$