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**Open Graded Friction  
Courses Reinforced with  
FORTA-FI (Aramid-  
Polyolefin) Fibers**

## Open Graded Friction Courses Reinforced with FORTA-FI (Aramid-Polyolefin) Fibers

### Abstract

Open Graded Friction Courses (OGFCs) are porous asphalt layers designed to improve roadway safety and environmental performance by enhancing water drainage, reducing hydroplaning, and lowering tire-pavement noise. However, their widespread use is limited by durability concerns such as raveling, stripping, and clogging, especially in colder climates. This study investigates the use of Aramid-Polyolefin fibers to improve the mechanical performance and longevity of OGFC mixtures.

Three OGFC mixtures were evaluated at the National Center for Asphalt Technology (NCAT) Test Track: (1) a 9.5 mm NMAS mix with cellulose fiber and SBS-modified binder (E9A), (2) a 12.5 mm NMAS mix with Aramid-Polyolefin fiber and SBS-modified binder (E9B), and (3) a 12.5 mm NMAS mix with GTR-modified binder and no fiber (E10). Laboratory testing included Cantabro loss for raveling resistance and tensile strength ratio (TSR) for moisture susceptibility. The Aramid-Polyolefin fiber mix (E9B) showed superior performance in both tests, reducing binder drain-down and enhancing resistance to cracking and moisture damage.

Field performance was monitored over three NCAT research cycles (2012–2021), with test sections subjected to approximately 30 million ESALs. All sections maintained low roughness and rutting, but only E9B exhibited no cracking after full traffic loading. These results confirm that Aramid-Polyolefin fibers significantly enhance OGFC durability without compromising permeability or surface smoothness. The findings support broader adoption of fiber-reinforced OGFCs, particularly in regions where durability has been a limiting factor.

**Keywords:** OGFC, Aramid, Fibers, Full-Scale Testing, Performance

### 1. Introduction

An Open Graded Friction Course (OGFC) is a thin surface layer on a pavement, characterized by an open gradation of asphalt mixture, primarily coarse aggregate, with minimal fine material. This unique composition yields a high content of interconnected air voids, typically ranging from 15% to 25% [1, 2]. Historically, the development of OGFC dates back to the 1930s with early field trials, and a more formal mixture design procedure appeared in the early 1970s [1, 3]. Early versions saw a rapid increase in use but were often discontinued in the 1980s due to widespread performance problems. Modern OGFC mixtures frequently incorporate polymer-modified asphalt (PMA) and additives like

Styrene-Butadiene-Styrene (SBS), Styrene-Butadiene (SB), or Ground Tire Rubber (GTR) to enhance durability [1, 4].

### **1.1 Key Benefits and Functional Mechanisms**

The porous structure of OGFCs provides several significant safety, economic, and environmental advantages compared to dense-graded asphalt mixtures [4, 5]. The high air void content allows for immediate internal drainage of surface water, preventing the build-up of a water film at the tire-pavement interface. This dramatically reduces the potential for hydroplaning [1, 6]. By draining water internally rather than expelling it from the surface, OGFC significantly reduces tire splash and spray, improving driver visibility [5, 7]. OGFCs maintain good high-speed frictional qualities under wet conditions because the macrotexture ensures tire-rubber contact [2, 6]. They also improve the night visibility of pavement markings by reducing surface reflectivity and glare.

OGFCs are generally quieter than conventional pavements, often providing a 3 to 5 decibel (dBA) reduction in tire noise [1, 6]. The void structure absorbs sound energy [1]. The porous nature makes OGFC an effective stormwater treatment, aiding runoff management and pollution prevention [8, 9].

### **1.2 Performance Challenges and Limitations**

Despite the clear benefits, OGFCs face persistent challenges limiting their widespread adoption, particularly in Northern climates [2, 10]. Raveling (the loss of aggregate from the surface) and stripping (loss of bond between asphalt and aggregate) are primary durability problems exacerbated by the high porosity and the increased presence of water [3, 10]. The internal voids can become clogged by dirt and debris over time, reducing the mix's permeability, drainage capability, and benefits of noise reduction [3, 5]. Preventive maintenance, such as cleaning the cavities to ensure a proper level of permeability, is critical but often challenging [4]. The permeability of OGFC does not seal the underlying pavement. This increased exposure to water can lead to stripping and debonding of the course below, especially if the OGFC is placed over a poorly sealed pavement [6, 10].

OGFC mixtures pose unique challenges in colder climates due to their specific snow and ice management requirements. Unlike dense-graded asphalt, which often melts moisture more effectively, OGFCs tend to retain ice for extended periods, increasing the risk of slippery surfaces. Additionally, the potential for damage during snow plowing is a significant concern, as the structure of OGFCs can be adversely affected by the heavy equipment used in snow removal. This combination of factors underscores the need for tailored strategies to ensure safety and durability in these colder regions.

OGFC mixtures typically cost 21% to 40% more than conventional dense-graded HMA due to extra mix components (e.g., polymer modifiers), specialized equipment, and sometimes slower production rates [1, 10]. Agencies generally do not credit the OGFC layer in the pavement structure due to its high porosity, meaning it does not add significant structural value to the pavement [10].

### **1.3 Modern Advancements and Research Focus**

Recent research has concentrated on materials and design improvements to address durability issues and extend the typical service life of 8 to 10 years [4, 6]. Studies have shown that epoxy-modified asphalt (EMA) significantly improves raveling resistance and durability in OGFC mixtures after extended aging [11]. High-performance polymer modifiers like SBS and rubber in OGFC mixtures are widespread [4]. Research continues to optimize aggregate gradation and binder content to balance permeability, friction, and durability [12]. Optimal gradation is crucial, as finer gradations can increase surface roughness but lead to lower porosity, while coarser mixtures may offer better internal drainage. Efforts are underway to develop implementable guidelines for design, performance, and maintenance, including methods to restore permeability, to ensure the long-term viability and cost-effectiveness of OGFC [4].

### **1.4 Key Benefits of Synthetic Fibers in OGFCs**

Synthetic fibers, such as polyester (PET), polypropylene (PP), Aramid, and glass fibers (GF), provide several critical enhancements to the OGFC mixture. The fibers disperse within the mix to create a three-dimensional reinforcement network. This network acts as a physical barrier that absorbs and stabilizes the asphalt binder, preventing it from draining out of the mixture during transportation and placement at high temperatures [13]. This stabilization allows for a potentially higher optimal asphalt content, which, in turn, can increase the thickness of the binder film coating the aggregates, leading to improved durability and longer service life.

Synthetic fibers directly address several of the durability issues commonly associated with the open structure of OGFCs. Fibers, particularly aramid and glass fibers, have high tensile strength and elongation potential. They can span micro-cracks and impede their propagation, enhancing the pavement's resistance to fatigue cracking and low-temperature cracking [13-16].

The reinforcement network stiffens the asphalt matrix, limiting aggregate movement and lateral flow under traffic load. Polyester and polyamide fibers, for example, have been shown to improve resistance to permanent deformation (rutting) [13-16]. The enhanced bonding and reinforcement can improve the mix's cohesion, making it more resistant to

raveling (loss of aggregate particles from the surface), a significant failure mode for porous asphalt [13-16].

Some synthetic fibers are characterized by a low absorption rate (compared to natural fibers), which can be a key advantage in water-prone OGFCs. The tight bonding between the fiber and asphalt mastic and the increased strength enhance the OGFC's resistance to moisture damage and stripping (the loss of adhesion between the asphalt binder and the aggregate due to water) [13-16].

## **2. Materials and Methods**

Based on concerns from transportation agencies in the United States about the durability of OGFCs and looking for technologies to enhance performance, an experiment that included field test sections was initiated in 2012 at the National Center for Asphalt Technology test track. The experiment included laboratory characterization and field testing of three types of OGFCs:

- A 9.5-mm Nominal Maximum Aggregate Size (NMAS) gradation was designed with a cellulose fiber and SBS-modified asphalt binder for the OGFC mixture in Section E9A.
- A 12.5-mm NMAS gradation containing the Aramid-Polyolefin fiber (instead of a cellulose fiber) was utilized in the OGFC mix design for Section E9B, also with an SBS-modified asphalt binder.
- A ground tire rubber (GTR) modified binder was used instead of SBS-modified binder for the OGFC mixture in Section E10 with a typical 12.5-mm NMAS gradation but without cellulose fiber.

Tables 1 show the gradations for the two nominal sizes used in the study. Table 2 shows the type and content of fiber in addition to the asphalt binder performance grade (PG) and content for each of the mixtures evaluated in this study.

**Table 1. OGFCs Gradations [18]**

Sieve Size, mm	Sieve Size, in	Percent Passing	
		9.5mm OGFC	12.5mm OGFC
19	¾	100	100
12.5	½	98.5	95.7
9.5	3/8	87.2	56.1
4.75	#4	32.4	15.7
2.36	#8	9.8	9.5
1.18	#16	5.7	7.1
0.6	#30	4.2	5.7
0.3	#50	3.1	4.5
0.15	#100	2.1	3.4
0.075	#200	1.4	2.6

**Table 2. Mixtures used in this Study [18]**

Section ID	NMAS, mm	Fiber Type and Content	Binder PG and content
E9A	9.5	Cellulose, 0.3%	SBS PG 76-22, 6.0%
E9B	12.5	Aramid-Polyolefin, 0.05%	SBS PG 76-22, 6.0%
E10	12.5	No Fiber	Rubber PG 76-22, 6.3%

The laboratory portion of the experiment included the Cantabro loss test (AASHTO T401) for abrasion resistance, and the tensile strength ratio for moisture susceptibility analysis (AASHTO T 283 without a freeze-thaw cycle). In contrast, in the field, data collection included the mean depth texture, international roughness index, rut depth measurements, and cracking evaluation.

Sections E9A, E9B, and E10 were milled and inlaid with the OGFC mixtures in 2012. Except for the changes made in the mix designs, the sections were paved following standard construction practices for OGFC mixtures in the state of Alabama. All the mixes were placed 0.75 inches thick on the NCAT Test Track with in-place air voids immediately after construction at approximately 20 percent.

Figure 1 shows the fibers used in this experiment. The fibers are 13% Aramid and 87% Polyolefin, five times stronger than steel's tensile strength. This high-performance fiber forms a 3D reinforcement matrix within the asphalt. Table 3 shows the properties of the fibers used in this study. For the specified dose of 0.05% by weight of the mixture, 19 million Aramid fibers are introduced per ton of asphalt concrete. The polyolefin fibers are

used as distribution agents during the production process and melt with the asphalt binder, resulting in a binder modification with a slight increase in viscosity.



Aramid Fibers



Polyolefin Fibers

**Figure 1. Aramid and Polyolefin Fibers**

**Table 3. Physical properties of the Fibers [19]**

<b>Fiber</b>	<b>Aramid</b>	<b>Polyolefin</b>
Specific Gravity	1.44	0.91
Density, kg/m <sup>3</sup>	1,440	910
Tensile Strength, MPa	2,758	N/A <sup>1</sup>
Operating Temperature, °C	-73 to 427	N/A <sup>1</sup>
Length, mm	19	19
Form	Monofilament <sup>2</sup>	Serrated

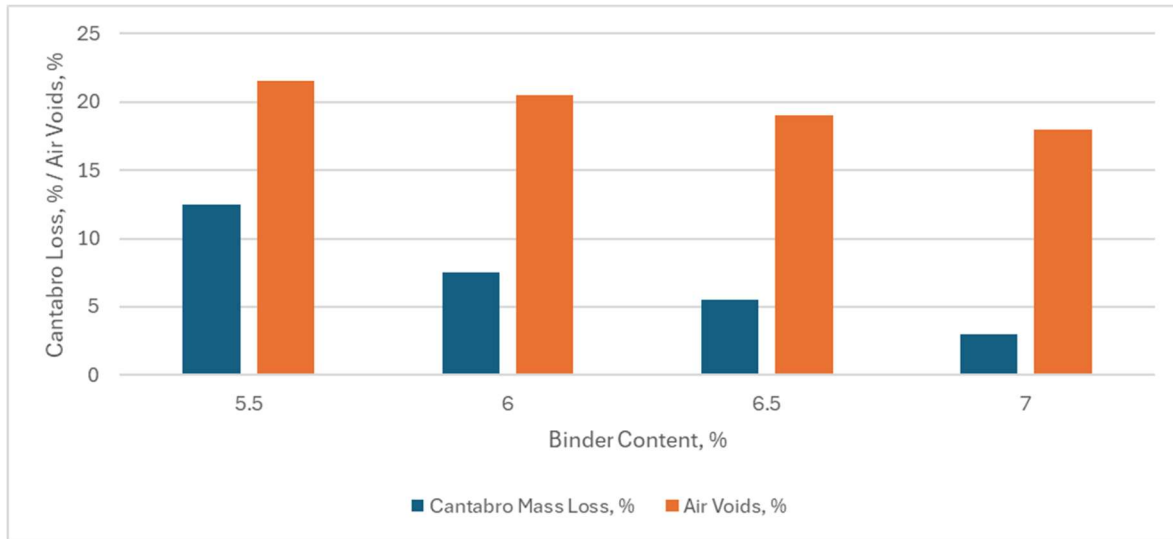
1. Fibers will melt or become plastically deformed during asphalt mix production.
2. Strands become fibrillated during asphalt mix production.

### 3. Results and Discussion

#### 3.1 Laboratory Test Results

During the mixture design process, the effect of the asphalt binder content and incorporation of the fibers was evaluated as part of the optimization process to obtain an air void content of about 15% and a maximum mass loss of 15%.

Figure 2 illustrates that as the asphalt content increases, the loss of Cantabro stone decreases. Additionally, it shows that higher asphalt content does not significantly affect the percentage of air voids. Increasing the asphalt content can enhance the resistance of OGFC mixtures to raveling without substantially reducing air voids or affecting potential permeability.

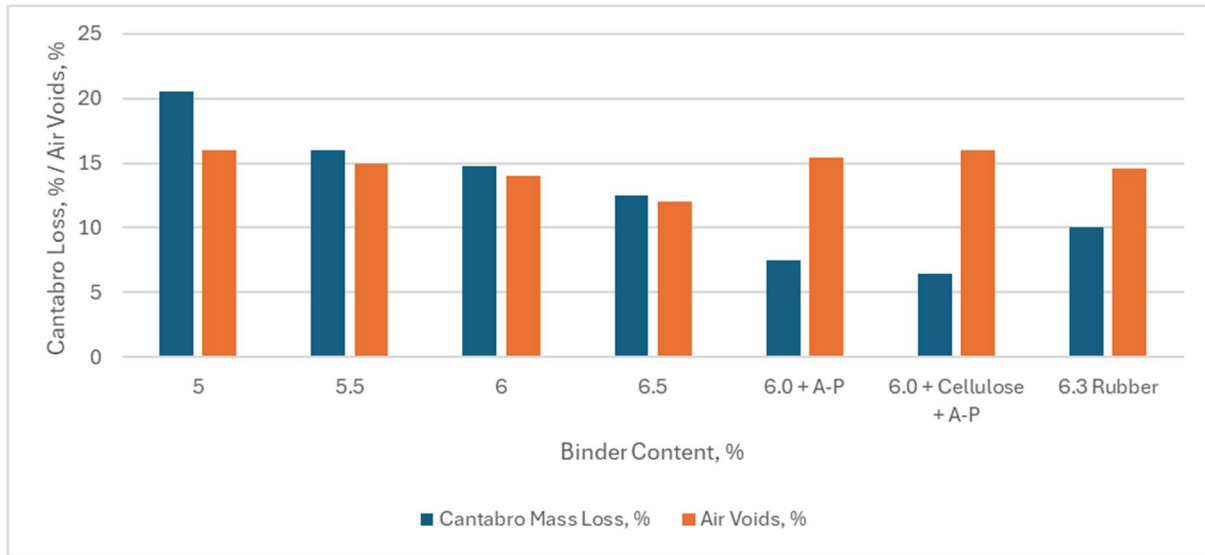


**Figure 2. Evaluation of binder content for the 9.5mm OGFC [Adapted from 20].**

The Cantabro mass loss for the 12.5 mm mixture was assessed during the mix design at four asphalt contents: 5.0%, 5.5%, 6.0%, and 6.5%, as illustrated in Figure 3. The results indicated that at least 6.0% asphalt content was required to limit mass loss to a maximum of 15%.

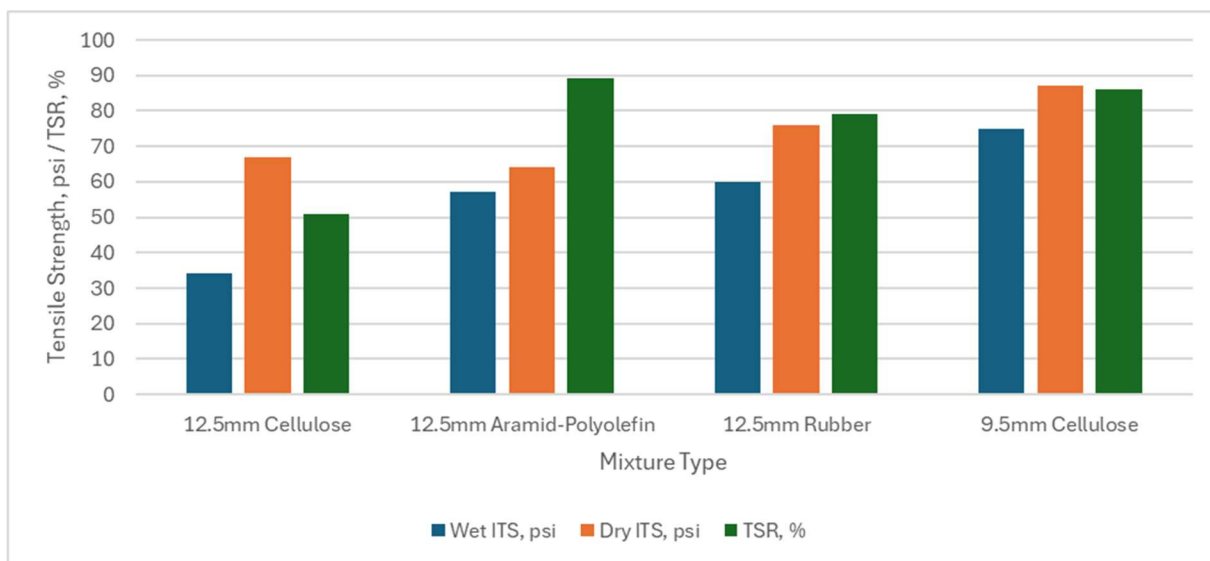
Two additional mixes were created using the optimum asphalt content of 6.0%, incorporating aramid-polyolefin fibers at a dosage rate of 0.05% by weight of the mix (about 1 lb/ton of mix). In the first mix, only the aramid-polyolefin fibers were used as a stabilizer for the binder film to prevent drain-down. In the second mix, cellulose fibers were added to evaluate whether the aramid-polyolefin fibers could effectively eliminate drain-down and improve resistance to raveling on their own, or if the combination of both fibers would provide additional benefits. One last mixture was created at 6.3% binder content with the ground tire rubber modifier. Even with the higher binder content, the mass loss of the mixture with rubber was significantly higher than that of the mixtures with fiber.

The results shown in Figure 3 clearly indicate that adding aramid-polyolefin fibers significantly improved resistance to raveling, as measured by the Cantabro test. Furthermore, the data suggest that including cellulose fibers alongside the aramid-polyolefin fibers was unnecessary. Consequently, Section E9B was constructed using only the synthetic fiber stabilizer in the mix.



**Figure 3. Evaluation of binder content and fiber addition for the 12.5mm OGFC [Adapted from 20 and 21].**

A comparison of the tensile strength results obtained during the mix design for each of the OGFC mixtures is presented in Figure 4. A previous study proposed a minimum splitting tensile strength of 50 psi for a performance-based mix design [17]. The results indicate that the mixture with a nominal maximum aggregate size (NMAS) of 9.5 mm exhibited the highest strength overall. Additionally, Figure 4 shows that the 12.5 mm mixture incorporating Aramid-Polyolefin fiber achieved the highest tensile strength ratio (TSR), making it less susceptible to potential moisture damage.

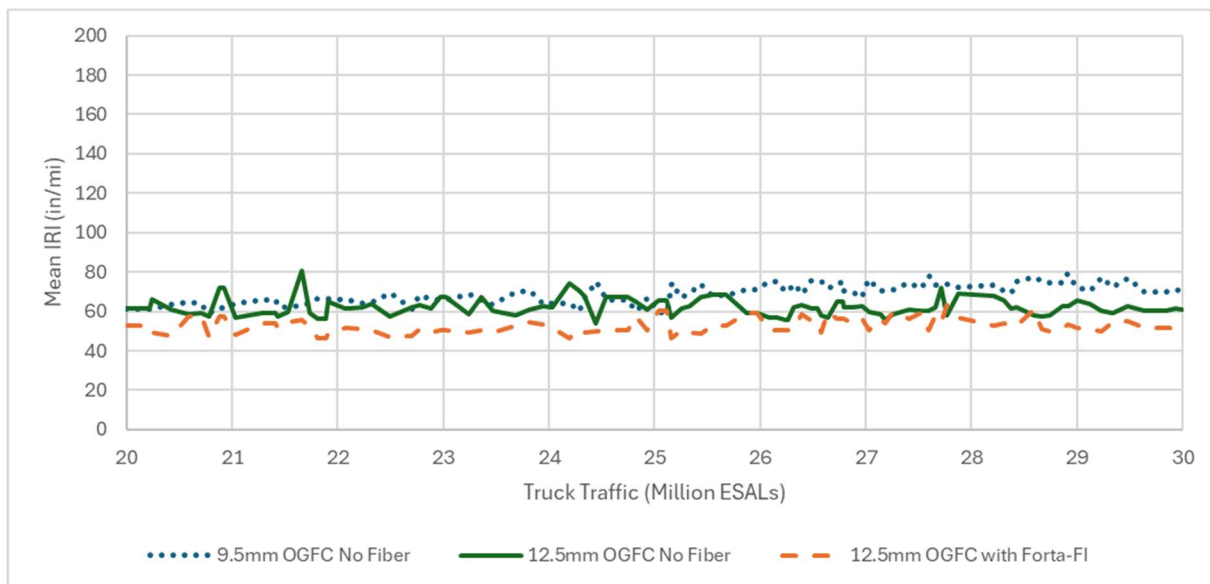


**Figure 4. Comparison of Tensile Strength Values [Adapted from 20].**

### 3.2 Field Test Results

After subjecting the three open-graded friction course (OGFC) mixtures to 20 million equivalent single axle loads (ESALs) between 2012 and 2017, they performed well on the track, showing no signs of raveling or cracking. As a result, load application was continued on these sections during the 2018 Test Track cycle, which lasted from 2018 to 2021, further to assess the long-term durability of the three OGFC mixtures. This section discusses the field performance of these mixtures over the three research cycles, from 2012 to 2021, during which they experienced approximately 30 million ESALs of truck traffic.

Roughness was measured following AASHTO R 57 standards using an Automatic Road Analyzer (ARAN) Van. The roughness for each wheel path was reported as the Mean International Roughness Index (MIRI) in inches per mile (in/mi). The relationship between roughness and traffic loading is illustrated in Figure x. Measurements taken over the past two test cycles, from 2015 to 2021, showed that the roughness in all sections remained consistent, indicating that these three subsections exhibit excellent smoothness.

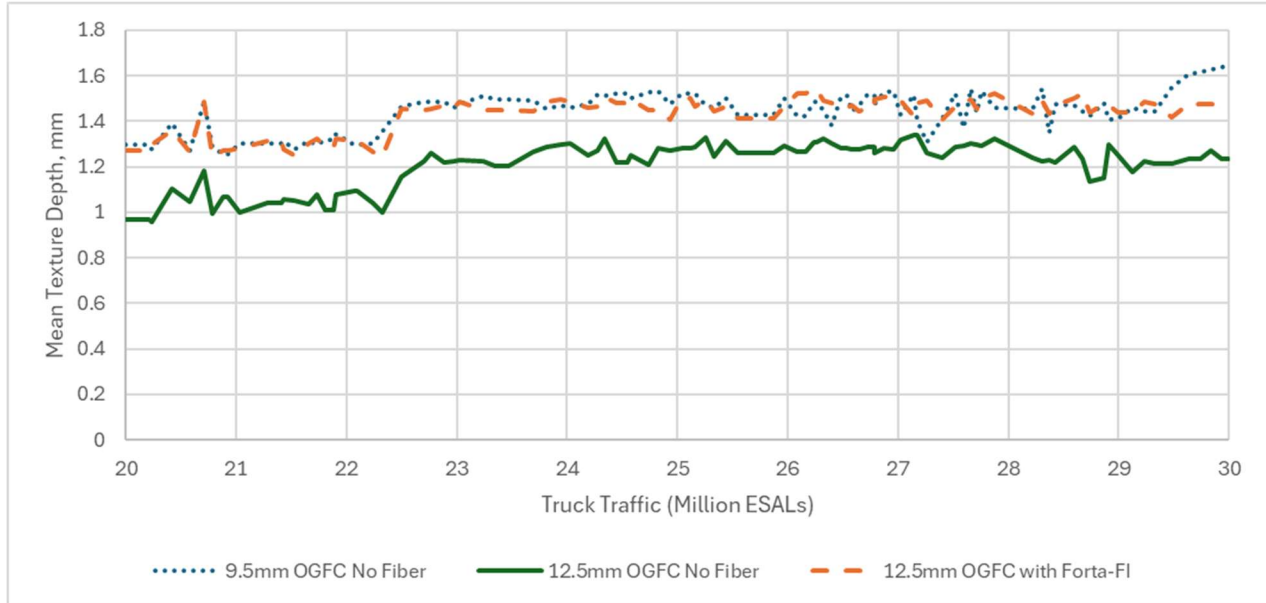


**Figure 5. Roughness Performance.**

Surface macrotexture measurements are an effective way to assess pavement durability. Durable pavements typically show smaller changes in surface texture over time and with traffic. The macrotexture in the wheel path is evaluated using mean texture depth (MTD), which tends to increase with the extent of raveling.

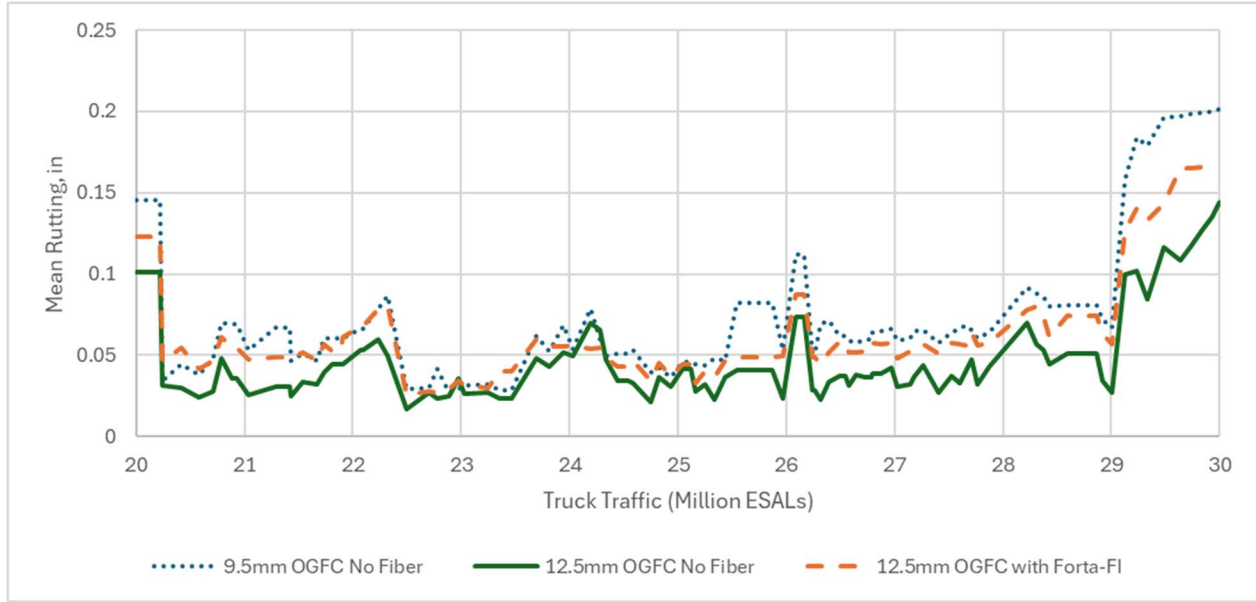
Figure 6 illustrates the macrotexture performance of the test sections in relation to traffic loading. The mean texture depth of the 9.5 mm mix in Section E9A was approximately the

same as that of the 12.5 mm mix with synthetic fiber in Section E9B, and both were higher than the 12.5 mm rubber-modified OGFC mix in Section E10. Additionally, the International Roughness Index (IRI) and MTD levels of the three test sections remained unchanged over the past two research cycles, indicating that raveling did not occur in these sections.



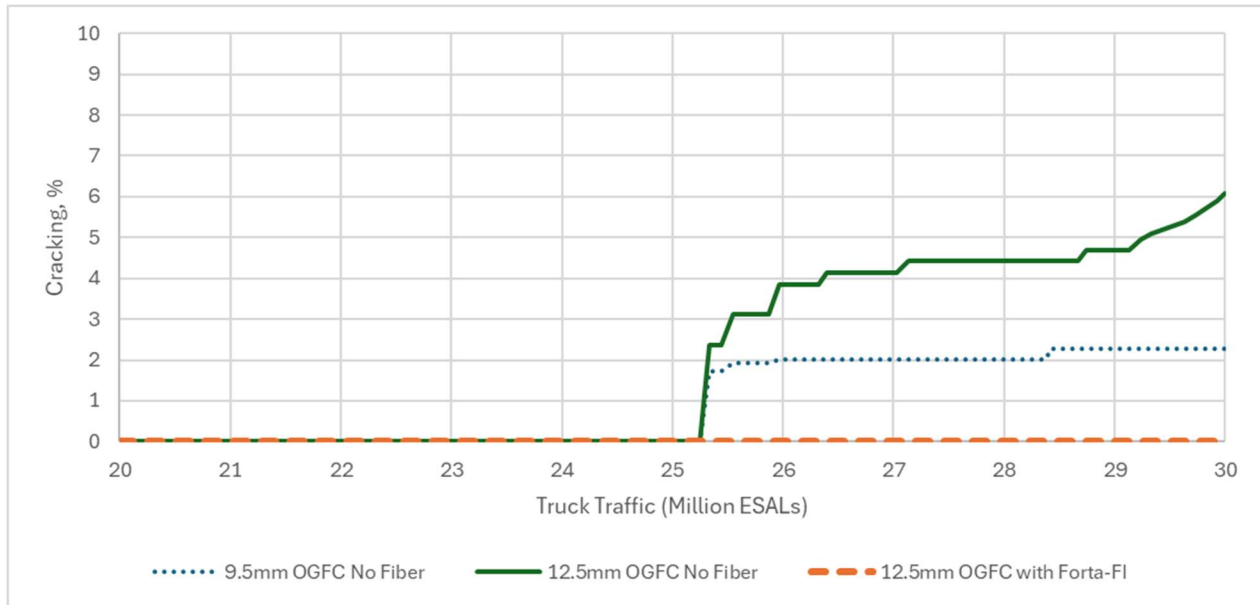
**Figure 6. Texture Test Results.**

Figure 7 illustrates that the three test sections exhibited low rut depths, remaining below 0.1 inches even after accumulating 25 million Equivalent Single Axle Loads (ESALs). After approximately 30 million ESALs of traffic, these sections maintained rut depths of less than 0.2 inches. This indicates that the OGFC mixtures demonstrated excellent long-term resistance to rutting.



**Figure 7. Rutting Performance.**

As shown in Figure 5, Section E9B exhibited no cracking after approximately 30 million Equivalent Single Axle Loads (ESALs) of truck traffic. In contrast, Sections E9A and E10 showed no signs of cracking until the accumulated traffic load reached 25 million ESALs. After 30 million ESALs, Section E9A displayed approximately 2.3% of the lane area with cracks, while Section E10 showed about 6.1% of the area exhibiting cracks. Overall, these three Open-graded Friction Course (OGFC) sections demonstrated excellent long-term resistance to cracking. Section E9B, which used synthetic fiber, had the best cracking after 30 million ESALs, compared to Section E9A (featuring a 9.5 mm OGFC mixture) and Section E10 (which utilized an RTR binder).



**Figure 8. Cracking Performance.**

#### 4. Conclusions

From 2012 to 2021, laboratory and field performance evaluations at the Test Track led to the following summarized conclusions.

- Increasing the asphalt content and adding fibers can enhance the resistance of mixtures to raveling without significantly reducing air voids or increasing potential permeability. The aramid-polyolefin fibers also improved resistance to raveling, as measured by the Cantabro test.
- The results suggest that including cellulose fibers alongside the aramid-polyolefin fibers was unnecessary. Thus, providing enough evidence to build the full-scale test section with just the aramid-polyolefin fiber.
- The roughness of all test sections remained consistent over the past three research cycles. From 2012 to 2021, the three sections demonstrated excellent resistance to rutting and cracking after enduring approximately 30 million Equivalent Single Axle Loads (ESALs).
- Compared to Sections E9A and E10, Section E9B, which contains Aramid-polyolefin fiber, showed no signs of cracking distress after 30 million Equivalent Single Axle Loads (ESALs).
- Based on the field's performance evaluation, adding Aramid-polyolefin fiber can enhance the long-term performance of OGFC mixtures.

## Acknowledgements

This study was sponsored by the Alabama Department of Transportation and testing was performed by the National Center for Asphalt Technology at Auburn University. Test results and performance data were extracted from several NCAT research reports and shared with the authors.

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